HAMPTON

CORPS OF ENGINEERS, U. S. ARMY

THE

# UNIFIED SOIL CLASSIFICATION SYSTEM

## APPENDIX A

## CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS



TECHNICAL MEMORANDUM NO. 3-357

PREPARED FOR

OFFICE, CHIEF OF ENGINEERS

BY

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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### 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 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.

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

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

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