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MILITARY STANDARD

UNIFIED SOIL CLASSIFICATION SYSTEM

FOR ROADS, AIRFIELDS,

EMBANKMENTS AND

FOUNDATIONS

FSC MISC

DEPARTMENT OF DEFENSE

Washington, D. C. 20301

UNIFIED SOIL CLASSIFICATION SYSTEM

FOR ROADS, AIRFIELDS, EMBANKMENTS AND FOUNDATIONS

MIL-STD-619B

1. This military standard is mandatory for use by all Departments and Agencies of the Department of Defense.

2. Recommended corrections, additions, or deletions should be addressed to U. S. Army Mobility Equipment Command, Directorate of Research, Development and Engineering, ATTN: SMEFB-RDE-KX, Fort Belvoir, Virginia, 22060.

FOREWORD

Soils are subjected to classification in order to provide a general concept of the engineering characteristics of foundation, embankment, and filter materials. In the preliminary design stage, classification provides guidance in locating areas for detailed subsurface exploration, and in selecting representative samples for the more complex design tests such as shear, consolidation, compaction, bearing, permeability, and swell. In preparing the final design, classification permits establishment of soil profiles, the location and limits of undesirable materials and potential borrow areas, and the critical foundation condition which governs the design.

During construction operations, classification provides a means of evaluating and controlling the quality of foundation and borrow materials.

Compliance with this standard will promote uniformity in soil classification terminology, test procedures, and interpretation of results. The standard will also provide a common basis for describing soil conditions that can be understood by both design and construction engineers.

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TABLES

1. SCOPE

This standard establishes criteria for the classification of soils by the Unified Soil Classification System, including classification of frozen soils.

2. REFERENCED DOCUMENTS

The issues of the following documents in effect on date of invitation for bids form a part of this standard to the extent specified herein:

GOVERNMENTAL STANDARDS

Military

MIL-STD-621 - Test Method for Pavement Subgrade, Subbase, and Base-Course Material.

3. DEFINITIONS

3.1 Classification system. 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 contributes its characteristics to the mixture. The Unified Classification System is based on those characteristics of the soil which indicate how it will behave as a construction material. This system is a modification of the original Casagrande Airfield Classification System. The following properties have been found most useful in predicting how a soil will behave as a construction material and consequently form the basis of the Unified System. The properties can be determined with very simple tests and, with experience, can be estimated with some accuracy:

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

In the Unified System, the soil is given a name which is intended to be a short description, and a letter symbol which consists of two letters indicating its principal characteristics. Table I summarizes the system, giving the names, letter symbols, and general information about the soils. In the Unified System, soils are divided into coarse-grained and fine-grained materials. For convenience, any soil having 50 percent or less passing the No. 200 sieve is termed coarse grained, and any soil having more than 50 percent passing the No. 200 sieve is termed fine grained.

3.1.1 Coarse-grained soils. The coarse-grained soils include gravels, gravelly soils, sands, and sandy soils. The letter G is used to indicate a gravel, and the letter S is used to indicate a sand. Gravel is material between 3 inches in diameter and the No. 4 (4.7 mm.) sieve size, and sand is material between the No. 4 sieve size and the No. 200 (0.074 mm.) sieve size. Where a mixture occurs, the primary name is the predominant fraction, and the minor fraction is used as an adjective. For example, a sandy gravel would be a mixture containing more gravel than sand. It will be noted on the grain-size distribution diagram, table V, that gravel is divided into coarse and fine, the division being at the 3/4-inch sieve size. Particles larger than 3 inches in diameter are termed cobbles. Sand is divided into coarse, medium, and fine, the divisions being at the No. 10 and 40 sieve sizes.

3.1.1.1 Coarse-grained soils with a small percentage of fines. When the coarse-grained soil has a small percentage of fines and is nonplastic, the shape of the grain-size distribution curve determines the second letter to be used in the symbol. A soil is considered poorly graded if the difference in size between the largest and smallest grains is small, that is, if the slope of the grain-size distribution curve is steep or if there is a deficiency in any one size of particles giving a characteristic "hump" to the grain-size distribution curve. Table V shows grain-size distribution curves for typical well graded and poorly graded soils. The letter P is used to indicate a poorly graded soil; for example, GP and SP indicate poorly graded gravels and sands. Well-graded soils are those which have a reasonably large spread between the largest and the finest particles and have no marked deficiency in any one size. The letter W is used to indicate a well-graded soil; for example, GW indicates a well-graded gravel, and SW indicates a well-graded sand.

3.1.1.2 Coarse-grained soils with a considerable percentage of fines. Sands and gravels that have a considerable percentage of fines or that exhibit plasticity are classified according to the liquid limit and plasticity index of the fraction passing the No. 40 sieve using table III. The letter M is used to indicate fines with little or no plasticity as GM or SM. The symbol M stands for fine-grained soils that exhibit silt-like characteristics. The letter C is used to indicate fines that exhibit plasticity as GC or SC. The symbol C stands for fine-grained soils that exhibit clay-like characteristics.

3.1.2 Fine-grained materials. The fine-grained soils are not divided according to grain size but according to plasticity and compressibility. Table III shows a plot of plasticity index versus liquid limit, and is used in establishing the group symbol for fine-grained soils.

3.1.2.1 ML and MH groups. The symbols L and H represent low and high compressibility, and an arbitrary dividing line between the two is set at a liquid limit of 50. The term "compressibility" implies volume change, shrinking during dry periods and swelling during wet periods, as well as consolidation under load. Therefore, the soils in the ML group are very fine sands 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 that have low plasticity.

3.1.2.2 CL and CH groups. In these groups, the symbol C stands for clay, with L and H denoting low or high compressibility as described in the preceding paragraph. The soils are primarily inorganic clays. Clays with liquid limits below 50 are classified as CL and are usually lean clays or sandy clays. Clays with liquid limits of 50 and above are classified as CH. These include the fat clays, gumbo clays, volcanic clays, and bentonite. The glacial clays of the northern United States cover a wide band in the CL and CH groups.

3.1.2.3 OL and OH groups. The soils in the OL and OH groups are characterized by the presence of organic matter, hence the symbol O. Organic silts and clays are classified in these groups. The materials have comparatively low plasticity indexes. The variation with liquid limit corresponds to the ML and MH groups.

3.1.3 Miscellaneous soil materials. Soils containing large percentages of fibrous organic matter such as peat and partially decomposed vegetation are designated by the letter symbol Pt. In addition, certain soils contain shells, concretions, cinders, and other nonsoil materials in sufficient quantities to warrant the includions of pertinent phrases in their classification.

3.1.4 Frozen soils. Special expansion of the Unified Soil Classification System is required for frozen soils because of the concise identification needed by scientists and engineers. Identification of seasonally frozen soil or permafrost according to structural divisions caused by freezing and thawing, such as "suprapermafrost" or "annual frost zone," as illustrated in figure 1, provides no information on those factors of appearance and physical properties that are essential guides to the nature and behavior of the materials in the frozen state and to the changes that may occur upon thawing. Also, such identification is not applicable to specimens frozen in the laboratory. Therefore, a frozen soil description and classification system that is independent of the geologic history or mode of origin of the material is needed. This system should also be capable of expansion or contraction in order to provide any desired degree of detail.

The system described herein affords these characteristics. The system can be used with any type of samples that show the natural structure of the material, such as specimens recovered from drill holes or test pits, or frozen in the laboratory. It may sometimes be found that a slightly different classification will be assigned if the material is inspected in full face in a test pit as compared with a small sample removed from the same location. This will generally have little practical significance, although test pit inspection gives the most valid results.

4. GENERAL REQUIREMENTS

4.1 Identification from laboratory results. In the usual operation, samples of the soils are obtained during the soil survey and are tested in the laboratory to determine the properties used to classify them. The principal tests are the mechanical analysis, liquid limit, and plastic limit tests. These are used for all soils except those in the Pt group which are identified by visual examination. With the percentages of gravel, sand, and fines and the liquid limit and plasticity index, the group symbol can be obtained from the chart in table IV by following the diagram down from top to bottom. For the gravels and sands containing 5 percent (or less) fines, it is necessary to study the shape of the grain-size distribution curve to establish whether the material is well graded or poorly graded (see 3.1.1). Also, for the fine-grained soils it is necessary to plot the liquid limit and plasticity index in table III to establish the correct symbol. Organic silts or clays (OL and OH) are subjected to liquid and plastic limit tests before and after oven-drying. An organic silt or clay will show a radical drop in these limits by oven-drying. An inorganic soil will show a slight drop that will not be significant. Where there is an appreciable drop, the values before drying should be used when the classification is determined from table III.

5. DETAIL REQUIREMENTS

5.1 Characteristics of unfrozen soil groups pertinent to roads and airfields.

5.1.1 General. 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 correct 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 correctly designed, water-collecting system. Strength requirements for base-course materials to be used immediately under pavements 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 in rigid pavement or of base materials in flexible pavement construction. While the correct 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, the grouping of soils in the classification system provides a general indication of their behavior in road and airfield construction.

5.1.2 Features shown on soils classification sheet. General characteristics of the soil groups pertinent to roads and airfields are presented in table V. The various features presented are discussed in the following paragraphs.

5.1.2.1 Subdivision of coarse-grained soil groups. In table V, column 3, (letter symbols) 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 and subbase 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; otherwise, the suffix u is used. Typical symbols for soils in these groups are GMd and SMu, etc.

5.1.2.2 Value of soils as subgrade or subbase materials. The descriptions in table V, columns 7, 8, and 9 give a general indication of the suitability of the soil groups for use as subgrade, 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 shall be reduced, depending on the potential action of the material, as shown in column 10. Correct design procedures should be used in situations where this is a problem. The coarse-grained soils in general make the best subgrade, subbase, and base materials. The GW group has excellent qualities as a subgrade and subbase and is good as a base material. The adjective "excellent" is not used for any of these 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 normally only slightly less desirable as subgrade or subbase materials, and under certain favorable conditions may be used as base materials. However, poor gradation and other factors could reduce the value of these soils to such extent that they offer only moderate strength and therefore their value as a base material is questionable. The GMu, GC, and SW groups are reasonably good as subgrade or select 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 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 materials, 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 subbases under bituminous pavements, but soils in the ML and CL groups may be used as select materials. The fibrous organic soils (group Pt) are very poor subgrade materials and should be removed wherever possible; otherwise, special construction measures should be adopted. They are not suitable as subbase and base materials. The CBR values shown in column 15 give a relative indication of the strength of the various soil groups as used in flexible pavement design. Similarly, values of subgrade modulus (k) in column 16 are relative indications of strengths from plate-bearing tests as used in rigid pavement design. As these tests are used for the design of pavements, actual test values should be used for this purpose instead of the approximate values shown in the tabulation. For wearing surfaces on unsurfaced roads, sand-clay-gravel mixtures (GC) are normally 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.

5.1.2.3 Potential frost action. The relative effects of frost action on the various soil groups are shown in table V, 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 high groundwater 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 3 percent by weight of grains finer than 0.02 mm. in diameter 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. In one a sufficient depth of acceptable granular material is placed over the soils to prevent freezing in the subgrade and the consequent detrimental effects of frost action. In the other method a reduced depth of granular material is used, thereby allowing freezing in the subgrade, and the design is based on the reduced strength of the subgrade during the frost-melting period. In many cases, appropriate drainage measures to prevent the accumulation of water in the soil pores help to diminish ice segregation in the subgrade and subbase.

5.1.2.4 Compressibility and expansion. These soil characteristics may be of two types insofar as their applicability to road and runway design is concerned. The first is the relatively long-term compression of 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, protection must be provided, as even small movements of this type soil may be detrimental to the base and wearing course of pavements. 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. This 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.

5.1.2.5 Drainage characteristics. The drainage characteristics of soils are a direct reflection of their permeability. The evaluation of drainage characteristics of soils for use in roads and runways is shown in table V, column 12. The presence of moisture in base, subbase, and subgrade materials, except in 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. Therefore, 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.

5.1.2.6 Compaction equipment. The compaction of soils for roads and runways, especially for the latter, requires that a high degree of density be attained at the time of construction 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 a base course and such materials require special treatment in compaction. Types of compaction equipment that will normally produce the desired densities are shown in table V, column 13. Several types of equipment are listed for some of the soil groups 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 sand, and sheepsfoot rollers for coarse-grained or fine-grained soils having the same 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 for airfield construction are shown in note 2 of table V. In column 14 are shown ranges of unit dry weight for soils compacted according to MIL-STD-621, method 100, compaction effort CE 55. These values are included primarily for guidance; design or control of construction should be based on test results.

5.2 Characteristics of unfrozen soil groups pertinent to embankments and foundations.

5.2.1 General. 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, consolidation, expansion, and compaction characteristics. Other features may be investigated for a specific problem, but in general some of 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.

5.2.2 Limitations. Only generalized characteristics of the soil groups are included in this standard, 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 worthwhile 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 normally 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 description of pertinent soil characteristics contained herein.

5.2.3 Features shown on soils classification sheet. General characteristics of the soil groups pertinent to embankments and foundations are presented in table VI. The various features are discussed in the following paragraphs.

5.2.3.1 Suitability of soils for embankments. Three major factors that influence the suitability of soils for use in embankments are permeability, strength, and ease of compaction. The gravelly and sandy soils with little or no fines, groups GW, GP, SW, and SP, are stable, pervious, and 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 correctly 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 sheepsfoot 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.

5.2.3.2 Permeability and seepage control. Since the permeability (table VI, column 8) and requirements for seepage control (table VI, 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.

5.2.3.3 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-drainage 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.

5.2.3.4 Seepage through foundations. As in the case of embankments, the use of the structure involved normally 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.

5.2.3.5 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 less pervious 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. 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 that will accomplish the desired results should be reached.

5.2.3.6 Compaction characteristics. The general compaction characteristics of the various soil groups are shown in table VI, column 9. The evaluations given and the equipment listed are based on average field conditions where correct 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 by about 2 inches. Granular soils with little or no fines generally show good compaction characteristics, with the well-graded materials, GW and SW, usually furnishing better results than the poorly-graded soils, GP and SP. The sandy soils in most cases are best compacted by crawler-type tractors; on the gravelly materials, rubber-tired equipment and sometimes steel-wheel rollers are also effective. Coarse-grained soils with fines of low plasticity, groups GM and SM, show good compaction characteristics with either sheepsfoot rollers or rubber-tired equipment; however, the range of moisture contents for effective compaction may be very narrow, and close moisture control is desirable. This is also 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. Ranges of unit dry weight of the soil groups for the standard AASHO (Proctor) compactive effort (MIS-STD-621, method 100, compactive effort CE 12) are shown in table VI, column 10. It is emphasized that these values are for guidance only and design or construction control should be based on laboratory test results.

5.2.3.7 Suitability of soils for foundations. Suitability of soils for foundations of embankments or structures is primarily dependent on the strength, expansion, and consolidation characteristics of the subsoils. Here again the type of structure and its use will largely govern the adaptability of a soil as an acceptable 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 acceptable 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 cannot be easily evaluated by a classification system such as used herein. For these reasons, only 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 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. Treatment will depend upon the structure involved.

5.3 Graphical presentation of unfrozen soils data. Normally the results of soils explorations are presented 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 as alternative, hatching symbols shown in table V and table VI, column 4 may be used. In addition, the natural water content of fine-graded soils should be shown along the sides 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 table V and table VI, column 5.

5.4 Features of the frozen soil classification system.

5.4.1 Parts of the system. The system for describing and classifying frozen soil is shown in table VII. As indicated in table VII, column 1, the frozen soil is identified in three steps denoted as parts I, II, and III. Under part I the soil phase is identified independently of the frozen state in accordance with the Unified Soil Classification System, a summary of which is shown in table I. Under part II, the soil characteristics resulting from the frozen state of the material are added to the soil description. Under part III important ice strata found in the soil are described.

5.4.1.1 Classification of frozen soil, major groups. As shown in table VII, columns 2 and 3, under part II, frozen soils are divided into two major groups: Soils in which segregated ice is not visible to the unaided eye (designation N), and soils in which segregated ice is visible (designation V). Since, as will be described, ice layers exceeding 1 inch in thickness are identified separately, the latter major grouping is applied only to soil containing ice layers 1 inch or less in thickness. Frozen soils in the N group will commonly, on inspection by the unaided eye, reveal the presence of ice within the soil voids by crystalline reflections or by a sheen on fractured or trimmed surfaces; however, the appearance is given that the water has frozen within the original voids in the soil, without segregation. Frozen soils in the V group give the opposite impression, and segregated ice is visible not merely as pinpoint crystalline reflections or a diffuse sheen but as separate ice inclusions of measurable dimensions.

5.4.1.2 Frozen soils in which segregated ice is not visible. As shown in table VII, columns 4 and 5 materials in which segregated ice is not visible to the unaided eye (designation N) are divided into two types:

(a) Nf (ice nonvisible; friable). This is poorly bonded or friable material in which segregated ice is not visible to the unaided eye. This condition exists when the degree of saturation is low. This type of frozen soil is illustrated in the lower portion of photographs 1 and 2 of figure 1.

(b) Nb (ice nonvisible; bonded). This is well-bonded frozen soil in which the ice cements the material into a hard solid mass, but segregated ice is not visible to the unaided eye. Soils showing this characteristic are generally at a moderate to high degree of saturation. When at high degree of saturation, they may or may not contain substantial quantities of microscopic segregated ice. On the basis of detailed examinations and tests, this subgroup may be further divided into the following subcategories:

(1) Nbn (without excess ice). No segregated ice is present, either visible to the unaided eye or microscopic. This type of frozen soil is illustrated in photographs 1 and 3, figure 1.

(2) Nbe (contains excess ice, microscopic). This condition may occur in very fine silty sands or coarse silts where excess ice is present but is so uniformly distributed that it is not easily apparent to the unaided eye. Appreciable settlement may occur in such soils upon thawing. This type of frozen soil is illustrated in photograph 4, figure 1.

5.4.1.3 Frozen soils in which ice is visible. The soils in which significant segregated ice is visible to the unaided eye (designation V) are divided into the following subgroups, arranged approximately in sequence of increasing ice content as commonly encountered:

Vx (ice visible; individual ice crystals or inclusions).
Vc (ice visible; ice coatings on particles).
Vr (ice visible; random or irregularly oriented ice formations).
Vs (ice visible; stratified or distinctly oriented ice formations).

The Vc type of frozen soil is shown in photograph 5, figure 2, Vr types of frozen soils are illustrated in photographs 6 and 7, figure 3, and Vs types in photographs 8, 9, and 10, figure 3.

5.4.1.4 Description of substantial ice strata. In table VII, columns 2 and 3, under part III, stubstantial ice strata greater than 1 inch in thickness are designated separately as ICE. In table VII, columns 4 and 5, the identification may fall into either of the following two broad categories:

Ice Plus Soil Type (ice with soil inclusions).
Ice (ice without soil inclusions).

5.4.1.5 Identification and description of frozen soils. Field identification guidance is presented in table VII, column 6. In addition to determination of major group and subgroup in accordance with table VII, columns 2 through 5, additional descriptive terms and data may be used as indicated therein. Some of the soils found in permafrost regions may also be described in exploration logs by special terms (such as "muskeg") for additional clarification. When more than one subgroup characteristic is present in the same material, multiple subgroup designations may be used, as Vs, r. Photograph 2, figure 1, shows an example of frozen soil of the latter type. When greater detail and more specific information is desired than is obtainable from visual inspection, physical tests and measurements may be performed on the frozen soil as indicated in table VII, column 7. A camera, a small-power hand magnifying lens, and pint-size graduated jars should be standard items of field equipment for soil and survey crews. To obtain a rough estimate of the possible presence of excess ice, a simple field test can be made by placing a lump of frozen soil in a jar, allowing it to melt and visually observing the relative volume of supernatant or free water standing above the soil after the lump was melted. By initially performing this test with specimens of known ice content, a basis for field judgment can be established. Since proportions of ice and soil may vary widely, it may sometimes be difficult to decide without such a test whether a given material falls, for example, in the category of frozen soil or of ice with soil inclusions. Material containing as much as 80 percent (by volume) ice and only 20 percent soil can sometimes give the appearance of being mostly soil. When more exact evaluation of presence of excess ice is required, specimens may be thawed in the laboratory in consolidometers or rubber membranes, or material may be thawed in place in the field. Only needed portions of the detail and descriptive material outlined in table VII, columns 4 and 7 should be used. In many of the simpler engineering applications, only a few of the most important elements need be recorded. For some investigations it may be sufficient to use the Nb designation without breakdown into Nbn or Nbe categories. In other applications it might even be sufficient to use only the N and V major group designations, to indicate whether or not segregated ice is visible. On the other hand, in many scientific studies very detailed records may be necessary.

5.4.1.6 Thaw characteristics. For engineering purposes, it is necessary to know whether significant settlement will take place upon thawing of the frozen soil. If the amount of ice present will produce more water upon melting than can be held in the voids of the soil, the material is "thaw-unstable" to a degree that is dependent upon the amount of the excess ice and the soil density. If all the melt water can be absorbed by the soil voids without significant settlement, the soil can be considered "thaw-stable." Table VII, columns 8 and 9 present guides for construction on soils subject to freezing and thawing. Frozen soils designated as Nf and Nbn are normally thaw-stable; that is, no detrimental settlement of structures would normally be anticipated if thawing occurred. Frozen soils in all other subgroups are potentially thaw-unstable and significant settlement of structures founded thereon may occur. Frozen openwork gravel is a special type of material which often proves difficult to evaluate as to its thaw-settlement potential. Although substantial amounts of pure ice are apparent in the voids of such material, sufficient point contacts between particles may exist to limit settlement on thaw to minor amounts. In critical cases, field thaw-settlement tests, using loaded plates and steam thawing, may be necessary. Frozen bedrock does not always provide a thaw-safe foundation. Therefore, when bedrock is encountered in subfreezing temperatures, careful observations should be made to determine the quantity and mode of occurrence of all ice formations in bedding planes, fissures, or other spaces.

5.4.1.7 Ice or water content of frozen saturated soils. In considerations involving frozen soils, the generally prevailing conditions include complete saturation of the soil phase and all of the water frozen. For these conditions, and assuming a specific gravity of the soil particles of 2.70, the relationships between the unit dry weight of soil, water content, and ice volume are shown in table VIII. This chart provides an expedient method for the estimation of the relationships between these variables. Use of the chart is indicated by the following example and illustrated by lines and arrows in table VIII. Assume a specimen of frozen silt with excess ice estimated at approximately 60 percent. Based on the appearance of the silt layers in the core, it is estimated that the normal dry unit weight of the silt is 95 pounds per cubic foot. The chart is then entered at 95 pounds per cubic foot on the left and a horizontal line is extended to the intersection of the sloping 60 percent excess ice line. The total porosity n, which in this case equals the proportion of ice volume of the total specimen, is then observed on the scale at the bottom of the plot (77 percent). The intersection of the vertical line (77 percent porosity) with the 100 percent saturation line indicates on the left scale the equivalent overall dry unit weight of the frozen specimen, i.e. 38 pounds per cubic foot. The curve in table VIII marked "Percent Volume of Ice vs. Water Content" shows the relationship between the water content of a frozen specimen and total volume of ice or porosity, n. For a porosity of 77 percent in the above example, the water content indicated by the right scale would be approximately 114 percent.

5.4.1.8 Graphical presentation of frozen soils data. Normally the results of soils explorations are presented on drawings as schematic representations of the borings or test pits, with the various soils encountered shown by appropriate symbols. The recommended procedure for graphical presentation of frozen soil classification consists of showing the applicable letter symbols for the soil phase in accordance with the Unified Soil Classification System for unfrozen soils, followed by the frozen soil designation. An illustrative example of the use of the frozen soil classification system in a typical exploration log is shown in table IX. For the purpose of easily identifying the frozen soil zones, a wide line is drawn down the left of the graphic log of the exploration within the range that the frozen material occurs.

Custodians:

Army - ME
Navy - YD
Air Force - 01

Review activities:

Army - CE
Air Force 26

User activities:

Navy - CG
Air Force - 11

Preparing activity:

Army - ME

Project No. MISC-0493

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

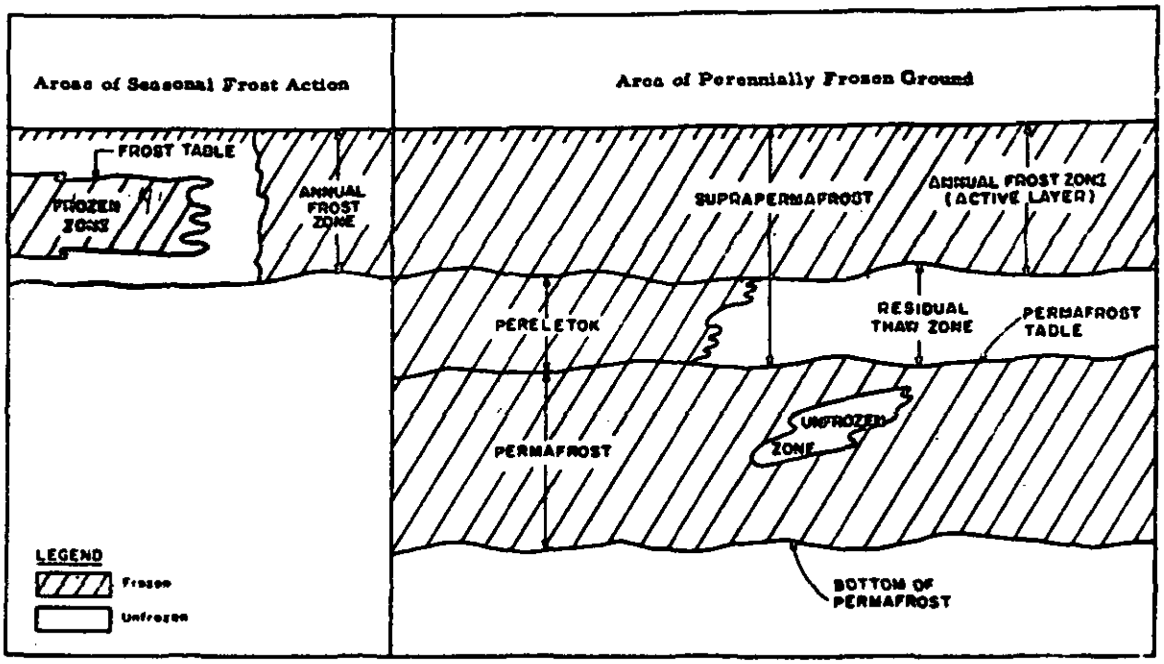


FIGURE 1. Illustration of frozen soil terminology.

DEFINITIONS OF SOIL AND OTHER TERMS RELATING TO FROZEN GROUND AREAS *

Annual frost zone (active layer). The top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, suprapermafrost and the annual frost zone are identical.

Excess ice. Ice in excess of the fraction which would be retained as water in the soil voids upon thawing.

Frost table. The surface, usually irregular, which represents the level, at any time in spring and summer, to which thawing of the seasonal frozen ground has penetrated.

Frozen zone. A range of depth within which the soil is frozen. The frozen zone may be bounded both top and bottom by unfrozen soil, or at the top by the ground surface.

Ground ice. A body of more or less clear ice within frozen ground.

Ice wedge. A wedge-shaped ice mass in permafrost, usually associated with fissure polygons.

Icing. A surface ice mass formed by freezing of successive sheets of water.

Muskeg. Poorly drained organic terrain consisting of a mat of living vegetation overlying peat of varying thickness, from a few inches to many feet.

Permafrost. Perennially frozen ground.

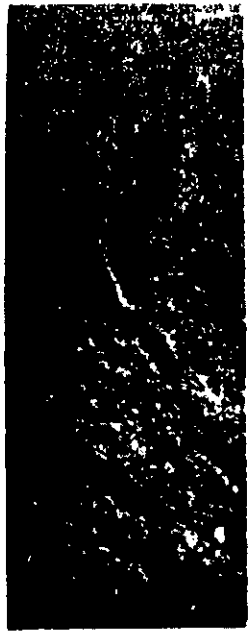
Permafrost table. The surface which represents the upper limit of permafrost.

Pereletok. A frozen layer at the base of the active layer which remains unthawed for one or two summers.

Residual thaw zone. A layer of unfrozen ground between the permafrost and the annual frost zone. This layer does not exist where annual frost extends to permafrost.

Suprapermafrost. The entire layer of ground above the permafrost table.

*For more complete list of definitions, see Hennion, F., "Frost and Permafrost Definitions." Highway Research Board Bulletin 111, 1955.



Photograph 1

Frozen fine SILT. Top portion well-bonded, saturated. Classification: ML, Nba

Bottom portion friable. Classification: ML, Nf

Photograph 2

Frozen lean CLAY. Ice lenses in top portion formed from moisture drawn from below. Classification: CL, Vs,r

Bottom portion medium bonded and somewhat friable. Classification: CL, Nf

Photograph 3

Frozen, well-graded silty SAND. Well-bonded. Classification: SM, Nbn

Photograph 4

Frozen fine SAND. Well-bonded, high degree of saturation. Classification: SM, Nbe

Photograph 5

Frozen, clayey sandy GRAVEL with ice coatings on numerous stones. Classification: GW-GC, Vs

SCALE IN INCHES

FIGURE 2. PHOTOGRAPHS OF FROZEN SOIL TYPES

Photograph 6

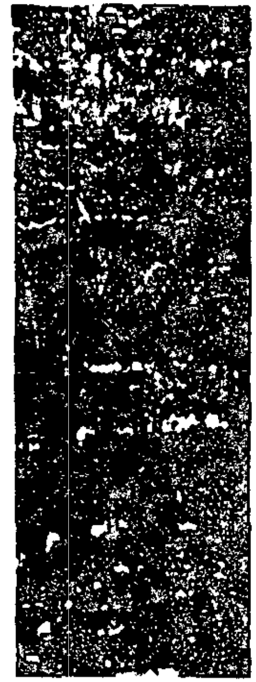
Frozen, clayey, gravelly SAND with considerable irregular ice segregation. Classification: SM, Vr

Photograph 7

Upper Portion: Frozen clayey SILT with occasional stones. Classification: ML-CL, Vr
Lower Portion: ICE, irregular, up to 2-inches thick, and containing some silt inclusions.

Photograph 8

Frozen lean CLAY with stratified ice lenses. Classification: CL-OL, Vs



Photograph 9

Frozen lean CLAY with stratified ice lenses. Classification: CL, Vs

Photograph 10

Upper Portion: Frozen silty CLAY, with stratified ice lenses. Classification: CL, Vs
Lower Portions: ICE with numerous clay inclusions. (Total ice volume approx. 87%).

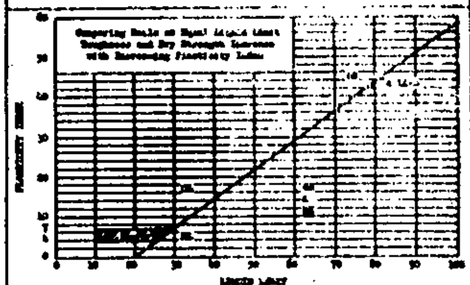
FIGURE 3. PHOTOGRAPHS OF FROZEN SOIL TYPES

UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

Major Divisions (1)	(2)	Group Symbols (3)	Typical Names (4)	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights) (5)			Information Required for Describing Soils (6)	Laboratory Classification Criteria (7)
Coarse-grained Soils: More than half of material is larger than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels: More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size.) Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.				Not meeting all gradation requirements for GW
	Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	Atterberg limits below "A" line or PI less than 4 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
		GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).				Atterberg limits above "A" line with PI greater than 7
	Sands: More than half of coarse fraction is smaller than No. 4 sieve size. Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.				$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
		SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	Not meeting all gradation requirements for SW
	Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).				Atterberg limits below "A" line or PI less than 4 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
		SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).				Atterberg limits above "A" line with PI greater than 7
				Identification Procedures on Fraction Smaller than No. 40 Sieve Size: Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)		
Fine-grained Soils: More than half of material is smaller than No. 200 sieve size.	Silts and Clays: Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.	
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium		
		OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	
	Silts and Clays: Liquid limit is greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium		
		CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High		
		OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).	
Highly Organic Soils		Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.				

Use grain-size curve in identifying the fractions as given under field identification.

Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% — GW, GP, SW, SP. More than 12% — GM, GC, SM, SC. 5% to 12% — Borderline cases requiring use of dual symbols.



For laboratory classification of fine-grained soils.

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

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

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

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Table I.

Adopted by Corps of Engineers and Bureau of Reclamation, January 1952. [illegible]

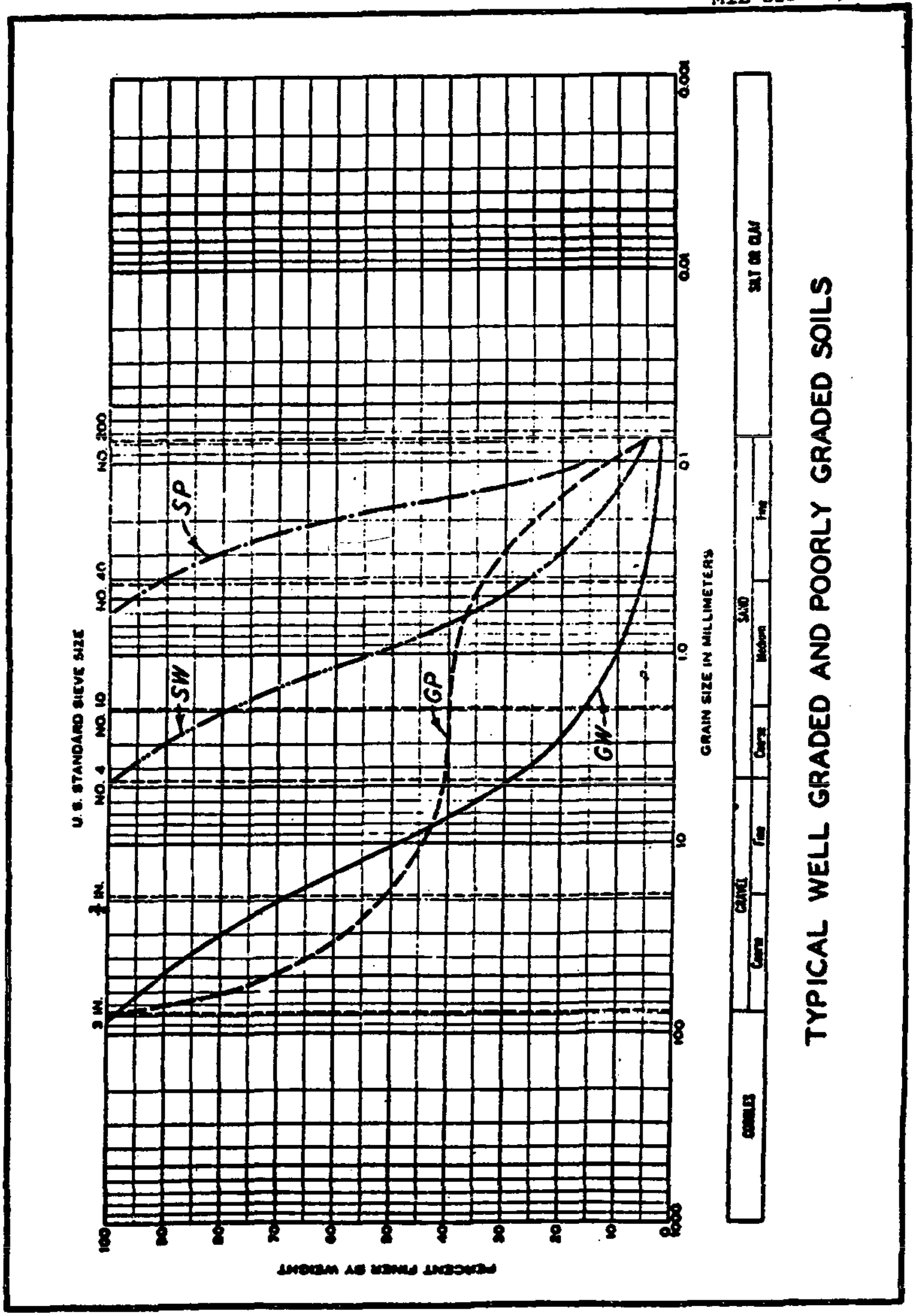
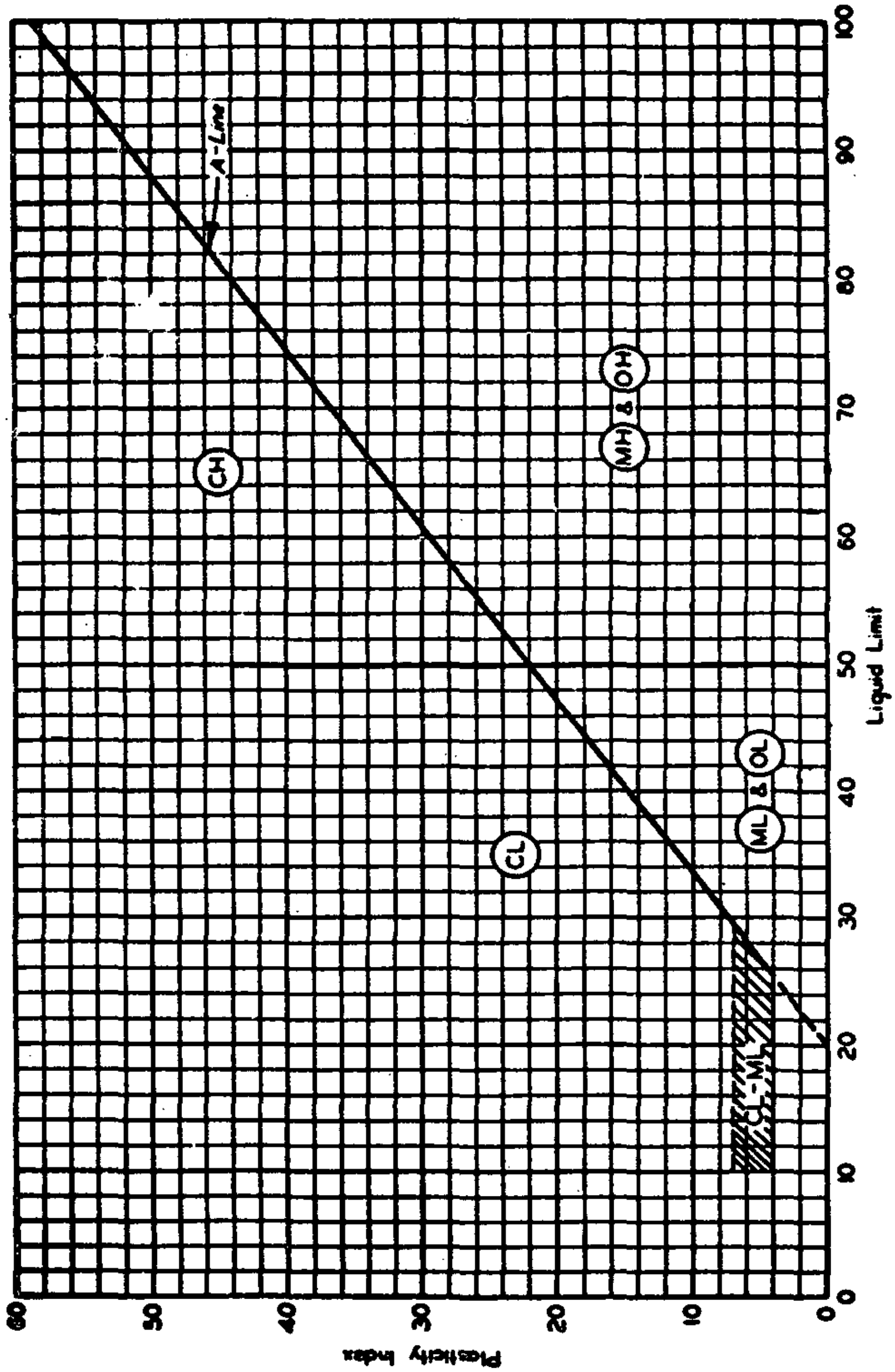

TYPICAL WELL GRADED AND POORLY GRADED SOILS
U. S. STANDARD SIEVE SIZE
3 IN.
¾ IN.
NO. 4
NO. 10
NO. 40
NO. 200
GRAIN SIZE IN MILLIMETERS
PERCENT FINER BY WEIGHT
SP
SW
GP
GW
COBBLES
GRAVEL
Coarse
Fine
SAND
Coarse
Medium
Fine
SILT OR CLAY

TABLE II.



PLASTICITY CHART

TABLE III.

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

PART I DESCRIPTION OF SOIL PHASE (a) (Independent of Frozen State)	Classify Soil Phase by the Unified Soil Classification System							
(1)	Major Group: Description (2)	Major Group: Designation (3)	Sub-Group: Description (4)	Sub-Group: Designation (5)	Field Identification (6)	Pertinent Properties of Frozen Materials Which May be Measured by Physical Tests to Supplement Field Identification (7)	Guide for Construction on Soils Subject to Freezing and Thawing: Thaw Characteristics (8)	Guide for Construction on Soils Subject to Freezing and Thawing: Criteria (9)
PART II DESCRIPTION OF FROZEN SOIL	Segregated ice is not visible by eye (b)	N	Poorly bonded or friable	Nf	Identify by visual examination. To determine presence of excess ice, use procedure under note (c) below and hand magnifying lens as necessary. For soils not fully saturated, estimate degree of ice saturation: Medium, Low. Note presence of crystals, or of ice coatings around larger particles.	In-Place Temperature Density and Void Ratio a. In Frozen State b. After Thawing in Place Water Content (total H_2O, including ice) a. Average b. Distribution Strength a. Compressive b. Tensile c. Shear d. Adfreeze Elastic Properties Plastic Properties Thermal Properties Ice Crystal Structure (using optical instruments) a. Orientation of Axes b. Crystal Size c. Crystal Shape d. Pattern of Arrangement	Usually thaw-stable	The potential intensity of ice segregation in a soil is dependent to a large degree on its void sizes and for pavement design purposes may be expressed as an empirical function of grain size as follows: Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weight are frost-susceptible for pavement design purposes. Gravels, well-graded sands and silty sands, especially those approaching the theoretical maximum density curve, which contain 1½ to 3 percent finer by weight than 0.02 mm size should be considered as possibly frost-susceptible and should be subjected to a standard laboratory frost susceptibility test to evaluate actual behavior during freezing. Uniform sandy soils may have as high as 10 percent of grains finer than 0.02 mm by weight without being frost-susceptible. However, their tendency to occur interbedded with other soils usually makes it impractical to consider them separately. Soils classed as frost-susceptible under the above pavement design criteria are likely to develop significant ice segregation and frost heave if frozen at normal rates with free water readily available. Soils so frozen will fall into the thaw-unstable category. However, they may also be classed as thaw-stable if frozen with insufficient water to permit ice segregation. Soils classed as non-frost-susceptible (NFS*) under the above criteria usually occur without significant ice segregation and are usually thaw-stable for pavement applications. However, the criteria are not exact and may be inadequate for some structure applications; exceptions may also result from minor soil variations. In permafrost areas, ice wedges, pockets, veins, or other ice bodies may be found whose mode of origin is different from that described above. Such ice may be the result of long-time surface expansion and contraction phenomena or may be glacial or other ice which has been buried under a protective earth cover.
			Well bonded: No excess ice	Nb: n				
			Well bonded: Excess ice	Nb: e				
	Segregated ice is visible by eye. (Ice 1 inch or less in thickness) (b)	V	Individual ice crystals or inclusions	Vx	For ice phase, record the following as applicable: Location, Orientation, Thickness, Length, Spacing, Hardness, Structure } per Part III below, Color; Size, Shape, Pattern of arrangement Estimate volume of visible segregated ice present as percent of total sample volume.		Usually thaw-unstable	
			Ice coatings on particles	Vc				
			Random or irregularly oriented ice formations	Vr				
			Stratified or distinctly oriented ice formations	Vs				
PART III DESCRIPTION OF SUBSTANTIAL ICE STRATA	Ice (Greater than 1 inch in thickness)	ICE	Ice with soil inclusions	ICE + soil type	Designate material as ICE (d) and use descriptive terms as follows, usually one item from each group, as applicable: Hardness: HARD, SOFT (of mass, not individual crystals) Structure: CLEAR, CLOUDY, POROUS, CANDLED, GRANULAR, STRATIFIED Color (Examples): COLORLESS, GRAY, BLUE Admixtures (Example): CONTAINS FEW THIN SILT INCLUSIONS	Same as Part II above, as applicable, with special emphasis on Ice Crystal Structure.		
			Ice without soil inclusions	ICE				

DEFINITIONS:

Ice Coatings on Particles are discernible layers of ice found on or below the larger soil particles in a frozen soil mass. They are sometimes associated with hoarfrost crystals, which have grown into voids produced by the freezing action.

Ice Crystal is a very small individual ice particle visible in the face of a soil mass. Crystals may be present alone or in a combination with other ice formations.

Clear Ice is transparent and contains only a moderate number of air bubbles. (e)

Cloudy Ice is translucent, but essentially sound and non-pervious. (e)

Porous Ice contains numerous voids, usually interconnected and usually resulting from melting at air bubbles or along crystal interfaces from presence of salt or other materials in the water, or from the freezing of saturated snow. Though porous, the mass retains its structural unity.

Candled Ice is ice which has rotted or otherwise formed into long columnar crystals, very loosely bonded together.

Granular Ice is composed of coarse, more or less equidimensional, ice crystals weakly bonded together.

Ice Lenses are lenticular ice formations in soil occurring essentially parallel to each other, generally normal to the direction of heat loss and commonly in repeated layers.

Ice Segregation is the growth of ice as distinct lenses, layers, veins, and masses in soils, commonly but not always oriented normal to direction of heat loss.

Well-bonded signifies that the soil particles are strongly held together by the ice and that the frozen soil possesses relatively high resistance to chipping or breaking.

Poorly-bonded signifies that the soil particles are weakly held together by the ice and that the frozen soil consequently has poor resistance to chipping or breaking.

Friable denotes a condition in which material is easily broken up under light to moderate pressure.

Thaw-Stable frozen soils do not, on thawing, show loss of strength below normal, long-time thawed values nor produce detrimental settlement.

Thaw-Unstable frozen soils show, on thawing, significant loss of strength below normal, long-time thawed values and/or significant settlement, as a direct result of the melting of the excess ice in the soil.

NOTES:

(a) When rock is encountered, standard rock classification terminology should be used.

(b) Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. However, the impression to the unaided eye is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.

(c) When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt and observing the quantity of supernatant water as a percent of total volume.

(d) Where special forms of ice, such as hoarfrost, can be distinguished, more explicit description should be given.

(e) Observer should be careful to avoid being misled by surface scratches or frost coating on the ice.

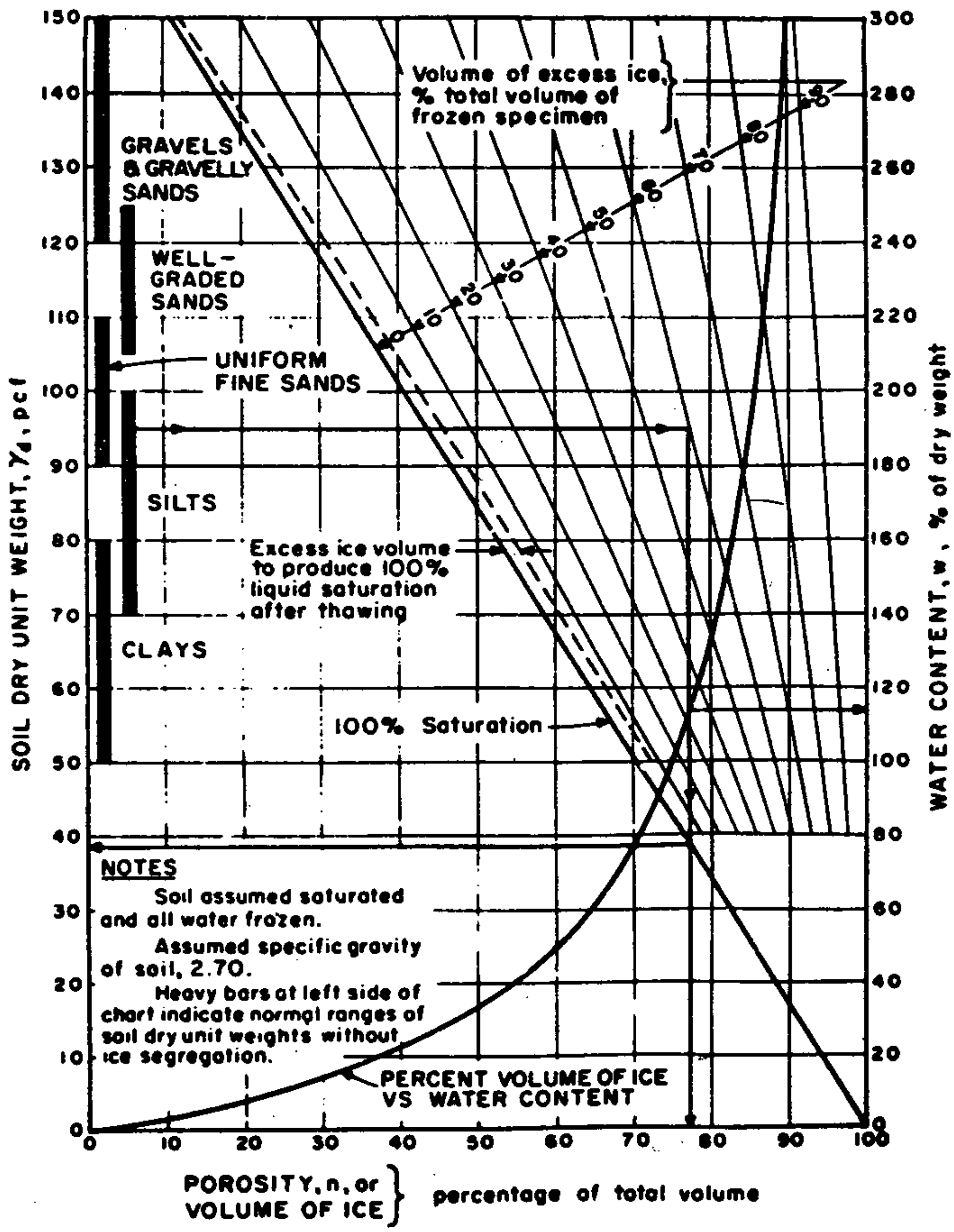
NOTES:

The letter symbols shown are to be affixed to the Unified Soil Classification letter designations, or may be used in conjunction with graphic symbols, in exploration logs or geological profiles. Example - a lean clay with essentially horizontal ice lenses.

The descriptive name of the frozen soil type and a complete description of the frozen material are the fundamental elements of this classification scheme. Additional descriptive data should be added where necessary. The letter symbols are secondary and are intended only for convenience in preparing graphical presentations. Since it is frequently impractical to describe ice formations in frozen soils by means of words alone, sketches and photographs should be used where appropriate, to supplement descriptions.

*The abbreviation NFS is commonly used to designate non-frost-susceptible materials on exploration logs and drawings.

Table VII.



SOIL DRY UNIT WEIGHT, ICE VOLUME, AND WATER CONTENT RELATIONSHIPS

Table VIII.

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

(1)	Major Group: Description (2)	Major Group: Designation (3)	Sub-Group: Description (4)	Sub-Group: Designation (5)	Field Identification (6)	Pertinent Properties of Frozen Materials Which May be Measured by Physical Tests to Supplement Field Identification (7)	Guide for Construction on Soils Subject to Freezing and Thawing: Thaw Characteristics (8)	Guide for Construction on Soils Subject to Freezing and Thawing: Criteria (9)
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(c) When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt and observing the quantity of supernatant water as a percent of total volume.

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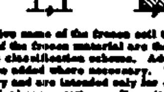

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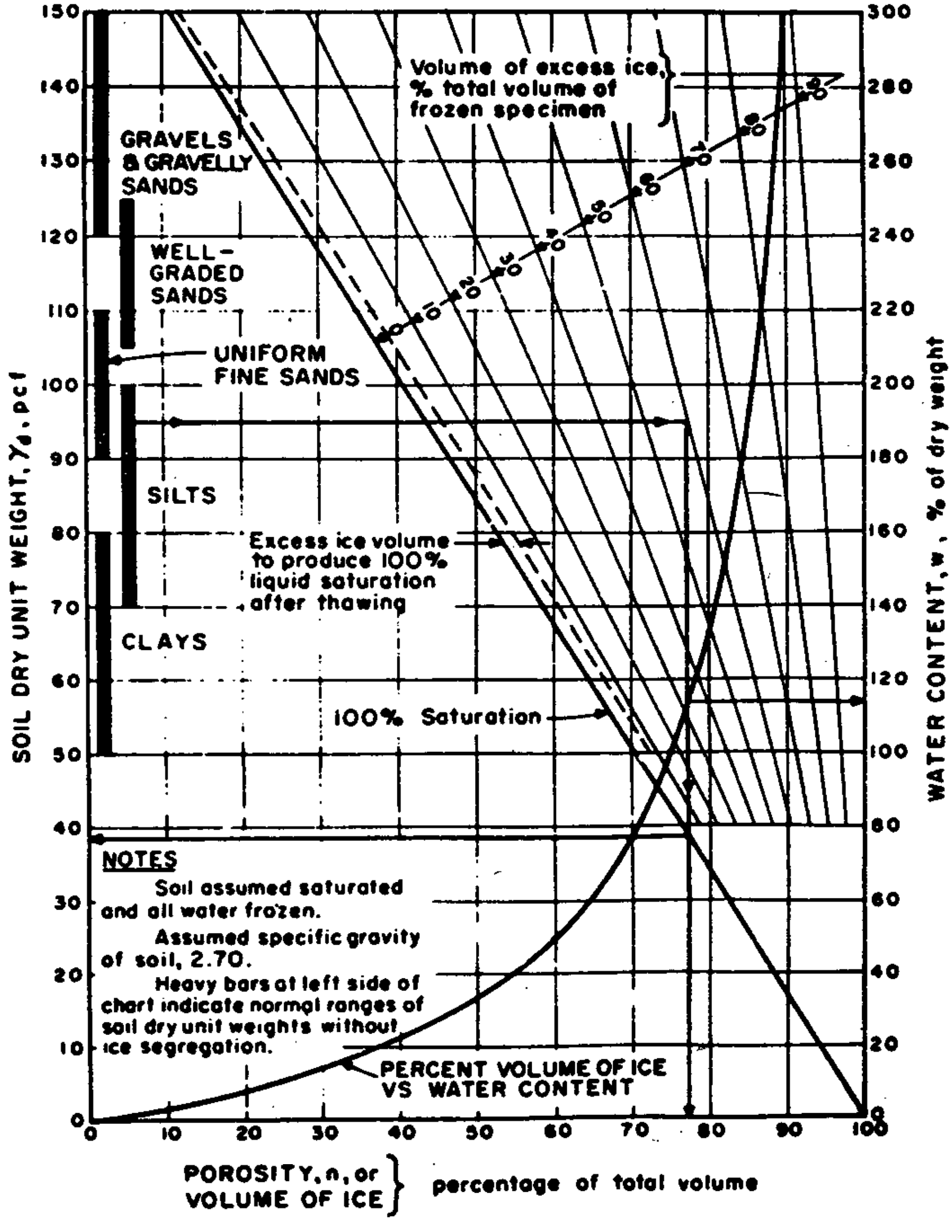

SOIL DRY UNIT WEIGHT, ICE VOLUME, AND WATER CONTENT RELATIONSHIPS

Table VIII.

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

Depth	Symbol	SOIL DESCRIPTION	ICE FEATURES
0.0* – 0.5	OL	Organic, sandy SILT, not frozen	None
0.5 – 1.8	GW	Brown, well-graded, sandy GRAVEL, medium compact, moist, not frozen	None
1.8 – 3.7	GW Nf	Brown well-graded, sandy GRAVEL, frozen, poorly bonded	No visible segregation, negligible thin ice film on gravel sizes and within larger voids
3.7 – 5.4	GW Nbn	Brown, well-graded, sandy GRAVEL, frozen, well bonded	No visible segregation
5.4 – 7.7	ML Vs	Black, micaceous, sandy SILT, frozen	Stratified horizontal ice lenses averaging 4 inches in horizontal extent, hairline to 1/4 inch in thickness, 1/2 to 3/4 inch spacing. Visible excess ice ~ 20±% of total volume. Ice lenses hard, clear, colorless.
7.7 – 9.1	ICE		Hard, slightly cloudy, colorless, few scattered inclusions of silty SAND
9.1 – 10.5		Dark brown PEAT, frozen, well bonded, high degree of saturation	~ 5% visible ice
10.5 – 14.3	MH Vr	Light brown SILT, frozen	Irregularly oriented ice lenses and layers 1/4 to 3/4 inch thick on random pattern grid approx. 3 to 4 inch spacing. Visible ice ~ 10±% of total volume. Ice moderately soft, porous, gray-white.
14.3 – 20.6 (16.0)		Bedrock. Laminated SHALE Top few feet weathered Bottom of exploration	1/16 inch thick ice lenses in fissures to 16.0 ft. None below

*Surface elevation 963.2 ft

Table IX. Example of the use of the frozen soil classification system in typical exploration.

343-217 (A-6)

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