CHAPTER 5

Soil Classification

Early attempts to classify soils were based primarily on grain size. These are the textural classification systems. In 1908, a system that recognized other factors was developed by Atterberg in Sweden and primarily used for agricultural purposes. Somewhat later, a similar system was developed and used by the Swedish Geotechnical Commission. In the United States, the Bureau of Public Roads System was developed in the late twenties and was in widespread use by highway agencies by the middle thirties. This system has been revised over time and is widely used today. The Airfieid Classification System was developed by Professor Arthur Casagrande of Harvard University during World War II. A modification of this system, the USCS, was adopted by the US Army Corps of Engineers and the Bureau of Reclamation in January 1952. A number of other soil classification systems are in use throughout the world, and the military engineer should be familiar with the most common ones.

The principal objective of any soil classification system is predicting the engineering properties and behavior of a soil based on a few simple laboratory or field tests. Laboratory and / or field test results are then used to identify the soil and put it into a group that has soils with similar engineering characteristics. Probably no existing classification system completely achieves the stated objective of classifying soils by engineering behavior because of the number of variables involved in soil behavior and the variety of soil problems encountered. Considerable progress has been made toward this goal, particularly in relationship to soil problems encountered in highway and airport engineering. Soil classification should not be regarded as an end in itself but as a tool to further your knowledge of soil behavior.

Section I. Unified Soil Classification System

SOIL CATEGORIES

Soils seldom exist in nature separately as sand, gravel, or any other single component. Usually they occur as mixtures with varying proportions of particles of different sizes. Each component contributes its characteristics to the mixture. The USCS is based on the characteristics of the soil that indicate how it will behave as a construction material.

In the USCS, all soils are placed into one of three major categories. They are—

- Coarse-grained.
- Fine-grained.
- Highly organic.

The USCS further divides soils that have been classified into the major soil categories by letter symbols, such as—

- S for sand.
- G for gravel.
- M for silt.
- C for clay.

A soil that meets the criteria for a sandy clay would be designated (SC). There are cases of borderline soils that cannot be classified by a single dual symbol, such as GM for silty gravel. These soils may require four letters to fully describe them. For example, (SM-SC) describes a sand that contains appreciable amounts of silt and clay.

Coarse-Grained Soils

Coarse-grained soils are defined as those in which at least half the material is retained on a Number 200 sieve. They are divided into two major divisions, which are—

- Gravels.
- Sands.

A coarse-grained soil is classed as gravel if more than half the coarse fraction by weight is retained on a Number 4 sieve. The symbol G is used to denote a gravel and the symbol S to denote a sand. No clearcut boundary exists between gravelly and sandy soils; as far as soil behavior is concerned, the exact point of division is relatively unimportant. Where a mixture occurs, the primary name is the predominant fraction and the minor fraction is used as an adjective. For example, a sandy gravel would be a mixture containing more gravel than sand by weight. Additionally, gravels are further separated into either coarse gravel or fine gravel with the 3/4-inch sieve as the dividing line and sands are either coarse, medium, or fine with the Number 10 and Number 40 sieves, respectively. The coarse- grained soils may also be further divided into three groups on the basis of the amount of fines (materials passing a Number 200 sieve) they contain. These amounts are—

- Less than 5 percent.
- More than 12 percent.
- Between 5 and 12 percent.

Coarse-grained soils with less than 5 percent passing the Number 200 sieve may fall into the following groups:

- (GW is well-graded gravels and gravel-sand mixtures with little or no fines. The presence of the fines must not notably change the strength characteristics of the coarse-grained fraction and must not interfere with its free-draining characteristics.
- (SW) is well-graded sands and gravelly sands with little or no fines. The grain-size distribution curves for (GW) and (SW) in *Figure* 4-9, *page 4-11,* are typical of soils included in these groups. Definite laboratory classification criteria have been established to judge if the soil is well-graded (see *Chapter 4).* For the (GW) group, the C_u must be greater than 4; for the (SW) group, greater than *6.* For both groups, the CC must be between 1 and 3.
- (GP) is poorly graded gravels and sandy gravel mixtures with little or no fines.
- (SF) is poorly graded sands and gravelly sands with little or no fines. These soils do not meet the gradation requirements established for the (GW) and (SW) groups. The grain-size distribution curve marked (GP) in *Figure 4-9, page 4-11,* is typical of a poorly graded gravel-sand mixture, while the curve marked (SP) is a poorly graded (uniform) sand.

Coarse-grained soils containing more than 12 percent passing the Number 200 sieve fall into the following groups:

- (GM) is silty gravel and poorly graded gravel/sand-silt mixtures.
- (SM) is silty sands and poorly graded sand-silt mixtures.

Gradation of these materials is not considered significant. For both of these groups, the Atterberg limits must plot below the A-line of the plasticity chart shown in *Figure 5-1.* A dual symbol system allows more precise classification of soils based on gradation and Atterberg limits.

- (GC) is clayey gravels and poorly graded gravel-sand-clay mixtures.
- (SC) is clayey sands and poorly graded sand-clay mixtures.

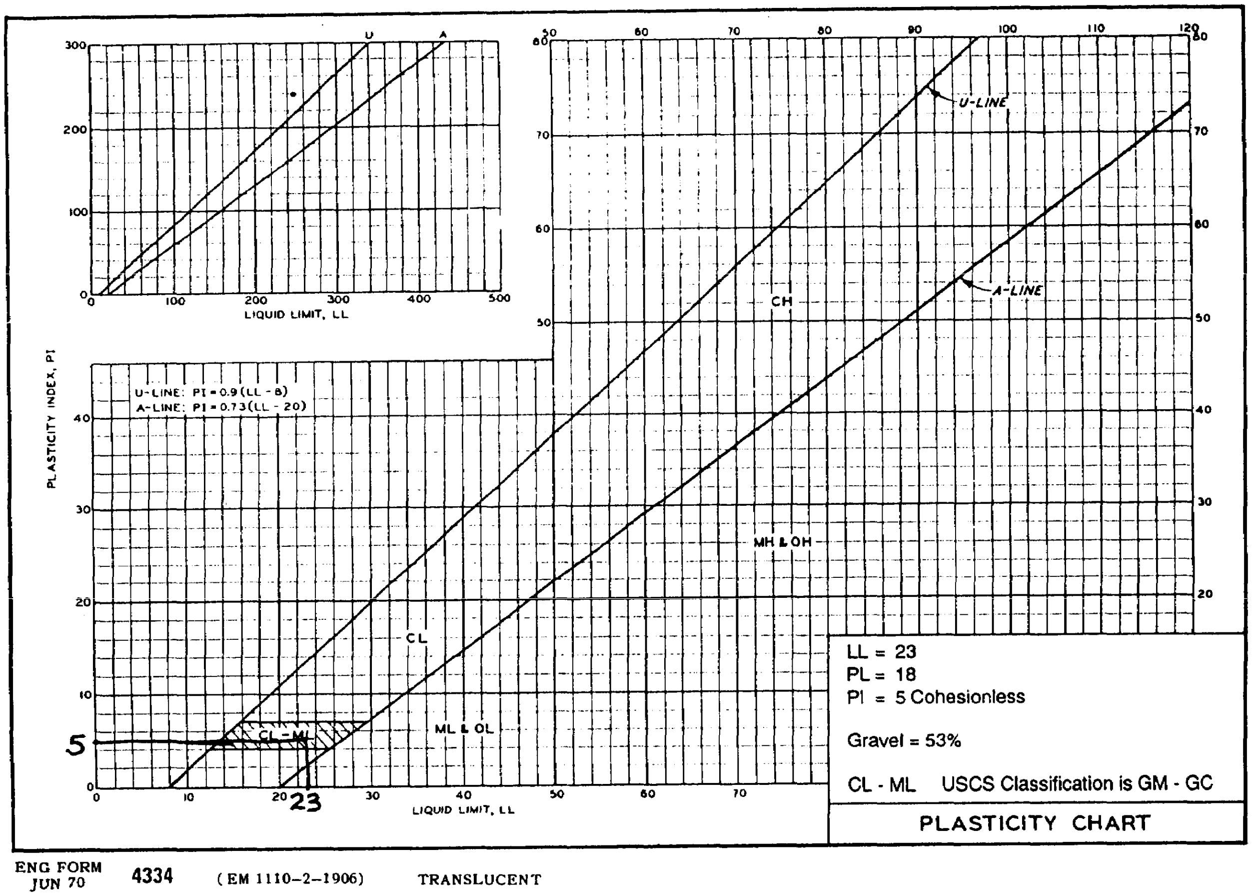


Figure 5-1. Sample plasticity chart.

Gradation of these materials is not considered significant. For both of these groups, the Atterberg limits plot above the A-line.

The use of the symbols M and C is based on the plasticity characteristics of the material passing the Number 40 sieve. The LL and PI are used in determining the plasticity of the fine materials. If the plasticity chart shown in *Figure 5-1* is analyzed with the LL and PI, it is possible to determine if the fines are clayey or silty. The symbol M is used to indicate that the material passing the Number 40 sieve is silty in character. M usually designates a fine-grained soil of little or no plasticity. The symbol C is used to indicate that the binder soil is clayey in character. A dual symbol system allows more precise classification of soils based on gradation and Atterberg limits.

For example, coarse-grained soils with between 5 and 12 percent of material passing the Number 200 sieve, and which meet the criteria for well-graded soil, require a dual symbol, such as—

- (GW-GM)
- (GP-GM)
- (GW-GC)
- (GP-GC)
- (SW-SC}
- (SW-SM)
- (SP-SC)
- (SP-SM)

Similarly, coarse-grained soils containing more than 12 percent of material passing the Number 200 sieve, and for which the limits plot in the hatched portion of the plasticity chart (see *Figure 5-1, page 5-3)*, are borderline between silt and clay and are classified as (SM-SC) or (GM-GC).

In rare instances, a soil may fall into more than one borderline zone. If appropriate symbols were used for each possible classification, the result would be a multiple designation using three or more symbols. This approach is unnecessarily complicated. It is considered best to use only a double symbol in these cases, selecting the two believed most representative of probable soil behavior. If there is doubt, the symbols representing the poorer of the possible groupings should be used. For example, a well-graded sandy soil with 8 percent passing the Number 200 sieve, with an LL of 28 and a PI of 9, would be designated as (SW-SC). If the Atterberg limits of this soil were such as to plot in the hatched portion of the plasticity chart (for example, an LL of 20 and a PI of 5), the soil could be designated either (SW-SC) or (SW-SM), depending on the judgment of the soils technician.

Fine-Grained Soils

Fine-g-rained soils are those in which more than half the material passes a Number 200 sieve. The fine-grained soils are not classified by grain size but according to plasticity and compressibility. Laboratory classification criteria are based on the relationship between the LL and the PI, determined from the plasticity chart shown in *Figure 5-1*, page *5-3*. The chart indicates two major groupings of fine-g-rained soils. These are—

- The L groups, which have LLs <50.
- The H groups, which have LLs ≥ of 50.

The symbols L and H represent low and high compressibility, respectively. Fine-grained soils are further divided based on their position above or below the A-line of the plasticity chart.

Typical soils of the (ML) and (MH) groups are inorganic silts. Those of low plasticity are in the (ML) group; others are in the (MH) group. Atterberg limits of these soils all plot below the A-line. The (ML) group includes-

- Very fine sands.
- Rock flours.
- Silty or clayey fine sands with slight plasticity.

Micaceous and diatom aceous soils generally fall into the (MH) group but may extend into the (ML) group with LLs<50. The same statement is true of certain types of kaolin clays, which have low plasticity. Plastic silts fall into the (MH) group.

In (CL) and (CH) groups, the C stands for clay, with L and H denoting low or high compressibility. These soils plot above the A-line and are principally inorganic clays. The (CL) group includes gravelly clays, sandy clays, silty clays, and lean clays. In the (CH) group are inorganic clays of high plasticity, including fat clays, the gumbo clays of the southern United States, volcanic clays, and bentonite. The glacial clays of the northern United States cover a wide band in the (CL) and (CH) groups.

Soils in the (OL) and (OH) groups are characterized by the presence of organic matter, hence the symbol O. The Atterberg limits of these soils generally plot below the A-line. Organic silts and organic silt clays of low plasticity fall into the (OL) group, while organic clays plot in the (OH) zone of the plasticity chart. Many organic silts, silt-clays, and clays deposited by rivers along the lower reaches of the Atlantic seaboard have LLs between 40 and 100 and plot below the A-line. Peaty soils may have LLs of several hundred percent and their Atterberg limits generally plot below the A-line.

Fine-grained soils having limits that plot in the shaded portion of the plasticity chart are given dual symbols (for example, (CL-ML)). Several soil types exhibiting low plasticity plot in this general region on the chart and no definite boundary between silty and clayey soils exists.

Highly Organic Soils

A special classification, (Pt), is reserved for the highly organic soils, such as peat, which have many undesirable engineering characteristics. No laboratory criteria are established for these soils, as they generally can be easily identified in the field by their distinctive color and odor, spongy feel, and frequently fibrous texture. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

Table 5-1, page 5-7, and Table 5-2, page 5-9, are major charts which present information applicable to the USCS and procedures to be followed in identifying and classifying soils under this system. Principal categories shown in the chart include—

- Soil groups, soil group symbols, and typical soil names.
- Laboratory classification criteria.
- Field identification procedures.
- Information for describing soils.

These charts are valuable aids in soil classification problems. They provide a simple systematic means of soil classification.

LABORATORY TESTING

Usually soil samples are obtained during the soil survey and are tested in the laboratory to determine test properties for classifying the soils. The principal tests are—

- Mechanical analysis.
- Liquid limit.
- Plastic limit.

These tests are used for all soils except those in the (Pt) group. With the percentages of gravel, sand, and fines and the LL and PI, the group symbol can be obtained from the chart in *Table 5-2, page 5-9,* by reading the diagram from top to bottom. For the gravels and sands containing 5 percent (or less) fines, the shape of the grain-size distribution curve can be used to establish whether the material is well-graded or poorly graded. For the fine-grained soils, it is necessary to plot the LL and PI in the drawing on *Figure 5-1, page 5-3,* to establish the proper symbol. Organic silts or clays (ML) and (MH) are subjected to LL and PL tests before and after oven drying. An organic silt or clay shows a radical drop in these limits as a result of oven drying. An inorganic soil shows a slight drop that is not significant. Where there is an appreciable drop, the predrying values should be used when the classification is determined from *Table 5-2, page 5-9.*

DESIRABLE SOIL PROPERTIES FOR ROADS AND AIRFIELDS

The properties desired in soils for foundations under roads and airfields are—

- Adequate strength.
- Resistance to frost action (in areas where frost is a factor).
- Acceptable compression and expansion.
- Adequate drainage.
- Good compaction.

Some of these properties may be supplied by proper construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water-collecting system. Strength requirements for base course materials are high, and only good quality materials are acceptable. However, low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying base materials or using a geotextile (see *Chapter 11).* Proper design of road and airfield pavements requires the evaluation of soil properties in more detail than possible by use of the general soils classification system. However, the grouping of soils in the classification system gives an initial indication of their behavior in road and airfield construction, which is useful in site or route selection and borrow source reconnaissance.

General characteristics of the soil groups pertinent to roads and airfields are in the soil classification sheet in *Table 5-3, page 5-11,* as follows:

- Columns 1 through 5 show major soil divisions, group symbols, hatching, and color symbols.
- Column 6 gives names of soil types.
- Column 7 evaluates the performance (strength) of the soil groups when used as subgrade materials that are not subject to frost action.
- Columns 8 and 9 make a similar evaluation for the soils when used as subbase and base materials.
- Column 10 shows potential frost action.
- Column 11 shows compressibility and expansion characteristics.
- Column 12 presents drainage characteristics.
- Column 13 shows types of compaction equipment that perform satisfactorily on the various soil groups.
- Column 14 shows ranges of unit dry weight for compacted soils.
- Column 15 shows ranges of typical California Bearing Ratio (CBR) values to be anticipated for use in airfield design.
- Column 16 gives ranges of modulus of subgrade reaction, k.

The various features are discussed in the following paragraphs.

Strength

In column 3 of *Table 5-3, page 5-11,* the basic soil groups (GM) and (SM) have each been subdivided into two groups designated by the following suffixes:

- d (represents desirable base and subbase materials).
- u (represents undesirable base and subbase materials).

This subdivision applies to roads and airfields only and is based on field observation and laboratory tests on soil behavior in these groups. The basis for the subdivision is the LL and PI of the fraction of the soil passing the Number 40 sieve. The suffix d is used when the LL is $\leq$ 25 and the PI is $\leq$ 5; the surfix u is used otherwise.

The descriptions in columns 7, 8, and 9 generally indicate the suitability of the soil groups for use as subgrade, subbase, or base materials not subjected to frost action. In areas where frost heaving is a problem, the value of materials as subgrades is reduced, depending on the potential frost action of the material (see column 10). Proper design procedures should be used in situations where frost action is a problem.

Coarse-Grained Soils. Generally, the coarse-grained soils make the best subgrade, subbase, and base materials. The (GW) group has excellent qualities as a base material. The adjective “excellent” is not used for any of these soils for base courses, because “excellent” should only be used to describe a high quality processed crushed stone. Poorly graded gravels and some silty gravels (groups (GP) and (GMd)) are usually only slightly less desirable as subgrade or subbase materials. Under favorable conditions, these gravels may be used as base materials; however, poor gradation and other factors sometimes reduce the value of these soils so they offer only moderate strength. For example—

- The (GMu), (GC), and (SW) groups are reasonably good subgrade or select materials but are generally poor to not suitable as base materials.
- The (SP) and (SMd) soils usually are considered fair to good subgrade and subbase materials but are generaily poor to not suitable as base materials.

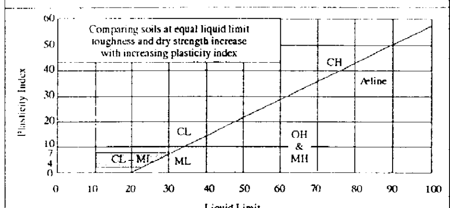
Fine-Grained Soils. The fine-grained soils range from fair to very poor subgrade materials as follows—

- Silts and lean clays (ML) and (CL) are fair to poor.
- Organic silts, lean organic clays, and micaceous or diatom aceous soils (OL) and (MH) are poor.
- Fat clays and fat organic clays (CH) and (OH) are poor to very poor.

Table 5-1. Unified soil classification (including identification and description).

Major Divisions (1)	(2)			Group Symbols (3)	Typical Names (4)	Field Identification Procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights) (5)	Information Required for Describing Soils (6)	Laboratory Classification Criteria (7)	
Coarse-grained soils More than half of the material is larger than No 200 sieve size (The No 200 sieve size is about the smallest particle visible to the naked eye)	Gravels More than half of coarse fraction is larger than No 4 sieve size (For visual classification, the 1/4 inch size may be used as equivalent to the 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	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.		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).			Atterberg limits below A-line or PI < 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 > 7
	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	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; aluvial sand; (SM)		$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
				SP	Poorly graded sands or gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing			Not meeting all gradation rquirements for SW
		Sands with fines (appreciable amount of fines)		SM	Silty sands, sand-silt mixture	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below).			Atterberg limits below A-line or PI < 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 > 7

Major Divisions (1)	(2)	Group Symbols (3)	Typical Names (4)	Identification procedures on fraction smaller than No 40 sieve size: Dry strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near PL)	Information Required for Describing Soils (6)
Fine-grained soils More than half of the material is smaller than No 200 seive size	Silts and clays LL < 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, and 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	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.
		OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow	Slight	
	Silts and clays LL > 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Slight to medium	Slow to none	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)
		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	
	Highly organic soils	Pt	Peat and other highly organic soils	Readily idenified by color, odor, spongy feel, and frequently by fibrous texture			



Plasiticity Chart
For laboratory classification of fine-grained soils

Field Identification Procedures for Fine-Grained Soils or Fractions

These procedures are to be performed on the minus No 40 sieve size particles, approximately 1/64 inch for field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (reaction to shaking)

After removing particles larger than Number 40 sieve size, prepare a pat of moist soil with a volume of about ½ cubic inch. 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 consists of 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 finally it 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 a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

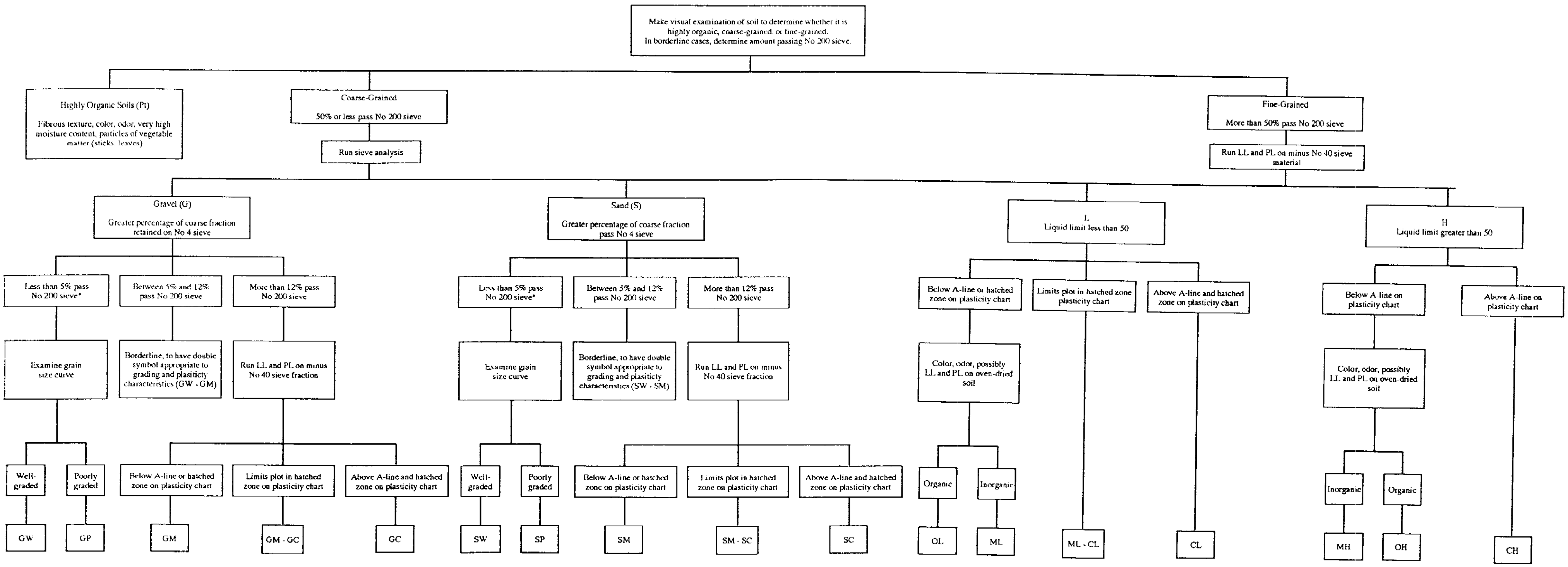
After removing particles larger than Number 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the charcter 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. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty, whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the Number 40 sieve size are removed, a specimen of soil about ½ cubic inch 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 ⅛ 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 more potent 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 that occur below the A-line.
Highly organic clays have a very weak and spongy feel at the plastic limit.

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

Table 5-2. Auxiliary laboratory identification procedure.



Note: Sieve sizes are US Standard.
* If fines interfere with free draining properties, use a double symbol such as (GW - GM).

Table 5-3. Characteristics pertinent to roads and airfields.

Major Divisions (1)	Major Divisions (2)	Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value as Subgrade When not Subject to Frost Action (7)	Value as Subbase When not Subject to Frost Action (8)	Value as Base When not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	Compaction Equipment (13)	Unit Dry Weight Pounds Per Cubic Foot (14)	Typical Design Values: CBR (15)	Typical Design Values: Subgrade Modulus k, Pounds Per Cubic Inch (16)
Coarse-grained soils	Gravel and gravelly soils	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125 – 140	40-80	300 – 500
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110 – 140	30-60	300 – 500
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired roller, sheeps-foot roller; close control of moisture	125 – 145	40-60	300 – 500
		GM u		Yellow		Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheeps-foot roller	115 – 135	20-30	200 – 500
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheeps-foot roller	130 – 145	20-40	200 – 500
	Sand and sandy soils	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110 – 130	20-40	200 – 400
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105 – 135	10-40	150 – 400
		SM d		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheeps-foot roller; close control of moisture	120 – 135	15-40	150 – 400
		SM u		Yellow		Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheeps-foot roller	100 – 130	10-20	100 – 300
		SC		Yellow	Clayey sands, sand-silt mixtures	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheeps-foot roller	100 – 135	5-20	100 – 300
Fine grained-soils	Silts and clays LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheeps-foot roller; close control of moisture	90 – 130	15 or less	100 – 200
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired roller, sheeps-foot roller	90 – 130	15 or less	50 – 150
		OL		Green	Organic silts and organic silt-clays of low plasticity	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired roller, sheeps-foot roller	90 – 105	5 or less	50 – 100
	Silts and clays LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	80 – 105	10 or less	50 – 100
		CH		Blue	Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	90 – 115	15 or less	50 – 150
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	80 – 110	5 or less	25 – 100
Highly organic soils		Pt		Orange	Peat and other highly organic soils	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical	–	–	–

Notes:

1. In column 3, the division of (GM) and (SM) groups into subdivisions of d and u are for roads and airfields only. Subdivision is on the basis of Atterberg limits: suffix d (for example GM_d) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u will be used otherwise.
2. In column 13, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed because variable soil charcteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.
   a. Processed base materials and other angular materials. Steel-wheeled and rubber-tired rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer materials subject to degradation.
   b. Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materials.
   c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:
      Crawler-type tractor - total weight in excess of 30,000 pounds.
      Rubber-tired equipment - wheel loads in excess of 15,000 pounds; wheel loads as high as 40,000 pounds may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 psi).
      Sheepsfoot roller - unit pressure (on 6- to 12- square-inch foot) to be in excess of 250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials. The area of the feet should be at least 5 percent of the total peripheral area of the drum, using the diameter measured to the faces of the feet.
3. In column 14, unit dry weights are for compacted soil at optimum moisture content for modified standard American Association of State Highway and Transportation Official (AASHTO) (standard Proctor) compactive effort CE 55.
4. In column 15, the maximum value that can be used in the design of airfields is, in some cases, limited by gradation and plasticity requirements.

These qualities are compensated for in flexible pavement design by increasing the thickness of overlying base material. In rigid pavement design, these qualifications are compensated for by increasing the pavement thickness or by adding a base course layer. None of the fine-grained soils are suitable as a subbase under bituminous pavements, but soils in the (ML) and (CL) groups may be used as select material. The fibrous organic soils (group (Pt)) are very poor subgrade materials and should be removed wherever possible; otherwise, special construction measures should be adopted. They are not suitable as subbase and base materials. The CBR values shown in column 15 give a relative indication of the strength of the various soil groups when used in flexible pavement design. Similarly, values of subgrade modulus (k) in column 16 are relative indications of strengths from plate-bearing tests when used in rigid pavement design. Actual test values should be used for this purpose instead of the approximate values shown in the tabulation.

For wearing surfaces on unsurfaced roads, slightly plastic sand-clay-gravel mixtures (GC) are generally considered the most satisfactory. However, they should not contain too large a percentage of fines, and the PI should be in the range of 5 to about 15.

Frost Action

The relative effects of frost action on the various soil groups are shown in column 10. Regardless of the frost susceptibility of the various soil groups, two conditions must be present simultaneously before frost action is a major consideration. These are-

- A source of water during the freezing period.
- A sufficient period for the freezing temperature to penetrate the ground.

Water necessary for the formation of ice lenses may become available from a high groundwater table, a capillary supply, water held within the soil voids, or through infiltration. The degree of ice formation that will occur is markedly influenced by physical factors, such as—

- Topographic position.
- Stratification of the parent soil,
- Transitions into a cut section.
- Lateral flow of water from side cuts.
- Localized pockets of perched groundwater,
- Drainage conditions.

In general, the silts and fine silty sands are most susceptible to frost. Coarse-grained materials with little or no fines are affected only slightly or not at all. Clays ((CL) and (CH)) are subject to frost action, but the loss of strength of such materials may not be as great as for silty soils. Inorganic soils containing less than 3 percent (by weight) of grains finer than 0.02 mm in diameter are considered non frost-susceptible. Where frost-susceptible soils occur in subgrades and frost is a problem, two acceptable methods of pavement design are available:

- Place a sufficient depth of acceptable granular material over the soils to limit the depth of freezing in the subgrade and thereby prevent the detrimental effects of frost action.
- Use a design load capacity during the period of the year when freezing conditions are expected.

In the second case, design is based on the reduced strength of the subgrade during the frost-melting period. Often an appropriate drainage measure to prevent the accumulation of water in the soil pores helps limit ice development in the subgrade and subbase.

Compression

The compression or consolidation of soils becomes a design factor primarily when heavy fills are made on compressible soils. The two types of compression are—

- Relatively long-term compression or consolidation under the dead weight of the structure.
- Short-term compression and rebound under moving wheel loads.

If adequate provision is made for this type of settlement during construction, it will have little influence on the load-carrying capacity of the pavement. However, when elastic soils subject to compression and rebound under wheel loads are encountered, adequate protection must be provided. Even small movements of this type soil may be detrimental to the base and wearing course of pavements. Fortunately, the free-draining, coarse-grained soils ((GW), (GP), (SW), and (SP)), which generally make the best subgrade and subbase materials, exhibit almost no tendency toward high compressibility or expansion. In general, the compressibility of soil increases with an increasing LL. However, compressibility is also influenced by soil structure, grain shape, previous loading history, and other factors not evaluated in the classification system. Undesirable compression or expansion characteristics may be reduced by distributing the load through a greater thickness of overlying material. These factors are adequately handled by the CBR method of design for flexible pavements. However, rigid pavements may require the addition of an acceptable base course under the pavement.

Drainage

The drainage characteristics of soils are a direct reflection of their permeability. The evaluation of drainage characteristics for use in roads and runways is shown in column 12 of *Table 5-3, page 5-11.* The presence of water in base, subbase, and subgrade materials, except for free-draining, coarse-grained soils, may cause pore water pressures to develop resulting in a loss of strength. The water may come from infiltration of groundwater or rainwater or by capillary rise from an underlying water table. While free-draining materials permit rapid draining of water, they also permit rapid ingress of water. If free-draining materials are adjacent to less pervious materials and become inundated with water, they may serve as reservoirs. Adjacent, poorly drained soils may become saturated. The gravelly and sandy soils with little or no fines (groups (GW), (GP), (SW), (SP)) have excellent drainage characteristics. The (GMd) and (SMd) groups have fair to poor drainage characteristics, whereas the (GMu), (GC), (SMu), and (SC) groups have very poor drainage characteristics or are practically impervious. Soils of the (ML), (MH), and (Pt) groups have fair to poor drainage characteristics. All other groups have poor drainage characteristics or are practically impervious.

Compaction

Compacting soils for roads and airfields requires attaining a high degree of density during construction to prevent detrimental consolidation from occurring under an embankment's weight or under traffic. In addition, compaction reduces the detrimental effects of water. Processed materials, such as crushed rock, are often used as a base course and require special treatment during compaction. Types of compaction equipment that may be used to achieve the desired soil densities are shown in *Table 5-3, column 13, page 5-11.* For some of the soil groups, several types of equipment are listed because variations in soil type within a group may require the use of a specific type of compaction equipment. On some construction projects, more than one type of compaction equipment may be necessary to produce the desired densities. For example, recommendations include—

- Steel-wheeled rollers for angular materials with limited amounts of fines.
- Crawler-type tractor or rubber-tired rollers for gravels and sand.
- Sheepsfoot rollers for coarse-grained or fine-grained soils having some cohesive qualities.
- Rubber-tired rollers for final compaction operations for most soil except those with a high LL (group H).

Suggested minimum weights of the various types of equipment are shown in note 2 of *Table 5-3, page 5-11.* Column 14 shows ranges of unit dry weight for soil compacted according to the moisture-density testing procedures outlined in Military Standard 621A, method 100. These values are included primarily for guidance; base design or control of construction should be based on laboratory test results.

DESIRABLE SOIL PROPERTIES FOR EMBANKMENTS AND FOUNDATIONS

Table 5-4 lists the soil characteristics pertinent to embankment and foundation

Table 5-4. Characteristics pertinent to embankment and foundation construction.

Major Divisions (1)	Major Divisions (2)	Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value for Embankments (7)	Permeability Centimeters Per Second (8)	Compaction Characteristics (9)	Standard AASHTO Maximum Unit Dry Weight Pounds Per Cubic Foot (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
Coarse-grained soils	Gravel and gravelly soils	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Very stable, pervious shells of dikes and dams	k > 10^{-2}	Good, tractor, rubber-tired roller, steel-wheeled roller	125 – 135	Good bearing value	Positive cutoff
		GP			Poorly graded gravels or gravel-sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	k > 10^{-2}	Good, tractor, rubber-tired roller, steel-wheeled roller	115 – 125	Good bearing value	Positive cutoff
		GM		Yellow	Silty gravels, gravel-sand-silt mixtures	Reasonably stable, not particularly suited to shells but may be used for impervious cores or blankets	k = 10^{-3} to 10^{-6}	Good, with close control, rubber-tired roller, sheepsfoot roller	120 – 135	Good bearing value	Toe trench to none
		GC			Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious cores	k = 10^{-6} to 10^{-8}	Fair, rubber-tired roller, sheepsfoot roller	115 – 130	Good bearing value	None
	Sand and sandy soils	SW		Red	Well-graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	k > 10^{-3}	Good, tractor	110 – 130	Good bearing value	Upstream blanket and toe drainage or wells
		SP			Poorly graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	k > 10^{-3}	Good, tractor	100 – 120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SM		Yellow	Silty sands, sand-silt mixtures	Fairly stable, not particularly suited to shells but may be used for impervious cores or dikes	k = 10^{-3} to 10^{-6}	Good, with close control, rubber-tired roller, sheepsfoot roller	110 – 125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SC			Clayey sands, sand-silt mixtures	Fairly stable, may be used for impervious core for flood-control structures	k = 10^{-6} to 10^{-8}	Fair, sheepsfoot roller, rubber-tired roller	105 – 125	Good to poor bearing value	None
Fine-grained soils	Silts and clays LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Poor stability, may be used for embankments with proper control	k = 10^{-3} to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95 – 120	Very poor, susceptible to liquefaction	Toe trench to none
		CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Stable, impervious cores, and blankets	k = 10^{-6} to 10^{-8}	Fair to good, sheepsfoot roller, rubber-tired roller	95 – 120	Good to poor bearing value	None
		OL			Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	k = 10^{-4} to 10^{-6}	Fair to poor, sheepsfoot roller	80 – 100	Fair to poor bearing value, may have excessive settlements	None
	Silts and clays LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	k = 10^{-4} to 10^{-6}	Poor to very poor, sheepsfoot roller	70 – 95	Poor bearing value	None
		CH			Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets, and dike sections	k = 10^{-6} to 10^{-8}	Fair to poor, sheepsfoot roller	75 – 105	Fair to poor bearing value	None
		OH			Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	k = 10^{-6} to 10^{-8}	Poor to very poor, sheepsfoot roller	65 – 100	Very poor bearing value	None
Highly organic soils		Pt		Orange	Peat and other highly organic soils	Not used for construction		Compaction not practical		Remove from foundations	

Notes:
1. Values in columns 7 and 11 are for guidance only. Design should be based on test results.
2. In column 9, the equipment listed will usually produce the desired densities with a reasonable number of passes when moisture conditions and the thickness of lift are properly controlled.
3. In column 10, unit dry weights are for compacted soil at optimum moisture content for standard AASHTO (standard Proctor) compactive effort CE 55.

construction. After the soil has been classified, look at column 3 and follow it downward to the soil class. *Table 5-4, page 5-15,* contains the same type of information as *Table 5-3, page 5-11,* except that column 8 lists the soil permeability and column 12 lists possible measures to control seepage. Material not pertinent to embankments and foundations, such as probable CBR values, are not contained in *Table 5-4, page 5-15.* Both tables are used in the same manner. Read the notes at the bottom of both tables carefully.

SOIL GRAPHICS

It is customary to present the results of soils explorations on drawings as schematic representations of the borings or test pits or on soil profiles with the various soils encountered shown by appropriate symbols. One approach is to write the group letter symbol in the appropriate section of the log. As an alternative, hatching symbols shown in column 4 of *Table 5-3, page 5-11,* may be used. In addition, show the natural water content of fine-grained soils along the side of the log. Use other descriptive remarks as appropriate. Colors may be used to delineate soil types on maps and drawings. A suggested color scheme to show the major soil groups is described in column 5. Boring logs are discussed in more detail in *Chapter 3.* Soil graphics generated in terrain studies usually use numeric symbols, each of which represents a USCS soil type.

FIELD IDENTIFICATION

The soil types of an area are an important factor in selecting the exact location of airfields and roads. The military engineer, construction foreman, and members of engineer reconnaissance parties must be able to identify soils in the field so that the engineering characteristics of the various soil types encountered can be compared. Because of the need to be economical in time, personnel, equipment, materiel, and money, selection of the project site must be made with these factors in mind. Lack of time and facilities often make laboratory soil testing impossible in military construction. Even where laboratory tests are to follow, field identification tests must be made during the soil exploration to distinguish between the different soil types encountered so that duplication of samples for laboratory testing is minimized. Several simple field identification tests are described in this manual. Each test may be performed with a minimum of time and equipment, although seldom will all of them be required to identify a given soil. The number of tests required depends on the type of soil and the experience of the individual performing them. By using these tests, soil properties can be estimated and materials can be classified. Such classifications are approximations and should not be used for designing permanent or semipermanent construction.

Procedures

The best way to learn field identification is under the guidance of an experienced soils technician. To learn without such assistance, systematically compare laboratory test results for typical soils in each group with the "feel" of these soils at various moisture contents.

An approximate identification of a coarse-grained soil can be made by spreading a dry sample on a flat surface and examining it, noting particularly grain size, gradation, grain shape, and particle hardness. All lumps in the sample must be thoroughly pulverized to expose individual grains and to obtain a uniform mixture when water is added to the fine-grained portion. A rubber-faced or wooden pestle and a mixing bowl is recommended for pulverizing. Lumps may also be pulverized by placing a portion of the sample on a firm, smooth surface and using the foot to mash it. If an iron pestle is used for pulverizing, it will breakup the mineral grains and change the character of the soil; therefore, using an iron pestle is discouraged.

Tests for identification of the fine-g-rained portion of any soil are performed on the portion of the material that passes a Number 40 sieve. This is the same soil fraction used in the laboratory for Atterberg limits tests, such as plasticity. If this sieve is not available, a rough separation may be made by spreading the material on a flat surface and removing the gravel and larger sand particles. Fine-grained soils are examined primarily for characteristics related to plasticity.

Equipment

Practically all the tests to be described may be performed with no equipment or accessories other than a small amount of water. However, the accuracy and uniformity of results is greatly increased by the proper use of certain equipment. The following equipment is available in nearly all engineer units (or may be improvised) and is easily transported:

- A Number 40 US standard sieve. Any screen with about 40 openings per lineal inch could be used, or an approximate separation may be used by sorting the materials by hand. Number 4 and Number 200 sieves are useful for separating gravels, sands, and fines.
- A pick and shovel or a set of entrenching tools for obtaining samples. A hand earth auger is useful if samples are desired from depths more than a few feet below the surface.
- A spoon issued as part of a mess equipment for obtaining samples and for mixing materials with water to desired consistency.
- A bayonet or pocket knife for obtaining samples and trimming them to the desired size.
- A small mixing bowl with a rubber-faced or wooden pestle for pulverizing the fine-grained portion of the soil. Both may be improvised by using a canteen cup and a wooden dowel.
- Several sheets of heavy nonabsorbent paper for rolling samples.
- A pan and a heating element for drying samples.
- A balance or scales for weighing samples.

Factors

The soil properties that form the basis for the Unified Soil Classification System are the—

- Percentage of gravels, sands, and fines.
- Shape of the grain-size distribution curve.
- Plasticity.

These same properties are to be considered in field identification. Other characteristics observed should also be included in describing the soil, whether the identification is made by field or laboratory methods.

Properties normally included in a description of a soil are—

- Color.
- Grain size, including estimated maximum grain size and estimated percent by weight of fines (material passing the Number 200 sieve),
- Gradation.
- Grain shape.
- Plasticity.
- Predominant type.
- Secondary components.
- Classification symbol.
- Other remarks, such as organic, chemical, or metallic content; compactness; consistency; cohesiveness near PL; dry strength; and source—residual or transported (such as eolian, water-borne, or glacial deposit).

An example of a soil description using the sequence and considering the properties referred to above might be—

- Dark brown to white.
- Coarse-grained soil, maximum particle size 2 ¾ inches, estimating 60 percent gravel, 36 percent sand, and 4 percent passing the Number 200 sieve.
- Poorly graded (insufficient fine gravel, gap-graded).
- Gravel particles subrounded to rounded.

- Nonplastic.
- Predominantly gravel.
- Considerable sand and a small amount of nonplastic fines (silt).
- (GP)
- Slightly calcareous, no dry strength, dense in the undisturbed state.

A complete description with the proper classification symbol conveys much more to the reader than the symbol or any other isolated portion of the description used alone.

Tests

The following tests can be performed to aid in field identification of soils:

Visual Examination Test. Determine the color, grain size, and grain shape of the coarse-grained portion of a soil by visual examination, The grain-size distribution may be estimated. To observe these properties, dry a sample of the material and spread it on a flat surface.

In soil surveys in the field, color is often helpful in distinguishing among various soil strata, and from experience with local soils, color may aid in identifying soil types. Since the color of a soil often varies with its moisture content, the condition of the soil when color is determined must always be recorded. Generally, more contrast occurs in these colors when the soil is moist, with all the colors becoming lighter as the moisture contents are reduced. In fine-grained soils, certain dark or drab shades of gray or brown (including almost-black colors) are indicative of organic colloidal matter ((OL) and (OH)). In contrast, clean and bright-looking colors (including medium and light gray, olive green, brown, red, yellow, and white) are usually associated with inorganic soils. Soil color may also indicate the presence of certain chemicals. Red, yellow, and yellowish-brown soil may be a result of the presence of iron oxides. White to pinkish colors may indicate the presence of considerable silica, calcium carbonate, or (in some cases) aluminum compounds. Grayish-blue, gray, and yellow mottled *colors* frequently indicate poor drainage.

Estimate the maximum particle size for each sample, thereby establishing the upper limit of the grain-size distribution curve for that sample. The naked eye can normally distinguish the individual grains of soil down to about 0,07 mm. All particles in the gravel and sand ranges are visible to the naked eye. Most of the silt particles are smaller than this size and are invisible to the naked eye. Material smaller than 0.75 mm will pass the Number 200 sieve.

Perform the laboratory mechanical analysis whenever the grain-size distribution of a soil sample must be determined accurately; however, the grain-size distribution can be approximated by visual inspection. The best way to evaluate a material without using laboratory equipment is to spread a portion of the dry sample on a flat surface. Then, using your hands or a piece of paper, separate the material into its various grain-size components. By this method, the gravel particles and some of the sand particles can be separated from the remainder. This will at least give you an opportunity to estimate whether the total sample is to be considered coarse-grained or fine-grained, depending on whether or not more than 50 percent of the material would pass the Number 200 sieve. Percentage of values refers to the dry weight of the soil fractions indicated as compared to the dry weight of the original sample. A graphical summary of the procedure is shown in *Figure 5-2, page 5-20*.

If you believe the material is coarse-grained, then consider the following criteria:

- Does less than 5 percent pass the Number 200 sieve?
- Are the fines nonplastic?

If both criteria can be satisfied and there appears to be a good representation of all grain sizes from largest to smallest, without an excessive deficiency of any one size, the material may be said to be well-graded ((GW) or (SW)). If any intermediate sizes appear to be missing or if there is too much of any one size, then the material is poorly graded ((GP) or (SP)). In some cases, it may only be

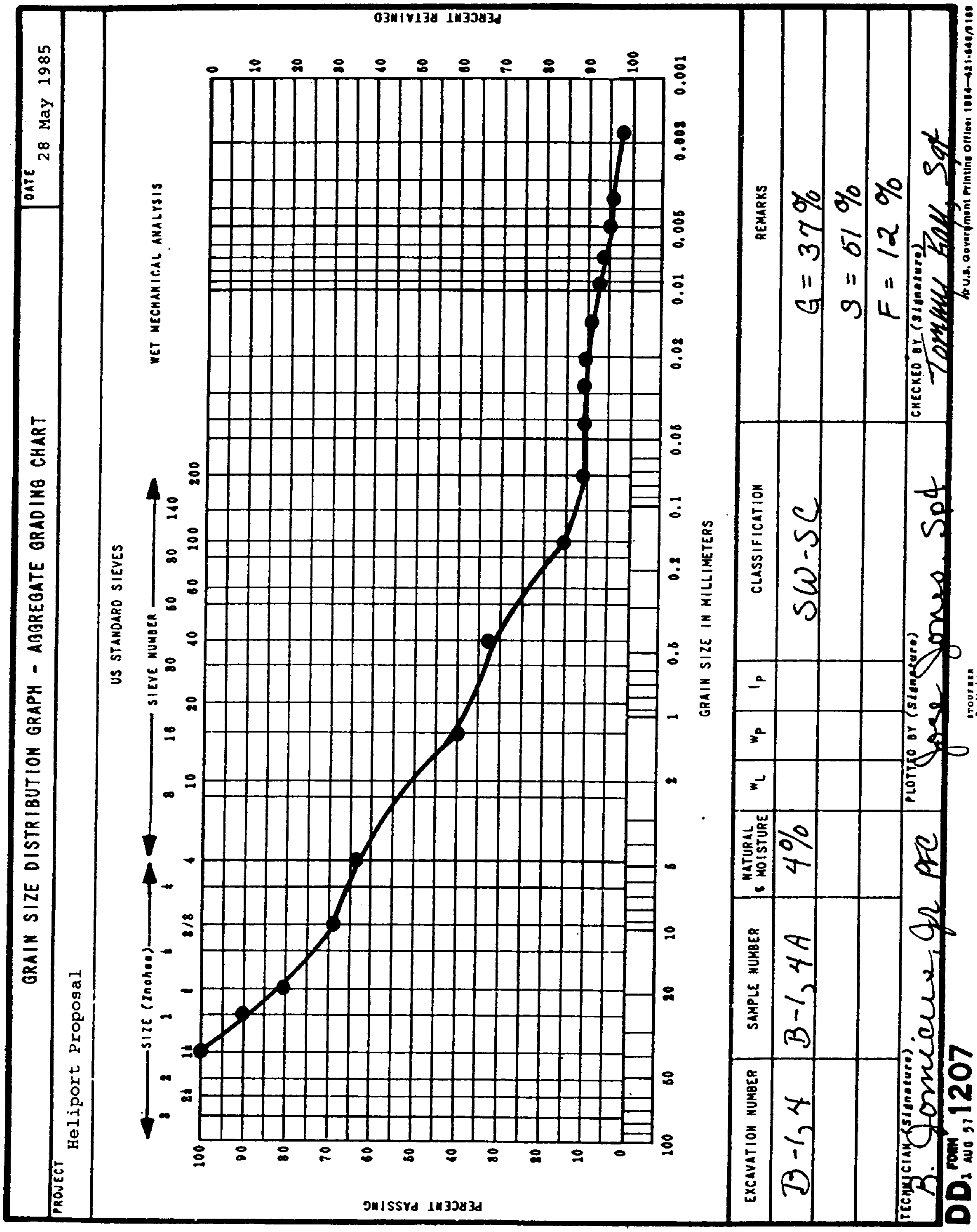


Figure 5-2. Graphical summary of grain-size distribution.

possible to take a few of the standard sieves into the field. When this is the case, take the Number 4, Number 40, and Number 200 sieves. The sample may be separated into gravels, sands, and fines by use of the Number 4 and Number 200 sieves. However, if there is a considerable quantity of fines, particularly clay particles, separation of the fines can only be readily accomplished by washing them through the Number 200 sieve. In such cases, a determination of the percentage of fines is made by comparing the dry weight of the original sample with that retained on the Number 200 sieve after washing. The difference between these two is the weight of the fines lost in the washing process. To determine the plasticity, use only that portion of the soil passing through a Number 40 sieve.

Estimating the grain-size distribution of a sample using no equipment is probably the most difficult part of field identification and places great importance on the experience of the individual making the estimate. A better approximation of the relative proportions of the components of the finer soil fraction may sometimes be obtained by shaking a portion of this sample into a jar of water and allowing the material to settle. It will settle in layers, with the gravel and coarse sand particles settling out almost immediately. The fine sand particles settle within a minute; the silt particles require as much as an hour; and the clay particles remain in suspension indefinitely or until the water is clear. In using this method, remember that the gravels and sands settle into a much more dense formation than either the silts or clays.

The grain shape of the sand and gravel particles can be determined by close examination of the individual grains. The grain shape affects soil stability because of the increased resistance to displacement found in the more irregular particles. A material with rounded grains has only the friction between the surfaces of the particles to help hold them in place. An angular material has this same friction force, which is increased by the roughness of the surface. In addition, an interlocking action is developed between the particles, which gives the soil much greater stability.

A complete description of a soil should include prominent characteristics of the undisturbed material. The aggregate properties of sand and gravel are described qualitatively by the terms “loose,” “medium,” and “dense.” Clays are described as “hard,” “stiff,” “medium, ” and “soft.”

These characteristics are usually evaluated on the basis of several factors, including the relative ease or difficulty of advancing the drilling and sampling tools and the consistency of the samples. In soils that are described as “soft,” there should be an indication of whether the material is loose and compressible, as in an area under cultivation, or spongy (elastic), as in highly organic soils. The moisture condition at the time of evaluation influences these characteristics and should be included in the report.

Breaking or Dry Strength Test. The breaking test is performed only on material passing the Number 40 sieve. This test, as well as the roll test and the ribbon test, is used to measure the cohesive and plastic characteristics of the soil. The testis normally made on a small pat of soil about ½ inch thick and about 2 inches in diameter. The pat is prepared by molding a portion of the soil in the wet plastic state into the size and shape desired and then allowing the pat to dry completely. Samples may be tested for dry strength in their natural conditions. Such a test may be used as an approximation; however, it should be verified later by testing a carefully prepared sample.

After the prepared sample is thoroughly dry, attempt to break it using the thumb and forefingers of both hands (see *Figure 5-3,page 5-22)*. If it can be broken, try to powder it by rubbing it with the thumb and fingers of one hand.

Typical reactions obtained in this test for various types of soils are described below.

- Very highly plastic soils. (CH); very high dry strength, Samples cannot be broken or powdered using finger pressure.

- Highly plastic soils, (CH); high dry strength. Samples can be broken with great effort but cannot be powdered.
- Medium plastic soils, (CL); medium dry strength. Samples can be broken and powdered with some effort.
- Slightly plastic soils, (ML), (MH), or (CL); low dry strength. Samples can be broken quite easily and powdered readily.
- Nonplastic soils, (ML) or (MH); very little or no dry strength. Samples crumble and powder on being picked up in the hands.

Figure 5-3. Breaking or dry strength test.

The breaking or dry strength test is one of the best tests for distinguishing between plastic clays and nonplastic silts or fine sands. However, a word of caution is appropriate. Dry pats of highly plastic clays quite often display shrinkage cracks. Breaking the sample along one of these cracks gives an indication of only a very small part of the true dry strength of the clay. It is important to distinguish between a break along such a crack and a clean, fresh break that indicates the true dry strength of the soil.

Roll or Thread Test. The roll or thread test is performed only on material passing the Number 40 sieve. Prepare the soil sample by adding water to the soil until the moisture content allows easy remolding of the soil without sticking to the fingers. This is sometimes referred to as being just below the "sticky limit." Using a nonabsorbent surface, such as glass or a sheet of heavy coated paper, rapidly roll the sample into a thread approximately 1/8 inch in diameter *Figure 5-4.*

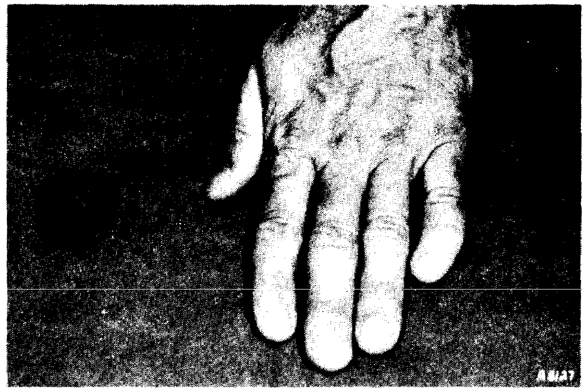


Figure 5-4. Roll or thread test.

A soil that can be rolled into a l/8-inch-diarneter thread at some moisture content has some plasticity. Materials that cannot be rolled in this manner are nonplastic or have very low plasticity. The number of times that the thread may be lumped together and the rolling process repeated without crumbling and breaking is a measure of the degree of plasticity of the soil. After the PL is reached, the degree of plasticity may be described as follows:

- Highly plastic soils, (CH). The soil may be remolded into a ball and the ball deformed under extreme pressure by the fingers without cracking or crumbling.
- Medium plastic soils, (CL). The soil may be remolded into a ball, but the ball will crack and easily crumble under pressure of the fingers.
- Low plastic soils, (CL), (ML), or (MH). The soil cannot be lumped together into a ball without completely breaking up.
- Organic materials, (OL) or (OH). Soils containing organic materials or mica particles will form soft spongy threads or balls when remolded.
- Nonplastic soils, (ML) or (MH). Nonplastic soils cannot be rolled into a thread at any moisture content.

From this test, the cohesiveness of the material near the PL may also be described as weak, firm, or tough. The higher the position of a soil on the plasticity chart, the stiffer are the threads as they dry out and the tougher are the lumps if the soil is remolded after rolling.

Ribbon Test. The ribbon test is performed only on the material passing the Number 40 sieve. The sample prepared for use in this test should have a moisture content slightly below the sticky limit. Using this material, form a roll of soil about ½ or ¾ inch in diameter and about 3 to 5 inches long. Place the material in the palm of the hand and, starting with one end, flatten the roll, forming a ribbon 1/8 to ¼ inch thick by squeezing it between the thumb and forefinger (see *Figure 5-5).* The sample should be handled carefully to form the maximum length of ribbon that can be supported by the cohesive properties of the material. If the soil sample holds together for a length of 8 to 10 inches without breaking, the material is considered to be both plastic and highly compressive (CH).

If soil cannot be ribboned, it is nonplastic (ML) Or (MH). If it can be ribboned only with difficulty into short lengths, the soil is considered to have low plasticity (CL). The roll test and the ribbon test complement each other in giving a clearer picture of the degree of plasticity of a soil.

Figure 5-5. Ribbon test (highly plastic clay).

Wet Shaking Test. The wet shaking test is performed only on material passing the Number 40 sieve. In preparing a portion of the sample for use in this test, moisten enough material with water to form a ball of material about ¾ inch in diameter. This sample should be just wet enough so that the soil will not stick to the fingers when remolding (just below the sticky limit) (see *Figure 5-6a, page 5-24).*

Place the sample in the palm of your hand and shake vigorously (see *Figure 5-6b, page 5-24).* Do this by jarring the hand on the table *or* some other firm object or by jarring it against the other hand. The soil has reacted to this test when, on shaking, water comes to the surface of the sample producing a smooth, shiny appearance (see *Figure 5-6c, page 5-24).* This appearance is frequently described as "livery." Then, squeeze the sample between the thumb and forefinger of the other hand. The surface water will quickly disappear, and the surface will become dull. The material will become firm and resist deformation. Cracks will occur as pressure is continued, with the sample finally crumbling like a brittle material. The vibration caused by the shaking of the soil sample tends to reorient the soil grains, decrease voids, and force water that had been within these voids to the surface. Pressing the sample between the fingers tends to disarrange the soil grains, increase the void space, and draw the water into the soil. If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together. This process only occurs when the soil grains are bulky and cohesionless.

Very fine sands and silts are readily identified by the wet shaking test. Since it is rare that fine sands and silts occur without some amount of clay mixed with them, there are varying degrees of reaction to this test. Even a small amount of clay tends to greatly retard this reaction. Descriptive terms applied to the different rates of reaction to this test are—

- Sudden or rapid.
- Sluggish or slow.
- No reaction.

(a) Sample is wet, but not sticky.

(b) Sample being shaken vigorously.

(c) Water on surface of sample.

Figure 5-6. Wet shaking test.

A sudden or rapid reaction to the shaking test is typical of nonplastic fine sands and silts. A material known as rock flour, which has the same size range as silt, also gives this type of reaction.

A sluggish or slow reaction indicates slight plasticity, such as that which might be found from a test of some organic or inorganic silts or from silts containing a small amount of clay.

Obtaining no reaction at all to this test does not indicate a complete absence of silt or fine sand. Even a slight content of colloidal clay imparts some plasticity and slows the reaction to the shaking test. Extremely slow or no reaction is typical of all inorganic clays and highly plastic clays.

Odor Test. Organic soils of the (OL) and (OH) groups have a distinctive musty, slightly offensive odor, which can be used as an aid in identifying such material. This odor is especially apparent from fresh samples. Exposure to air gradually reduces the odor, but heating a wet sample rejuvenates the odor. Organic soils are undesirable as foundation or base course material and are usually removed from the construction site.

Bite or Grit Test. The bite or grit test is a quick and useful method of distinguishing among sands, silts, or clays. In this test, a small pinch of the soil material is ground lightly between the teeth and identified.

A sandy soil may be identified because the sharp, hard particles of sand grate very harshly between the teeth and will be highly objectionable. This is true even of the fine sand.

The silt grains of a silty soil are so much smaller than sand grains that they do not feel nearly so harsh between the teeth. Silt grains are not particularly objectionable, although their presence is still easily detected.

The clay grains of a clayey soil are not gritty but feel smooth and powdery, like flour, between the teeth. Dry lumps of clayey soils stick when lightly touched with the tongue.

Slaking Test. The slaking test is useful in determining the quality of certain shales and other soft rocklike materials. The test is performed by placing the soil in the sun or in an oven to dry and then allowing it to soak in water for a period of at least 24 hours. The strength of the soil is then examined. Certain types of shale completely disintegrate, losing all strength.

Other materials that appear to be durable rocks may be crumbled and readily broken by hand after such soaking. Materials that have a considerable reduction in strength are undesirable for use as base course materials.

Acid Test. The acid test is used to determine the presence of calcium carbonate. It is performed by placing a few drops of HC1 on a piece of soil. A fizzing reaction (effervescence) to this test indicates the presence of calcium carbonate.

CAUTION

HC1 may cause burns. Use appropriate measures to protect the skin and eyes. If it is splashed on the skin or in the eyes, immediately flush with water and seek medical attention.

Calcium carbonate is normally desirable in a soil because of the cementing action it provides to add to the soil's stability. In some very dry noncalcareous soils, the absorption of the acid creates the illusion of effervescence. This effect can be eliminated in dry soils by moistening the soil before applying the acid.

Since cementation is normally developed only after a considerable curing period, it cannot be counted on for strength in most military construction. This test permits better understanding of what appears to be abnormally high strength values on fine-grained soils that are tested in-place where this property may exert considerable influence.

Shine Test. The shine testis another means of measuring the plasticity characteristics of clays. A slightly moist or dry piece of highly plastic clay will give a definite shine when rubbed with a fingernail, a pocketknife blade, or any smooth metal surface. On the other hand, a piece of lean clay will not display any shine but will remain dull.

Feel Test. The feel test is a general-purpose test and one that requires considerable experience and practice before reliable results can be obtained. This test will be used more as familiarity with soils increases. Moisture content and texture can be readily estimated by using the feel test.

The natural moisture content of a soil indicates drainage characteristics, nearness to a water table, or other factors that may affect this property. A piece of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency. The consistency is described by such terms as "hard," stiff," "brittle," "friabie," "sticky," "plastic," or "soft." Remold the soil by working it in the hands and observing any changes. By this test, the natural water content is estimated relative to the LL or PL of the soil. Clays that turn almost liquid on remolding are probably near or above the LL. If the clay remains stiff and crumbles on being remolded, the natural water content is below the PL.

The term "texture," as applied to the fine-grained portion of a soil, refers to the degree of fineness and uniformity. Texture is described by such expressions as "floury," "smooth," "gritty," or "sharp," depending on the feel when the soil is rubbed between the fingers. Sensitivity to this sensation may be increased by rubbing some of the material on a more tender skin area, such as the inside of the wrist. Fine sand will feel gritty. Typical dry silts will dust readily and feel relatively soft and silky to the touch. Clay soils are powdered only with difficulty but become smooth and gritless like flour.

Hasty Field Identification

With the standard methods of field identification supplemented with a few simplified field tests, an approximate and hasty classification of almost any soil can be obtained. The simple or hasty tests outlined in *Figure 5-7, page 5-26,* will, for the most part,

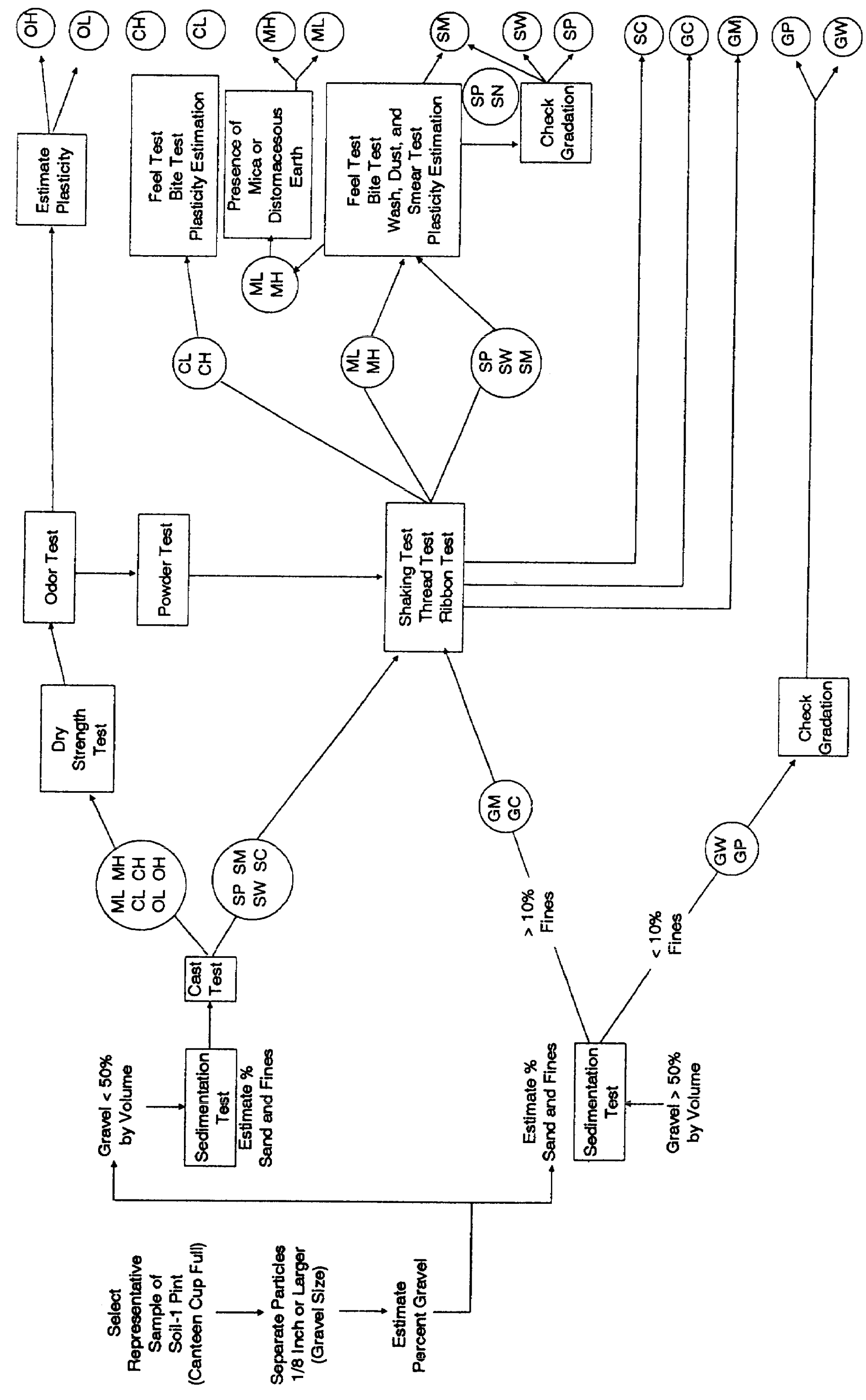


Figure 5-7. Suggested procedure for hasty field identification.

1. Select a random but typical sample of soil.

2. Separate the gravel.
   (a) Remove from the sample all particles larger than 1/4 inch in diameter.
   (b) Estimate the percent of gravel.

3. Use the sedimentation test to determine the percent of sand.
   (a) Place the sample (less gravel) in a canteen cup and fill it with water.
   (b) Shake the mixture vigorously.
   (c) Allow the mixture to stand for 30 seconds to settle out.
   (d) Pour the water containing the suspended fines into another container.
   (e) Repeat steps (b) through (d) until the water poured off is clear.
   (f) Dry the soil left in the cup (sand).
   (g) Estimate the percent of sand.

4. Compare the gravels, sands, and fines.
   (a) The gravels have been estimated in test (2), step (b).
   (b) The sands have been estimated in test (3), step (g).
   (c) Dry the soil remaining in the second container (fines).
   (d) Estimate the percent of fines.

5. Cast test.
   (a) Compress a handful of moist (but not sticky) soil into a ball or cigar-shaped cast.
   (b) Observe the ability of the cast to withstand handling without crumbling.
   (c) If the cast crumbles when touched, the sample is a sand with little or no fines (SW) or (SP).
   (d) If the cast withstands careful handling, the sample is a sand with an appreciable amount of fines (SM) or (SC).
   (e) If the cast can be handled freely or withstands rough handling, the sample is either silt, clay, or organic.

6. Dry strength test.*
   (a) Form a moist pat 2 inches in diameter by 1/2 inch thick.
   (b) Allow it to dry with low heat.
   (c) Place the dry pat between the thumb and index finger only and attempt to break it.
   (d) If breakage is easy, it is a slightly plastic silt (ML).
   (e) If breakage is difficult, it is a medium plastic and medium compressible clay (CL) or a highly compressible silt (MH).
   (f) If breakage is impossible, it is a highly plastic and highly compressible clay (CH).

7. Odor test.
   (a) Heat the sample with a match or open flame.
   (b) If the odor becomes musty or foul smelling, there is a strong indication that organic material is present.

8. Powder test.*
   (a) Rub a portion of the broken pat with the thumb and attempt to flake particles off.
   (b) If the pat powders, it is silt.
   (c) If the pat does not powder, it is clay.

9. Wet shaking test.*
   (a) Place the pat of moist (not sticky) soil in the palm of the hand (the volume is about 1/2 cubic inch).
   (b) Shake the hand vigorously and strike it against the other hand.
   (c) Observe how rapidly water rises to the surface.
   (d) If it is fast, the sample is silty. If there is no reaction, the sample is clayey (C).

* Tests conducted on material smaller than 1/32 inch in diameter (passes Number 40 sieve).

Figure 5-7. Suggested procedure for hasty field identification (continued).

10. Thread test.*
    (a) Form a ball of moist soil (marble size).
    (b) Attempt to roll the ball into a thread 1/8 inch in diameter.
    (c) If a thread is easily obtained, it is clay.
    (d) If a thread cannot be obtained, it is silt.

11. Ribbon test.*
    (a) Form a cylinder of soil that is approximately the shape and size of a cigar.
    (b) Flatten the cylinder over the index finger with the thumb, attempting to form a ribbon 8 to 9 inches long, 1/8 to 1/4 inch thick, and 1 inch wide.
    (c) If 8 to 9 inches is obtained, it is (CH); if less than 8 inches is obtained, it is (CL); if there is no ribbon, it is silt (ML) or sand.

12. Shine test.*
    (a) Draw a smooth surface, such as a knife blade or a thumbnail, over a pat of slightly moist soil.
    (b) If the surface becomes shiny and lighter in texture, the sample is a highly plastic compressible clay (CH).
    (c) If the surface remains dull, the sample is a low plasticity compressible clay (CL).
    (d) If the surface remains very dull or granular, the sample is silt or sand.

13. Feel test.*
    (a) Rub a portion of dry soil over a sensitive portion of the skin, such as the inside of the wrist.
    (b) If the feel is harsh and irritating, the sample is silt (ML) or sand.
    (c) If the feel is smooth and floury, the sample is clay.

14. Grit or bite test.*
    (a) Place a pinch of the sample between the teeth and bite.
    (b) If the sample feels gritty, the sample is silt (ML) or sand.
    (c) If the sample feels floury, the sample is clay.

15. Wash, dust, and smear test.*
    (a) Drop a completely dry sample of soil from a height of 1 to 2 feet onto a solid surface.
    (b) If a fairly large amount of dust is produced, the sample is a silty sand (SM).
    (c) If very little dust is produced, the sample is a clean sand (SW or SP). Check the gradation.
    (d) Smear a moistened (just below "sticky limit") sample of soil between the thumb and forefinger.
    (e) If a gritty, harsh feel is produced, the soil contains a small amount of silt (SW or SP). Check the gradation.
    (f) If a rough, less harsh feel is produced, the soil contains about 10 percent silt (SM).

16. Plasticity estimation.
    (a) Remove all particles coarser than a grain of sugar or table salt from the sample.
    (b) From the remaining soil particles, mold a small cube to the consistency of stiff putty.
    (c) Dry the cube in the air or sunlight.
    (d) Crush the cube between the fingers.
    (e) If the cube falls apart easily, the soil is nonplastic; PI range, 0 to 3.
    (f) If the cube is easily crushed, the soil is slightly plastic; PI range, 4 to 8.
    (g) If the cube is difficult to crush, the soil is medium plastic; PI range, 9 to 30.
    (h) If the cube is impossible to crush, the soil is highly plastic; PI range, 31 or more.

* Tests conducted on material smaller than 1/32 inch in diameter (passes Number 40 sieve).

Figure 5-7. Suggested procedure for hasty field identification (continued).

eliminate the need for specialized equipment such as sieves. The results will give at least a tentative classification to almost any soil. The schematic diagram in *Figure 5-7, page 5-26,* may be used as a guide to the testing sequence in the process of assigning a symbol to a sample of soil.

OPTIMUM MOISTURE CONTENT (OMC)

To determine whether a soil is at or near OMC, mold a golf-ball-size sample of the soil with your hands. Then squeeze the ball between your thumb and forefinger. If the ball shatters into several fragments of rather uniform size, the soil is near or at OMC. If the ball flattens out without breaking, the soil is wetter than OMC. If, on the other hand, the soil is difficult to roil into a ball or crumbles under very little pressure, the soil is drier than OMC.

Section II. Other Soil Classification Systems

COMMONLY USED SYSTEMS

Information about soils is available from many sources, including publications, maps, and reports. These sources may be of value to the military engineer in studying soils in a given area. For this reason, it is important that the military engineer have some knowledge of other commonly used systems. *Table 5-5* gives approximate equivalent groups for the USGS, Revised Public Roads System, and the Federal Aviation Administration (FAA) System.

Revised Public Roads System

Most civil agencies concerned with highways in the United States classify soil by the Revised Public Roads System. This includes the Bureau of Public Roads and most of the state highway departments. The Public Roads System was originated in 1931. Part of the original system, which applied to uniform subgrade soils, used a number of tables and charts based on several routine soil tests to permit placing of a given soil into one of eight principal groups, designated A-1 through A-8. The system was put into use by many agencies. As time passed, it became apparent that some of the groups were too broad in coverage because somewhat different soils were classed in the same group. A number of the agencies using the system modified it to

Table 5-5. Comparison of the USCS, Revised Public Roads System, and FAA System.

USCS	Revised Public Roads System	Federal Aviation Administration System	
GW	A-1-a	Gravelly soils not included directly	
GP	A-1-a		
GM	A-1-a, A-2-4 or 5		
GC	A-2-6 or 7		
SW	A-1-b	E-1, 2 or 3	E-4 or 5 (usually SM or SC)
SP	A-3		
SM	A-1-b, A-2-4 or 5		
SC	A-2-6 or 7		
MI	A-4	E-6	E-8 (usually L group) E-9 (usually not CH)
CL	A-6, A-7-5		
OL	A-4, A-7-5	E-6	
MH	A-5		
CH	A-7	E-10, 11 or 12	
OH	A-7		
Pt		E-13	

Note: Groups are only approximately equivalent, since different limiting values are used in each system.

suit their purposes. Principal modifications included breaking down some of the broad groups into subgroups of more limited scope. The revisions culminated in a comprehensive committee report that appeared in the *Proceedings of the 25th Annual Meeting of the Highway Research Board (1945).* This same report contains detailed information relative to the Airfield Classification System and the Federal Aviation Administration System. The Revised Public Roads System is primarily designed for the evaluation of subgrade soils, although it is useful for other purposes also.

Basis. *Table 5-6* shows the basis of the Revised Public Roads System. Soils are classed into one of two very broad groups. They are—

- Granular materials, which contain < 35 percent of material passing a Number 200 sieve.
- Silt-clay materials, which contain > 35 percent of material passing a Number 200 sieve.

There are seven major groups, numbered A-1 through A-7, together with a number of suggested subgroups. The A-8 group of the original system, which contained the highly organic soils such as peat, is not included in the revised system. The committee felt that no group was needed for these soils because of their ready identification by appearance and odor. Whether a soil is silty or clayey depends on its PI. "Silty" is applied to material that has a PI < 10 and "clayey" is applied to a material that has a PI ≥ 10.

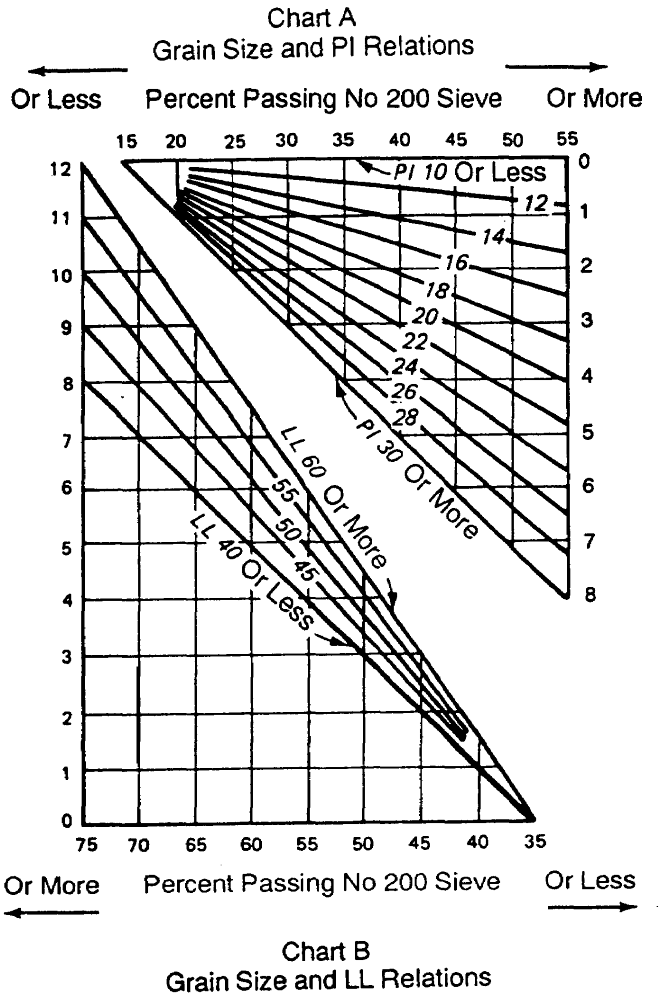
Figure 5-8 shows the formula for group index and charts to facilitate its computation. The group index was devised to provide a basis for approximating within-group evaluations. Group indexes range from 0 for the best subgrade soils to 20 for the poorest. Increasing values of the group index within each basic soil group reflect the combined effects of increasing LLs and PIs and decreasing percentages of coarse material in decreasing the load-carrying capacity of subgrades. *Figure 5-9, page 5-32,* graphically shows the ranges of LL and PI for the silt-clay groups. It is particularly useful for subdividing the soils of the A-7 group.

Procedure. *Table 5-6* is used in a left-to-right elimination process, and the given soil is placed into the first group or subgroup in

Table 5-6. Revised Public Roads System of soil classification.

General Classification	Granular Materials (35 percent or less of total sample passing No 200 sieve)							Silt-Clay Materials (More than 35 percent of total sample passing No 200 sieve)			
Group classification	A-1			A-2							
	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7 A-7-5 A-7-6
Sieve analysis, percent passing:											
No 10 sieve	50 max	—	—	—	—	—	—	—	—	—	—
No 40 sieve	30 max	50 max	51 min	—	—	—	—	—	—	—	—
No 200 sieve	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of portion passing:											
Liquid limit		—	—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	min*
Plasticity index		6 max	NP**	10 max	10 max	11 min	11 min	10 max	10 max	10 max	10 max
Group index[6]		0	0		0		4 max	8 max	12 max	16 max	20 max

* PI of A-7-5 subgroup is ≤ LL minus 30. PI of A-7-6 subgroup is > LL minus 30.



Group Index = Sum of Readings on Both Vertical Scales

The group index formula is as follows:

Group index = $0.2a + 0.005ac + 0.01bd$ where

a = that portion of percentage passing No 200 sieve greater than 35 percent and not exceeding 75 percent, expressed as a positive whole number (1 to 40)

b = that portion of percentage passing No 200 sieve greater than 15 percent and not exceeding 55 percent, expressed as a positive whole number (1 to 40)

c = that portion of the numerical LL greater than 40 and not exceeding 60, expressed as a positive whole number number (1 to 20)

d = that portion of the numerical PI greater than 10 and not exceeding 30, expressed as a positive whole number (1 to 20)

Figure 5-8. Group index formula and charts, Revised Public Roads System.

which it fits. In order to distinguish the revised from the old system, the group symbol is given, followed by the group index in parentheses (for example, A-4(5)). The fact that the A-3 group is placed ahead of the A-2 group does not imply that it is a better subgrade material. This arrangement is used to facilitate the elimination process. The classification of some borderline soils requires judgment and experience. The assignment of the group designation is often accompanied by the writing of a careful description, as in the USCS. Detailed examples of the classification procedure are given later in this chapter.

Agricultural Soil Classification System

Many reports published for agricultural purposes can be useful to the military engineer. Two phases of the soil classification system used by agricultural soil scientists are discussed here. These are—

- Grain-size classification (textural classification).
- Pedological classification.

Textural Classification. Information about the two textural classification systems of the US Department of Agriculture is contained in *Figure 5-10, page 5-33, and Table 5-7, page 5-34.* The chart and table are largely self-explanatory. The grain-size limits, which are applicable to the categories shown, are as follows:

- Coarse gravel, retained on Number 4 sieve.
- Fine gravel, passing Number 4 and retained on Number 10 sieve.
- Coarse sand, passing Number 10 and retained on Number 60 sieve.
- Fine sand, passing Number 60 and retained on Number 270 sieve (0.05 mm).
- Silt, 0.05 to 0.005 mm.
- Clay, below 0.005 mm.

Pedological Classification. Soil profile and pedology were discussed in *Chapter 1.* Agricultural soil scientists have devised a complete and complex system for describing and classifiing surface soils. No attempt will

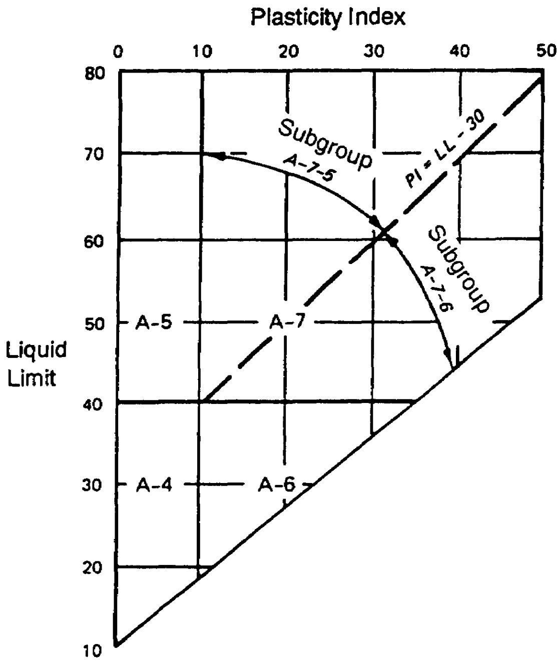


Figure 5-9. Relationship between LL and PI for silt-clay groups, Revised Public Roads System.

be made to discuss this system in detail here. The portion of the system in which engineers are principally interested refers to the terms used in mapping limited areas. Mapping is based on—

- Series.
- Type.
- Phase.

The designation known as soil series is applied to soils that have the same genetic horizons, possess similar characteristics and profiles, and are derived from the same parent material. Series names follow no particular pattern but are generally taken from the geographical place near where they were first found. The soil type refers to the texture of the upper portion of the soil profile. Several types may, and usually do, exist within a soil series. Phase is variation, usually of minor importance, in the soil type.

A mapping unit may be "Emmet loamy sand, gravelly phase" or any one of the large number of similar designations. Soils given the same designation generally have the same agricultural properties wherever they are encountered. Many of their engineering properties may also be the same. The mapping unit in which a given soil is placed is determined by a careful examination of the soil sample obtained by using an auger to bore or by observing highway cuts, natural slopes, and other places where the soil profile is exposed. Particularly important factors are—

- Color.
- Texture.
- Organic material.
- Consistency.

Other important factors are—

- Slope.
- Drainage.
- Vegetation.
- Land use.

Agricultural soil maps prepared from field surveys show the extent of each important soil type and its geographical location. Reports that accompany the maps contain word descriptions of the various types, some laboratory test results, typical profiles, and soil properties important to agricultural use. Frequently prepared on a county basis, soil surveys (maps and reports) are available for many areas in the United States and in many foreign countries. For installation projects, check with the Natural Resources Branch or Land Management Branch of the Directorate of Engineering and Housing for a copy of the soil survey. For off-post projects, request a copy of the soil survey from the county Soil Conservation Service (SCS). The information contained in the soil survey is directly useful to engineers.

Geological Soil Classification

Geologists classify soils according to their origin (process of formation) following a pattern similar to that used in *Chapter 1*. *TM 5-545* gives a geological classification of soil deposits and related information.

TYPICAL SOIL CLASSIFICATION

The following paragraphs concern the classification of four inorganic soil types on the

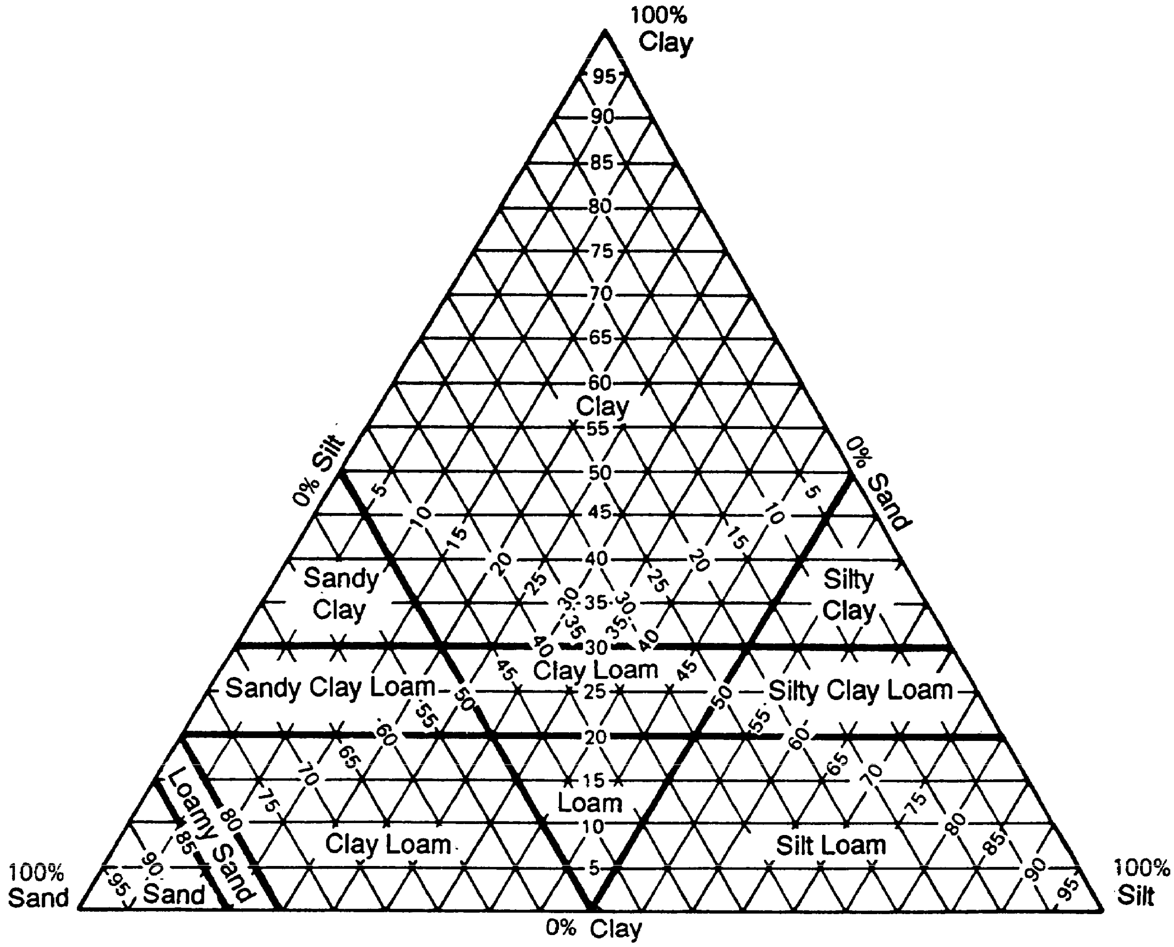


Figure 5-10. US Department of Agriculture textural classification chart.

basis of laboratory test data. Each soil is classified under the Unified Soil Classification System, the Revised Public Roads System, and the Agricultural Soil Classification System. *Table 5-8, page 5-35*, shows the information known about each soil.

Unified Soil Classification System

The results of the classification of the four soil types under this system are as follows:

Soil Nunzber 1. The soil is fine-grained since more than half passes the Number 200 sieve. The LL is less than 50; therefore, it must be (ML) or (CL) since it is inorganic. On the plasticity chart, it falls below the A-line; therefore, it is a sandy silt (ML).

Soil Number 2. The soil is fine-grained since more than half passes the Number 200 sieve. The LL is more than 50; therefore, it must be (MH) or (CH). On the plasticity chart, it falls above the A-line; therefore, it is a sandy clay (CH).

Soil Number 3. The soil is coarse-grained since very little passes the Number 200 sieve. It must be a sand since it all passes the Number 10 sieve. The soil contains less than 5 percent passing the Number 200 sieve; therefore, it must be either an (SW) or an (SP) (see *Table 5-2, page 5-9)*. The value of $C_u = 2$ will not meet requirements for (SW); therefore, it is a poorly graded sand (SP).

Soil Number 4. The soil is coarse-grained since again very little passes the Number 200 sieve. It must be a gravel since more than half of the coarse fraction is larger than a Number 4 sieve. Since the soil contains less

Table 5-7. Agricultural Soil Classification System.

Gradation Limits of Textural Soil Groups*

First place the soil in Textural Group I, II, or III according to clay content (column 7); then according to silt content (column 6) or silt and clay content combined (column 5); and finally the sand content and gravel content (columns 1 to 4 inclusive). When clay content approaches the upper limit for that group, it is called "heavy," such as "heavy clay loam," and a "light" soil when approaching the lower clay limit.

Soil texture	(1) Fine and coarse gravel, percent	(2) Coarse sand and gravel, percent	(3) Sand and gravel, percent	(4) Fine sand, percent	(5) Silt and clay, percent	(6) Silt, percent	(7) Clay, percent
Group IA: Sands and Gravels							
Gravel	85 to 100	—	—	—	0 to 15	—	0 to 20
Gravel and sand	50 to 85	—	—	—	0 to 15	—	0 to 20
Sand and gravel	25 to 50	—	—	—	0 to 15	—	0 to 20
Coarse sand	0 to 25	50 to 100	—	—	0 to 15	—	0 to 20
Sand	0 to 25	0 to 50	—	0 to 50	0 to 15	—	0 to 20
Fine sand	0 to 25	—	—	50 to 100	0 to 15	—	0 to 20
Group IB: Loamy Sands							
Gravelly, loamy, coarse sand	25 to 85	50 to 85	—	—	15 to 20	—	0 to 20
Gravelly, loamy sand	25 to 50	25 to 50	—	0 to 50	15 to 20	—	0 to 20
Gravelly, loamy, fine sand	25 to 35	—	—	50 to 60	15 to 20	—	0 to 20
Loamy, coarse sand	0 to 25	50 to 85	—	—	15 to 20	—	0 to 20
Loamy sand	0 to 25	0 to 50	—	0 to 50	15 to 20	—	0 to 20
Loamy, fine sand	0 to 25	—	—	50 to 85	15 to 20	—	0 to 20
Group IC: Sandy Loams							
Gravelly, coarse, sandy loam	25 to 85	30 to 80	—	—	20 to 50	—	0 to 20
Gravelly, sandy loam	25 to 50	25 to 50	—	0 to 50	20 to 50	—	0 to 20
Gravelly, fine, sandy loam	25 to 30	—	—	50 to 55	20 to 50	—	0 to 20
Coarse, sandy loam	0 to 25	50 to 80	—	—	20 to 50	—	0 to 20
Sandy loam	0 to 25	0 to 50	—	0 to 50	20 to 50	—	0 to 20
Fine, sandy loam	0 to 25	—	—	50 to 80	20 to 50	—	0 to 20
Groups ID: Loams and Silt Loams							
Gravelly loam	25 to 50	—	—	—	50 to 70	30 to 50	0 to 20
Gravelly, silt loam	25 to 50	—	—	—	50 to 100	50 to 80	0 to 20
Loam	0 to 25	—	—	—	50 to 70	30 to 50	0 to 20
Silt loam	0 to 25	—	—	—	50 to 100	50 to 80	0 to 20
Silt	0 to 25	—	—	—	50 to 100	80 to 100	0 to 20
Groups II: Clay Loams							
Gravelly, sandy, clay loam	25 to 80	—	50 to 80	—	—	—	20 to 30
Gravelly, clay loam	50 to 50	—	25 to 50	—	—	20 to 50	20 to 30
Gravelly, silty, clay loam	25 to 30	—	0 to 30	—	—	50 to 55	20 to 30
Sandy, clay loam	0 to 25	—	50 to 80	—	—	0 to 30	20 to 30
Clay loam	0 to 25	—	20 to 50	—	—	20 to 50	20 to 30
Silty, clay loam	0 to 25	—	0 to 30	—	—	50 to 80	20 to 30
Group III: Clays							
Gravelly, sandy clay	25 to 70	—	50 to 70	—	—	—	30 to 100
Gravelly clay	25 to 50	—	25 to 50	—	—	0 to 45	30 to 100
Sandy clay	0 to 25	—	50 to 70	—	—	0 to 20	30 to 100
Silty clay	0 to 25	—	0 to 20	—	—	50 to 70	30 to 100
Clay	0 to 25	—	0 to 50	—	—	0 to 20	30 to 100

* The basic concept for this textural classification is from the US Bureau of Chemistry and Soils.

Table 5-8. Classification of four inorganic soil types.

	Soil Number			
	1	2	3	4
Mechanical Analysis (Percent Passing, by Weight)				
3-inch sieve	- - -	- - -	- - -	100.0
3/4-inch sieve	- - -	- - -	- - -	56.0
Number 4 sieve	- - -	- - -	- - -	30.0
Number 10 sieve	100.0	100.0	100.0	16.4
Number 40 sieve	85.2	97.6	85.0	7.2
Number 60 sieve	- - -	- - -	20.0	5.0
Number 200 sieve	52.1	69.8	1.2	3.5
Number 270 sieve	48.2	65.0	- - -	- - -
Numerical Values				
C_u	- - -	- - -	2.0	12.5
C_c	- - -	- - -	- - -	2.2
Plasticity Characteristics				
Liquid limit	29	67	21	- - -
Plasticity index	5	39	NP*	- - -

* Nonplastic

than 5 percent passing the Number 200 sieve, it is either (GW) or (GP) (see *Table 5-2, page 5-9).* It meets the gradation requirements relative to CU and CC; therefore, it is a well-graded gravel (GW).

Revised Public Roads Classification System

The results of the classification of the four soil types under this system are as follows:

Soil Number 1. To calculate the group index, refer to *Figure 5-8, page 5-31.* From chart A, read 0; from chart B, read 3; therefore, the group index = 0 + 3 = 3. *Table 5-6, page 5-30,* shows by a left-to-right elimination process, that the soil cannot be in one of the granular materials groups, since more than 35 percent passes a Number 200 sieve. It meets the requirements of the A-4 group; therefore, it is A-4(3).

Soil Number 2. The group index= 8 + 10 = 18. *Table 5-6, page 5-30,* shows that the soil falls into the A-7 group, since this is the only group that will permit a group index value as high as 18. *Figure 5-9, page 5-32,* shows that it falls in the A-7-6 subgroup; therefore, A-7-6(18).

Soil Number 3. The group index= 0 + 0 = 0 This is one of the soils described as granular material. It will not meet the requirements of an A-1 soil, since it contains practically no fines. It does not meet the requirements of the A-3 group; therefore, it is A-3(0) (see *Table 5-6, page 5-30).*

Soil Number 4. The group index= 0 + 0 = 0. This is obviously a granular material and meets the requirements of the A-l-a (0) (see *Table 5-6, page 5-30).*

Agricultural Soil Classification System

Although the values are not given in the previous tabulation, assume that 12 percent of Soil Number 1 and 35 percent of Soil Number 2 are in the range of clay sizes that is below 0.005 mm.

Soil Number 1. This soil contains 100 - 48.2 = 51.8 percent sand, since the opening of a Number 270 sieve is 0.05 mm. The soil is then composed of 52 percent sand, 36 percent silt, and 12 percent clay. *Figure 5-10, page 5-33,* classifies this soil as a sandy loam.

Soil Number 2. This soil contains approximately 35 percent sand, 30 percent silt, and 35 percent clay. *Figure 5-10, page 5-33,* classifies this soil as clay.

Soil Number 3. This soil is 99 percent sand; therefore, it can only be classified as sand.

Soil Number 4. This soil contains approximately 70 percent coarse gravel, 14 percent fine gravel, 13 percent sand, and 3 percent silt and clay combined. It cannot be classified by using *Figure 5-10, page 5-33,* because the chart does not cover gravels and gravelly sands. *Table 5-7, page 5-34,* classifies the material as gravel and sand.

COMPARISON OF CLASSIFICATION SYSTEMS

Table 5-9 is a summary of the classification of the soils in question under the three different classification systems considered.

Table 5-9. Comparison of soils under three classification systems.

Soil Number	Unified Soil Classification System	Revised Public Roads System	Agricultural Soil Classification System
1	ML	A-4(3)	Sandy loam
2	CH	A-7-6(18)	Clay
3	SP	A-3(0)	Sand
4	GW	A-1-a(0)	Gravel and sand