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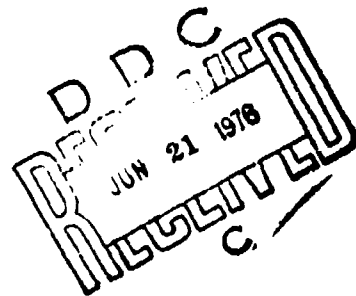
THE UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
EMBANKMENTS AND FOUNDATIONS

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
ROADS AND AIRFIELDS



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Preface

The purpose of this manual is to describe and explain the use of the "Unified Soil Classification System" in order that identification of soil types will be on a common basis throughout the agencies using this system.

The program of military airfield construction undertaken by the Department of the Army in 1941 revealed at an early stage that existing soil classifications were not entirely applicable to the work involved. In 1942 the Corps of Engineers tentatively adopted the "Airfield Classification" of soils which had been developed by Dr. Arthur Casagrande of the Harvard University Graduate School of Engineering. As a result of experience gained since that time, the original classification has been expanded and revised in cooperation with the Bureau of Reclamation so that it applies not only to airfields but also to embankments, foundations, and other engineering features.

Acknowledgment is made to Dr. Arthur Casagrande, Professor of Soil Mechanics and Foundation Engineering, Harvard University, for permission to incorporate in this manual considerable information from the paper "Classification and Identification of Soils" published in Transactions, American Society of Civil Engineers, volume 113, 1948. This manual was prepared under the direction of the Office, Chief of Engineers, by the Soils Division, Waterways Experiment Station.

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UNIFIED SOIL CLASSIFICATION SYSTEM

Introduction

Need for a classification system

1. 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 it is seldom that any particular system has 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, so that it may be said that there are as many classification systems as there are engineers using them. 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 to another engineer not familiar with the region 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 unified soil classification system

2. The unified soil classification system is based on the

identification of 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, but are usually found as mixtures with varying proportions of particles of different sizes; each component part contributes its characteristics to the soil mixture. The unified soil classification system 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.

- a. Percentages of gravel, sand, and fines (fraction passing No. 200 sieve).
- b. Shape of the grain-size-distribution curve.
- c. Plasticity and compressibility characteristics.

In the unified soil classification system the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

Purpose and scope of manual

3. It is the purpose of this manual to describe the various soil groups in detail and to discuss the methods of identification in order 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. This procedure is described in the main text of this manual. The classification of the soils in these groups according to their engineering behavior for various types of construction, such as

embankments, foundations, roads, and airfields, is treated separately in appendices hereto which will be issued as the need arises. It is recognized that the unified classification system in its present form may not prove entirely adequate in all cases. However, it is intended that the classification of soils in accordance with this system have some degree of elasticity, and that the system not be followed blindly nor regarded as completely rigid.

Definitions of soil components

4. 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 unified soil classification the names "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 presented below. The limiting boundaries between the various size ranges have been arbitrarily set at certain U. S. Standard sieve sizes in accordance with the following tabulation:

Component	Size Range
Cobbles	Above 3 in.
Gravel	3 in. to No. 4 (4.76 mm)
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 (4.76 mm)
Sand	No. 4 (4.76 mm) to No. 200 (0.074 mm)
Coarse sand	No. 4 (4.76 mm) to No. 10 (2.0 mm)
Medium sand	No. 10 (2.0 mm) to No. 40 (0.42 mm)
Fine sand	No. 40 (0.42 mm) to No. 200 (0.074 mm)
Fines (silt or clay)	Below No. 200 (0.074 mm)

These ranges are shown graphically on the grain-size sheet, plate 1. In

the finest soil component (below 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 liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2), and is "clay" if the liquid limit and plasticity index plot above the "A" line on the chart (all Atterberg limits tests 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 in the name of a soil, as explained later.

The Classification System

5. A short discussion of the unified soil classification sheet, table 1, is presented in order that the succeeding detailed description may be more easily understood. This sheet is designed to apply generally to the identification of soils regardless of the intended engineering uses. The first three columns of the classification sheet show the major divisions of the classification 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 4. The field procedures for identifying soils by general characteristics and from pertinent tests and visual observations are shown in column 5. The desired descriptive information for a complete identification of a soil is presented in column 6. In column 7 are presented the laboratory

classification criteria by which the various soil groups are identified and distinguished. Table 2 shows an auxiliary schematic method of classifying soils from the results of laboratory tests. The application and use of this chart are discussed in greater detail under a subsequent heading in this manual.

Soil groups and group symbols

6. Major divisions. Soils are primarily divided into coarse-grained soils, fine-grained soils, and highly organic soils. On a textural basis, coarse-grained soils are those that have 50 per cent or less of the constituent material passing the No. 200 sieve, and fine-grained soils are those that have more than 50 per cent 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 (symbol G), and sands and sandy soils (symbol S). Fine-grained soils are subdivided on the basis of the liquid limit; symbol L is used for soils with liquid limits of 50 and less, and symbol H for soils with liquid limits in excess of 50 (see plate 2). Peat and other highly organic soils are designated by the symbol Pt and are not subdivided.

7. Subdivisions, coarse-grained soils. 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 purposes of identification, coarse-grained soils are classed as gravels (G) if the greater percentage of the coarse fraction (retained on No. 200 sieve) is larger than the No. 4 sieve and as sands (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 gravel (G) and sand (S) groups are each divided into four secondary groups as follows:

- a. Well-graded material with little or no fines. Symbol W. Groups GW and SW.
- b. Poorly-graded material with little or no fines. Symbol P. Groups GP and SP.
- c. Coarse material with nonplastic fines or fines with low plasticity. Symbol M. Groups GM and SM.
- d. Coarse material with plastic fines. Symbol C. Groups GC and SC.

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

- a. Inorganic silts and very fine sandy soils; silty or clayey fine sands; micaceous and diatomaceous soils; elastic silts. Symbol M. Groups ML and MH.
- b. Inorganic clays. Symbol C. Groups CL and CH.
- c. Organic silts and clays. Symbol O. Groups OL and OH.

Discussion of Coarse-grained Soils

GW and SW groups

9. These groups comprise well-graded gravelly and sandy soils having little or no nonplastic fines (less than 5 per cent 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 per cent fines that exhibit plasticity, this

information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." In areas subject to frost action, the material should not contain more than about 3 per cent of soil grains smaller than 0.02 mm in size. Typical examples of GW and SW soils are shown on plate 3.

GP and SP groups

10. Poorly-graded gravels and sands containing little or no non-plastic fines (less than 5 per cent 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." Typical examples of various types of GP and SP soils are shown on plate 4.

GM and SM groups

11. In general, the GM and SM groups comprise gravels or sands with fines (more than 12* per cent passing the No. 200 sieve) having low or no plasticity. The plasticity index and liquid limit (based on minus No. 40 sieve fraction) of soils in the group should plot below the "A" line on

* In the preceding two paragraphs soils of the GW, GP, SW, and SP groups were defined as having less than 5 per cent passing the No. 200 sieve. Soils which have between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 23 under that heading.

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. Typical examples of types of GM and SM soils are shown on plate 5.

GC and SC groups

12. In general, the GC and SC groups comprise gravelly or sandy soils with fines (more than 12 per cent passing the No. 200 sieve) which have either low or high plasticity. The plasticity index and liquid limit of soils (fraction passing the No. 40 sieve) 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. Typical examples of GC and SC soils are shown on plate 6.

Discussion of Fine-grained Soils

ML and MH groups

13. In these groups the symbol H has been used to designate

predominantly silty materials and micaceous or diatomaceous soils. The symbols L and H represent low and high liquid limits, respectively, and an arbitrary dividing line between the two is set at a liquid limit 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 liquid limit is less than 50. The same is true for certain types of kaolin clays and some illite clays having relatively low plasticity. Typical examples of soils in the ML and MH groups are shown on plate 7.

CL and CH groups

14. In these groups the symbol C stands for clay, with L and H denoting low or high liquid limit. The soils are primarily inorganic clays. Low plasticity clays are classified as CL and are usually lean clays, sandy clays, 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 United States cover a wide band in the CL and CH groups. Typical examples of soils in these groups are shown on plate 8.

OL and OH groups

15. 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. Typical examples of OL and OH soils are presented on plate 9.

Discussion of Highly Organic Soils

Pt group

16. The highly organic soils usually are very compressible and have undesirable construction characteristics. They are not subdivided and are classified into one group with 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

17. The unified soil classification is so arranged 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 by means of laboratory tests on the materials. 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. Methods of general identification of soils are discussed in the following paragraphs, and a laboratory testing procedure is presented. It is emphasized that the two methods of identification are never entirely separated. Certain characteristics can only be estimated by visual examination, and 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 advantage in grouping soils in such a manner that only a minimum number of laboratory tests need be run.

General Identification

18. The easiest way of learning field identification of soils is under the guidance of experienced personnel. Without such assistance, field identification may be learned by systematically comparing the numerical test results for typical soils in each group with the "feel" of the material while field identification procedures are being performed.

Coarse-grained soils

19. Texture and composition. In field identification of coarse-grained materials a dry sample is spread on a flat surface and examined to determine gradation, grain size and shape, and mineral composition. Considerable experience is required to differentiate, on the basis of a visual examination, between well-graded and poorly-graded soils. The durability of the grains of a coarse-grained soil may require a careful examination, depending on the use to which the soil is to be put. Pebbles and sand grains consisting of sound rock are easily identified. Weathered material is recognized from its discolorations and the relative ease with which the grains can be crushed. Gravels consisting of weathered granitic rocks, quartzite, etc., are not necessarily objectionable for construction purposes. On the other hand, coarse-grained soils containing fragments of shaley rock may be unsuitable because alternate wetting and drying may result in their partial or complete disintegration. This property can be identified by a slaking test.

The particles are first thoroughly oven- or sun-dried, then submerged in water for at least 24 hours, and finally their strength is tested and compared with the original strength. Some types of shales will completely disintegrate when subjected to such a slaking test.

20. Examination of fine fraction. Reference to the identification sheet (table 1) shows that classification criteria of the various coarse-grained soil groups are based on the amount of material passing the No. 200 sieve and the plasticity characteristics of the binder fraction (passing the No. 40 sieve). Various methods may be used to estimate the percentage of material passing the No. 200 sieve; the choice of method will depend on the skill of the technician, the equipment at hand, and the time available. One method, decantation, consists of mixing the soil with water in a suitable container and pouring off the turbid mixture of water and fine soil; successive decantations will remove practically all of the fines and leave only the sand and gravel sizes in the container. A visual comparison of the residue with the original material will give some idea of the amount of fines present. Another useful method is to put a mixture of soil and water in a test tube, shake it thoroughly, and allow the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 seconds. If the assumption is made that the soil weight is proportional to its volume, this method may be used to estimate the amount of fines present. A rough estimate of the amount of fines may be made by spreading the sample out on a level surface and making a visual estimate of the percentage of fine particles present. The presence of fine sand can

usually be detected by rubbing a sample between the fingers; silt or clay particles feel smooth and stain the fingers, whereas the sand feels gritty and does not leave a stain. The "teeth test" is sometimes used for this purpose, and consists of biting a portion of the sample between the teeth. Sand feels gritty whereas silt and clay do not; clay tends to stick to the teeth while silt does not. If there appears to be more than about 12 per cent of the material passing the No. 200 sieve, the sample should be separated as well as possible by hand, or by decantation and evaporation, removing all of the gravel and coarse sand, and the characteristics of the fine fraction determined. The binder is mixed with water and its dry strength and plasticity characteristics are examined. Criteria for dry strength are shown in column 5 of the classification sheet, table 1; evaluation of soils according to dry strength and plasticity criteria is discussed in succeeding paragraphs in connection with fine-grained soils. Identification of active cementing agents other than clay usually is not possible by visual and manual examination, since such agents may require a curing period of days or even weeks. In the absence of such experience the soils should be classified tentatively into their apparent groups, neglecting any possible development of strength because of cementation.

Fine-grained soils

21. The principal procedures for field identification of fine-grained soils are the test for dilatancy (reaction to shaking), the examination of plasticity characteristics, and the determination of dry strength. In addition, observations of color and odor are of value, particularly for organic soils. Descriptions of the field identification

procedures are presented in the following paragraphs. The dilatancy, plasticity, and dry strength tests are performed on the fraction of the soil finer than the No. 40 sieve. Separation of particles coarser than the No. 40 sieve is done most expediently in the field by hand. However, separation by hand probably will be most effective for particles coarser than the No. 10 sieve. Some effort should be made to remove the No. 10 to No. 40 fraction but it is believed that any particles in this size range remaining after hand separation would have little effect on the field identification procedures.

22. Dilatancy. The soil is prepared for test by removing particles larger than about the No. 40 sieve size (by hand) and adding enough water, if necessary, to make the soil soft but not sticky. The pat of moist soil should have a volume of about 1/2 cubic inch. The pat of soil is alternately shaken horizontally in the open palm of one hand, which is struck vigorously against the other hand several times, and then squeezed between the fingers. A fine-grained soil that is nonplastic or exhibits very low plasticity will become livery and show free water on the surface while being shaken. Squeezing will cause the water to disappear from the surface and the sample to stiffen and finally crumble under increasing finger pressure, like a brittle material. If the water content is just right, shaking the broken pieces will cause them to liquefy again and flow together. A distinction may be made between rapid, slow, or no reaction to the shaking test, depending on the speed with which the pat changes its consistency and the water on the surface appears or disappears. Rapid reaction to the shaking test is typical for nonplastic, uniform fine sand, silty sand (SP, SM), and inorganic silts (ML)

particularly of the rock-flour type, also for diatomaceous earth (MH). The reaction becomes somewhat more sluggish with decreasing uniformity of gradation (and increase in plasticity up to a certain degree). Even a slight content of colloidal clay will impart to the soil some plasticity and slow up materially the reaction to the shaking test. Soils which react in this manner are somewhat plastic inorganic and organic silts (ML, OL), very lean clays (CL), and some kaolin-type clays (ML, MH). Extremely slow or no reaction to the shaking test is characteristic of all typical clays (CL, CH) as well as of highly plastic organic clays (OH).

23. Plasticity characteristics. Examination of the plasticity characteristics of fine-grained soils or of the fine fraction of coarse-grained soils is made with a small moist sample of the material. Particles larger than about the No. 40 sieve size are removed (by hand) and a specimen of soil about the size of a 1/2-in. cube is molded to the consistency of putty. If the soil is too dry, water must be added and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. The sample is rolled by hand on a smooth surface or between the palms into a thread about 1/8 in. 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 higher the position of a soil above the "A" line on the plasticity chart, plate 2 (CL, CH), the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the

soil is remolded after rolling. Soils slightly above the "A" line (CL, CH) form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily. Soils below the "A" line (ML, MH, OL, OH) form a weak thread and, with the exception of the OH soils, cannot be lumped together into a coherent mass below the plastic limit. Plastic soils containing organic material or much mica (well below the "A" line) form threads that are very soft and spongy near the plastic limit. The binder fraction of coarse-grained soils may be examined in the same manner as fine-grained soils. In general, the binder fraction of coarse-grained soils with silty fines (GM, SM) will exhibit plasticity characteristics similar to the ML soils, and that of coarse-grained soils with clayey fines (GC, SC) will be similar to the CL soils.

24. Dry strength. The resistance of a piece of dried soil to crushing by finger pressure is an indication of the character of the colloidal fraction of a soil. To initiate the test, particles larger than the No. 40 sieve size are removed from the soil (by hand) and a specimen is molded to the consistency of putty, adding water if necessary. The moist pat of soil is allowed to dry (in oven, sun, or air) and is then crumbled between the fingers. Soils with slight dry strength crumble readily with very little finger pressure. All nonplastic ML and MH soils have almost no dry strength. Organic silts and lean organic clays of low plasticity (OL), as well as very fine sandy soils (SM), have slight dry strength. Soils of medium dry strength require considerable finger pressure to powder the sample. Most clays of the CL group and some OH soils exhibit medium dry strength. This is also true of the fine

fraction of gravelly and sandy soils having a clay binder (GC and SC). Soils with high dry strength can be broken but cannot be powdered by finger pressure. High dry strength is indicative of most CH clays, as well as some organic clays of the OH group having very high liquid limits and located near the A-line. In some instances high dry strength in the undisturbed state may be furnished by a cementing material such as calcium carbonate or iron oxide.

25. Color. In field soil surveys color is often helpful in distinguishing between various soil strata, and to an engineer with sufficient preliminary experience with the local soils, color may also be useful for identifying individual soils. The color of the moist soil should be used in identification as soil color may change markedly on drying. To the experienced eye certain dark or drab shades of gray or brown, including almost black colors, are indicative of fine-grained soils containing organic colloidal matter (OL, OH). In contrast, brighter colors, including medium and light gray, olive green, brown, red, yellow, and white, are generally associated with inorganic soils. Use of the Munsell soil color charts and plates, prepared for the U. S. Department of Agriculture by the Munsell Color Company, Baltimore, Maryland, is suggested in the event more precise soil color descriptions are desired or to facilitate uniform naming of soil colors.

26. Odor. Organic soils of the OL and OH groups usually have a distinctive odor which, with experience, can be used as an aid in the identification of such materials. This odor is especially apparent from fresh samples. It gradually diminishes on exposure to air, but can be revived by heating a wet sample.

Highly organic soils

27. The field identification of highly organic soils (group Pt) is relatively easy inasmuch as these soils are characterized by undecayed or partially carbonized particles of leaves, sticks, grass, and other vegetable matter which impart to the soil a typical fibrous texture. The color ranges generally from various shades of dull brown to black. A distinct organic odor is also characteristic of the soil. The water content is usually very high. Another aid in identification of these soils may be the location of the soil with respect to topography: low-lying, swampy areas usually contain highly organic soils.

Laboratory Identification

28. The identification of soils in the laboratory is accomplished 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 per cent finer (or passing) by weight against a logarithmic scale of grain size in millimeters. Plate 1 is a typical grain-size chart. Plasticity characteristics are evaluated by means of the liquid and plastic limits tests on the soil fraction finer than the No. 40 sieve. A suggested laboratory method of identification is presented schematically in the chart shown as table 2 and is discussed in the succeeding paragraphs. It should be recognized that although a definite procedure for identification is outlined on the chart, the laboratory technician engaged in classification may be able to use "short cuts" in his work after he becomes thoroughly familiar with the criteria for each soil group.

Identification of major soil groups

29. Reference to the identification procedure chart, table 2, shows that the first step in the laboratory identification of 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, using the procedures outlined for field identification. 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 per cent or less passing the No. 200 sieve identifies the soil as coarse grained, and more than 50 per cent 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 behavior of the soil. After the major group in which the soil belongs is established, the identification procedure is continued in accordance with the proper headings in the chart.

Identification of subgroups, coarse-grained soils

30. Gravels (G) or sands (S). A complete sieve analysis is run on coarse-grained soils and the gradation curve is 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 in order to define the gradation curve below 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 gravel (G); if there is a greater percentage of sand than gravel the material is classed as sand (S). Once again the distinction between these groups is purely arbitrary for convenience in following the system. The next identification 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.

31. GW, SW, GP, and SP groups. These groups comprise nonplastic soils having less than 5 per cent passing the No. 200 sieve and in which the fine fraction does not interfere with the soils' 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. 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 (plate 3); the uniformity coefficient (60 per cent grain diameter divided by the 10 per cent grain diameter) of well-graded gravels is greater than 4, and of well-graded sands is greater than 6. In addition, the gradation curves should meet the following qualification in order to be classed as well graded.

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

where D_{30} = grain diameter at 30 per cent passing

D_{60} = grain diameter at 60 per cent passing

D_{10} = grain diameter at 10 per cent passing

The foregoing expression, termed a coefficient of curvature, insures

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, SP) are those having nearly straight line gradations (plate 4, fig. 1, curve 3), convex gradations, nearly vertical (uniform) gradations (plate 4, fig. 1, curve 1), and gradation curves with "humps" typical of skip-graded materials (plate 4, fig. 1, curve 2).

32. GM, SM, GC and SC groups. The soils in these groups are composed of those materials having more than a 12* per cent fraction passing the No. 200 sieve; they may or may not exhibit plasticity. For identification, the liquid and plastic limits tests are required on the fraction finer than the No. 40 sieve. The tests should be run on representative samples of moist material, and 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 liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2) are classed as GM or SM (plate 5). Gravels and sands in which the liquid limit and plasticity index plot above the "A" line on the plasticity chart are classed as GC or SC (plate 6). 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.

* In the preceding paragraph soils of the GW, GP, SW, and SP groups were defined as having less than a 5 per cent fraction passing the No. 200 sieve. Soils having between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33.

33. Borderline soils. Coarse-grained soils containing between 5 and 12% material passing the No. 200 sieve are classed as borderline and carry a dual symbol, e.g., GW-GM. Similarly, coarse-grained soils having less than 5% 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. Additional discussion of borderline classification is presented in paragraphs 38-41.

Identification of sub-
groups, fine-grained soils

34. Use of plasticity chart. Once the identity of a fine-grained soil has been established, further identification is accomplished principally by the liquid and plastic limits tests in conjunction with the plasticity chart (plate 2). The plasticity chart was developed by Dr. Casagrande as the result of considerable experience with the behavior of soils in many different regions. It is a plot of liquid limit versus plasticity index on which is imposed a diagonal line called the "A" line and a vertical line at a liquid limit 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 liquid limit of 50 separates silts and clays of low liquid limit (L) from those of high liquid limit (H). In the low part of the chart below a liquid limit 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. 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 as discussed later. The various soil groups are shown in their respective positions on the plasticity chart. Experience has shown that compressibility is approximately proportional to liquid limit and that soils having the same liquid limit possess approximately equal compressibility, assuming that other factors are essentially the same. On comparing the physical characteristics of soils having the same liquid limit, one finds that with increasing plasticity index, 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 approximately 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.

35. ML, CL, and OL groups. A soil having a liquid limit of less than 50 falls into the low liquid limit (L) group. A plot of the liquid limit and plasticity index on the plasticity chart will show whether it 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 (plate 8, fig. 1). Soils plotting below the "A" line or cross-hatched zone are inorganic silts or very fine sandy silts, ML (plate 7, fig. 1), or organic silts or organic silt-clays of low

plasticity, OL (plate 9, fig. 1). 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 as explained in the preceding paragraphs under field identification. However, in doubtful cases a comparison may be made between the liquid and plastic limits of a moist sample and one that has been oven-dried. An organic soil will show a radical drop in plasticity after oven-drying or air-drying. An inorganic soil will generally show a change in the limits values of only 1 or 2% 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, the determination of organic content may be made by chemical methods, but the procedures just described are usually sufficient.

36. MH, CH, and OH groups. Soils with a liquid limit greater than 50 are classed in group H. To identify such soils, the liquid limit and plasticity index values are plotted on the plasticity chart. If the points fall above the "A" line, the soil classifies as CH; if it falls 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.

Identification of highly organic soils

37. Little more can be said as to the laboratory identification of

highly organic soils (Pt) than has been stated previously under field identification. 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 per cent, 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 liquid and plastic limits. Such materials usually have a liquid limit of several hundred per cent and fall well below the "A" line on the plasticity chart.

Borderline classifications

38. 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 would 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.

39. Coarse-grained soils. It will be recalled that in previous

discussions (paragraph 31) the coarse-grained soils were classified in the GW, GP, SW, and SP groups if they contained less than 5% 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% passing the No. 200 sieve (paragraph 32). The range between 5 and 12% passing the No. 200 sieve is designated as borderline, and 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% passing the No. 200 sieve and with $LL = 28$ and $PI = 9$ would be designated as SW-SC. Another type of borderline classification occurs for those soils containing appreciable amounts of fines, groups GM, GC, SM, and SC, and whose Atterberg limits 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.

40. Fine-grained soils. Mention has been made of a zone on the plasticity chart (plate 2) below a liquid limit of about 29 and ranging between plasticity index 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 (ML-CL, etc.) is used.

41. "Silty" and "clayey." It will be noted on the classification sheet, table 1, that the adjectives "silty" and "clayey" may be used as part of the descriptive name for 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 unified soil classification the terms "silt" and "clay" are used to describe those soils with Atterberg limits 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 $LL = 40$ and $PI = 16$ may be called a silty clay. In general, the adjective "silty" is not applied to clay soils having a liquid limit in excess of about 60.

Expansion of Classification

42. It may be necessary, in some cases, to expand the unified classification system by subdivision of existing groups in order to classify soils for a particular use. The indiscriminate use of subdivisions is discouraged and careful study should be given any soil group before such a step is adopted. In all cases subdivisions should be designated preferably by a suffix to an existing group symbol. The suffix should be selected carefully so that 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 in order that anyone unfamiliar with it may understand the subdivision properly.

Descriptive Soil Classification

43. 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, plate 1. 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, 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

44. Column 4 of the classification sheet, table 1, lists typical names given 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, caliches, coral, shale, etc., 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

45. 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, etc., 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, drainage, etc., are pertinent to the descriptive classification. Pertinent items to be used in describing soils are shown in column 6 of table 1. In order to achieve uniformity in estimating 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 below:

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

Several examples of descriptive classifications are shown below:

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

Table 1

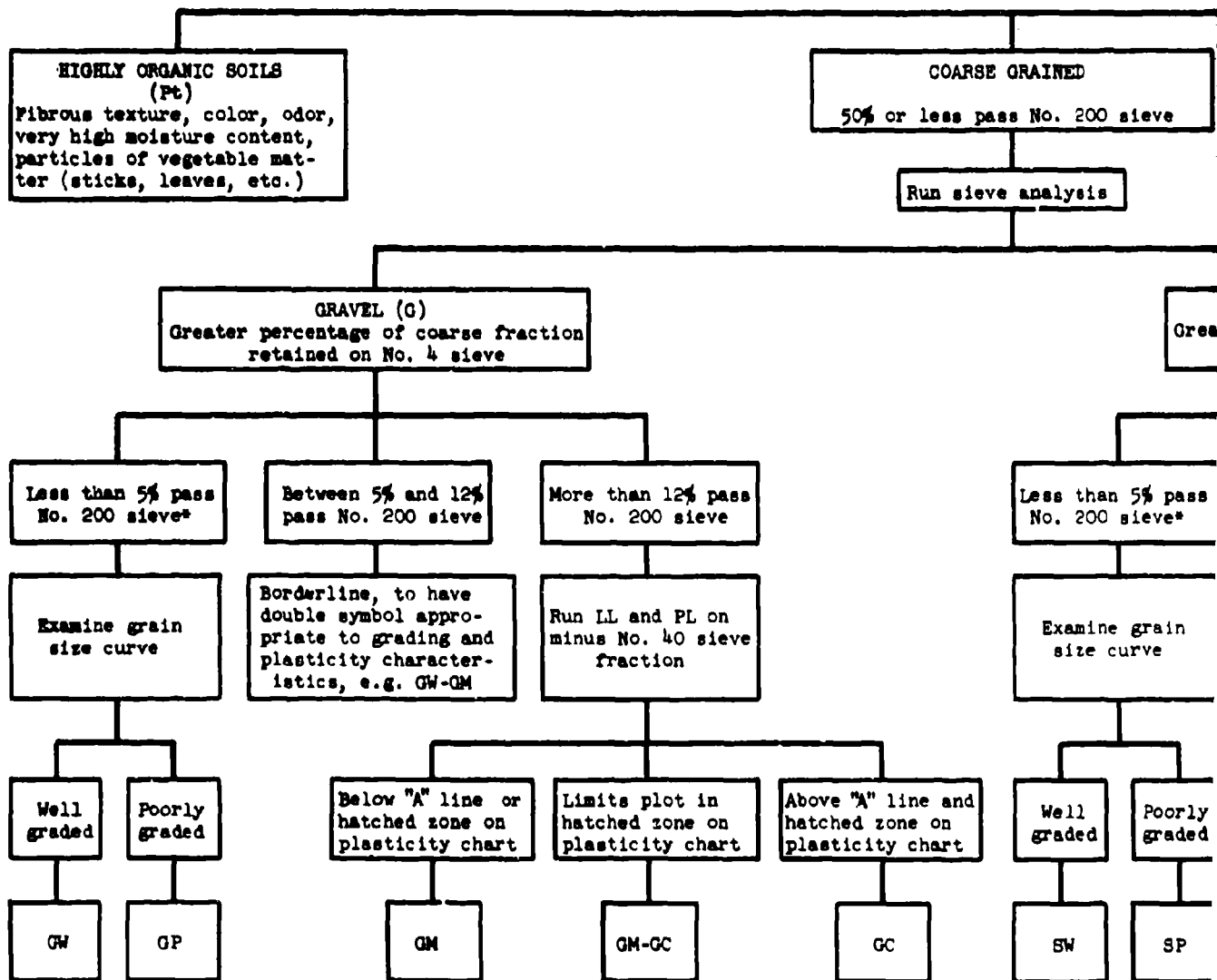
UNIFIED SOIL CLASSIFICATION (Including Identification and Description)								
Major Division	Index Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 75 μ and tactile reaction or estimated weight)	Information Required for Describing Soils				
Coarse-grained Soils More than half of particles is larger than 2.0 mm size.	Gravel More than half of coarse fraction is larger than 4.75 mm size. (If a visual classification is made, it may be used as evidence to support a size classification.)	SW	Well-sorted gravel, gravel-sand mixtures, little or no fines.	Wide range in grain size and substantial amount of all intermediate particle sizes.	For unit, tested soils and information on stratification, degree of compaction, cementation, moisture conditions, and drainage characteristics.			
		GW	Gravelly sand, gravel-sand mixtures, little or no fines.	Irregularly one size or a range of sizes with some intermediate sizes missing.				
		GM	Silty gravel, gravel-sand mixtures.	Nonplastic fines or fines with low plasticity (for identification procedure see MU below).				
		GC	Clayey gravel, gravel-sand mixtures.	Plastic fines (for identification procedure see CU below).				
		Silty sand: (little or no gravel)	SW	Well-sorted sand, generally, little or no fines.			Wide range in grain size and substantial amount of all intermediate particle sizes.	
			GW	Gravelly sand or silty gravelly sand, little or no fines.			Irregularly one size or a range of sizes with some intermediate sizes missing.	
	Sandy with fines (little or no gravel)	GM	Silty sand, gravelly mixtures.	Nonplastic fines or fines with low plasticity (for identification procedure see MU below).				
		GC	Clayey sand, gravelly mixtures.	Plastic fines (for identification procedure see CU below).				
		Identification Procedure on Plasticity Chart (see Fig. 1)						
Fine-grained Soils More than half of particles is smaller than 2.0 mm size.	Clay and silt More than half of fine fraction is smaller than 0.075 mm size.	ML	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None	For unit, tested soils and information on stratification, degree of compaction, cementation, moisture conditions, and drainage characteristics.	
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
	Silt and clay More than half of fine fraction is smaller than 0.075 mm size.	ML	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None	For unit, tested soils and information on stratification, degree of compaction, cementation, moisture conditions, and drainage characteristics.	
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
	Clay More than half of fine fraction is smaller than 0.075 mm size.	ML	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None	For unit, tested soils and information on stratification, degree of compaction, cementation, moisture conditions, and drainage characteristics.	
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		
		OL	Inorganic silts and very fine to clay, weak fines, little or no gravel, little or no clay, with slight plasticity.	Non-plastic	Low to slight	None		

A

UNITED STATES CLASSIFICATION
(Including Identification and Description)

Field Identification Procedures (Inachieve particles larger than 2 mm and small particles on estimated weight)		Inventory Required for Identification		Laboratory Identification Criteria	
Source:	Wide range in grain size and substantial amount of all intermediate particle sizes.	For undisturbed soils and information on identification degree of a specific sample, identification criteria and laboratory procedures are required.		$C_1 = \frac{b}{C_2} \text{ Greater than } 1$ $C_2 = \frac{(b_1)^2}{(b_2)^2} \text{ Between 1 and 1}$	
Mixture:	Predominantly one size or a range of sizes with some intermediate size material.	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		Not meeting all identification requirements for SW Anteriorly little more A line or B line than 1 Anteriorly little more A line with B greater than 1	
Source:	Nonplastic fines or fines with low plasticity (for identification procedures see M2 below).	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		$C_1 = \frac{b}{C_2} \text{ Greater than } 1$ $C_2 = \frac{(b_1)^2}{(b_2)^2} \text{ Between 1 and 1}$	
Mixture:	Plastic fines (for identification procedures see C1 below).	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		Not meeting all identification requirements for SW Anteriorly little more A line or B line than 1 Anteriorly little more A line with B greater than 1	
Source:	Wide range in grain size and substantial amount of all intermediate particle sizes.	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		$C_1 = \frac{b}{C_2} \text{ Greater than } 1$ $C_2 = \frac{(b_1)^2}{(b_2)^2} \text{ Between 1 and 1}$	
Mixture:	Predominantly one size or a range of sizes with some intermediate size material.	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		Not meeting all identification requirements for SW Anteriorly little more A line or B line than 1 Anteriorly little more A line with B greater than 1	
Source:	Nonplastic fines or fines with low plasticity (for identification procedures see M2 below).	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		$C_1 = \frac{b}{C_2} \text{ Greater than } 1$ $C_2 = \frac{(b_1)^2}{(b_2)^2} \text{ Between 1 and 1}$	
Mixture:	Plastic fines (for identification procedures see C1 below).	Give typical other features approximate percent area of soil not present, make note of secondary, surface modification, and frequency of occurrence of other pertinent descriptive features than and about in procedures.		Not meeting all identification requirements for SW Anteriorly little more A line or B line than 1 Anteriorly little more A line with B greater than 1	

[illegible]



Note: Sieve sizes are U. S. Standard.

* If fines interfere with free draining properties use double symbol such as GW-GM, etc.

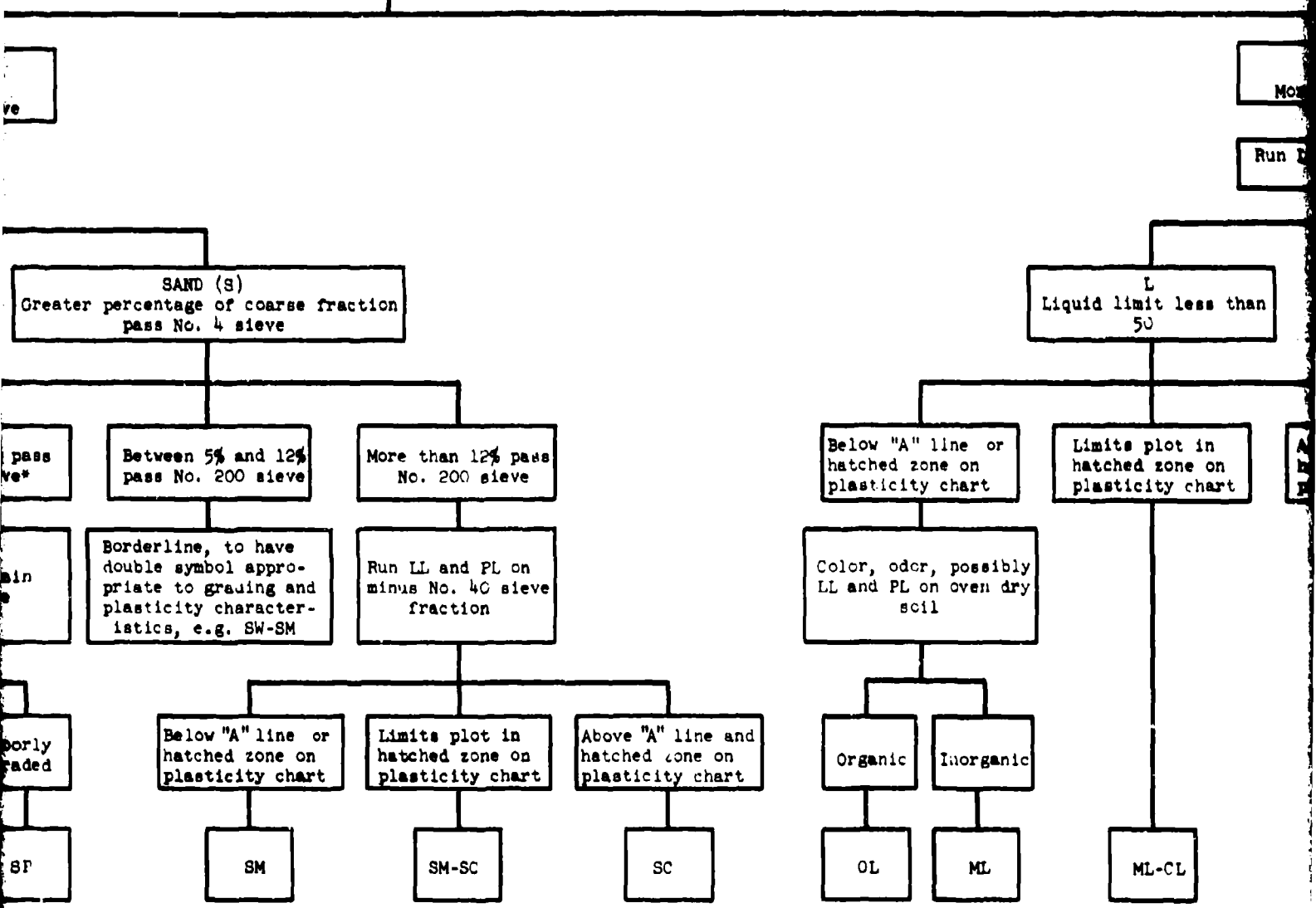
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A

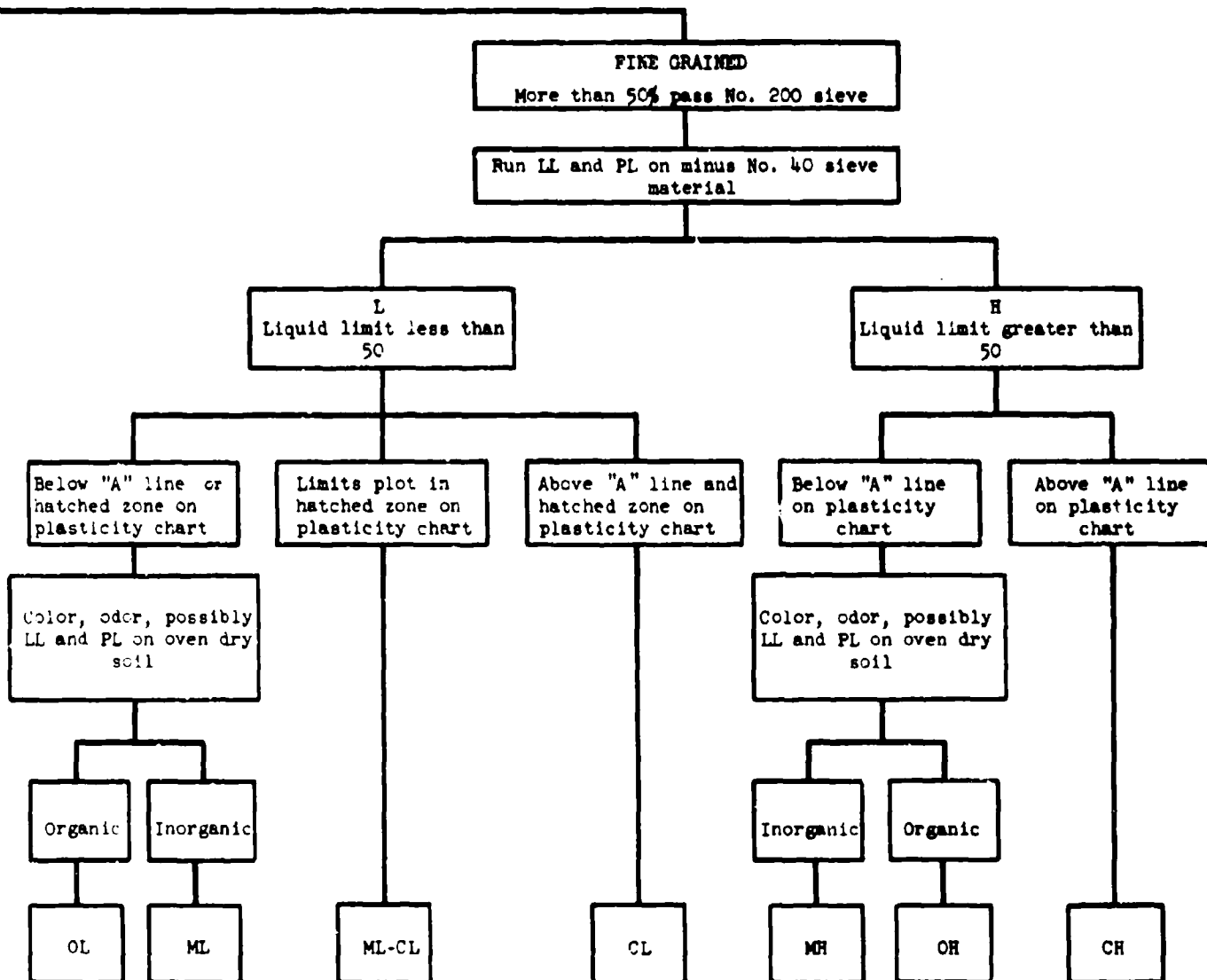
Table 2

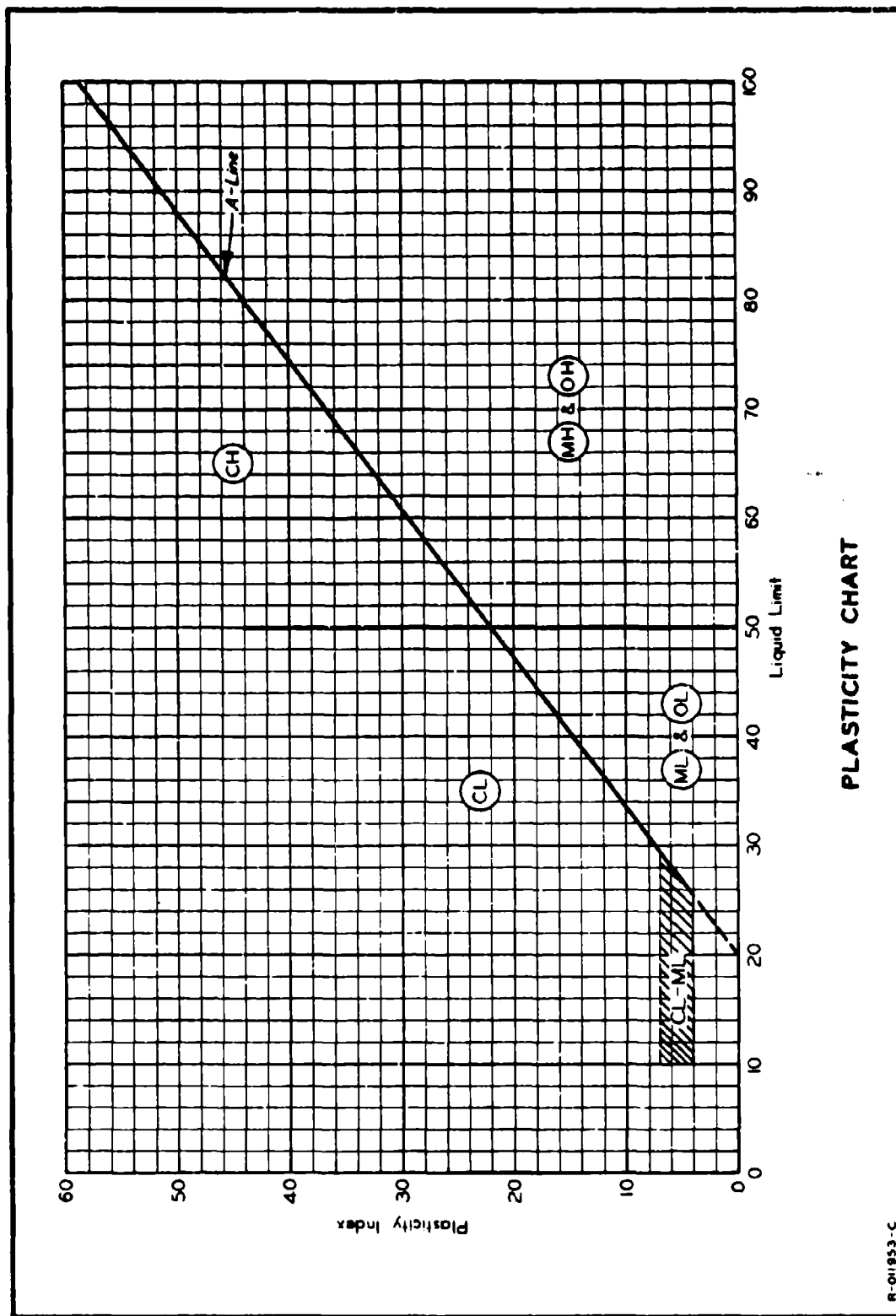
AUXILIARY LABORATORY IDENTIFICATION PROCEDURE

Make visual examination of soil to determine whether it is HIGHLY ORGANIC, COARSE GRAINED, OR FINE GRAINED. In borderline cases determine amount passing No. 200 sieve.



B





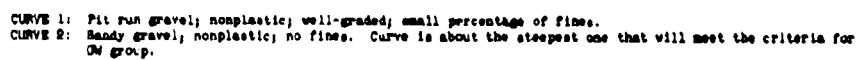


FIG. 1

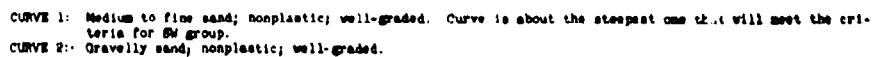
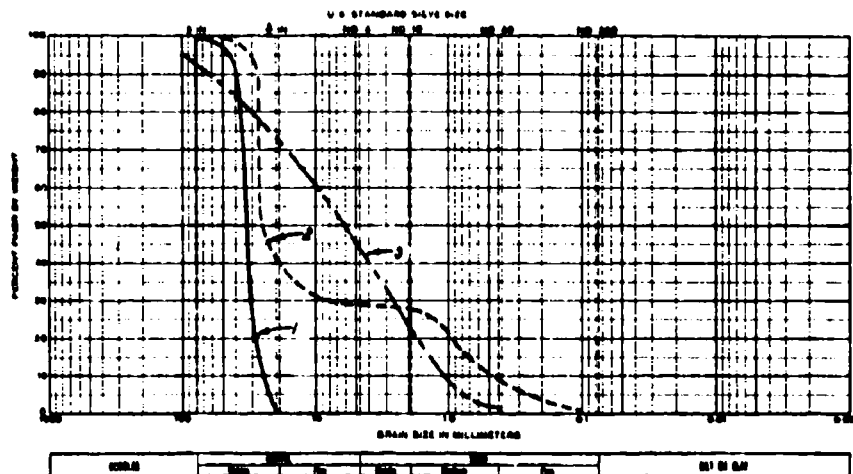


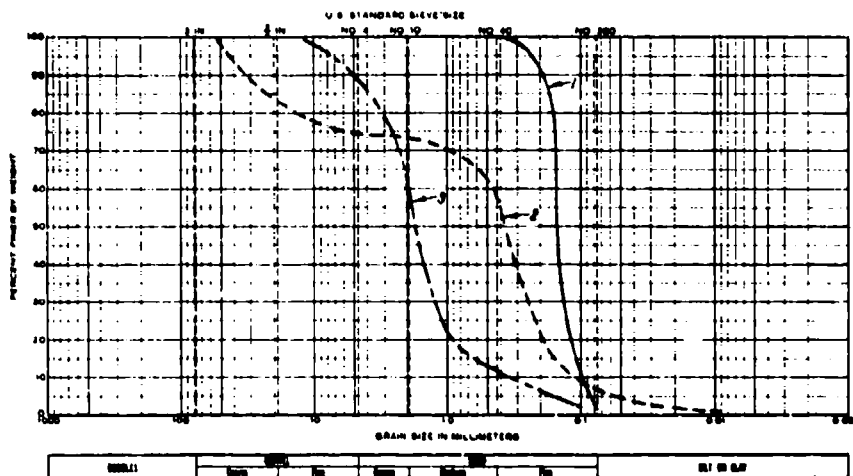
FIG. 2

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CURVE 1: Uniform coarse gravel; nonplastic. Very uniform gradation.
 CURVE 2: Gravel-sand mixture; nonplastic. Gravel is almost all of one size (3/4- to 1-in.), no fine gravel present. Poorly graded.
 CURVE 3: Sandy gravel; nonplastic. All sizes are present, but gradation does not meet curvature criterion for GW.

GP GROUP
 FIG. 1

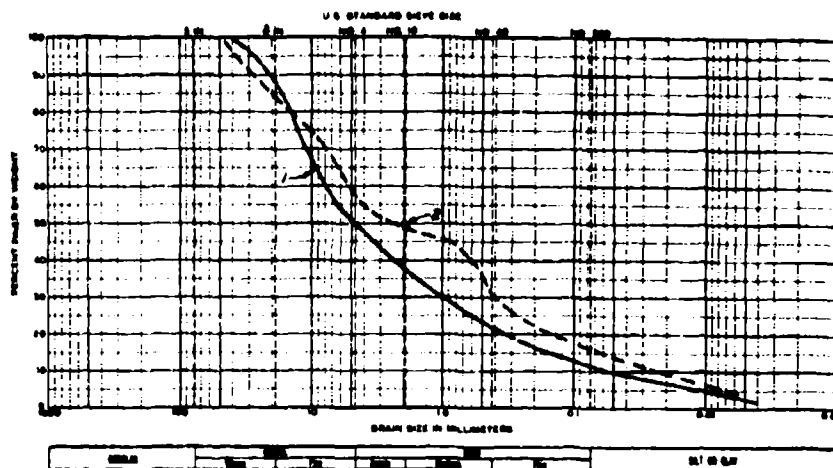


CURVE 1: Uniform fine sand; nonplastic.
 CURVE 2: Poorly graded gravelly sand mixture; nonplastic. Approximately 7 per cent fines makes this a borderline soil, symbol SP-SM.
 CURVE 3: Coarse to medium sand; nonplastic. Approaching uniform gradation; does not meet curvature criterion for SW.

SP GROUP
 FIG. 2

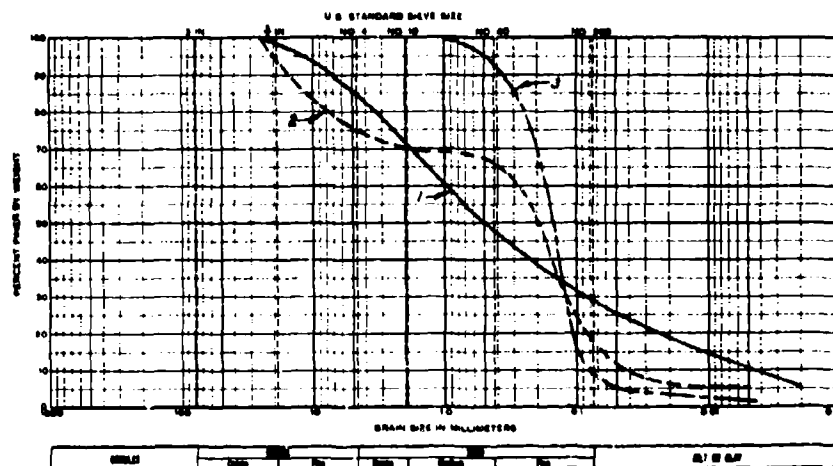
TYPICAL EXAMPLES GP AND SP SOILS

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CURVE 1: Crushed limestone, LL-16, PI-8. Well-graded. Made excellent base course material.
 CURVE 2: Gravel-sand-silt mixture; LL-72, PI-6. Poorly graded.

GM GROUP
FIG. 1

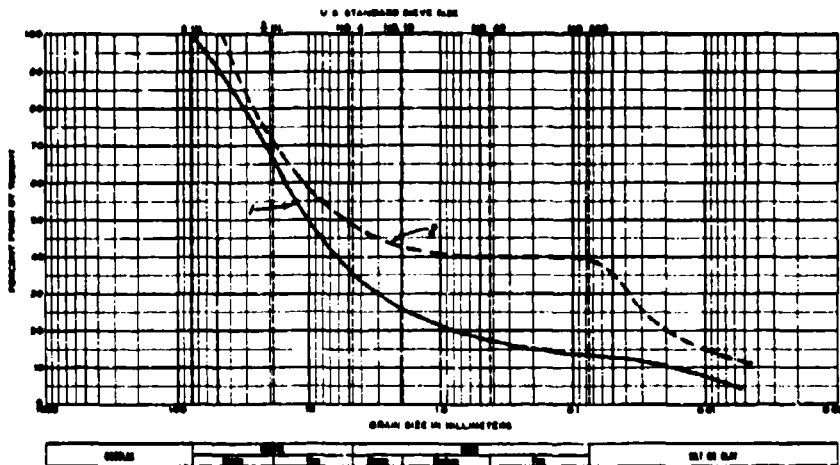


CURVE 1: Silty gravelly sand; nonplastic. Micaceous silt stabilized with sandy chert gravel.
 CURVE 2: Mixture of gravel-sand and fine silty sand; nonplastic. Poorly graded mixture; note absence of coarse and medium sand.
 CURVE 3: Silty fine sand; LL-72, PI-5. Uniform gradation, amount passing No. 200 sieve, and Atterberg limits classify soil as borderline in SP-BM-SC groups. Classify as SP-BM.

SM GROUP
FIG. 2

TYPICAL EXAMPLES GM AND SM SOILS

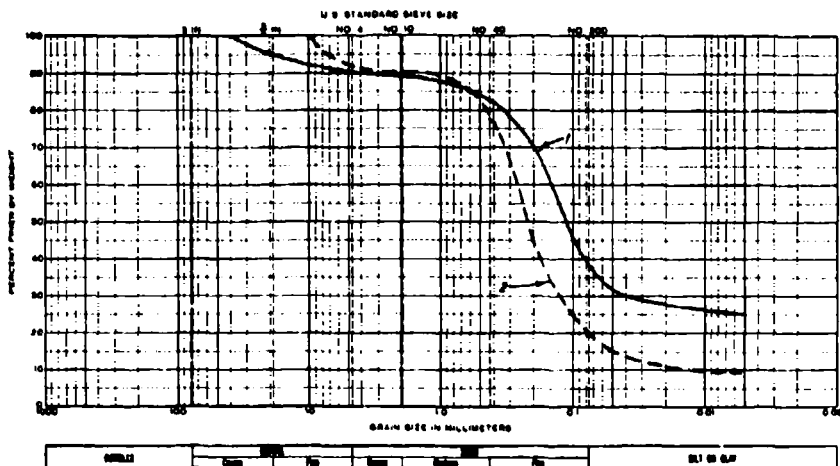
008032-C



CURVE 1: Clay-gravel (chert); LL-40, PI-19. Fairly low percentage of plastic fines.
 CURVE 2: Natural mixture of gravel and clay; LL-46, PI-20. Very poorly graded; almost no sand sizes present.

GC GROUP

FIG. 1



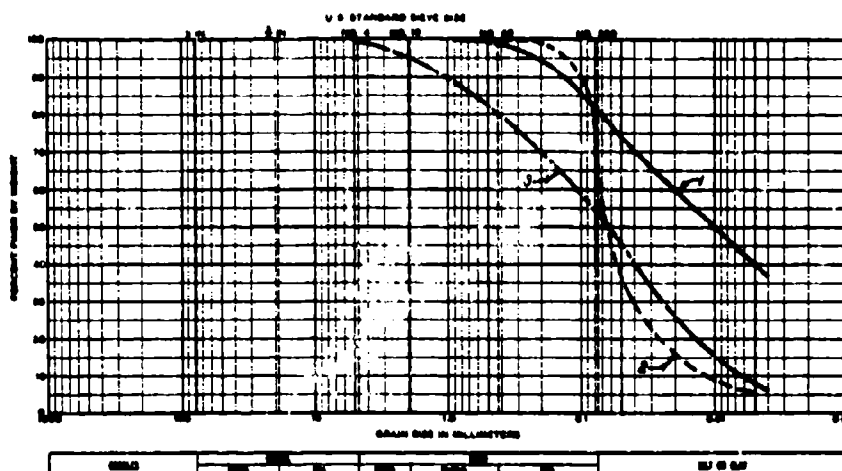
CURVE 1: Clayey sand; LL-23, PI-10. Poorly graded mixture of sand-clay and fine silty sand.
 CURVE 2: Limerock and sand mixture; LL-23, PI-0. Poorly graded.

SC GROUP

FIG. 2

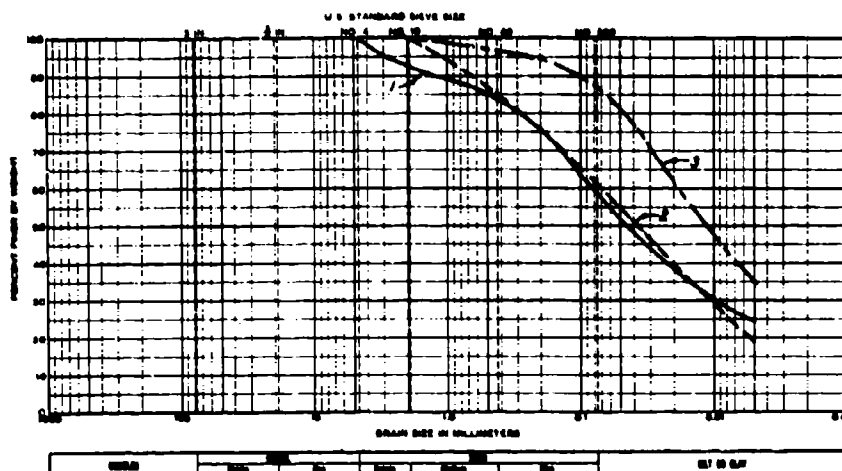
TYPICAL EXAMPLES GC AND SC SOILS

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CURVE 1: Clayey silt; LL-46, PI-16.
 CURVE 2: Uniform sandy silt; LL-30, PI-3.
 CURVE 3: Sandy silt; LL-34, PI-3.
 GENERAL: Note curves 2 and 3 have about the same plasticity but vary in grain size distribution.

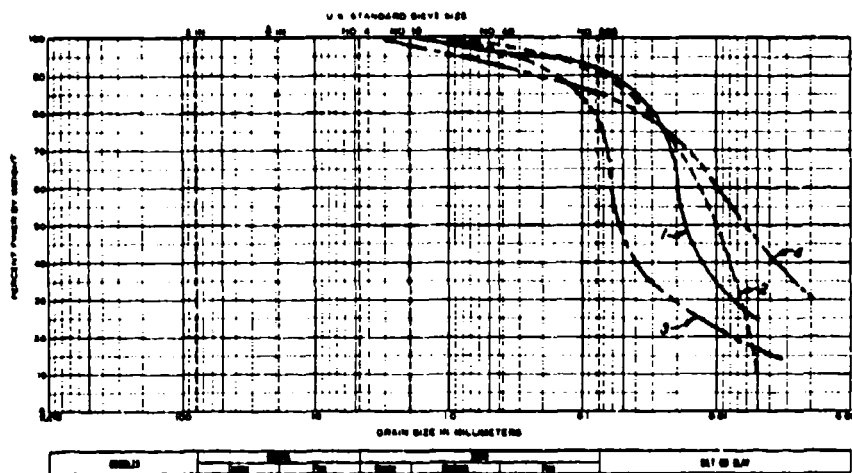
ML GROUP
 FIG. 1



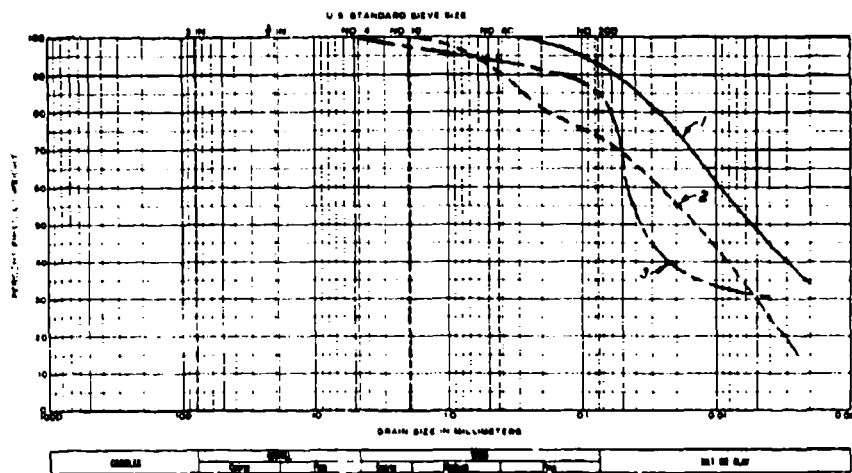
CURVE 1: Micaceous sandy silt; LL-55, PI-6.
 CURVE 2: Sandy silt; LL-67, PI-27.
 CURVE 3: Clayey silt; LL-54, PI-24.
 GENERAL: Note curves 1 and 2 have approximately the same grain size but are widely different in plasticity.

MH GROUP
 FIG. 2

TYPICAL EXAMPLES
 ML AND MH SOILS



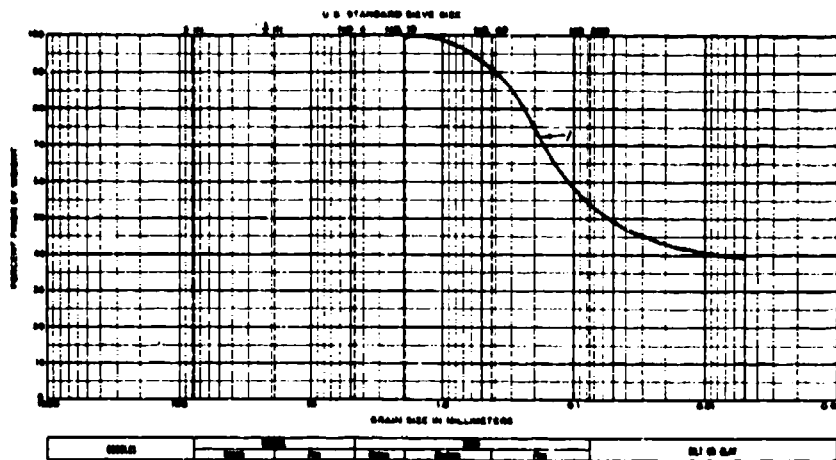
CL GROUP
FIG. 1



CH GROUP
FIG. 2

TYPICAL EXAMPLES CL AND CH SOILS

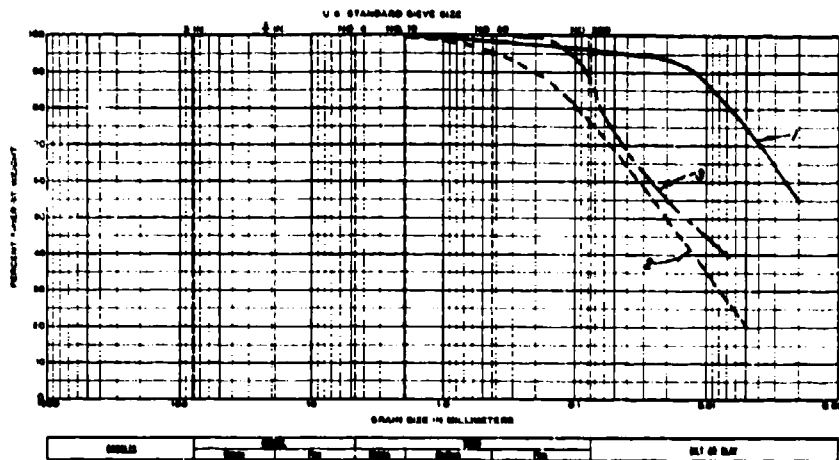
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CURVE 1: Organic sandy clay; LL-46, PI-15.

OL GROUP

FIG. 1



CURVE 1: Organic clay (tidal flats); LL-95, PI-39.
 CURVE 2: Alkali clay with organic matter; LL-66, PI-27.
 CURVE 3: Organic silt; LL-70, PI-13 (natural water content); LL-53, PI-19 (oven dried).

OH GROUP

FIG. 2

TYPICAL EXAMPLES
 OL AND OH SOILS

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PLATE 9

TECHNICAL MEMORANDUM NO. 3-357

**APPENDIX A
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
EMBANKMENTS AND FOUNDATIONS**



March 1953

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Office, Chief of Engineers
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**Conducted by
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Vicksburg, Mississippi**

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UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

Introduction

1. 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 above 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, and 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.

2. It should be borne in mind by engineers using the classification

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 upon practically any foundation; this is in accordance with the worth-while principle of utilizing the materials available for construction. 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. The use to which a structure is to be put is often the principal deciding factor in the selection of soil types as well as the type of protective measures that will be utilized. 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 Shown on Soils Classification Sheet

3. General characteristics of the soil groups pertinent to embankments and foundations are presented in table A1. Columns 1 through 5 of the table show major soil divisions, group symbols, and hatching and color symbols; names of soil types are given in column 6. The basic features are the same as those presented in the soils classification manual. Columns 7 through 12 show the following: column 7, suitability of the materials for use in embankments (strength and permeability characteristics); column 8, the minimum or range of permeability values to be expected for the soil groups; columns 9 and 10, general compaction

characteristics; column 11, the suitability of the soils for foundations (strength and consolidation); and column 12, 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.

Suitability of soils for embankments

4. 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 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 utilize 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 insure 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 a sheepfoot roller or rubber-tired roller. The MH soils, while not desirable for rolled-fill construction, may be utilized 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 utilized to advantage in blankets and stability berms where strength is not of importance.

Permeability and seepage control

5. 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: (1) seepage through embankments; (2) seepage through foundations; and (3) control of uplift pressures. These are discussed in relation to the soil groups in the following paragraphs.

6. 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, 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 upon the material that they drain; in general, free-draining sands (SW, SP) or gravels (GW, GP) are preferred, but a silty sand (SM) may effectively drain a clay (CL, CH) and be entirely satisfactory.

7. 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, 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, 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.

8. 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, 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, 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 upon a careful evaluation of conditions that do or can exist, and an economical solution reached that will accomplish the desired results.

Compaction characteristics

9. In column 9 of the table are shown 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 is required to secure the

desired density. For lift construction of embankments, the sheepsfoot roller and rubber-tired roller 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 thus affording better moisture distribution. Rubber-tired equipment referred to in the table is considered to be heavily loaded compactors or earth-moving equipment with a minimum wheel load of 15,000 lb. If ordinary wobble-wheel rollers are used for compaction, the thickness of compacted lift is usually reduced to about 2 in. 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 generally 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. In column 10 of table A1 are shown ranges of unit dry weight of the soil groups for the standard AASHTO (Proctor) compactive effort. It is emphasized that these values are for guidance only and design or construction control should be based on laboratory test results.

Suitability of soils for foundations

10. Suitability of soils for foundations of embankments or structures is primarily dependent on the strength and consolidation characteristics of the subsoils. Here again 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, etc., may be small in order 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 are dependent upon a number of variables, such as structure, in-place density, moisture content, cycles of loading in their geologic history, etc., 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, 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, SM) may exhibit variable bearing capacity depending on their density; this is true to some extent for all the 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 capacity, 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, Pt, generally are 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 upon the structure involved.

Graphical Presentation of Soils Data

11. 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 shown by 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 various combinations of materials found in the explorations. This system has been adapted to the various soil groups in the unified soil classification system and the appropriate symbols are shown in column 4 of table A1. As an alternative to the hatching symbols, they may be omitted and the appropriate group letter symbol (CL, etc.) written in the boring log. In addition to the symbols on logs of borings, the effective size, D_{10} (grain size in mm corresponding to 10 per cent finer by weight), 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 special 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 A1.

Table A1

CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

Major Divisions (1) (2)		Letter (3)	Symbol		Name (6)	Value for Embankments (7)	Permeability cm Per Sec (8)	Compaction
			Hatching (4)	Color (5)				
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 steel-wheeled
		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 steel-wheeled
		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 cl rubber-tired, roller
		GC			Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-roller
	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
		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
		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 cl rubber-tired, roller
		SC			Clayey sands, sand-silt mixtures	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot rubber tired
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, essential, roller, sheepsfoot
		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, roller, rubber-tired
		OL			Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, roller
	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, roller
		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, roller
		OH			Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, roller
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not used for construction		Cc

- 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 are as shown.
3. Column 10, unit dry weights are for compacted soil at optimum moisture content for Standard AASHTO (Standard Proctor) compactive effort.

A

Table A1

FACTORS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

Value for Embankments (7)	Permeability cm Per Sec (8)	Compaction Characteristics (9)	Std AASHTO Max Unit Dry Weight Lb Per Cu Ft (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
Stable, pervious shells and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	125-135	Good bearing value	Positive cutoff
Highly stable, pervious of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	115-125	Good bearing value	Positive cutoff
Highly stable, not particu- larly limited to shells, but may be used for impervious cores or rolls	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepfoot roller	120-135	Good bearing value	Toe trench to none
Stable, may be used for core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepfoot roller	115-130	Good bearing value	None
Stable, pervious sections, protection required	$k > 10^{-3}$	Good, tractor	110-130	Good bearing value	Upstream blanket and toe drainage or wells
Highly stable, may be used 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
Stable, not particularly limited to shells, but may be used for impervious cores or rolls	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepfoot roller	110-125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
Stable, use for impervious flood control rolls	$k = 10^{-6}$ to 10^{-8}	Fair, sheepfoot roller, rubber tired	105-125	Good to poor bearing value	None
Stability, may be used for dikes with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepfoot roller	95-120	Very poor, suscepti- ble to liquefaction	Toe trench to none
Impervious cores and rolls	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepfoot roller, rubber tired	95-120	Good to poor bearing	None
Stable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepfoot roller	80-100	Fair to poor bearing, may have excessive settlements	None
Stability, core of hydraulic fill, not desirable in rolled construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepfoot roller	70-95	Poor bearing	None
Stability with flat slopes, rolls, blankets and dike	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepfoot roller	75-105	Fair to poor bearing	None
Stable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepfoot roller	65-100	Very poor bearing	None
Not used for construction	Compaction not practical		Remove from foundations		

Notes.
Reasonable number of passes when moisture conditions and thickness of lift are properly controlled.
Standard AASHTO (Standard Proctor) compactive effort.

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B

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APPENDIX B
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
ROADS AND AIRFIELDS



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UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX BCHARACTERISTICS OF SOIL GROUPS PERTAINING TO
ROADS AND AIRFIELDSIntroduction

1. 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. Certain 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 use of 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 Shown on Soils Classification Sheet

2. General characteristics of the soil groups pertinent to roads and airfields are presented in table B1. 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; column 8 and column 9 make a similar evaluation for the soils when used as subbase and base materials; potential frost action is shown in column 10; compressibility and expansion characteristics are shown in column 11; 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 California Bearing Ratio (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

3. It will be noted in column 3, letter symbols, that 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 liquid limit and plasticity index of the fraction of the soil passing the No. 40 sieve. The suffix d is used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u is used otherwise. Typical symbols for soils in these groups are GMD and SMu, etc.

Values of soils as subgrade, subbase, or base materials

4. The descriptions in columns 7, 8, and 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. It is noted that the adjective "excellent" is not used for any of the soils for base courses; it is considered that the adjective "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 such extent that they offer only moderate strength and therefore 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 usually are 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 the addition of 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 California Bearing Ratio (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.

5. 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 plasticity index should be in the range of 5 to about 15.

Potential frost action

6. 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. These are 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 ground-water table, capillary supply, water held within the soil voids, or through infiltration. The degree of ice formation that will occur in any given case is markedly 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 ground water, 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 per cent of grains finer than 0.02 mm in diameter by weight are generally nonfrost-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 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

7. These characteristics of soils may be of two types insofar as their applicability to road and runway design is concerned. The first is the relatively long-term compression or consolidation under the dead weight of the structure, and 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 load-carrying capacity of the pavement. 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 type 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 increasing liquid limit. 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 distribution of load through a greater thickness of overlying material. This, in general, 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

8. 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 rain water 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, and 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

9. 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 in order 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. It may be noted 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 sheepfoot 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 of high liquid limit (group H). Suggested minimum weights of the various types of equipment are shown in note 2 of the table. In column 14 are shown ranges of unit dry weight for soils compacted according to test method 100 (CE 55 compaction effort).

MIL-STD-621A. These values are included primarily for guidance; design or control of construction should be based on test results.

Graphical Presentation of Soils Data

10. 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 letter symbol (CL, etc.) may be written in the appropriate section of the log. As an alternative, hatching symbols shown in column 4 of table B1 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 special 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 B1.

Table B1

Characteristics Pertinent to Roads and Airfields

Major Divisions (1) (2)		Symbol			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)
		Letter (3)	Hatching (4)	Color (5)					
COARSE- GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Black	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Good	None to very slight
		GP			Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good	Fair to good	None to very slight
		GM		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good	Fair to good	Slight to medium
						Good	Fair	Poor to not suitable	Slight to medium
		GC		Clayey gravels, gravel-sand-clay mixtures	Good	Fair	Poor to not suitable	Slight to medium	
	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
		SP			Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair	Poor to not suitable	None to very slight
		SM		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to good	Poor	Slight to high
						Fair	Poor to fair	Not suitable	Slight to high
		SC		Clayey sands, sand-clay mixtures	Poor to fair	Poor	Not suitable	Slight to high	
FINE- GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 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
		CL			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
		OL			Organic silts and organic silt-clays of low plasticity	Poor	Not suitable	Not suitable	Medium to high
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable	Not suitable	Medium to very high
		CH			Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitable	Not suitable	Medium
		OH			Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable	Not suitable	Medium
	HIGHLY ORGANIC SOILS		Pe		Orange	Peat and other highly organic soils	Not suitable	Not suitable	Not suitable

Notes:

1. The Major Division of Material is grouped into subdivisions of 1 and 2, and 3, and 4, and 5, and 6, and 7, and 8, and 9, and 10, and 11, and 12, and 13, and 14, and 15, and 16, and 17, and 18, and 19, and 20, and 21, and 22, and 23, and 24, and 25, and 26, and 27, and 28, and 29, and 30, and 31, and 32, and 33, and 34, and 35, and 36, and 37, and 38, and 39, and 40, and 41, and 42, and 43, and 44, and 45, and 46, and 47, and 48, and 49, and 50, and 51, and 52, and 53, and 54, and 55, and 56, and 57, and 58, and 59, and 60, and 61, and 62, and 63, and 64, and 65, and 66, and 67, and 68, and 69, and 70, and 71, and 72, and 73, and 74, and 75, and 76, and 77, and 78, and 79, and 80, and 81, and 82, and 83, and 84, and 85, and 86, and 87, and 88, and 89, and 90, and 91, and 92, and 93, and 94, and 95, and 96, and 97, and 98, and 99, and 100, and 101, and 102, and 103, and 104, and 105, and 106, and 107, and 108, and 109, and 110, and 111, and 112, and 113, and 114, and 115, and 116, and 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Table D

Characteristics Pertinent to Roads and Airfields

Value as Base 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 lb per cu ft (14)	Typical Design Values Subgrade modulus lb per cu in.	
							CBR (15)	lb per cu in. (16)
Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125-140	40-60	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, sheepfoot 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, sheepfoot roller	115-135	20-30	200-300
	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	130-145	20-40	200-300
to good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110-130	20-40	200-400
	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105-135	10-40	150-400
to good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheepfoot roller; close control of moisture	120-135	15-40	150-400
to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	100-130	10-20	100-300
	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	100-135	5-20	100-300
suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheepfoot roller; close control of moisture	90-130	15 or less	100-200
suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired roller, sheepfoot roller	90-130	15 or less	50-150
suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired roller, sheepfoot roller	90-105	5 or less	50-100
suitable	Not suitable	Medium to very high	High	Fair to poor	Sheepfoot roller, rubber-tired roller	80-105	10 or less	50-100
suitable	Not suitable	Medium	High	Practically impervious	Sheepfoot roller, rubber-tired roller	90-115	15 or less	50-150
suitable	Not suitable	Medium	High	Practically impervious	Sheepfoot roller, rubber-tired roller	80-110	5 or less	25-100
suitable	Not suitable	Slight	Very high	Fair to poor	Compaction of practical	-	-	-

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basis of Atterberg limits; suffix "S" (e.g., 2MS) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less. In some instances, several types of equipment or a combination of two types may be necessary. Rubber-tired equipment is recommended for better results.

Materials.
Fines.

the required densities for some material (e.g., test at depth of pressure of approximately 1 to 1.5 psi).
may be necessary to obtain the required densities for some material (e.g., test at depth of the feet down).

requirements.

B-8

B