Appendix B

The Unified Soil Classification System

The adoption of the principles of soil mechanics by the engineering profession has inspired numerous attempts to devise a simple classification system that will tell the engineer the properties of a given soil. As a consequence, many classifications have come into existence based on certain properties of soils such as texture, plasticity, strength, and other characteristics. A few classification systems have gained fairly wide acceptance, but rarely has any system provided the complete information on a soil that the engineer needs. Nearly every engineer who practices soil mechanics will add judgment and personal experience as modifiers to whatever soil classification system he uses. Obviously, within a given agency (where designs and plans are reviewed by persons entirely removed from a project) a common basis of soil classification is necessary so that when an engineer classifies a soil as a certain type, this classification will convey the proper characteristics and behavior of the material. Further than this, the classification should reflect those behavior characteristics of the soil that are pertinent to the project under consideration.

BASIS OF THE USCS

The USCS is based on identifying soils according to their textural and plasticity qualities and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component. They are usually found as mixtures with varying proportions of particles of different sizes; each component part contributes its characteristics to the soil mixture. The USCS is based on those characteristics of the soil that indicate how it will behave as an engineering construction material. The following properties have been found most useful for this purpose and form the basis of soil identification. They can be determined by simple tests and, with experience, can be estimated with some accuracy.

- Percentages of gravel, sand, and fines (fraction passing the No. 200 sieve).
- Shape of the grain-size-distribution curve.
- Plasticity and compressibility characteristics. In the USCS, the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

PURPOSE AND SCOPE

It is the purpose of this appendix to describe the various soil groups in detail and to discuss the methods of identification so that a uniform classification procedure may be followed by all who use the system. Placement of the soils into their respective groups is accomplished by visual examination and laboratory tests as a means of basic identification. It is recognized that the USCS in its present form may not prove entirely adequate in all cases. However, it is intended that the classification of soils according to this system have some degree of elasticity and that the system not be followed blindly nor regarded as completely rigid.

DEFINITIONS OF SOIL COMPONENTS

Before soils can be classified properly in any system, including the one presented in this manual, it is necessary to establish a basic terminology for the various soil components and to define the terms used. In the USCS, the terms cobbles, gravel, sand, and fines (silt or clay) are used to designate the size ranges of soil particles. The gravel and sand ranges are further subdivided into the groups as presented in *Table B-1*. The limiting boundaries between the various size ranges have been arbitrarily set at certain US standard sieve sizes as listed in *Table B-1*. In the finest soil component (below the No. 200 sieve), the terms silt and clay are used respectively to distinguish materials exhibiting lower plasticity from those with higher plasticity. The minus No. 200 sieve material is silt if the LL and PI plot below the “A” line on the plasticity chart and is clay if the LL and PI plot above the “A” line on the chart (all LL and PL tests are based on minus No. 40 sieve fraction of a soil). The foregoing definition holds for inorganic silts and clays and for organic silts but is not valid for organic clays since these latter soils plot below the “A” line. The names of the basic soil components can be used as nouns or adjectives when describing or classifying a soil.

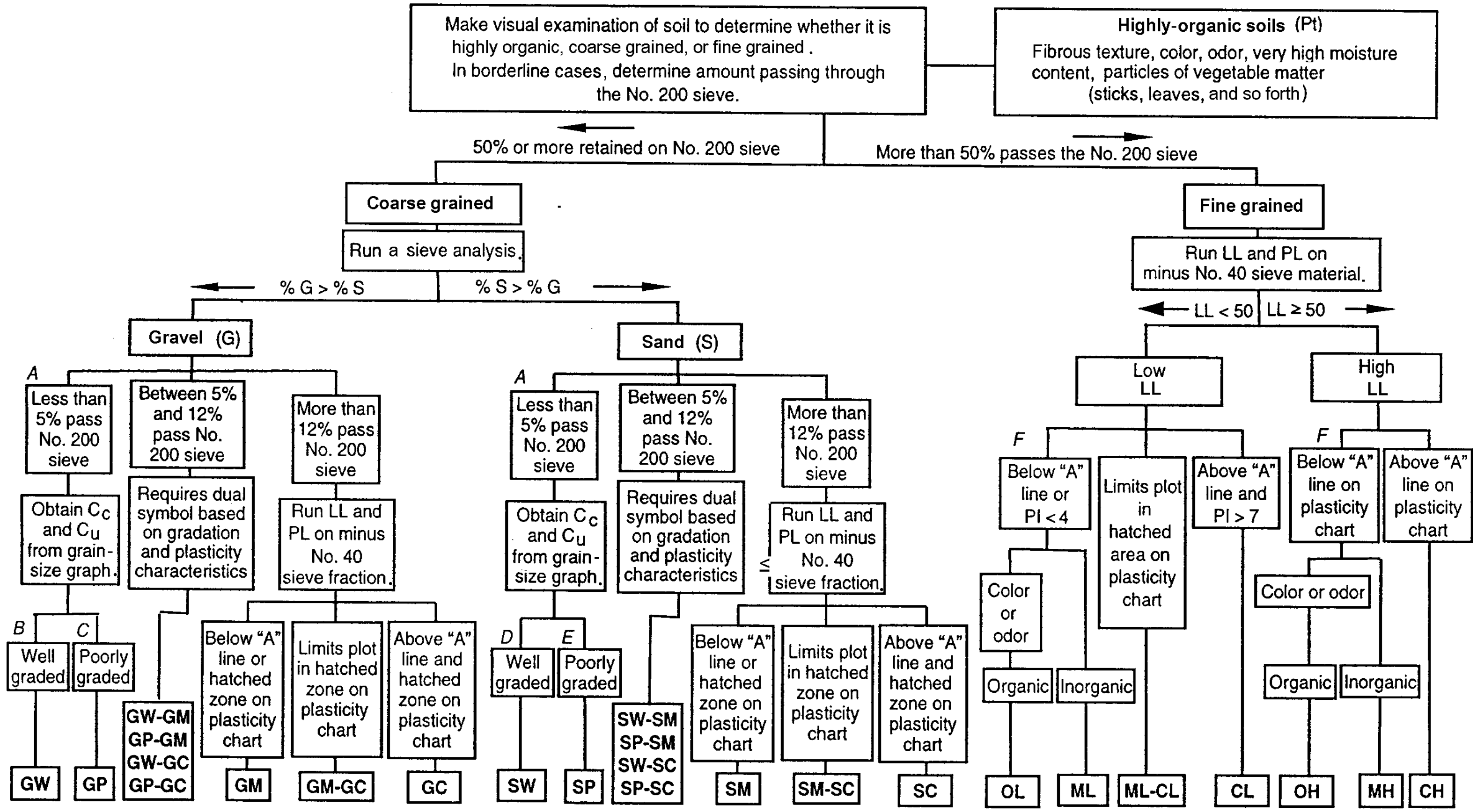
THE CLASSIFICATION SYSTEM

In its simplest form, *Figure B-1* illustrates the process of the classification system. The following paragraphs provide detailed information on the soil properties and groups as they pertain to the system.

Table B-1. Soil particle-size ranges

Component	Size Range
Cobbles	Above 3 inches
Gravel	3 inches to No. 4 sieve
Coarse	3 inches to 3/4 inch
Fine	3/4 inch to No. 4 sieve
Sand	No. 4 to No. 200 sieves
Coarse	No. 4 to No. 10 sieves
Medium	No. 10 to No. 40 sieves
Fine	No. 40 to No. 200 sieves
Fines (clay or silt)	Below No. 200 sieve (no minimum size)

A short discussion of the USCS procedures (see *Figure B-1, page B-3*) is presented so that the succeeding detailed description may be better understood. The procedures are designed to apply generally to the



A If fines interfere with free-draining properties, use a double symbol such as GW-GM.
B For well-graded gravel, the C_u must be > 4 and the C_c must be ≥ 1 and ≤ 3.
C For poorly graded gravel, the C_u must be ≤ 4 and/or the C_c is < 1 or > 3.
D For well graded sand, the C_u must be > 6 and the C_c must be ≥ 1 and ≤ 3.
E For poorly graded sand, the C_u must be ≤ 6 and/or the C_c is < 1 or > 3.
F In cases where organic material can't be determined by color or odor, a LL and PL test must be conducted on a sample of natural moisture content and a sample that has been oven-dried. Organic soils will show a radical drop in plasticity for the oven-dried sample compared to the retained-moisture sample. Inorganic soils generally fall within ± 1 or 2 percent of each other.

Figure B-1. USCS procedures

identification of soils regardless of the intended engineering uses. *Table B-2, pages B-6 and B-7*, also assists in identifying the symbols and soil descriptions within this system. *Figure B-1* shows the schematic method of classifying soils from the results of laboratory tests. Columns 1 through 5 of *Table B-2, pages B-6 and B-7* identify the three major divisions of the classification system and the group symbols that distinguish the individual soil types. Names of typical and representative soil types found in each group are shown in column 6.

SOIL GROUPS AND GROUP SYMBOLS

Soils are primarily identified as coarse grained, fine grained, and highly organic. On a textural basis, coarse-grained soils are those that have 50 percent or more by weight of the overall soil sample retained on the No. 200 sieve; fine-grained soils are those that have more than 50 percent by weight passing the No. 200 sieve. Highly-organic soils are, in general, readily identified by visual examination. The coarse-grained soils are subdivided into gravel and gravelly soils (G) and sands and sandy soils (S). Fine-grained soils are subdivided on the basis of their LL and plasticity properties; the symbol L is used for soils with LLs of 50 and less and the symbol H for soils with LLs in excess of 50. Peat and other highly organic soils are designated by the symbol Pt and are not subdivided.

In general practice there is no clear-cut boundary between gravelly soils and sandy soils and, as far as behavior is concerned, the exact point of division is relatively unimportant. For identification purposes, coarse-grained soils are classified as G if the greater percentage of the coarse fraction (that which is retained on the No. 200 sieve) is larger than the No. 4 sieve. They are classed as S if the greater portion of the coarse fraction is finer than the No. 4 sieve. Borderline cases may be classified as belonging to both groups. The G and S groups are each divided into four secondary groups as follows:

- Well-graded material with little or no fines—symbol W, groups GW and SW.
- Poorly graded material with little or no fines—symbol P, groups GP and SP.
- Coarse material with nonplastic fines or fines with low plasticity—symbol M, groups GM and SM.
- Coarse material with plastic fines—symbol C, groups GC and SC.

The fine-grained soils are subdivided into groups based on whether they have a relatively low (L) or high (H) LL. These two groups are further subdivided as follows:

- Inorganic silts and very fine sandy soils, silty or clayey fine sands, micaceous and diatomaceous soils, and elastic silts—symbol M, groups ML and MH.
- Inorganic clays—symbol C, groups CL and CH.
- Organic silts and clays—symbol O, groups OL and OH.

Coarse-Grained Soils

In the following paragraphs, soils of the GW, GP, SW, and SP groups are defined as having less than 5 percent passing the No. 200 sieve. Soils which have between 5 and 12 percent passing the No. 200 sieve are classed as borderline and will be discussed later in this appendix.

GW and SW Groups

These groups comprise well-graded gravelly and sandy soils having little or no nonplastic fines (less than 5 percent passing the No. 200 sieve). The presence of the fines must not noticeably change the strength characteristics of the coarse-grained fraction and must not interfere with its free-draining characteristics. If the material contains less than 5 percent fines that exhibit plasticity, this information should be evaluated and the soil classified and discussed subsequently under “Laboratory Identification.” In areas subject to frost action, the material should not contain more than 3 percent of soil grains smaller than 0.02 millimeter in size.

GP and SP Groups

Poorly-graded gravels and sands containing little or no nonplastic fines (less than 5 percent passing the No. 200 sieve) are classed in the GP and SP groups. The materials may be classed as uniform gravels, uniform sands, or nonuniform mixtures of very coarse material and very fine sand, with intermediate sizes lacking (sometimes called skip graded, gap graded, or step graded). The latter group often results from borrow excavation in which gravel and sand layers are mixed. If the fine fraction exhibits plasticity, this information should be evaluated and the soil classified as discussed subsequently under “Laboratory Identification.”

GM and SM Groups

In general, the GM and SM groups comprise gravels or sands with fines (more than 12 percent passing the No. 200 sieve) having low or no plasticity. The PI and LL of soils in the group should plot below the “A” line on the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly graded materials are included. Some of the sands and gravels in this group will have a binder composed of natural cementing agents, so proportioned that the mixture shows negligible swelling or shrinkage. Thus, the dry strength of such materials is provided by a small amount of soil binder or by cementation of calcareous material or iron oxide. The fine fraction of other materials in the GM and SM groups may be composed of silts or rock-flour types having little or no plasticity, and the mixture will exhibit no dry strength.

GC and SC Groups

In general, the GC and SC groups comprise gravelly or sandy soils with fines (more than 12 percent passing the No. 200 sieve) which have either low or high plasticity. The PI and LL of soils in the group should plot above the “A” line on the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does variation in gradation. The fine fraction is generally composed of clays.

Table B-2. Characteristics of soil groups pertaining to embankments and foundations

Major Divisions (1)	(2)	Letter (3)	Symbols: Hatching (4)	Symbols: Color (5)	Name (6)	Value for Embankments (7)	Permeability cm per sec (8)
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	$k > 10^{-2}$
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$
		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}
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}
	Sand and Sandy Soils	SW		Red	Well-graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	$k > 10^{-3}$
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$
		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}
		SC		Yellow	Clayey sands, sand-silt mixtures	Fairly stable, use for impervious core or flood-control structures	$k = 10^{-6}$ to 10^{-8}
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}
		CL		Green	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}
		OL		Green	Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}
	Silts and Clays LL $\geq$ 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}
		CH		Blue	Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}
Highly Organic Soils		Pt		Orange	Peat and other highly organic soils	Not used for construction	

NOTES: **1. Values in columns 7 and 11 are for guidance only. Design should be based on actual test results.**

2. The equipment listed in column 9 will usually produce the desired densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled.

3. The range of dry unit weights listed in column 10 are for compacted soil at OMC when using the Standard Proctor Test (ASTM 1557-91).

Table B-2. Characteristics of soil groups pertaining to embankments and foundations (continued)

Compaction Characteristics (9)	Max Dry Unit Weight Std Proctor (pcf) (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
Good; tractor, rubber-tired, or steel-wheeled roller	125 -135	Good bearing value	Positive cutoff
Good; tractor, rubber-tired, or steel-wheeled roller	115 -125	Good bearing value	Positive cutoff
Good; with close control; rubber-tired or sheepsfoot roller	120 -135	Good bearing value	Toe trench to none
Fair; rubber-tired or sheepsfoot roller	115 -130	Good bearing value	None
Good; tractor	110 -130	Good bearing value	Upstream blanket and toe drainage or wells
Good; tractor	100 -120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
Good with close control; rubber-tired or sheepsfoot roller	110 -125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
Fair; sheepsfoot or rubber-tired roller	105 -125	Good to poor bearing value	None
Good to poor; close control essential; rubber-tired or sheepsfoot roller	95 -120	Very poor, susceptible to liquefaction	Toe trench to none
Fair to poor; sheepsfoot or rubber-tired roller	95 -120	Good to poor bearing value	None
Fair to poor; sheepsfoot roller	80 -100	Fair to poor bearing value, may have excessive settlements	None
Poor to very poor; sheepsfoot roller	70 - 95	Poor bearing value	None
Fair to poor; sheepsfoot roller	75 -105	Fair to poor bearing value	None
Poor to very poor; sheepsfoot roller	65 - 100	Very poor bearing value	None
Compaction not practical		Remove from foundations	

Fine-Grained Soils

The following paragraphs discuss fine-grained soils in their subgroupings:

ML and MH Groups

In these groups, the symbol M has been used to designate predominantly silty materials and micaceous or diatomaceous soils. The symbols L and H represent low and high LLs, respectively, and an arbitrary dividing line between the two is set at an LL of 50. The soils in the ML and MH groups are sandy silts, clayey silts, or inorganic silts with relatively low plasticity. Also included are loess-type soils and rock flours. Micaceous and diatomaceous soils generally fall within the MH group but may extend into the ML group when their LL is less than 50. The same is true for certain types of kaolin clays and some elite clays having relatively low plasticity.

CL and CH Groups

In these groups, the symbol C stands for clay, with L and H denoting low or high LL. These soils are primarily inorganic clays. Low-plasticity clays are classified as CL and are usually lean, sandy, or silty clays. The medium and high plasticity clays are classified as CH. These include the fat clays, gumbo clays, certain volcanic clays, and bentonite. The glacial clays of the northern US cover a wide band in the CL and CH groups.

OL and OH Groups

The soils in the OL and OH groups are characterized by the presence of organic matter, hence the symbol O. Organic silts and clays are classified in these groups. The materials have a plasticity range that corresponds with the ML and MH groups.

Highly-Organic Soils

The highly-organic soils usually are very compressible and have undesirable construction characteristics. They are classified into one group, designated by the symbol Pt. Peat, humus, and swamp soils with a highly-organic texture are typical soils of the group. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

IDENTIFICATION OF SOIL GROUPS

The USCS is arranged so that most soils may be classified into at least the three primary groups (coarse grained, fine grained, and highly organic) by means of visual examination and simple field tests. Classification into the subdivisions can also be made by visual examination with some degree of success. More positive identification may be made through laboratory testing. However, in many instances a tentative classification determined in the field is of great benefit and may be all the identification that is necessary, depending on the purposes for which the soils in question are to be used. The general or field-identification methods as well as the individual laboratory test methods are all explained in great detail in Chapter 2. It is emphasized that the two methods of identification are never entirely separated. Certain characteristics can only be estimated by visual examination. In borderline cases, it may be necessary to verify the classification by laboratory tests. Conversely, the field methods are entirely practical for preliminary laboratory identification and may be used to an advantage in grouping soils in such a manner that only a minimum number of laboratory tests need be run.

LABORATORY IDENTIFICATION

Identifying soils in the laboratory is done by determining the gradation and plasticity characteristics of the materials. The gradation is determined by sieve analysis, and a grain-size curve is usually plotted as percent finer (or passing) by weight against a logarithmic scale of grain size in millimeters. DD Form 1207 is typically used for this purpose. Plasticity characteristics are evaluated by means of the LL and PL tests on the soil fraction finer than the No. 40 sieve. The laboratory test procedures for the LL and PL determination can be found in Section IV of Chapter 2.

MAJOR SOIL GROUPS

In the laboratory-identification procedures shown in *Figure B-1, page B-3*, the first step in identifying a soil is to determine whether it is coarse grained, fine grained, or highly organic. This may be done by visual examination in most cases. In some borderline cases, as with very-fine sands or coarse silts, it may be necessary to screen a representative dry sample over a No. 200 sieve and determine the percentage passing. Fifty percent or less passing the No. 200 sieve identifies the soil as coarse grained, and more than 50 percent identifies the soil as fine grained. The percentage limit of 50 has been selected arbitrarily for convenience in identification, as it is obvious that a numerical difference of 1 or 2 in this percentage will make no significant change in the soil’s behavior. After the major group is established, the identification procedure is continued according to the proper headings in *Figure B-1*.

Coarse-Grained Soils

A complete sieve analysis must be run on coarse-grained soils and a gradation curve plotted on a grain-size chart. For some soils containing a substantial amount of fines, it may be desirable to supplement the sieve analysis with a hydrometer analysis to define the gradation curve for particle sizes smaller than the No. 200 sieve size. Preliminary identification is made by determining the percentage of material in the gravel (above No. 4 sieve) and sand (No. 4 to No. 200 sieve) sizes. If there is a greater percentage of gravel than sand, the material is classed as G; if there is a greater percentage of sand than gravel, the material is classed as S. Once again, the distinction between these groups is purely arbitrary for convenience in following the system. The next step is to determine the amount of material passing the No. 200 sieve. Since the subgroups are the same for gravels and sands, they will be discussed jointly in the following paragraphs.

GW, SW, GP, and SP Groups

These groups comprise nonplastic soils having less than 5 percent passing the No. 200 sieve and in which the fine fraction does not interfere with the soil’s free-draining properties. If the above criteria are met, an examination is made of the shape of the grain-size curve. Materials that are well graded are classified as GW or SW; poorly graded materials are classified as GP or SP.

A soil’s gradation curve and curve data should meet the following qualifications to be classed as well graded:

- The grain-size distributions of well-graded materials generally plot as smooth and regular concave curves with no sizes lacking or no excess of material in any size range.
- The coefficient of uniformity (C_u) of well-graded gravels is greater than 4 and of well-graded sands is greater than 6. The C_u is determined by dividing the grain-size diameter passing at 60 percent by the grain-size diameter passing at 10 percent.
- The coefficient of curvature (C_c) must be between 1 and 3. The C_c is determined by the following formula:

$$\frac{(D_{30})^2}{D_{60} \times D_{10}} = \textit{between 1 and 3}$$

where—

D_{30} = *grain diameter at 30 percent passing*

D_{60} = *grain diameter at 60 percent passing*

D_{10} = *grain diameter at 10 percent passing*

The C_c ensures that the grading curve will have a concave curvature within relatively narrow limits for a given D_{60} and D_{10} combination. All gradations not meeting the foregoing criteria are classed as poorly graded. Thus, poorly graded soils (GP and SP) are those having nearly straight-line gradations, convex gradations, nearly vertical gradations, and “hump” gradations typical of skip-graded materials.

NOTE: In the preceding paragraph, soils of the GW, GP, SW, and SP groups were defined as having less than a 5 percent fraction passing the No. 200 sieve. Soils having between 5 and 12 percent passing the No. 200 sieve are classed as borderline and are discussed later.

GM, SM, GC and SC Groups

The soils in these groups are composed of those materials having more than a 12 percent fraction passing the No. 200 sieve. They may or may not exhibit plasticity. For identification, the LL and PL tests are required on the fraction finer than the No. 40 sieve. The tests should be run on representative samples of moist material—not on air- or oven-dried soils. This precaution is desirable as drying affects the limits values to some extent, as will be explained further in the discussion of fine-grained soils. Materials in which the LL and PI plot below the “A” line on the plasticity chart (see *Figure 2-54, page 2-100*) are classed as GM or SM. Gravels and sands in which the LL and PI plot above the “A” line on the plasticity chart are classed as GC or SC. It is considered that in the identification of materials in these groups, the plasticity characteristics overshadow the gradation characteristics; therefore, no distinction is made between well- and poorly graded materials.

Borderline Soils

Coarse-grained soils containing between 5 and 12 percent material passing the No. 200 sieve are classed as borderline and carry a dual symbol (for example, GW-GM). Similarly, coarse-grained soils having less than 5 percent passing the No. 200 sieve but which are not free draining, or wherein the fine fraction exhibits plasticity, are also classed as borderline and are given a dual symbol.

Fine-Grained Soils

Once the identity of a fine-grained soil has been established, further identification is accomplished principally by the LL and PL tests in conjunction with the plasticity chart. The plasticity chart is a plot of LL versus PI on which is imposed a diagonal line called the "A" line and a vertical line at a LL of 50. The "A" line is defined by the equation PI = 0.73 (LL-20). The "A" line above a liquid limit of about 29 represents an important empirical boundary between typical inorganic clays (CL and CH), which are generally located above the line and plastic soils containing organic colloids (OL and OH) or inorganic silty soils (ML and MH). The vertical line at an LL of 50 separates silts and clays of low LL (L) from those of high LL (H). In the low part of the chart below an LL of about 29 and in the range of PI from 4 to 7, there is considerable overlapping of the properties of the clayey and silty soil types. Hence, the separation between CL and OL or ML soil types in this region is accomplished by a cross-hatched zone on the plasticity chart between 4 and 7 PI and above the "A" line. The CL soils in this region are those having a PI above 7 while OL or ML soils are those having a PI below 4.

Soils plotting within the cross-hatched zone should be classed as borderline. The various soil groups are shown in their respective positions on the plasticity chart. Experience has shown that compressibility is about proportional to the LL and that soils having the same LL possess about equal compressibility (assuming that other factors are essentially the same). On comparing the physical characteristics of soils having the same LL, you find that with increasing the PI, the cohesive characteristics increase and the permeability decreases. From plots of the results of limits tests on a number of samples from the same fine-grained deposit, it is found that for most soils these points lie on a straight line or in a narrow band that is almost parallel to the "A" line. With this background information in mind, the identification of the various groups of fine-grained soils is discussed in the following paragraphs.

ML, CL, and OL Groups

A soil having an LL of less than 50 falls into the low LL (L) group. A plot of the LL and PI on the plasticity chart will show whether the soil falls above or below the "A" line and cross-hatched zone. Soils plotting above the "A" line and cross-hatched zone are classed as CL and are usually typical inorganic clays. Soils plotting below the "A" line or cross-hatched zone are inorganic silts or very fine sandy silts (ML) or organic silts or organic silt-clays of low plasticity (OL). Since two groups fall below the "A" line or cross-hatched zone, further identification is necessary. The distinguishing factor between the ML and OL groups is the absence or presence of organic matter. This is usually identified by color and odor. However, a comparison may be made between the LL and PL of a moist sample and one that has been oven-dried.

An organic soil will show a radical drop in plasticity after oven- or air-drying. An inorganic soil will generally show a change in the limits values of only 1 or 2 percent, which may be either an increase or a decrease. For the foregoing reasons, the classification should be based on the plot of limits values determined before drying. Soils containing organic matter generally have lower specific gravities and may have decidedly higher water contents than inorganic soils; therefore, these properties may be of assistance in identifying organic soils. In special cases, determining the organic content may be made by chemical methods, but the procedures just described are usually sufficient.

MH, CH, and OH Groups

Soils with an LL greater than 50 are classed in group H. To identify such soils, the LL and PI values are plotted on the plasticity chart. If the points fall above the "A" line, the soil classifies as CH; if they fall below the "A" line, a determination is made as to whether or not organic material is present (as described in the preceding paragraph). Inorganic materials are classed as MH and organic materials are classed as OH.

Highly-Organic Soils

Little more can be said as to the laboratory identification of highly-organic soils (Pt) than has been identified in the field-identification procedures. These soils are usually identified readily on the basis of color, texture, and odor. Moisture determinations usually show a natural water content of several hundred percent, which is far in excess of that found for most soils. Specific gravities of the solids in these soils may be quite low. Some peaty soils can be remolded and tested for the LLs and PLs. Such materials usually have an LL of several hundred percent and fall well below the "A" line on the plasticity chart.

Borderline Classifications

It is inevitable in the use of the classification system that soils will be encountered that fall close to the boundaries established between the various groups. In addition, boundary zones for the amount of material passing the No. 200 sieve and for the lower part of the plasticity chart have been incorporated as a part of the system, as discussed subsequently. The accepted rule in classifying borderline soils is to use a double symbol (for example, GW-GM). It is possible, in rare instances, for a soil to fall into more than one borderline zone and, if appropriate symbols were used for each possible classification, the result should be a multiple designation consisting of three or more symbols. This approach is unnecessarily complicated, and it is considered best to use only a double symbol in these cases, selecting the two that are believed most representative of the probable behavior of the soil. In cases of doubt, the symbols representing the poorer of the possible groupings should be used.

Coarse-Grained Soils

In previous discussions, the coarse-grained soils were classified in the GW, GP, SW, and SP groups if they contained less than 5 percent of material passing the No. 200 sieve. Similarly, soils were classified in the GM, GC, SM, and SC groups if they had more than 12 percent passing the No. 200 sieve. The range between 5 and 12 percent passing the No. 200 sieve is designated as borderline. Soils falling within it are assigned a double symbol depending on both the gradation characteristics of the coarse fraction and the plasticity characteristics of the minus No. 40 sieve fraction. For example, a well-graded sandy soil with 8 percent passing the No. 200 sieve, a LL of 28, and a PI of 9 would be designated as SM-SC. Another type of borderline classification occurs for those soils containing appreciable amounts of fines (groups GM, GC, SM, and SC) and whose LL and PL values plot in the lower portion of the plasticity chart. The method of classifying these soils is the same as for fine-grained soils plotting in the same region, as presented in the following paragraph.

Fine-Grained Soils

Discussion has been presented of a zone on the plasticity chart below a LL of about 29 and ranging between PI values of 4 and 7. Several soil types exhibiting low plasticity plot in this general region on the plasticity chart, and no definite boundary between silty and clayey soils exists. Thus, if a fine-grained soil, groups CL and ML, or the minus No. 40 sieve fraction of a coarse-grained soil (groups GM, GC, SM, and SC) plots within the cross-hatched zone on the plasticity chart, a double symbol (such as ML-CL) is used.

Note that in the descriptive name of the soil type as indicated on *Table B-2, pages B-6 and B-7,* silty and clayey may be used to describe silt or clay soils. Since the definitions of these terms are now somewhat different from those used by many soils engineers, it is considered advisable to discuss their connotation as used in this system. In the USCS, the terms silt and clay are used to describe those soils with LLs and PLs plotting respectively below and above the “A” line and cross-hatched zone on the plasticity chart. As a logical extension of this concept, the terms silty and clayey may be used as adjectives in the soil names when the limits values plot close to the “A” line. For example, a clay soil with an LL of 40 and a PI of 16 may be called a silty clay. In general, the adjective silty is not applied to clay soils having an LL in excess of about 60.

Expansion of Classification

In some cases, it may be necessary to expand the USCS by subdividing existing groups to classify soils for a particular use. The indiscriminate use of subdivisions is discouraged and careful study should be given to any soil group before adopting such a step. In all cases, subdivisions should be designated preferably by a suffix to an existing group symbol. The suffix should be selected carefully so there will be no confusion with existing letters that already have meanings in the classification system. In each case where an existing group is subdivided, the basis and criteria for the subdivision should be explained so that anyone unfamiliar with it may understand the subdivision properly.

Descriptive Soil Classification

At many stages in the soils investigation of a project—from the preliminary boring log to the final report—the engineer finds it convenient to give the soils he is working with a name rather than an impersonal classification symbol (such as GC). This results primarily from the fact that he is accustomed to talking in terms of gravels, sands, silts, and clays and finds it only logical to use these same names in presenting the data. The soil names have been associated with certain grain sizes in the textural classification as shown on the grain-size chart. Such a division is generally feasible for the coarse-grained soils; however, the use of such terms as silt and clay may be entirely misleading on a textural basis. For this reason, the terms silt and clay have been defined on a plasticity basis, as discussed previously. Within a given region of the country, the use of a name classification based on texture is often feasible since the general behavior of similar soils is consistent over the area. However, in another area, the same classification may be entirely inadequate. The descriptive classification, if used intelligently, has a rightful place in soil mechanics, but its use should be carefully evaluated by all concerned.

Description From Classification Sheet

Column 6 of *Table B-2, pages B-6 and B-7,* lists typical names given to the soil types usually found within the various classification groups. By following either the field- or laboratory-investigation procedure and determining the proper classification group in which the soil belongs, it is usually an easy matter to select an appropriate name from the classification sheet. Some soils may be readily identified and properly named by only visual inspection. A word of caution is considered appropriate on the use of the classification system for certain soils (such as marls, calyces, coral, and shale) where the grain size can vary widely depending on the amount of mechanical breakdown of soil particles. For these soils, the group symbol and textural name have little significance and the locally used name may be important.

Other Descriptive Terms

Records of field explorations in the form of boring logs can be of great benefit to the engineer if they include adequate information. In addition to the group symbol and the name of the soil, the general characteristics of the soils as to plasticity, strength, moisture, and so forth provide information essential to a proper analysis of a particular problem. Locally accepted soil names should also be used to clarify the data to local bidders and to protect the government against later legal claims. For coarse-grained soils, the size of particles, mineralogical composition, shape of grains, and character of the binder are relevant features. For fine-grained soils, strength, moisture, and plasticity characteristics are important. When describing undisturbed soils, such characteristics as stratification, structure, consistency in the undisturbed and remolded states, cementation, and drainage are pertinent to the descriptive classification. Pertinent items to be used in describing soils are shown in column 6 of *Table B-3, pages B-16 and B-17*. To achieve uniformity in estimating the consistency of soils, it is recommended that the Terzaghi classification based on unconfined compressive strength be used as a tentative standard. This classification is given in *Table B-4, page B-18*.

Several examples of descriptive classifications are shown below:

- Uniform, fine, clean sand with rounded grains—SP.
- Well-graded gravelly silty sand; angular chert gravel, 1/2 inch maximum size; silty binder with low plasticity, well-compacted and moist—SM.
- Light brown, fine, sandy silt; very low plasticity; saturated and soft in the undisturbed state—ML.
- Dark gray, fat clay; stiff in the undisturbed state; soft and sticky when remolded—CH.

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

The major properties of a soil proposed for use in an embankment or foundation that are of concern to the design or construction engineer are its strength, permeability, and consolidation and compaction characteristics. Other features may be investigated for a specific problem, but in general, some or all of the properties mentioned are of primary importance in an earth-embankment or foundation project of any magnitude. It is common practice to evaluate the properties of the soils in question by means of laboratory or field tests and to use the results of such tests as a basis for design and construction. The factors that influence strength, consolidation, and other characteristics are numerous, and some of them are not completely understood; consequently, it is impractical to evaluate these features by means of a general soils classification. However, the soil groups in a given classification do have reasonably similar behavior characteristics. While such information is not sufficient for design purposes, it will give the engineer an indication of the behavior of a soil when used as a component in construction. This is especially true in the preliminary examination for a project when neither time nor money for a detailed soils-testing program is available.

Keep in mind that only generalized characteristics of the soil groups are included therein, and they should be used primarily as a guide and not as the complete answer to a problem. For example, it is possible to design and construct an earth embankment of almost any type of soil and on practically any foundation. However, when a choice of materials is possible, certain of the available soils may be better-suited to the job than others. It is on this basis that the behavior characteristics of soils are presented in the following paragraphs and on the classification sheet. A structure's use is often the principal deciding factor in selecting soil types as well as the type of protective measures that will be used. Since each structure is a special problem within itself, it is impossible to cover all possible considerations in the brief description of pertinent soil characteristics contained in this appendix.

FEATURES ON THE SOILS-CLASSIFICATION SHEET

General characteristics of the soil groups pertinent to embankments and foundations are presented in *Table B-2, pages B-6 and B-7*. Columns 1 through 5 show major soil divisions, group symbols, and the hatching and color symbols. The names of soil types are given in column 6. The basic features are the same as those presented previously in soils classification. Columns 7 through 12 show the following: the suitability of the materials for use in embankments (strength and permeability characteristics); the minimum or range of permeability values to be expected for the soil groups; general compaction characteristics; the suitability of the soils for foundations (strength and consolidation); and the requirements for seepage control, especially when the soils are encountered in the foundation for earth embankments (permeability). Brief discussions of these features are presented in the following paragraphs.

Table B-3. Characteristics of soil groups pertaining to roads and airfields

Major Divisions (1)	(2)	Letter (3)	Symbols: Hatching (4)	Symbols: Color (5)	Name (6)	Value As Subgrade When not Subject to Frost Action (7)	Value As Subbase When not Subject to Frost Action (8)
Coarse-Grained Soils	Gravel and Gravelly Soils	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good
		GM u		Yellow		Good	Fair
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Fair
	Sand and Sandy Soils	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to good
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair
		SM d		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to good
		SM u		Yellow		Fair	Poor to fair
		SC		Yellow	Clayey sands, sand-silt mixtures	Poor to fair	Poor
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
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitable
		OL		Green	Organic silts and organic silt-clays of low plasticity	Poor	Not suitable
	Silts and Clays LL ≥ 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable
		CH		Blue	Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitable
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable
Highly Organic Soils		Pt		Orange	Peat and other highly-organic soils	Not suitable	Not suitable

NOTES: **1. Divisions of the GM and SM groups (column 3) into subdivisions of d and u are applicable to roads and airfields only. Subdivision is based on the LL and PI; suffix d (for example, GMd) will be used when the LL is 25 or less and the PI is 5 or less; the suffix u will be used otherwise.**

Table B-3. Characteristics of soil groups pertaining to roads and airfields (continued)

Value As Base When not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	Compaction Equipment (13)	Dry Unit Weight (pcf) (14)	Typical Design Values: CBR (15)	Typical Design Values: Subgrade Modulus k (lb per cu in) (16)
Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125 -140	40 - 80	300 - 500
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
Fair to Good	Slight to medium	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	125 -145	40 - 60	300 - 500
Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115 -135	20 - 30	200 - 500
Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	130 -145	20 - 40	200 - 500
Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110 -130	20 - 40	200 - 400
Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	105 -135	10 - 40	150 - 400
Poor	Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	120 -135	15 - 40	150 - 400
Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100 -130	10 - 20	100 - 300
Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100 -135	5 - 20	100 - 300
Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	90 -130	15 or less	100 - 200
Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired roller, sheepsfoot roller	90 -130	15 or less	50 - 150
Not suitable	Medium to high	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	90 -105	5 or less	50 - 100
Not suitable	Medium to very high	High	Fair to poor	Rubber-tired roller, sheepsfoot roller	80 -105	10 or less	50 - 100
Not suitable	Medium	High	Practically impervious	Rubber-tired roller, sheepsfoot roller	90 -115	15 or less	50 - 150
Not suitable	Medium	High	Practically impervious	Rubber-tired roller, sheepsfoot roller	80 -110	5 or less	25 - 100
Not suitable	Slight	Very high	Fair to poor	Compaction not practical	-	-	-

NOTES (continued):

2. The equipment listed in column 13 will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness lift are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics 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 material. 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 load 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. The range of dry unit weights listed in column 14 are for compacted soil at OMC when using the Standard Proctor Test (ASTM 1557-91).

4. The maximum CBR values (column 15) that can be used in design of airfields is, in some cases, limited by gradation and plasticity requirements.

Table B-4. Terzaghi classification

Unconfined Compressive Strength (Tons/Sq Ft)	Consistency
< 0.25	Very soft
0.25 to 0.50	Soft
0.50 to 1.00	Medium
1.00 to 2.00	Stiff
2.00 to 4.00	Very stiff
> 4.00	Hard

Suitability of Soils for Embankments

Three major factors that influence the suitability of soils for use in embankments are permeability, strength, and ease of compaction. The gravelly and sandy soils with little or no fines (groups GW, GP, SW, and SP) are stable, pervious, and able to attain good compaction with crawler-type tractors and rubber-tired rollers. The poorly graded materials may not be quite as desirable as those which are well graded, but all of the materials are suitable for use in the pervious sections of earth embankments. Poorly graded sands (SP) may be more difficult to use and, in general, should have flatter embankment slopes than the SW soils. The gravels and sands with fines (groups GM, GC, SM, and SC) have variable characteristics depending on the nature of the fine fraction and the gradation of the entire sample. These materials are often sufficiently impervious and stable to be used for impervious sections of embankments. The soils in these groups should be carefully examined to ensure that they are properly zoned with relation to other materials in an embankment.

Of the fine-grained soils, the CL group is best adapted for embankment construction; the soils are impervious, fairly stable, and give fair to good compaction with sheepsfoot or rubber-tired rollers. The MH soils, while not desirable for rolled-fill construction, may be used in the core of hydraulic-fill structures. Soils of the ML group may or may not have good compaction characteristics and, in general, must be closely controlled in the field to secure the desired strength. CH soils have fair stability when used on flat slopes but have detrimental shrinkage characteristics which may necessitate blanketing them or incorporating them in thin interior cores of embankments. Soils containing organic matter (groups OL, OH, and Pt) are not commonly used for embankment construction because of the detrimental effects of the organic matter present. Such materials may often be used to advantage in blankets and stability berms where strength is not important.

Permeability and Seepage Control

Since the permeability (column 8) and requirements for seepage control (column 12) are essentially functions of the same property of a soil, they will be discussed jointly. The subject of seepage in relation to embankments and foundations may be roughly divided into three categories:

- Seepage through embankments.
- Seepage through foundations.
- Control of uplift pressures.

These are discussed in relation to the soil groups in the following paragraphs.

Seepage Through Embankments

In the control of seepage through embankments, it is the relative permeability of adjacent materials rather than the actual permeability of such soils that governs their use in a given location. An earth embankment is not watertight, and the allowable quantity of seepage through it is largely governed by the use to which the structure is put. For example, in a flood-control project, considerable seepage may be allowed and the structure will still fulfill the storage requirements; whereas for an irrigation project, much less seepage is allowable because pool levels must be maintained. The more impervious soils (GM, GC, SM, SC, CL, MH, and CH) may be used in core sections or in homogeneous embankments to retard the flow of water. Where it is important that seepage not emerge on the downstream slope or the possibility of drawdown exists on upstream slopes, more pervious materials are usually placed on the outer slopes. The coarse-grained, free-draining soils (GW, GP, SW, SP) are best-suited for this purpose. Where a variety of materials is available, they are usually graded from least pervious to more pervious from the center of the embankment outward. Care should be used in the arrangement of materials in the embankment to prevent piping within the section. The foregoing statements do not preclude the use of other arrangements of materials in embankments. Dams have been constructed successfully entirely of sand (SW, SP, and SM) or of silt (ML) with the section made large enough to reduce seepage to an allowable value without the use of an impervious core. Coarse-grained soils are often used in drains and toe sections to collect seepage water in downstream sections of embankments. The soils used will depend largely on the material that they drain; in general, free-draining sands (SW and SP) or gravels (GW and GP) are preferred, but a silty sand (SM) may effectively drain a clay (CL and CH) and be entirely satisfactory.

Seepage Through Foundations

As in the case of embankments, the use of the structure involved often determines the amount of seepage control necessary in foundations. Cases could be cited where the flow of water through a pervious foundation would not constitute an excessive water loss and no seepage control measures would be necessary if adequate provisions were made against piping in critical areas. If seepage control is desired, then the more pervious soils are the soils in which necessary measures must be taken. Free-draining gravels (GW and GP) are capable of carrying considerable quantities of water, and some means of positive control (such as a cutoff trench) may be necessary. Clean sands (SW and SP) may be controlled by a cutoff or by an upstream impervious blanket. While a drainage trench at the downstream toe or a line of relief wells will not reduce the amount of seepage, either will serve to control seepage and route the flow into collector systems where it can be led away harmlessly. Slightly less pervious material (such as silty gravels [GM], silty sands [SM], or silts [ML]) may require a minor amount of seepage control such as that afforded by a toe trench, or if they are sufficiently impervious, no control may be necessary. The relatively impervious soils (GC, SC, CL, OL, MH, CH, and OH) usually pass such a small volume of water that seepage control measures are not necessary.

Control of Uplift Pressures

The problem of control of uplift pressures is directly associated with pervious foundation soils. Uplift pressures may be reduced by lengthening the path of seepage (by a cutoff or upstream blanket) or by measures for pressure relief in the form of wells, drainage trenches, drainage blankets, or pervious downstream shells. Free-draining gravels (GW and GP) may be treated by any of the aforementioned procedures; however, to obtain the desired pressure relief, the use of a positive cutoff may be preferred, as blanket, well, or trench installations would probably have to be too extensive for economical accomplishment of the desired results. Free-draining sands (SW and SP) are generally less permeable than the gravels and, consequently, the volume of water that must be controlled for pressure relief is usually less. Therefore a positive cutoff may not be required and an upstream blanket, wells, or a toe trench may be entirely effective. In some cases a combination of blanket and trench or wells may be desirable.

Silty soils (silty gravels [GM], silty sands [SM], and silts [ML]) usually do not require extensive treatment; a toe drainage trench or well system may be sufficient to reduce uplift pressures. The more impervious silty materials may not be permeable enough to permit dangerous uplift pressures to develop, and in such cases, no treatment is indicated. In general, the more impervious soils (GC, SC, CL, OL, MH, CH, and OH) require no treatment for control of uplift pressures. However, they do assume importance when they occur as a relatively thin top stratum over more pervious materials. In such cases, uplift pressures in the lower layers acting on the base of the impervious top stratum can cause heaving and formation of boils; treatment of the lower layer by some of the methods mentioned above is usually indicated in these cases. It is emphasized that control of uplift pressures should not be applied indiscriminately just because certain types of soils are encountered. Rather, the use of control measures should be based on a careful evaluation of conditions that do or can exist, and an economical solution should be reached that will accomplish the desired results.

Compaction Characteristics

Column 9 of *Table B-2, pages B-6 and B-7*, shows the general compaction characteristics of the various soil groups. The evaluations given and the equipment listed are based on average field conditions where proper moisture control and thickness of lift are attained and a reasonable number of passes of the compaction equipment are required to secure the desired density. For lift construction of embankments, the sheepsfoot and rubber-tired rollers are commonly used pieces of equipment. Some advantages may be claimed for the sheepsfoot roller in that it leaves a rough surface that affords better bond between lifts and it kneads the soil—affording better moisture distribution. Rubber-tired equipment referred to in the table is considered to be heavily loaded compactors or earthmoving equipment with a minimum wheel load of

15,000 pounds. If ordinary wobble-wheel rollers are used for compaction, the thickness of a compacted lift is usually reduced to about 2 inches.

Granular soils with little or no fines generally show good compaction characteristics, with the well-graded materials (GW and SW) usually furnishing better results than the poorly graded soils (GP and SP). The sandy soils, in most cases, are best compacted by crawler-type tractors; on the gravelly materials, rubber-tired equipment and sometimes steel-wheel rollers are also effective. Coarse-grained soils with fines of low plasticity (groups GM and SM) show good compaction characteristics with either sheepsfoot rollers or rubber-tired equipment; however, the range of moisture contents for effective compaction may be very narrow and close moisture control is desirable. This is also true of the silty soils in the ML group. Soils of the ML group may be compacted with rubber-tired equipment or with sheepsfoot rollers. Gravels and sands with plastic fines (groups GC and SC) show fair compaction characteristics, although this quality may vary somewhat with the character and amount of fines.

Rubber-tired or sheepsfoot rollers may be used. Sheepsfoot rollers are generally used for compacting fine-grained soils. The compaction characteristics of such materials are variable—lean clays and sandy clays (CL) being the best, fat clays and lean organic clays or silts (OL and CH) fair to poor, and organic or micaceous soils (MH and OH) usually poor.

For most construction projects of any magnitude, it is highly desirable to investigate the compaction characteristics of the soil by means of a field test section. Column 10 shows the ranges of unit dry weight for soils compacted according to the compaction test method as described in ASTM 1557-91 and Chapter 2 of this manual. It is emphasized that these values are for guidance only. Design or construction control should be based on laboratory test results.

Suitability of Soils for Foundations

Suitability of soils for foundations of embankments or structures depends primarily on the strength and consolidation characteristics of the subsoils. The type of structure and its use will largely govern the adaptability of a soil as a satisfactory foundation. For embankments, large settlements may be allowed and compensated for by overbuilding; whereas the allowable settlement of structures (such as control towers) may be small to prevent overstressing the concrete or steel of which they are built or because of the necessity for adhering to established grades. Therefore, a soil may be entirely satisfactory for one type of construction but may require special treatment for other types.

Strength and settlement characteristics of soils depend on a number of variables (such as structure, in-place density, moisture content, and cycles of loading in their geologic history) which are not readily evaluated by a classification system such as used here. For these reasons, only very general statements can be made as to the suitability of the various soil types as foundations. This is especially true for fine-grained soils.

In general, the gravels and gravelly soils (GW, GP, GM, and GC) have good bearing capacity and undergo little consolidation under load. Well-graded sands (SW) usually have a good bearing value. Poorly graded sands and silty sands (SP and SM) may exhibit variable bearing capacity depending on their density. This is true to some extent for all coarse-grained soils but is especially critical for uniformly graded soils of the SP and SM groups. Such soils, when saturated, may become “quick” and present an additional construction problem. Soils of the ML group may be subject to liquefaction and may have poor bearing capacities, particularly where heavy structure loads are involved. Of the fine-grained soils, the CL group is probably the best from a foundation standpoint, but in some cases, the soils may be soft and wet and exhibit poor bearing capacity and fairly large settlements under load. Soils of the MH groups and normally consolidated CH soils may show poor bearing capacity and large settlements. Organic soils (OL and OH) have poor bearing capacity and usually exhibit large settlement under load.

For most of the fine-grained soils discussed above, the type of structure foundation selected is governed by such factors as the bearing capacity of the soil and the magnitude of the load. It is possible that simple spread footings might be adequate to carry the load without excessive settlement in many cases. If the soils are poor and structure loads are relatively heavy, then alternate methods are indicated. Pile foundations may be necessary in some cases and in special instances—particularly in the case of some CH and OH soils—it may be desirable and economically feasible to remove such soils from the foundation. Highly-organic soils are generally very poor foundation materials. These may be capable of carrying very light loads but, in general, are unsuited for most construction purposes. If highly-organic soils occur in the foundation, they may be removed (if limited in extent), they may be displaced (by dumping firmer soils on top), or piling may be driven through them to a stronger layer. Proper treatment will depend on the structure involved.

GRAPHICAL PRESENTATION OF SOILS DATA

It is customary to present the results of soils explorations on drawings or plans as schematic representations of the borings or test pits with the soils encountered using various symbols. Commonly used hatching symbols are small, irregular round symbols for gravel; dots for sand; vertical lines for silts; and diagonal lines for clays. Combinations of these symbols represent the various combinations of materials found in the explorations. This system has been adapted to the various soil groups in the USCS and the appropriate symbols are shown in column 4 of *Table B-2, pages B-6 and B-7*. As an alternative to the hatching symbols, they may be omitted and the appropriate group letter symbol written in the boring log. In addition to the symbols on logs of borings, the effective size of coarse-grained soils and the natural water content of fine-grained soils should be shown by the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain instances, the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of *Table B-2*.

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

The properties desired in soils for foundations under roads and airfields and for base courses under flexible pavements are adequate strength, good compaction characteristics, adequate drainage, resistance to frost action in areas where frost is a factor, and acceptable compression and expansion characteristics. Some of these properties, if inadequate in the soils available, 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 (to be used immediately under the pavement of a flexible pavement structure) 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 concrete pavement or of base materials in flexible pavement construction. From the foregoing brief discussion, it may be seen that the proper design of roads and airfield pavements requires the evaluation of soil properties in more detail than is possible by using the general soils classification system. However, the grouping of soils in the classification system is such that a general indication of their behavior in road and airfield construction may be obtained.

FEATURES ON THE SOILS-CLASSIFICATION SHEET

General characteristics of the soil groups pertinent to roads and airfields are presented in *Table B-3, pages B-16 and B-17*. 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 will not be 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 gives ranges of typical CBR values; and column 16 gives ranges of modulus of subgrade reaction (k). The various features presented are discussed in the following paragraphs.

Subdivision of Coarse-Grained Soil Groups

Note that in column 3 the basic soil groups (GM and SM) have each been subdivided into two groups designated by the suffixes d and u which have been chosen to represent desirable and less desirable (undesirable) base materials, respectively. This subdivision applies to roads and airfields only and is based on field observation and laboratory tests on the behavior of the soils in these groups. Basis for the subdivision is the LL and PI of the fraction of the soil passing the No. 40 sieve. The suffix d is used when the LL is 25 or less and the PI is 5 or less; otherwise, the suffix u is used. Typical symbols for soils in these groups are GMd and SMu.

Values of Soils as Subgrade, Subbase, or Base Materials

The descriptions in columns 7 through 9 give a general indication of the suitability of the soil groups for use as subgrades, subbase, or base materials, provided they are not subject to frost action. In areas where frost heaving is a problem, the value of materials as subgrades or subbases will be reduced, depending on the potential frost action of the material as shown in column 10. Proper design procedures should be used in situations where this is a problem. The coarse-grained soils, in general, are the best subgrade, subbase, and base materials. The GW group has excellent qualities as a subgrade and subbase, and is good as base material. Note that the adjective “excellent” is not used for any of the soils for base courses; “excellent” should be used in reference to 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 and, under favorable conditions, may be used as base materials for certain conditions. However, poor gradation and other factors sometimes reduce the value of such soils to the extent that they offer only moderate strength, and their value as a base material is less. The GMu, GC, and SW groups are reasonably good subgrade materials but are generally poor to not suitable as bases. The SP and SMd soils are usually considered fair to good subgrade and subbase materials but, in general, are poor to not suitable for base materials. The SMu and SC soils are fair to poor subgrade and subbase materials and are not suitable for base materials. The fine-grained soils range from fair to very poor subgrade materials as follows:

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

These qualities are compensated for in flexible pavement design by increasing the thickness of overlying base material and in rigid pavement design by increasing the pavement thickness or by adding a base-course layer. None of the fine-grained soils are suitable as subbase or base materials. 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 as used in flexible pavement design. Similarly, values of subgrade modulus (k) in column 16 are relative indications of strengths from plate-bearing tests as used in rigid pavement design. As these tests are used for the design of pavements, actual test values should be used for this purpose instead of the approximate values shown in the tabulation.

For wearing surfaces on unsurfaced roads, 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.

Potential 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 will be a major consideration—a source of water during the freezing period and 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 or a capillary supply, within the soil voids, or through infiltration. The degree of ice formation that will occur in any given case is influenced by environmental factors such as topographic position, stratification of the parent soil, transitions into cut sections, lateral flow of water from side cuts, localized pockets of perched groundwater, and drainage conditions. In general, the silts and fine silty sands are the worst offenders as far as frost is concerned. Coarse-grained materials with little or no fines are affected only slightly if 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 three percent of grains finer than 0.02 millimeter in diameter by weight are generally not frost susceptible. Where frost-susceptible soils are encountered in subgrades and frost is a definite problem, two acceptable methods of design of pavements are available. Either a sufficient depth of acceptable granular material is placed over the soils to prevent freezing in the subgrade and thereby prevent the detrimental effects of frost action or a reduced depth of granular material is used, thereby allowing freezing in the subgrade, and the design is based on the reduced strength of the subgrade during the frost-melting period. In many cases, appropriate drainage measures to prevent the accumulation of water in the soil pores will help to diminish ice segregation in the subgrade and subbase.

Compressibility and Expansion

Two types of soil characteristics are applicable to road and runway design. The first is the relatively long-term compression or consolidation under the dead weight of the structure; the second is the short-term compression and rebound under moving wheel loads. The long-term consolidation of soils becomes a factor in design primarily when heavy fills are made on compressible soils. If adequate provision is made for this type of settlement during construction, it will have little influence on the pavement's load-carrying capacity. However, when elastic soils subject to compression and rebound under wheel load are encountered, adequate protection must be provided, as even small movements of this soil may be detrimental to the base and wearing course of pavements.

It is fortunate that the free-draining, coarse-grained soils (GW, GP, SW, and SP), which in general make the best subgrade and subbase materials, exhibit almost no tendency toward high compressibility or expansion. In general, the compressibility of soils increases with an increasing LL. The foregoing is not completely true, as compressibility is also influenced by soil structure, grain shape, previous loading history, and other factors that are not evaluated in the classification system. Undesirable compressibility or expansion characteristics may be reduced by distributing the load through a greater thickness of overlying material. This is 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 Characteristics

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. The presence of moisture in base, subbase, and subgrade materials—except for free-draining, coarse-grained soils—may cause the development of pore water pressures and loss of strength. The moisture may come from infiltration of rainwater or by capillary rise from an underlying water table. While free-draining materials permit rapid draining of water, they permit rapid ingress of water also. If such materials are adjacent to less-pervious materials and have free access to water they may serve as reservoirs to saturate the less-pervious materials. It is obvious, therefore, that in most instances adequate drainage systems should be provided. The gravelly and sandy soils with little or no fines (groups GW, GP, SW, and SP) have excellent drainage characteristics. The GMd and SMd groups have fair-to-poor drainage characteristics, whereas the GMu, GC, SMu, and SC groups may be practically impervious. Soils of the ML, MH, and Pt groups have fair-to-poor drainage characteristics. All of the other groups have poor drainage characteristics or are practically impervious.

Compaction Equipment

The compaction of soils for roads and runways, especially for the latter, requires that a high degree of density be attained at the time of construction so that detrimental consolidation will not take place under traffic. In addition, the detrimental effects of water are lessened in cases where saturation or near saturation takes place. Processed materials, such as crushed rock, are often used as base course and such materials require special treatment in compaction. Types of compaction equipment that will usually produce the desired densities are shown in column 13. Note that several types of equipment are listed for some of the soil groups; this is because variations in soil type within a given group may require the use of different equipment. In some cases, more than one type of equipment may be necessary to produce the desired densities.

Steel-wheeled rollers are recommended for angular materials with limited amounts of fines, crawler-type tractors or rubber-tired rollers for gravels and sands, and sheepsfoot rollers for coarse-grained or fine-grained soils having some cohesive qualities. Rubber-tired rollers are also recommended for final compaction operations for most soils except those with a high LL. Suggested minimum weights of the various types of equipment are shown in note 2 of *Table B-3, pages B-16 and B-17*. Column 14 shows ranges of unit dry weight for soils compacted according to the compaction test method as described in ASTM 1557-91 and Chapter 2. These values are included primarily for guidance. Design or control of construction should be based on actual test results.

GRAPHICAL PRESENTATION OF SOILS DATA

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. As one approach, the group's letter symbol may be written in the appropriate section of the log. As an alternative, the hatching symbols shown in column 4 of *Table B-2, pages*

B-6 and B-7, or *Table B-3*, *pages B-16 and B-17*, may be used. In addition, the natural-water content of fine-grained soils should be shown along the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain instances, the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is indicated in column 5 of *Tables B-2* or *B-3*.

RETURN TO TOC