Soil Mechanics: *Description and Classification*

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This manual is an update of the 3rd Edition prepared by Parsons Brinckerhoff Quade & Douglas, Inc, in 2000. Author: Richard Cheney, PE. The authors of the 1st and 2nd editions prepared by the FHWA in 1982 and 1993, respectively, were Richard Cheney, PE and Ronald Chassie, PE.

16. Abstract

The Reference Manual for Soils and Foundations course is intended for design and construction professionals involved with the selection, design and construction of geotechnical features for surface transportation facilities. The manual is geared towards practitioners who routinely deal with soils and foundations issues but who may have little theoretical background in soil mechanics or foundation engineering. The manual's content follows a project-oriented approach where the geotechnical aspects of a project are traced from preparation of the boring request through design computation of settlement, allowable footing pressure, etc., to the construction of approach embankments and foundations. Appendix A includes an example bridge project where such an approach is demonstrated. Recommendations are presented on how to layout borings efficiently, how to minimize approach embankment settlement, how to design the most cost-effective pier and abutment foundations, and how to transmit design information properly through plans, specifications, and/or contact with the project engineer so that the project can be constructed efficiently.

The objective of this manual is to present recommended methods for the safe, cost-effective design and construction of geotechnical features. Coordination between geotechnical specialists and project team members at all phases of a project is stressed. Readers are encouraged to develop an appreciation of geotechnical activities in all project phases that influence or are influenced by their work.

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CHAPTER 4.0
ENGINEERING DESCRIPTION, CLASSIFICATION AND CHARACTERISTICS OF SOILS AND ROCKS

The geotechnical specialist is usually concerned with the design and construction of some type of geotechnical feature constructed on or out of a geomaterial. For engineering purposes, in the context of this manual, the geomaterial is considered to be primarily rock and soil. A geomaterial intermediate between soil and rock is labeled as an intermediate geomaterial (IGM). These three classes of geomaterials are described as follows:

- **Rock** is a relatively hard, naturally formed solid mass consisting of various minerals and whose formation is due to any number of physical and chemical processes. The rock mass is generally so large and so hard that relatively great effort (e.g., blasting or heavy crushing forces) is required to break it down into smaller particles.

- **Soil** is defined as a conglomeration consisting of a wide range of relatively smaller particles derived from a parent rock through mechanical weathering processes that include air and/or water abrasion, freeze-thaw cycles, temperature changes, plant and animal activity and by chemical weathering processes that include oxidation and carbonation. The soil mass may contain air, water, and/or organic materials derived from decay of vegetation, etc. The density or consistency of the soil mass can range from very dense or hard to loose or very soft.

- **Intermediate geomaterials** (IGMs) are transition materials between soils and rocks. The distinction of IGMs from soils or rocks for geotechnical engineering purposes is made purely on the basis of strength of the geomaterials. Discussions and special design considerations of IGMs are beyond the scope of this document.

The following three terms are often used by geotechnical specialists to describe a geomaterial: **identification**, **description** and **classification**. For soils, these terms have the following meaning:

- **Identification** is the process of determining which components exist in a particular soil sample, i.e., gravel, sand, silt, clay, etc.

- **Description** is the process of estimating the relative percentage of each component to prepare a word picture of the sample (ASTM D 2488). Identification and description are accomplished primarily by both a visual examination and the feel of the sample, particularly when water is added to the sample. Description is usually performed in the field and may be reevaluated by experienced personnel in the laboratory.

- **Classification** is the laboratory-based process of grouping soils with similar engineering characteristics into categories. For example, the Unified Soil Classification System, USCS, (ASTM D 2487), which is the most commonly used system in geotechnical work, is based on grain size, gradation, and plasticity. The AASHTO system (M 145), which is commonly used for highway projects, groups soils into categories having similar load carrying capacity and service characteristics for pavement subgrade design.

It may be noted from the above definitions that the description of a geomaterial necessarily includes its identification. Therefore, as used in this document, the term "description" is meant to include "identification."

The important distinction between classification and description is that standard AASHTO or ASTM laboratory tests must be performed to determine the classification. It is often unnecessary to perform the laboratory tests to classify every sample. Instead soil technicians are trained to identify and describe soil samples to an accuracy that is acceptable for design and construction purposes. ASTM D 2488 is used for guidance in such visual and tactile identification and description procedures. These visual/tactile methods provide the basis for a preliminary classification of the soil according to the USCS and AASHTO system.

During progression of a boring, the field personnel should describe only the soils encountered. Group symbols associated with classification should not be used in the field. It is important to send the soil samples to a laboratory for accurate visual description and classification by a laboratory technician experienced in soils work, as this assessment will provide the basis for later testing and soil profile development. Classification tests can be performed in the laboratory on representative samples to verify the description and assign appropriate group symbols based on a soil classification system (e.g., USCS). If possible, the moisture content of every sample should be determined since it is potentially a good indicator of performance. The test to determine the moisture content is simple and inexpensive to perform.

4.01 Primary References

The primary references for this Chapter are as follows:

ASTM (2006). *Annual Book of ASTM Standards – Sections 4.02, 4.08, 4.09 and 4.13.* ASTM International, West Conshohocken, PA.

AASHTO (2006). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing,* Parts I and II, American Association of State Highway and Transportation Officials, Washington, D.C.

FHWA (2002a). *Geotechnical Engineering Circular 5 (GEC5) - Evaluation of Soil and Rock Properties*. Report No FHWA-IF-02-034. Authors: Sabatini, P.J, Bachus, R.C, Mayne, P.W., Schneider, J.A., Zettler, T.E., Federal Highway Administration, U.S. Department of Transportation.

4.1 SOIL DESCRIPTION

Soil description/identification is the systematic naming of individual soils in both written and spoken forms (ASTM D 2488, AASHTO M 145). Soil classification is the grouping of soils with similar engineering properties into a category by using the results of laboratory-based index tests, e.g., group name and symbol (ASTM D 2487, AASHTO M 145). It is important to distinguish between a visual description of a soil and its classification in order to minimize potential conflicts between general visual evaluations of soil samples in the field and more precise laboratory evaluations supported by index tests.

The soil's description should include as a **minimum**:

- Apparent consistency (e.g., soft, firm, etc. for fine-grained soils) or density adjective (e.g., loose, dense, etc. for coarse-grained soils);
- Water content condition adjective (e.g., dry, moist, wet);
- Color description (e.g., brown, gray, etc.);
- Main soil type name, often presented in all capital letters (e.g. SAND, CLAY);
- Descriptive adjective for main soil type (e.g., fine, medium, coarse, well-rounded, angular, etc. for coarse-grained soils; organic, inorganic, compressible, laminated, etc., for fine-grained soils);
- Particle-size distribution adjective for gravel and sand (e.g., uniform, well-graded,

gap-graded);

- Plasticity adjective (e.g., high, low) and soil texture (e.g., rough, smooth, slick, waxy, etc.) for inorganic and organic silts or clays;
- Descriptive term for minor type(s) of soil (with, some, trace, etc.);
- Minor soil type name with "y" added if the fine-grained minor component is less than 30 percent but greater than 12 percent or the coarse-grained minor component is 30 percent or more (e.g., silty for fine grained minor soil type, sandy for coarse-grained minor soil type);
- Descriptive adjective "with" if the fine-grained minor soil type is 5 to 12 percent (e.g., with clay) or if the coarse-grained minor soil type is less than 30 percent but 15 percent or more (e.g., with gravel). Note: some practices use the descriptive adjectives "some" and "trace" for minor components;
- Inclusions (e.g., concretions, cementation);
- Geological name (e.g., Holocene, Eocene, Pleistocene, Cretaceous), if known, in parenthesis or in notes column.

The various elements of the soil description are generally stated in the order given above. For example, a soil description might be presented as follows:

Fine-grained soils: Soft, wet, gray, high plasticity CLAY, with f. Sand; (Alluvium)

Coarse-grained soils: Dense, moist, brown, silty m-f SAND, with f. Gravel to c. Sand; (Alluvium)

When minor changes occur within the same soil layer (e.g., a change in apparent density), the boring log should indicate a description of the change, such as "same, except very dense."

4.1.1 Consistency and Apparent Density

The consistency of fine-grained soils and apparent density of coarse-grained soils can be estimated from the energy-corrected SPT N-value, N_{60}. The consistency of clays and silts varies from very soft to firm to stiff to hard. The apparent density of coarse-grained soil ranges from very loose to dense to very dense. Suggested guidelines for estimating the in-place apparent density or consistency of soils are given in Tables 4-1 and 4-2, respectively.

Table 4-1
Evaluation of the apparent density of coarse-grained soils (after Peck, *et al.*, 1974)

N_{60}	Apparent Density	Relative Density, %
0 – 4	Very loose	0 – 20
>4 - 10	Loose	20 – 40
>10 - 30	Medium dense	40 – 70
>30 - 50	Dense	70 – 85
>50	Very Dense	85 – 100
The above guidance may be misleading in gravelly soils.		

Table 4-2
Evaluation of the consistency of fine-grained soils (after Peck, *et al.*, 1974)

N_{60}	Consistency	Unconfined Compressive Strength, q_u, ksf (kPa)	Results of Manual Manipulation
<2	Very soft	< 0.5 (<25)	Specimen (height = twice the diameter) sags under its own weight; extrudes between fingers when squeezed.
2 - 4	Soft	0.5 – 1 (25 – 50)	Specimen can be pinched in two between the thumb and forefinger; remolded by light finger pressure.
4 - 8	Medium stiff	1 – 2 (50 – 100)	Can be imprinted easily with fingers; remolded by strong finger pressure.
8 - 15	Stiff	2 – 4 (100 – 200)	Can be imprinted with considerable pressure from fingers or indented by thumbnail.
15 - 30	Very stiff	4 – 8 (200 – 400)	Can barely be imprinted by pressure from fingers or indented by thumbnail.
>30	Hard	> 8 >400	Cannot be imprinted by fingers or difficult to indent by thumbnail.
Note that N_{60}-values should not be used to determine the design strength of fine grained soils.			

The apparent density or consistency of the soil formation can vary from these empirical correlations for a variety of reasons. Judgment remains an important part of the visual identification process. Field index tests (e.g., smear test, dried strength test, thread test) which will be described in the next section are suggested as aids in estimating the consistency of fine grained soils.

In some cases the sampler may pass from one layer into another of markedly different properties; for example, from a dense sand into a soft clay. In attempting to identify apparent density, an assessment should be made as to what part of the blow count corresponds to each layer since the sampler begins to reflect the presence of the lower layer before it actually reaches it.

4.1.2 Water Content (Moisture)

The relative amount of water present in the soil sample should be described by an adjective such as dry, moist, or wet as indicated in Table 4-3.

Table 4-3
Adjectives to describe water content of soils (ASTM D 2488)

Description	Conditions
Dry	No sign of water and soil dry to touch
Moist	Signs of water and soil is relatively dry to touch
Wet	Signs of water and soil definitely wet to touch; granular soil exhibits some free water when densified

4.1.3 Color

The color must be described when the sample is first retrieved in the field at the as-sampled water content since the color may change with changes in the water content. Primary colors should be used (brown, gray, black, green, white, yellow, red). Soils with different shades or tints of basic colors are described by using two basic colors; e.g., gray-green. Some agencies may require use of the Munsell color system (USDA, 1993). When the soil is marked with spots of color, the term “mottled” can be applied. Soils with a homogeneous texture but having color patterns that change and are not considered mottled can be described as “streaked.”

4.1.4 Type of Soil

The constituent parts of a given soil type are defined on the basis of texture in accordance with particle-size designators separating the soil into coarse-grained, fine-grained, and highly organic designations. Soil with more than 50 percent by weight of the particles larger than the U.S. Standard No. 200 sieve (0.075 mm) is designated coarse-grained. Soil (inorganic and organic) with 50 percent or more by weight of the particles finer than the No. 200 sieve (0.075 mm) is designated fine-grained. Soil primarily consisting of less than 50 percent by volume of organic matter, dark in color, and with an organic odor is designated as organic soil. Soil with organic content more than 50 percent is designated as peat. The soil type designations used by FHWA follow ASTM D 2487; i.e., gravel, sand, silt, clay, organic silt, organic clay, and peat.

4.1.4.1 Coarse-Grained Soils (Gravel and Sand)

Coarse-grained soils consist of a matrix of either gravel or sand in which more than 50 percent by weight of the soil is retained on the No. 200 sieve (0.075 mm). Coarse-grained soils may contain fine-grained soil, i.e., soils passing the No. 200 sieve (0.075 mm), but the percent by weight of the fine-grained portion is less than 50 percent. The gravel and sand components are defined on the basis of particle size as indicated in Table 4-4. The particle-size distribution is identified as well graded or poorly graded. Well graded coarse-grained soil contains a good representation of all particle sizes from largest to smallest, with ≤12 percent fines. Poorly graded coarse-grained soil is uniformly graded, i.e., most of the coarse-grained particles are about the same size, with ≤ 12 percent fines. Gap graded coarse grained soil can be either a well graded or poorly graded soil lacking one or more intermediate sizes within the range of the gradation.

Gravels and sands may be described by adding particle-size distribution adjectives in front of the soil type in accordance with the criteria given in Table 4-5. Based on correlation with laboratory tests, the following simple field identification tests can be used as an aid in identifying granular soils.

Table 4-4
Particle size definition for gravels and sands (after ASTM D 2488)

Component	Grain Size	Determination
Boulders*	12” + (300 mm +)	Measurable
Cobbles*	3” to 12” (300 mm to 75 mm)	Measurable
Gravel		
Coarse	¾” – 3” (19 mm to 75 mm)	Measurable
Fine	¾” to #4 sieve (¾” to 0.187”) (19 mm to 4.75 mm)	Measurable
Sand		
Coarse	#4 to #10 sieve (0.19” to 0.079”) (4.75 mm – 2.00 mm)	Measurable and visible to the eye
Medium	#10 to #40 sieve (0.079” to 0.017”) (2.00 mm – 0.425 mm)	Measurable and visible to the eye
Fine	#40 to #200 sieve (0.017” to 0.003”) (0.425 mm- 0.075 mm)	Measurable but barely discernible to the eye
*Boulders and cobbles are not considered soil or part of the soil's classification or description, except under miscellaneous description; i.e., with cobbles at about 5 percent (volume).		

Table 4-5
Adjectives for describing size distribution for sands and gravels (after ASTM D 2488)

Particle-Size Adjective	Abbreviation	Size Requirement
Coarse	c.	< 30% m-f sand or < 12% f. gravel
Coarse to medium	c-m	< 12% f. sand
Medium to fine	m-f	< 12% c. sand and > 30% m. sand
Fine	f.	< 30% m. sand or < 12% c. gravel
Coarse to fine	c-f	> 12% of each size[1]

[1] 12% and 30% criteria can be modified depending on fines content. The key is the shape of the particle-size distribution curve. If the curve is relatively straight or dished down, and coarse sand is present, use c-f, also use m-f sand if a moderate amount of m. sand is present. If one has any doubts, determine the above percentages based on the amount of sand or gravel present.

Feel and Smear Tests: A pinch of soil is handled lightly between the thumb and fingers to obtain an impression of the grittiness (i.e., roughness) or softness (smoothness) of the constituent particles. Thereafter, a pinch of soil is smeared with considerable pressure between the thumb and forefinger to determine the degrees of grittiness (roughness), or the softness (smoothness) of the soil. The following guidelines may be used:

- Coarse- to medium-grained sand typically exhibits a very gritty feel and smear.
- Coarse- to fine-grained sand has less gritty feel, but exhibits a very gritty smear.
- Medium- to fine-grained sand exhibits a less gritty feel and smear that becomes softer (smoother) and less gritty with an increase in the fine sand fraction.
- Fine-grained sand exhibits a relatively soft feel and a much less gritty smear than the coarser sand components.
- Silt components less than about 10 percent of the total weight can be identified by a slight discoloration of the fingers after smear of a moist sample. Increasing silt increases discoloration and softens the smear.

Sedimentation Test: A small sample of soil is shaken in a test tube filled with water and allowed to settle. The time required for the particles to fall a distance of 4-inches (100 mm) is about 1/2 minute for particle sizes coarser than silt. About 50 minutes would be required for particles of 0.0002 in (0.005 mm) or smaller (often defined as "clay size") to settle out.

For sands and gravels containing more than 5 percent fines, the type of inorganic fines (silt or clay) can be identified by performing a shaking/dilatancy test. See fine-grained soils section.

Visual Characteristics: Sand and gravel particles can be readily identified visually, but silt particles are generally indistinguishable to the eye. With an increasing silt component, individual sand grains become obscured, and when silt exceeds about 12 percent, the silt almost entirely masks the sand component from visual separation. Note that gray fine-grained sand visually appears to contain more silt than the actual silt content.

4.1.4.2 Fine-Grained Soils

Fine-grained soils are those having 50 percent or more by weight pass the No. 200 sieve. The so-called fines are either inorganic or organic silts and/or clays. To describe fine-grained soils, plasticity adjectives and soil-type adjectives should be used to further define the soil's plasticity and texture. The following simple field identification tests can be used to estimate the degree of plasticity of fine-grained soils.

Shaking (Dilatancy) Test (Holtz and Kovacs, 1981). Water is dropped or sprayed on a portion of a fine-grained soil sample mixed and held in the palm of the hand until it shows a wet surface appearance when shaken or bounced lightly in the hand or a sticky nature when touched. The test involves lightly squeezing the wetted soil sample between the thumb and forefinger and releasing it alternatively to observe its reaction and the speed of the response. Soils that are predominantly silty (nonplastic to low plasticity) will show a dull dry surface upon squeezing and a glassy wet surface immediately upon release of the pressure. This phenomenon becomes less and less pronounced in soils with increasing plasticity and decreasing dilatancy,

Dry Strength Test (Holtz and Kovacs, 1981). A relatively undisturbed portion of the sample is allowed to dry out and a fragment of the dried soil is pressed between the fingers. Fragments which cannot be crumbled or broken are characteristic of clays with high plasticity. Fragments which can be disintegrated with gentle finger pressure are characteristic of silty materials of low plasticity. Thus, in generally, fine-grained materials with relatively high dry strength are clays of high plasticity and those with relatively little dry strength are predominantly silts.

Thread Test (After Burmister, 1970). Moisture is added to or worked out of a small ball (about 1.5 in (40 mm) diameter) of fine grained soil and the ball kneaded until its consistency approaches medium stiff to stiff (compressive strength of about 2,100 psf (100 kPa)). This condition is observed when the material just starts to break or crumble. A thread is then rolled out between the palm of one hand and the fingers of the other to the smallest diameter possible before disintegration of the sample occurs. The smaller the thread achieved, the higher the plasticity of the soil. Fine-grained soils of high plasticity will have threads smaller than 0.03 in (3/4 mm) in diameter. Soils with low plasticity will have threads larger than 0.12 in (3 mm) in diameter.

Smear Test (FHWA, 2002b). A fragment of soil smeared between the thumb and forefinger or drawn across the thumbnail will, by the smoothness and sheen of the smear surface, indicate the plasticity of the soil. A soil of low plasticity will exhibit a rough textured, dull smear while a soil of high plasticity will exhibit a slick, waxy smear surface.

Table 4-6 identifies field methods to approximate the plasticity range for the dry strength, thread, and smear tests.

Table 4-6
Field methods to describe plasticity (FHWA, 2002b)

Plasticity Range	Adjective	Dry Strength	Smear Test	Thread Smallest Diameter, in (mm)
0	Nonplastic	none - crumbles into powder with mere pressure	gritty or rough	ball cracks
1 - 10	low plasticity	low - crumbles into powder with some finger pressure	rough to smooth	1/4 – 1/8 (6 to 3)
>10 - 20	medium plasticity	medium - breaks into pieces or crumbles with considerable finger pressure	smooth and dull	1/16 (1.5)
>20 - 40	high plasticity	high - cannot be broken with finger pressure; spec. will break into pieces between thumb and a hard surface	Shiny	0.03 (0.75)
>40	very plastic	very high - can't be broken between thumb and a hard surface	very shiny and waxy	0.02 (0.5)

4.1.4.3 Highly Organic Soils

Colloidal and amorphous organic materials finer than the No. 200 sieve (0.075 mm) are identified and classified in accordance with their drop in plasticity upon oven drying (ASTM D 2487). Further identification markers are:

1. dark gray and black and sometimes dark brown colors, although not all dark colored soils are organic;
2. most organic soils will oxidize when exposed to air and change from a dark gray/black color to a lighter brown; i.e., the exposed surface is brownish, but when the sample is pulled apart the freshly exposed surface is dark gray/black;
3. fresh organic soils usually have a characteristic odor that can be recognized,

particularly when the soil is heated;

4. compared to inorganic soils, less effort is typically required to pull the material apart and a friable break is usually formed with a fine granular or silty texture and appearance;
5. workability of organic soils at the plastic limit is weaker and spongier than an equivalent inorganic soil;
6. the smear, although generally smooth, is usually duller and appears more silty than an equivalent inorganic soil's; and
7. the organic content of organic soils can also be determined by the combustion test method (AASHTO T 267, ASTM D 2974).

Fine-grained soils, where the organic content appears to be less than 50 percent of the volume (about 22 percent by weight), should be described as soils with organic material or as organic soils such as clay with organic material or organic clays etc. If the soil appears to have an organic content greater than 50 percent by volume it should be described as peat. The engineering behavior of soils below and above the 50 percent dividing line is entirely different. It is therefore critical that the organic content of soils be determined both in the field and in the laboratory (AASHTO T 267, ASTM D 2974). Simple field or visual laboratory identification of soils as organic or peat is neither advisable nor acceptable.

It is very important not to confuse topsoil with organic soils or peat. Topsoil is the relatively thin layer of soil found on the surface composed of partially decomposed organic materials, such as leaves, grass, small roots etc. Topsoil contains many nutrients that sustain plant and insect life and should not be used to construct geotechnical features or to support engineered structures.

4.1.4.4 Minor Soil Type(s)

Two or more soil types may be present in many soil formations,. When the percentage of the fine-grained minor soil type is less than 30 percent but greater than 12 percent, or the total sample or the coarse-grained minor component is 30 percent or more of the total sample, the minor soil type is indicated by adding a "y" to its name (e.g., f. gravelly, c-f. sandy, silty, clayey). Note the gradation adjectives are given for granular soils, while the plasticity adjective is omitted for the fine-grained soils.

When the percentage of the fine-grained minor soil type is 5 to 12 percent or for the coarse-grained minor soil type is less than 30 percent but 15 percent or more of the total sample, the minor soil type is indicated by adding the descriptive adjective "with" to the group name (i.e., with clay, with silt, with sand, with gravel, and/or with cobbles).

Some local practices also use the descriptive adjectives “some” and “trace” for minor components as follows:

- "trace" when the percentage is between 1 and 12 percent of the total sample; or
- "some" when the percentage is greater than 12 percent and less than 30 percent of the total sample.

4.1.4.5 Inclusions

Additional inclusions or characteristics of the sample can be described by using "with" and the descriptions described above. For example:

- with petroleum odor
- with organic matter
- with foreign matter (roots, brick, etc.)
- with shell fragments
- with mica
- with parting(s), seam(s), etc. of (give soil’s complete description)

4.1.4.6 Other Descriptors

Depending on local conditions, the soils may be described based on reaction to HCl acid, and type and degree of cementation. ASTM D 2488 provides guidance for such descriptors.

4.1.4.7 Layered Soils

Soils of different types can be found in repeating layers of various thickness. It is important that all such formations and their thicknesses are noted. Each layer is described as if it is a non-layered soil by using the sequence for soil descriptions discussed above. The thickness and shape of layers and the geological type of layering are noted according to the descriptive terms presented in Table 4-7. The thickness designation is given in parentheses before the type of layer or at the end of each description, whichever is more appropriate.

Examples of descriptions for layered soils are:

- Medium stiff, moist to wet 0.2 to 0.75 in (5 to 20 mm) interbedded seams and layers of gray, medium plastic, silty CLAY and lt. gray, low plasticity SILT; (Alluvium).

- Soft moist to wet varved layers of gray-brown, high plasticity CLAY (0.2 to 0.75-in (5 to 20 mm)) and nonplastic SILT, trace f. sand (0.4 to 0.6 in (10 to 15 mm)); (Alluvium).

Table 4-7
Descriptive terms for layered soils (NAVFAC, 1986a)

Type of Layer	Thickness	Occurrence
Parting	< 1/16" (< 1.5 mm)	
Seam	1/16 to ½" (1.5 mm to 12 mm)	
Layer	½" to 12" (12 mm to 300 mm)	
Stratum	> 12" (>300 mm)	
Pocket		Small erratic deposit
Lens		Lenticular deposit
Varved (also layered)		Alternating seams or layers of silt and/or clay and sometimes fine sand
Occasional		One or less per 12" (300 mm) of thickness or laboratory sample inspected
Frequent		More than one per 12" (300 mm) of thickness or laboratory

4.1.4.8 Geological Name

The soil description should include the geotechnical specialist's assessment of the origin of the soil unit and the geologic name, if known. This information is generally placed in parentheses or brackets at the end of the soil description or in the field notes column of the boring log. Some examples include:

a. *Washington, D.C.*-Cretaceous Age Material with SPT N-values between 30 and 100: Very hard gray-blue silty CLAY (CH), moist **[Potomac Group Formation]**

b. *Newport News, VA*-Miocene Age Marine Deposit with SPT N-values around 10 to 15: Stiff green sandy CLAY (CL) with shell fragments, calcareous **[Yorktown Formation].**

c. *Tucson, AZ* – Holocene Age Alluvial Deposit with SPT N-values around 35: Cemented clayey SAND (SC), dry [**Pantano Formation].**

4.2 SOIL CLASSIFICATION

As previously indicated, final identification with classification is best performed in the laboratory. This process will lead to more consistent final boring logs and avoid conflicts with field descriptions. The Unified Soil Classification System (USCS) group name and symbol (in parenthesis) appropriate for the soil type in accordance with AASHTO M 145 (or ASTM D 3282) or ASTM D 2487 is the most commonly used system in geotechnical work and is covered in this section. For classification of highway subgrade material, the AASHTO classification system (see Section 4.2.2) is used. The AASHTO classification system is also based on grain size and plasticity.

4.2.1 Unified Soil Classification System (USCS)

The Unified Soil Classification System (ASTM D 2487) groups soils with similar engineering properties into categories base on grain size, gradation and plasticity. Table 4-8 provides a simplification of the group breakdown based on percent passing No. 200 sieve (0.075 mm) and Table 4-9 provides an outline of the complete laboratory classification method. The procedures, along with charts and tables, for classifying coarse-grained and fine-grained soils follow.

Table 4-8
Basic USCS soil designations based on percent passing No. 200 sieve (0.075 mm) (after ASTM D 2487; Holtz and Kovacs, 1981)

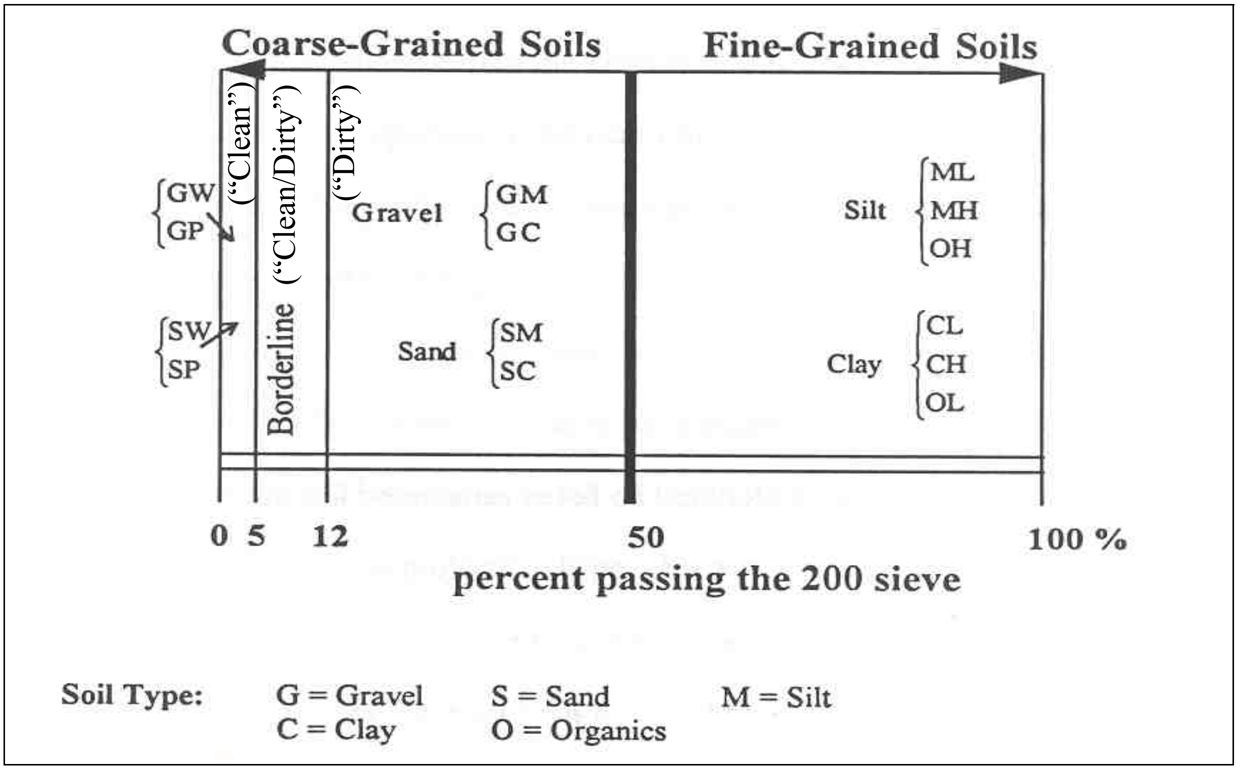


Table 4-9
Soil classification chart (laboratory method) (after ASTM D 2487)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[a]			Soil Classification: Group Symbol	Soil Classification: Group Name[b]
COARSE-GRAINED SOILS (Sands and Gravels) - more than 50% retained on No. 200 (0.075 mm) sieve **FINE-GRAINED (Silts and Clays) -** 50% or more passes the No. 200 (0.075 mm) sieve				
GRAVELS More than 50% of coarse Fraction retained on No. 4 Sieve	CLEAN GRAVELS < 5% fines	$C_u \geq 4$ and $1 \leq C_c \leq 3$[e]	GW	Well-graded gravel[f]
		$C_u < 4$ and/or $1 > C_c > 3$[e]	GP	Poorly-graded gravel[f]
	GRAVELS WITH FINES > 12% of fines[c]	Fines classify as ML or MH	GM	Silty gravel[f,g,h]
		Fines classify as CL or CH	GC	Clayey gravel[f,g,h]
SANDS 50% or more of coarse fraction passes No. 4 Sieve	CLEAN SANDS < 5% fines[d]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[e]	SW	Well-graded Sand[i]
		$C_u < 6$ and/or $1 > C_c > 3$[e]	SP	Poorly-graded sand[i]
	SANDS WITH FINES > 12% fines[d]	Fines classify as ML or MH	SM	Silty sand[g,h,i]
		Fines classify as CL or CH	SC	Clayey sand[g,h,i]
SILTS AND CLAYS Liquid limit less than 50	Inorganic	PI > 7 and plots on or above "A" line[j]	CL	Lean clay[k,l,m]
		PI < 4 or plots below "A" line[j]	ML	Silt[k,l,m]
	Organic	$\frac{\text{Liquid limit - overdried}}{\text{Liquid limit - not dried}} < 0.75$	OL	Organic clay[k,l,m,n]
				Organic silt[k,l,m,o]
SILTS AND CLAYS Liquid limit 50 or more	Inorganic	PI plots on or above "A" line	CH	Fat clay[k,l,m]
		PI plots below "A" line	MH	Elastic silt[k,l,m]
	Organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OH	Organic clay[k,l,m,p]
				Organic silt[k,l,m,q]
Highly fibrous organic soils	Primary organic matter, dark in color, and organic odor		Pt	Peat

Table 4-9 (Continued)

Soil classification chart (laboratory method) (after ASTM D 2487)

NOTES:

a Based on the material passing the 3 in (75 mm) sieve.

b If field sample contained cobbles and/or boulders, add "with cobbles and/or boulders" to group name.

c Gravels with 5 to 12% fines require dual symbols:
- GW-GM, well-graded gravel with silt
- GW-GC, well-graded gravel with clay
- GP-GM, poorly graded gravel with silt
- GP-GC, poorly graded gravel with clay

d Sands with 5 to 12% fines require dual symbols:
- SW-SM, well-graded sand with silt
- SW-SC, well-graded sand with clay
- SP-SM, poorly graded sand with silt
- SP-SC, poorly graded sand with clay

e $C_u = \dfrac{D_{60}}{D_{10}} \quad C_c = \dfrac{(D_{30})^2}{(D_{10})(D_{60})}$

[C_u: Uniformity Coefficient; C_c: Coefficient of Curvature]

f If soil contains ≥ 15% sand, add "with sand" to group name.

g If fines classify as CL-ML, use dual symbol GC-GM, SC-SM.

h If fines are organic, add "with organic fines" to group name.

i If soil contains ≥ 15% gravel, add "with gravel" to group name.

j If the liquid limit and plasticity index plot in hatched area on plasticity chart, soil is a CL-ML, silty clay.

k If soil contains 15 to 29% plus No. 200 (0.075 mm), add "with sand" or "with gravel," whichever is predominant.

l If soil contains ≥ 30% plus No. 200 (0.075mm), predominantly sand, add "sandy" to group name.

m If soil contains ≥ 30% plus No. 200 (0.075 mm), predominantly gravel, add "gravelly" to group name.

n PI ≥ 4 and plots on or above "A" line.

o PI < 4 or plots below "A" line.

p PI plots on or above "A" line.

q PI plots below "A" line.

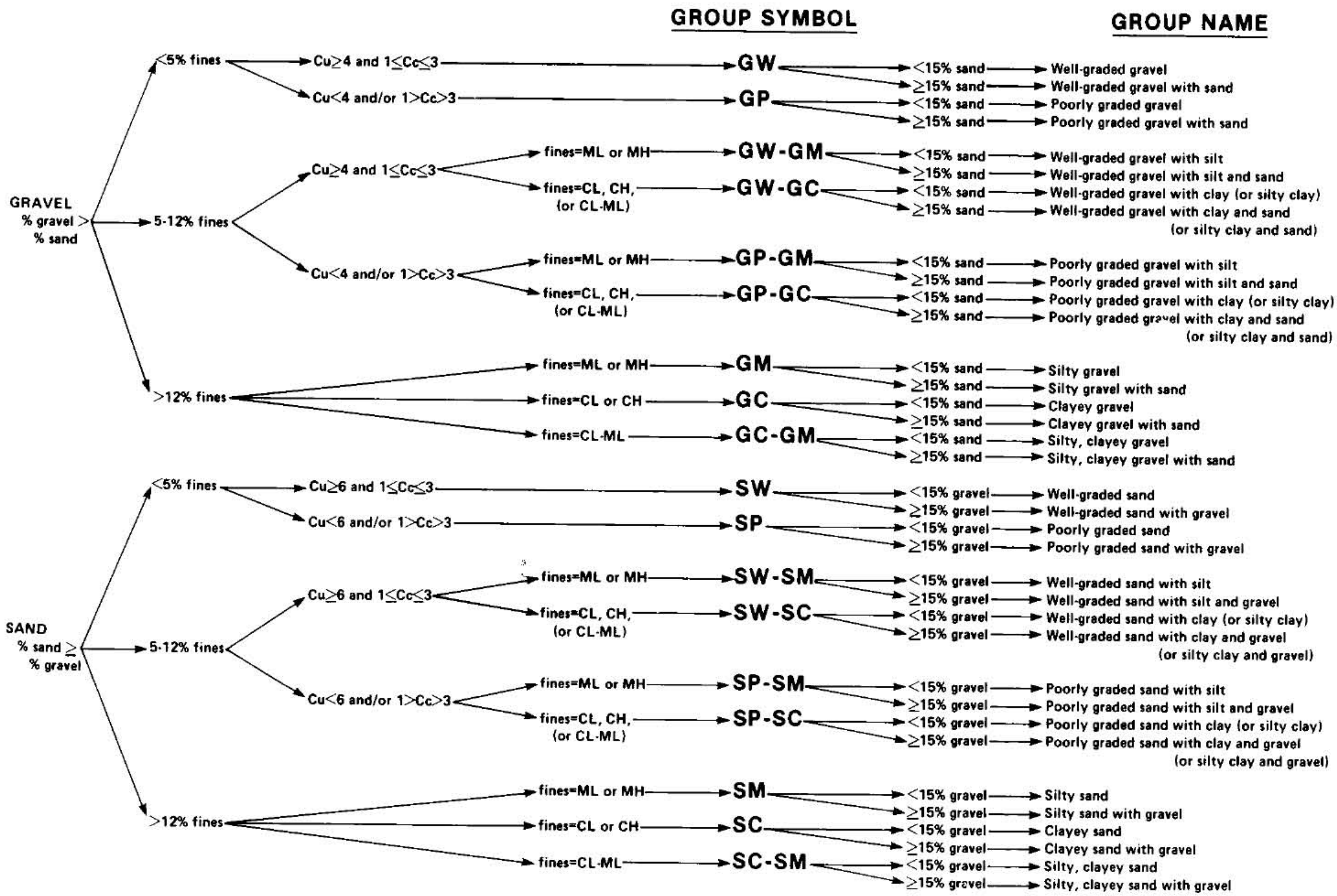


Figure 4-1: Flow chart to determine the group symbol and group name for coarse-grained soils (ASTM D 2487).

4.2.1.1 Classification of Coarse-Grained Soils

Coarse-grained soils are defined as those in which 50 percent or more by weight are retained on the No. 200 sieve (0.075 mm). The flow chart to determine the group symbol and group name for coarse-grained soils is given in Figure 4-1. This figure is identical to Figure 3 in ASTM D 2487 except for the recommendation to capitalize the primary soil type; e.g., GRAVEL.

- **The shape of the grain-size distribution (GSD) curve or "gradation curve" as it is frequently called, is one of the more important aspects in a soil classification system for coarse-grained soils.** The shape of the gradation curve can be characterized by a pair of "shape" parameters called the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, to which numerical values may be assigned. By assigning numerical values to such shape parameters it becomes possible to compare grain-size distribution curves for different soils without having to plot them on the same diagram. In order to define shape parameters certain characteristic particle sizes must be identified that are common to all soils. Since the openings of a sieve are square, particles of many different shapes are able to pass through a sieve of given size even though the abscissa on the gradation curve is expressed in terms of particle "diameter," which implies a spherical-shaped particle. Therefore, the "diameter" shown on the gradation curve is an effective diameter so that the characteristic particle sizes that must be identified to define the shape parameters are in reality effective grain sizes (EGS).

  A useful EGS for the characterizing the shape of the gradation curve is the grain size for which 10 percent of the soil by weight is finer. This EGS is labeled D_{10}. This size is convenient because Hazen (1911) found that the ease with which water flows through a soil is a function of the D_{10}. In other words, Hazen found that the sizes smaller than the D_{10} affected the permeability more than the remaining 90 percent of the sizes. Therefore, the D_{10} is a logical choice as a characteristic particle size. Other convenient sizes were found to be the D_{30} and the D_{60}, which pertain to the grain size for which thirty and sixty percent, respectively, of the soil by weight is finer. These EGSs are used as follows in the Unified Soil Classification System (USCS) for the classification of coarse grained soils.

- **Slope of the gradation curve**: The shape of the curve could be defined relative to an arbitrary slope of a portion of the gradation curve. Since one EGS has already been identified as the D_{10}, the slope of the gradation curve could be described by identifying another convenient point (EGS) that is "higher" on the curve. Hazen selected this other convenient size as the D_{60} that indicates the particle size for which 60 percent of the soil by weight is finer. The slope between the D_{60} and the D_{10} can then be related to the degree of uniformity of the sample through a parameter called the "Coefficient of Uniformity" or the "Uniformity Coefficient," C_u, which is expressed as follows:

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{4-1}$$

- **Curvature of the gradation curve**: The second "shape" parameter is used to evaluate the curvature of the gradation curve between the two arbitrary points, D_{60} and D_{10}. A third EGS, D_{30}, that indicates the particle size for which 30 percent of the soil by weight is finer, is chosen for this purpose. The curvature of the slope between the D_{60} and the D_{10} can then be related to the three EGS' through a parameter called the "Coefficient of Curvature" or the "Coefficient of Concavity" or the "Coefficient of Gradation," C_c, which is expressed as follows:

$$C_c = \frac{D_{30}^2}{D_{60} \text{ x } D_{10}} \quad \text{4-2}$$

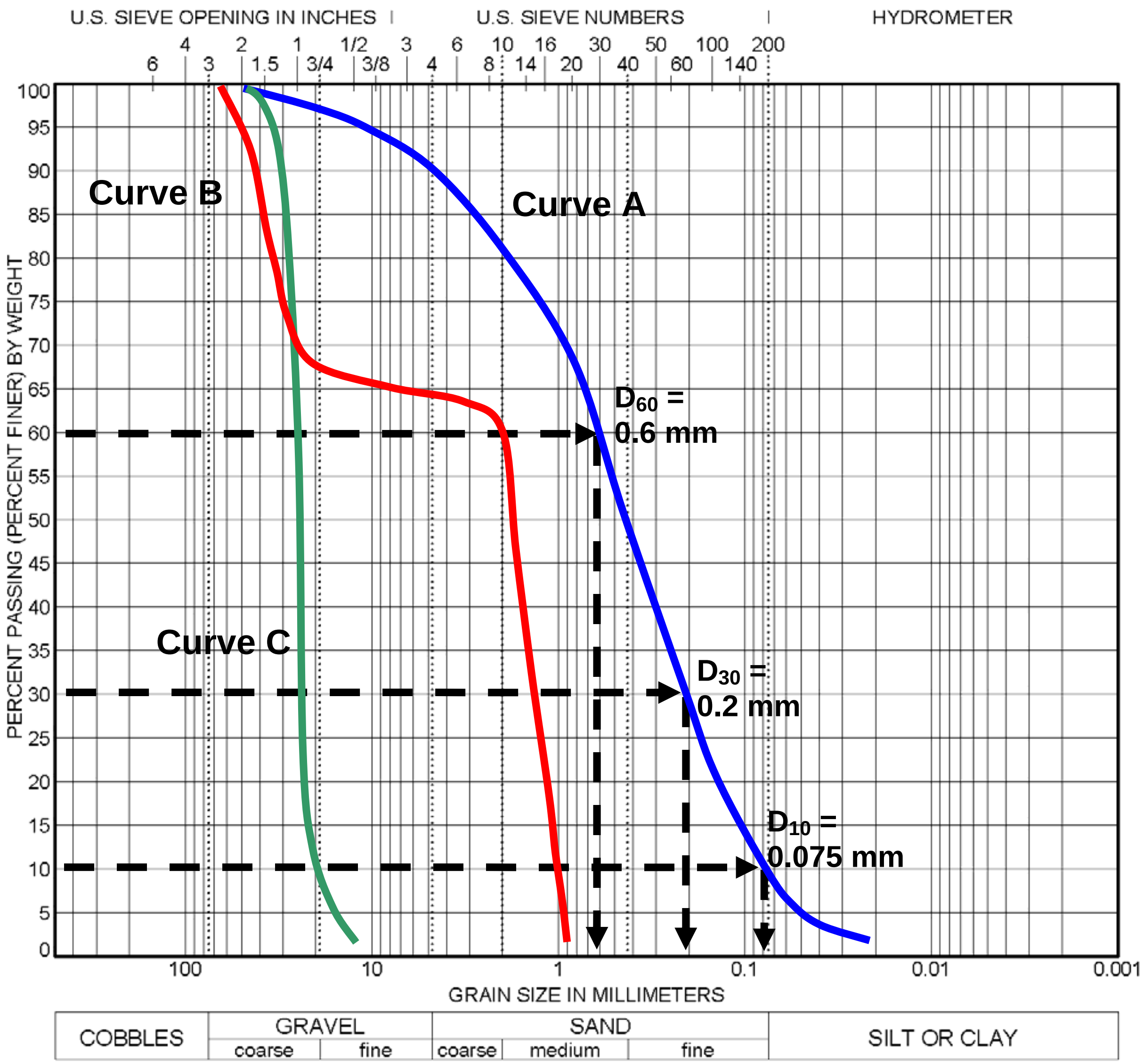
By use of the two "shape" parameters, C_u and C_c, the uniformity of the coarse-grained soil (gravel and sand) can now be classified as well-graded (non-uniform), poorly graded (uniform), or gap graded (uniform or non-uniform). Table 4-10 presents criteria for such classifications.

Table 4-10

Gradation based on C_u and C_c parameters

Gradation	**Gravels**	**Sands**
Well-graded	$C_u \geq 4$ and $1 < C_c < 3$	$C_u \geq 6$ and $1 < C_c < 3$
Poorly graded	$C_u < 4$ and $1 < C_c < 3$	$C_u < 6$ and $1 < C_c < 3$
Gap graded*	C_c not between 1 and 3	C_c not between 1 and 3
*Gap-graded soils may be well-graded or poorly graded. In addition to the C_c value it is recommended that the shape of the GSD be the basis for definition of gap-graded.		

C_u and C_c are statistical parameters and provide good initial guidance. However, **the plot of the GSD curve must always be reviewed in conjunction with the values of C_u and C_c to avoid incorrect classification.** Examples of the importance of reviewing the GSD curves are presented in Figure 4-2 and discussed subsequently.



Curve	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Gradation
A	0.075	0.2	0.6	8.0	0.9	Well graded (1)
B	1	1.5	2	2.0	1.12	Poorly graded - Gap graded (2)
C	19	25	27	1.4	1.2	Poorly graded

(1) Soil does not meet C_u and C_c criteria for well-graded soil but GSD curve clearly indicates a well-graded soil

(2) The C_u and C_c parameters indicate a uniform (or poorly) graded material, but the GSD curve clearly indicates a gap-graded soil.

Note: For clarity only the D_{10}, D_{30}, and D_{60} sizes for Curve A are shown on the figure.

Figure 4-2. Evaluation of type of gradation for coarse-grained soils.

Discussion of Figure 4-2: Curve A in Figure 4-2 has C_u = 8 and C_c = 0.9. The soil represented by Curve A would not meet the criteria listed in Table 4-10 for well-graded soil, but yet an examination of the GSD curve shows that the soil is well-graded. Examination of the GSD curve is even more critical for the case of gap graded soils because the largest particle size evaluated by parameters C_u and C_c is D_{60} while the gap grading may occur at a size larger than D_{60} size as shown for a 2/3:1/3 proportion of gravel: sand mix represented by Curve B in Figure 4-2. Based on the criteria in Table 4-10, the soil represented by Curve B would be classified as a uniform or poorly graded soil which would be an incorrect classification. Such incorrect classifications can and do occur on construction sites where the contractor may (a) simply mix two stockpiles of uniformly graded soils leftover from a previous project. (b) use multiple sand and gravel pits to obtain borrow soils, and/or (c) mix soils from two different seams or layers of poorly graded material in the same gravel pit. Figure 4-2 is an illustration on the importance of evaluating the shape of the GSD curve in addition to the statistical parameters C_u and C_c. Practical aspects of the engineering characteristics of granular soils are discussed in Section 4.4.

4.2.1.2 Classification of Fine-Grained Soils

Fine-grained soils, or “fines,” are those in which 50 percent or more by weight pass the No. 200 (0.075 mm) sieve, The classification of fine-grained soils is accomplished by use of the plasticity chart (Figure 4-3). For fine-grained organic soils, Table 4-11 may be used. Inorganic silts and clays are those that do not meet the organic criteria as given in Table 4-11. The flow charts to determine the group symbol and group name for fine-grained soils are given in Figure 4-4a and 4-4b. These figures are identical to Figures 1a and 1b in ASTM D 2487 except that they are modified to show the soil type capitalized; e.g., CLAY. Dual symbols are used to classify organic silts and clays whose liquid limit and PI plot above the "A"-line, for example, CL-OL instead of OL and CH-OH instead of OH. To describe the fine-grained soil types more fully, plasticity adjectives and soil types used as adjectives should be used to further define the soil type's texture, plasticity, and location on the plasticity chart (see Table 4-12). Examples using Table 4-11 are given in Table 4-12. An example description of fine-grained soils is as follows:

Soft, wet, gray, high plasticity CLAY, with f. Sand; Fat CLAY (CH); (Alluvium)

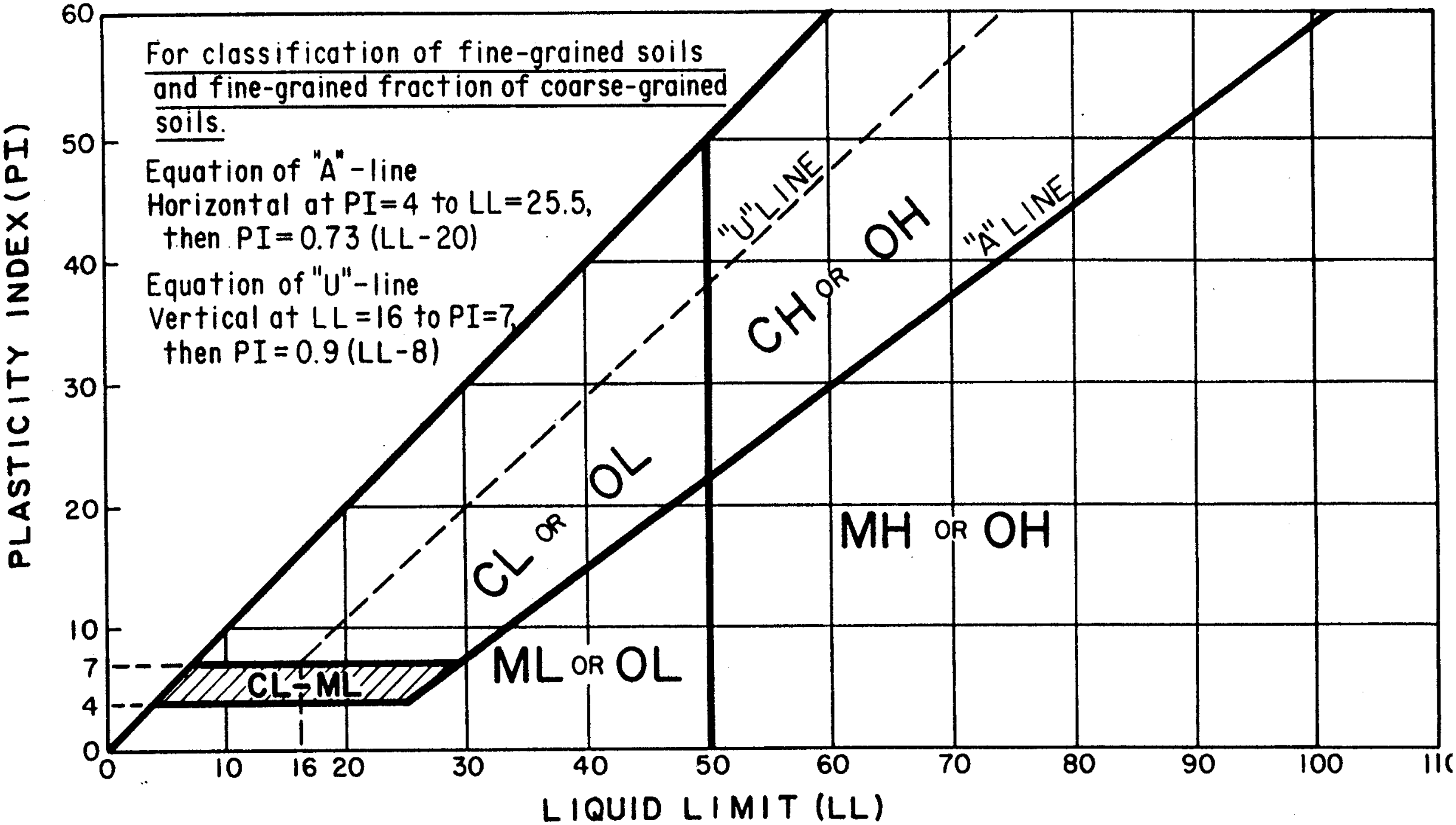


Figure 4-3. Plasticity chart for Unified Soil Classification System (ASTM D 2487).

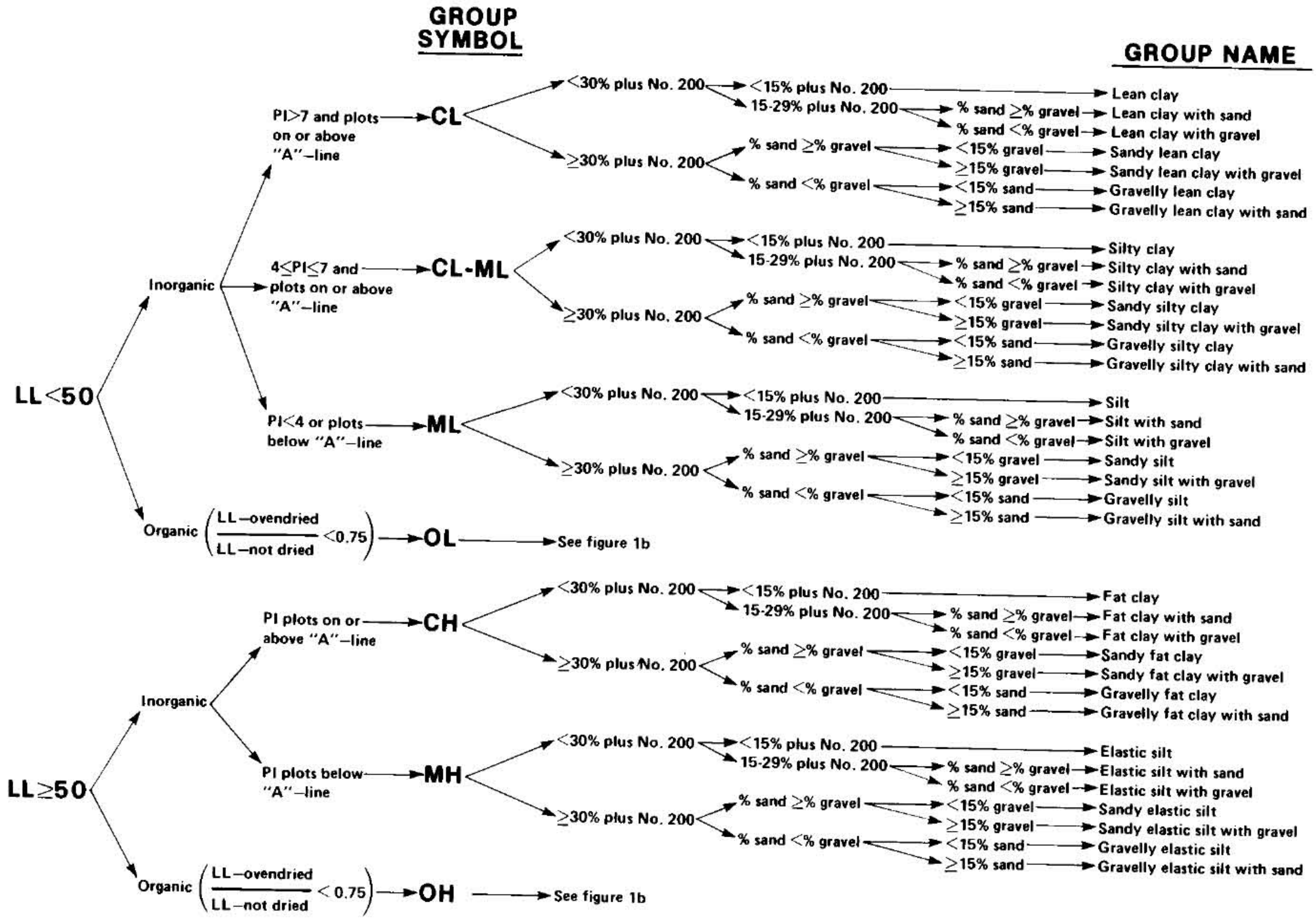


Figure 4-4a. Flow chart to determine the group symbol and group name for fine-grained soils (ASTM D 2487).

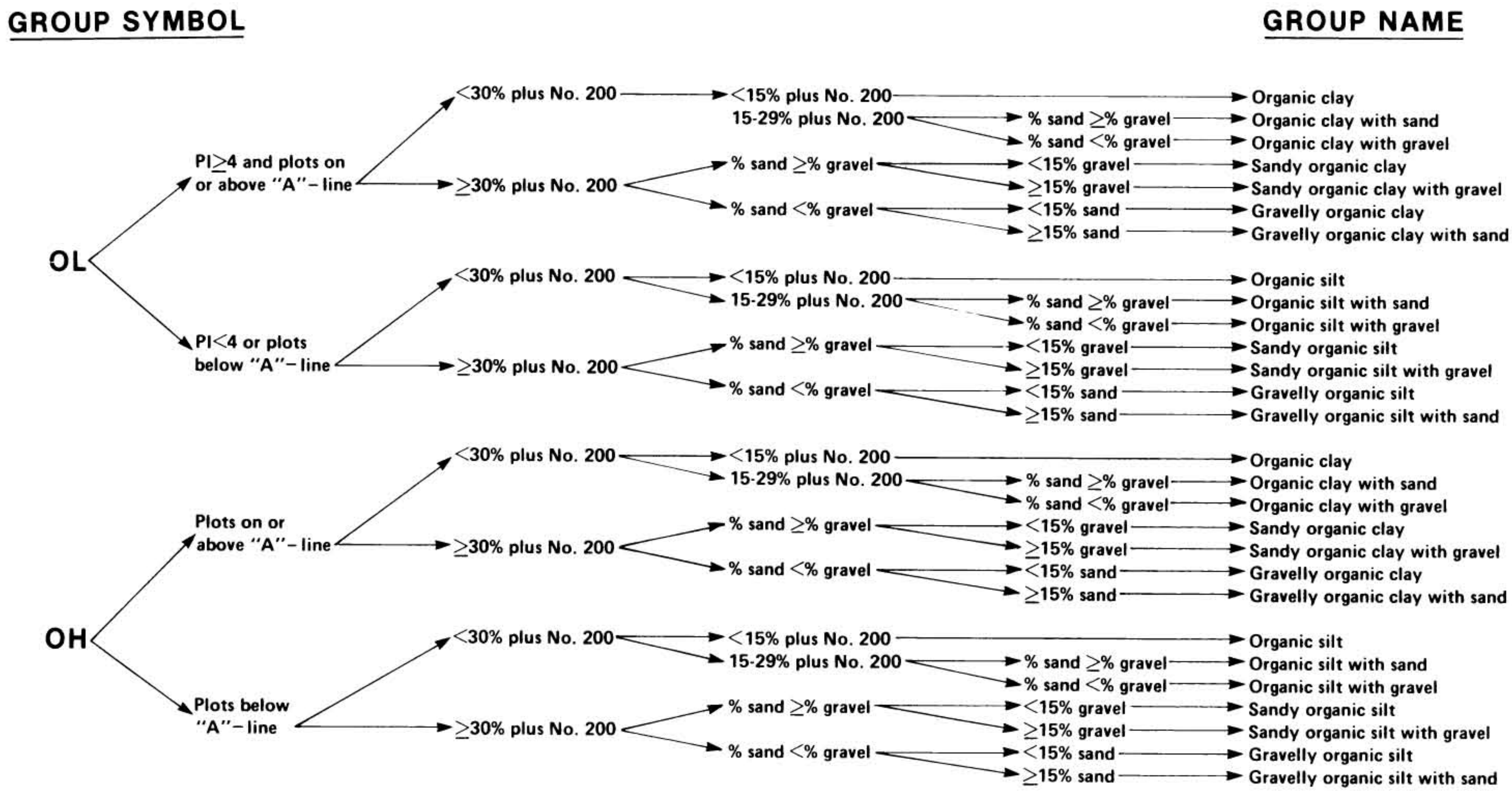


Figure 4-4b. Flow chart to determine the group symbol and group name for organic soils (ASTM D 2487).

Table 4-11
Soil plasticity descriptors (based on Figures 4-3, 4-4a and 4-4b)

Plasticity Index Range	Plasticity Adjective	Adjective for Soil Type, Texture, and Plasticity Chart Location		
		ML & MH (Silt)	CL & CH (Clay)	OL & OH (Organic Silt or Clay)[1]
0	nonplastic	-	-	ORGANIC SILT
1 - 10	low plasticity	-	silty	ORGANIC SILT
>10 - 20	medium plasticity	Clayey	silty to no adj.	ORGANIC clayey SILT
>20 - 40	high plasticity	Clayey	-	ORGANIC silty CLAY
>40	very plastic	Clayey	-	ORGANIC CLAY
Soil type is the same for above or below the “A”-line; the dual group symbol (CL-OL or CH-OH) identifies the soil types above the “A”-line.				

Table 4-12
Examples of description of fine-grained soils (based on Figures 4-3, 4-4a and 4-4b)

Group Symbol	PI	Group Name	Complete Description For Main Soil Type (Fine-Grained Soil)
CL	9	lean CLAY	low plasticity silty CLAY
ML	7	SILT	low plasticity SILT
ML	15	SILT	medium plastic clayey SILT
MH	21	elastic SILT	high plasticity clayey SILT
CH	25	fat CLAY	high plasticity silty CLAY or high plasticity CLAY, depending on smear test (for silty relatively dull and not shiny or just CLAY for shiny, waxy)
OL	8	ORGANIC SILT	low plasticity ORGANIC SILT
OL	19	ORGANIC SILT	medium plastic ORGANIC clayey SILT
CH	>40	fat CLAY	very plastic CLAY

4.2.2 AASHTO Soil Classification System

The AASHTO soil classification system is shown in Table 4-13. The AASHTO classification system is useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases and bases.

According to this system, soil is classified into seven major groups, A-1 through A-7. Soils classified under groups A-1, A-2 and A-3 are granular materials where 35% or less of the particles pass through the No. 200 sieve (0.075 mm). Soils where more than 35% pass the No. 200 sieve (0.075 mm) are classified under groups A-4, A-5, A-6 and A-7. Soils where more than 35% pass the No. 200 sieve (0.075 mm) are mostly silt and clay-size materials. The classification procedure is shown in Table 4-13. The classification system is based on the following criteria:

i *Grain Size*: The grain size terminology for this classification system is as follows:

- **Gravel**: fraction passing the 3 in (75 mm) sieve and retained on the No. 10 (2 mm) sieve.
- **Sand**: fraction passing the No. 10 (2 mm) sieve and retained on the No. 200 (0.075 mm) sieve
- **Silt and clay**: fraction passing the No. 200 (0.075 mm) sieve

ii *Plasticity*: The term *silty* and *clayey* are used as follows:

- **Silty**: use when the fine fractions of the soil have a plasticity index of 10 or less.
- **Clayey**: use when the fine fractions have a plasticity index of 11 or more.

iii. If cobbles and boulders (size larger than 3 in (75 mm)) are encountered they are excluded from the portion of the soil sample on which the classification is made. However, the percentage of material is recorded.

To evaluate the quality of a soil as a highway subgrade material, a number called the *group index* (GI) is also incorporated along with the groups and subgroups of the soil. The group index is written in parenthesis after the group or subgroup designation. The group index is given by Equation 4-3 where F is the percent passing the No. 200 (0.075 mm) sieve, LL is the liquid limit, and PI is the plasticity index.

$$GI = (F-35)[0.2+0.005(LL-40)] + 0.01(F-15)(PI-10) \qquad 4\text{-}3$$

Table 4-13

AASHTO soil classification system based on AASHTO M 145 (or ASTM D 3282)

GENERAL CLASSIFICATION	**GRANULAR MATERIALS (35 percent or less of total sample passing No. 200 sieve (0.075 mm)**							**SILT-CLAY MATERIALS (More than 35 percent of total sample passing No. 200 sieve (0.075 mm)**			
GROUP CLASSIFICATION	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, percent passing:											
No. 10 (2 mm)	50 max.										
No. 40 (0.425 mm)	30 max.	50 max.	51 min.								
No. 200 (0.075 mm)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No 40 (0.425 mm)											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

<u>Classification procedure:</u>
With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from left into which the test data will fit is the correct classification.

*Plasticity Index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity Index of A-7-6 subgroup is greater than LL minus 30 (see Fig 4-5).

**See group index formula (Eq. 4-3). Group index should be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-7-5(17), etc.

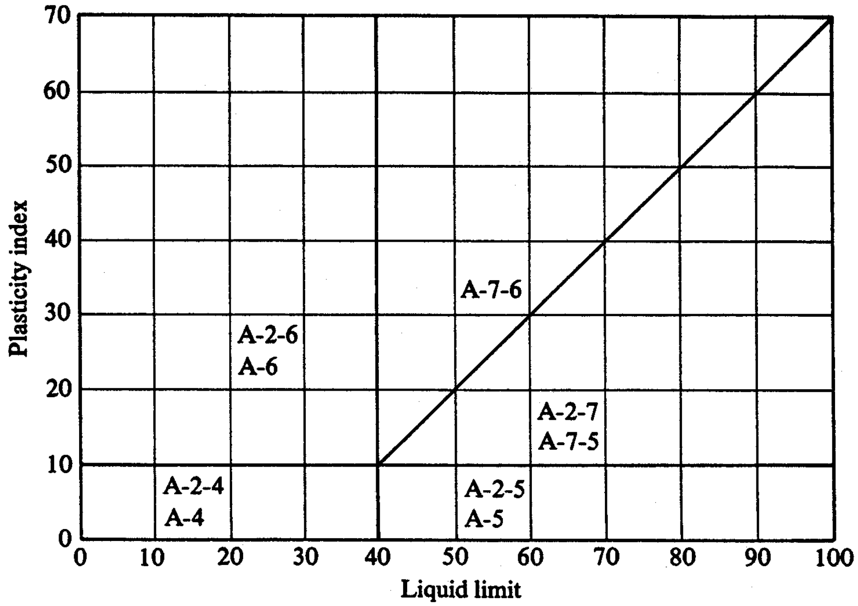


Figure 4-5. Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6 and A-7 per AASHTO M 145 (or ASTM D 3282).

The first term of Equation 4-3 is the partial group index determined from the liquid limit. The second term is the partial group index determined from the plasticity index. Following are some rules for determining group index:

- If Equation 4-3 yields a negative value for GI, it is taken as zero.
- The group index calculated from Equation 4-3 is rounded off to the nearest whole number, e.g., GI=3.4 is rounded off to 3; GI=3.5 is rounded off to 4.
- There is no upper limit for the group index.
- The group index of soils belonging to groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 will always be zero.
- When the group index for soils belonging to groups A-2-6 and A-2-7 is calculated, the partial group index for PI should be used, or

$$GI=0.01(F-15)(PI-10) \qquad 4\text{-}4$$

In general, the quality of performance of a soil as a subgrade material is inversely proportional to the group index.

A comparison of the USCS and AASHTO system is shown in Figures 4-6 and 4-7.

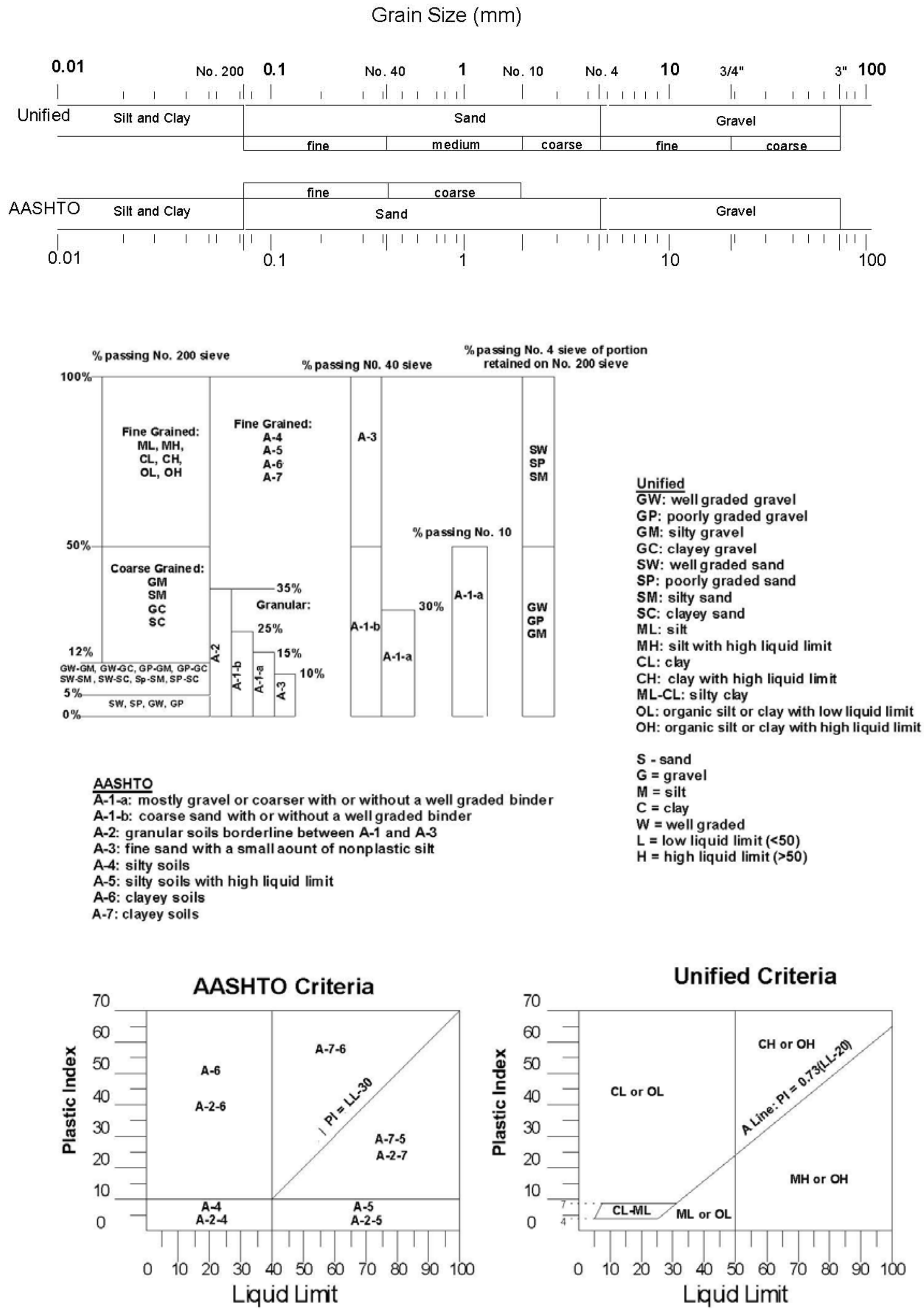


Figure 4-6. Comparison of the USCS with the AASHTO soil classification system (after Utah DOT – Pavement Design and Management Manual, 2005).

Soil Group in Unified System	Comparable Soil Groups in AASHTO System		
	Most Probable	Possible	Possible but Improbable
GW	A-1-a	—	A-2-4, A-2-5, A-2-6, A-2-7
GP	A-1-a	A-1-b	A-3, A-2-4, A-2-5, A-2-6, A-2-7
GM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6	A-4, A-5, A-6, A-7-5, A-7-6, A-1-a
GC	A-2-6, A-2-7	A-2-4, A-6	A-4, A-7-6, A-7-5
SW	A-1-b	A-1-a	A-3, A-2-4, A-2-5, A-2-6, A-2-7
SP	A-3, A-1-b	A-1-a	A-2-4, A-2-5, A-2-6, A-2-7
SM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6, A-4, A-5	A-6, A-7-5, A-7-6, A-1-a
SC	A-2-6, A-2-7	A-2-4, A-6, A-4, A-7-6	A-7-5
ML	A-4, A-5	A-6, A-7-5	—
CL	A-6, A-7-6	A-4	—
OL	A-4, A-5	A-6, A-7-5, A-7-6	—
MH	A-7-5, A-5	—	A-7-6
CH	A-7-6	A-7-5	—
OH	A-7-5, A-5	—	A-7-6
Pt	—	—	—

Soil Group in AASHTO System	Comparable Soil Groups in Unified System		
	Most Probable	Possible	Possible but Improbable
A-1-a	GW, GP	SW, SP	GM, SM
A-1-b	SW, SP, GM, SM	GP	—
A-3	SP	—	SW, GP
A-2-4	GM, SM	GC, SC	GW, GP SW, SP
A-2-5	GM, SM	—	GW, GP, SW, SP
A-2-6	GC, SC	GM, SM	GW, GP SW, SP
A-2-7	GM, GC, SM, SC	—	GW, GP, SW, SP
A-4	ML, OL	CL, SM, SC	GM, GC
A-5	OH, MH, ML, OL	—	SM, GM
A-6	CL	ML, OL, SC	GC, GM, SM
A-7-5	OH, MH	ML, OL, CH	GM, SM, GC, SC
A-7-6	CH, CL	ML, OL, SC	OH, MH, GC, GM, SM

Figure 4-7. Comparison of soil groups in the USCS with the AASHTO Soil Classification Systems (Holtz and Kovacs, 1981).

4.3 ENGINEERING CHARACTERISTICS OF SOILS

The major engineering characteristics of the main soil groups discussed in the previous section as related to foundation design are summarized as follows. A discussion on the practical aspects of the engineering characteristics is presented for granular and fine-grained soils following these summaries.

4.3.1 Engineering Characteristics of Coarse-Grained Soils (Sands and Gravels)

- Generally very good foundation material for supporting structures and roads.
- Generally very good embankment material.
- Generally the best backfill material for retaining walls.
- Might settle under vibratory loads or blasts.
- Dewatering may be difficult in open-graded gravels due to high permeability.
- Generally not frost susceptible.

4.3.2 Engineering Characteristics of Fine-Grained Soils (Inorganic Clays)

- Generally possess low shear strength.
- Plastic and compressible.
- Can lose part of shear strength upon wetting.
- Can lose part of shear strength upon disturbance.
- Can shrink upon drying and expand upon wetting.
- Generally very poor material for backfill.
- Generally poor material for embankments.
- Can be practically impervious.
- Clay slopes are prone to landslides.

4.3.3 Engineering Characteristics of Fine-Grained Soils (Inorganic Silts)

- Relatively low shear strength.
- High capillarity and frost susceptibility.
- Relatively low permeability.
- Frost heaving susceptibility
- Difficult to compact.

4.3.4 Engineering Characteristics of Organic Soils

The term organic designates those soils, other than topsoil, that contain an appreciable amount of vegetative matter and occasionally animal organisms in various states of decomposition. Any soil containing a sufficient amount of organic matter to influence its engineering properties is called an organic soil. The organic matter is objectionable for three main reasons:

1. Reduces load carrying capacity of soil.
2. Increases compressibility considerably.
3. Frequently contains toxic gasses that are released during the excavation process.

Generally organic soils, whether peat, organic clays, organic silts, or even organic sands, are not used as construction materials.

4.4 PRACTICAL ASPECTS OF ENGINEERING CHARACTERISTICS OF COARSE-GRAINED SOILS

Grain size distribution is the single most important element in the design of structures on, in, or composed of granular soils. As discussed in Chapter 2, grain size distribution is determined by sieving a dried soil sample of known weight through a nest of U.S. Standard sieves with decreasing mesh opening sizes. Figures 2-3 and 4-2 presented sample grain size distribution curves, also known as gradation curves, and introduced the terminology "well graded," "poorly graded," and "gap graded."

Much can be learned about a soil's behavior from the shape and location of the curve. For instance, the "well graded" curve shown in Figure 4-2 represents a non-uniform soil with a wide range of particle sizes that are evenly distributed. Densification of a well-graded soil causes the smaller particles to move into the voids between the larger particles. As the voids in the soil are reduced, the density and strength of the soil increase. Specifications for select structural fill should contain required ranges of different particle sizes so that a dense, non-compressible backfill can be achieved with reasonable compactive effort. For example, the well-graded soil represented by Curve A shown in Figure 4-2 could be specified by providing the gradation limits listed in Table 4-14.

As shown by Curve C in Figure 4-2, a poorly graded or uniform soil is composed of a narrow range of particle sizes. When compaction is attempted, inadequate distribution of particle sizes prevents reduction of the volume of voids by infilling with smaller particles. Such uniform soils should be avoided as select fill material. However, uniform soils do have an important use as drainage materials. The relatively large and permanent void spaces act as conduits to carry water. Obviously, the larger the average particle size the larger the void space. The "French drain" is an example of the engineering use of a coarse uniform soil. Table 4-15 presents a typical specification for drainage materials having a narrow band of particle sizes. For material specifications related to drain material, it is important to specify that gap-graded materials shall not be acceptable. This is because gap-graded materials have variable permeabilities that may cause malfunction of the drain with associated damage to the geotechnical feature associated with the drain.

Table 4-14
Example gradation limits of well-graded granular material
(see Curve A in Figure 4-2)

Sieve Size	Percent Passing by Weight
2″ (50.8 mm)	100
#10 (2 mm)	75-90
#40 (0.425 mm)	40-60
#200 (0.075 mm)	0 – 15

Table 4-15
Example gradation limits of drainage materials
(see Curve C in Figure 4-2)

Sieve Size	Percent Passing by Weight
2″ (50.8 mm)	100
1 ½ ″ (37.5 mm)	90-100
¾ ″ (19 mm)	0-15

4.5 PRACTICAL ASPECTS OF ENGINEERING CHARACTERISITICS OF FINE-GRAINED SOILS

As indicated in Chapter 2, the plasticity index (PI) is the difference between the liquid limit (LL) and the plastic limit (PL). The PI represents the range of water content over which the soil remains plastic. In general, the greater the PI, the greater the amount of clay particles present and the more plastic the soil. The more plastic a soil, the more likely it will be to have the following characteristics:

1. Be more compressible.
2. Have greater potential to shrink upon drying and/or swell upon wetting.
3. Be less permeable.

In addition to the PI, the Liquidity Index (LI) is a useful indicator of the engineering characteristics of fine-grained soils. Table 2-4 in Chapter 2 identifies the strength and deformation characteristics of fine-grained soils in terms of the LI.

4.7 SUBSURFACE PROFILE DEVELOPMENT

The mark of successfully accomplishing a subsurface exploration is the ability to draw a subsurface profile of the project site complete with soil types, rock interfaces, and the relevant design properties. The subsurface profile is a visual display of subsurface conditions as interpreted from all of the methods of explorations and testing described previously. Uncertainties in the development of a subsurface exploration usually indicate the need for additional explorations or testing. Because of the diverse nature of the geologic processes that contribute to soil formation, actual subsurface profiles can be extremely varied both vertically and horizontally, and can differ significantly from interpreted profiles developed from boring logs. Therefore, subsurface profiles developed from boring logs should contain some indication that the delineation between strata do not necessarily suggest that distinct boundaries exist between the strata or that the interpolations of strata thickness between borings are necessarily correct. The main purpose of subsurface profiles is to provide a starting point for design and not necessarily to present an accurate description of subsurface conditions.

In the optimum situation, the subsurface profile is developed in stages. First, a rough profile is established from the driller's logs by the geotechnical specialist. The object is to discover any obvious gaps or question marks while the drill crew is still at the site so that additional work can be performed immediately. Once a crew has left the site, a delay of months may occur before their schedule permits them to reoccupy the site, not to mention the additional cost to remobilize/demobilize. The drilling inspector or crew chief should be required to call the project geotechnical specialist when the last scheduled boring has begun to request instructions for any supplemental borings.

When all borings are completed and laboratory visuals and moisture content data received, the initial subsurface profile should be revised. Estimated soil layer boundaries and accurate soil descriptions should be established for soil deposits. Estimated bedrock interfaces should be identified. Most importantly, the depth to perched or regional groundwater should be indicated. The over-complication of the profile by noting minute variations between adjacent soil samples can be avoided by:

1. Reviewing the geologic history of the site, e.g., if the soil map denotes a lakebed deposit overlying a glacial till deposit, do not subdivide the lakebed deposit because adjacent samples have differing amounts of silt and clay. Realize before breaking down the soil profile that probably only two layers exist and variations are to be expected within each. Important variations such as the average thickness of silt and clay varves can be noted adjacent to the visual description of the layer.

2. Remembering that the soil samples examined are only a minute portion of the soil underlying the site and must be considered in relation to adjacent samples as well as adjacent borings.

A few simple rules should be followed at this stage to interpret the available data properly:

1. Review the USDA Soil Survey map for the county and determine major surface and near-surface deposits that can be expected at the site.

2. Examine the subsurface log containing SPT results and the laboratory visual descriptions with accompanying moisture contents.

3. Review representative soil samples to check laboratory identifications and to calibrate your interpretations with those of the laboratory technicians who performed the visual description.

4. Establish rational mechanics for drawing the soil profile. For example:

    a. Use a vertical scale of 1 in equals 10 ft or 20 ft; generally, any smaller scale tends to compress data visually and prevent proper interpretation.

    b. Use a horizontal scale equal to the vertical scale, if possible, to simulate actual relationships. However, the total length should be kept within 36 inches (920 millimeter) to permit review in a single glance.

When the subsurface layer boundaries and descriptions have been established, determine the extent and details of laboratory testing. Do not casually read the driller's log and randomly select certain samples for testing. Plan the test program intelligently from the subsurface profile and for the proposed feature. Identify major soil deposits and assign appropriate tests for the design project under investigation.

The final subsurface profile is the geotechnical specialist's best interpretation of all available subsurface data. The final subsurface profile should include the following:

- interpreted boundaries of soil and rock
- the average physical properties of the soil layers, e.g., unit weight, shear strength, etc.
- a visual description of each layer including USCS symbols for soil classification
- location of the ground water level, and

- notations for special items such as boulders, artesian pressure, etc.

If the inclusion of all of the information listed above clutters the subsurface profile, then complementary tables containing some of that information should be developed to accompany the profile. Figures 4-8 and 4-9 show a typical boring location plan and an interpreted subsurface profile. Note that **the interpreted boundaries of rock and groundwater profiles are for internal agency use. Such interpretations should not be presented in bid documents.** Another example of boring location plan and subsurface profile is presented in Chapter 11 (Geotechnical Reports).

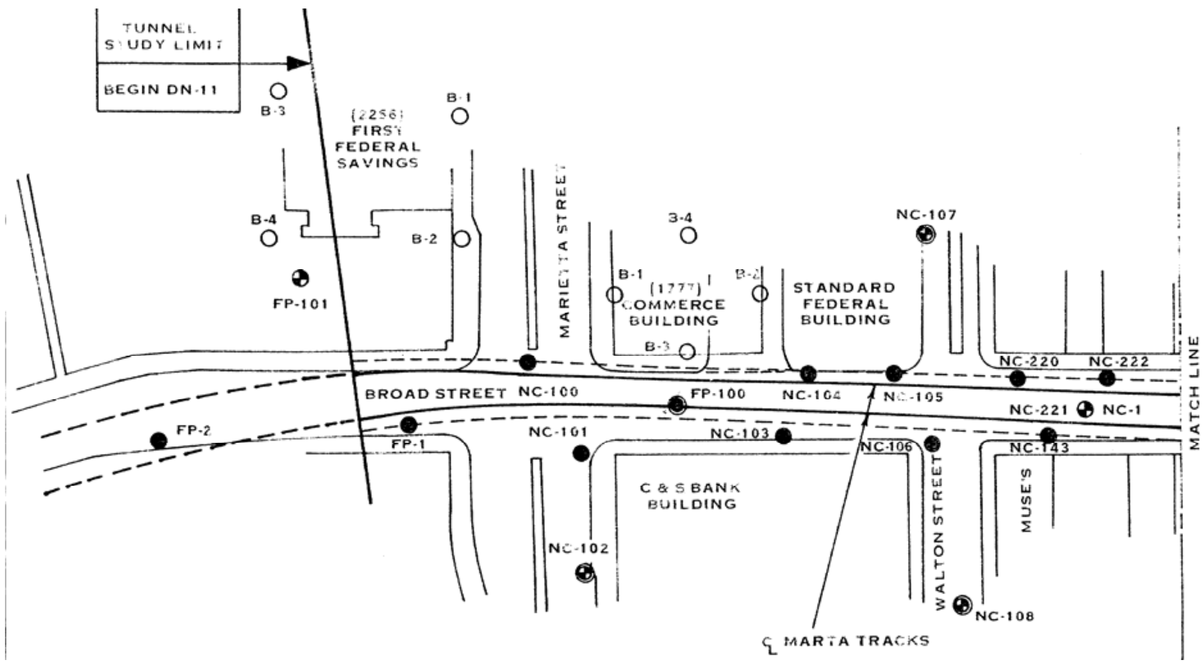


Figure 4-8. Example boring location plan (FHWA, 2002a).

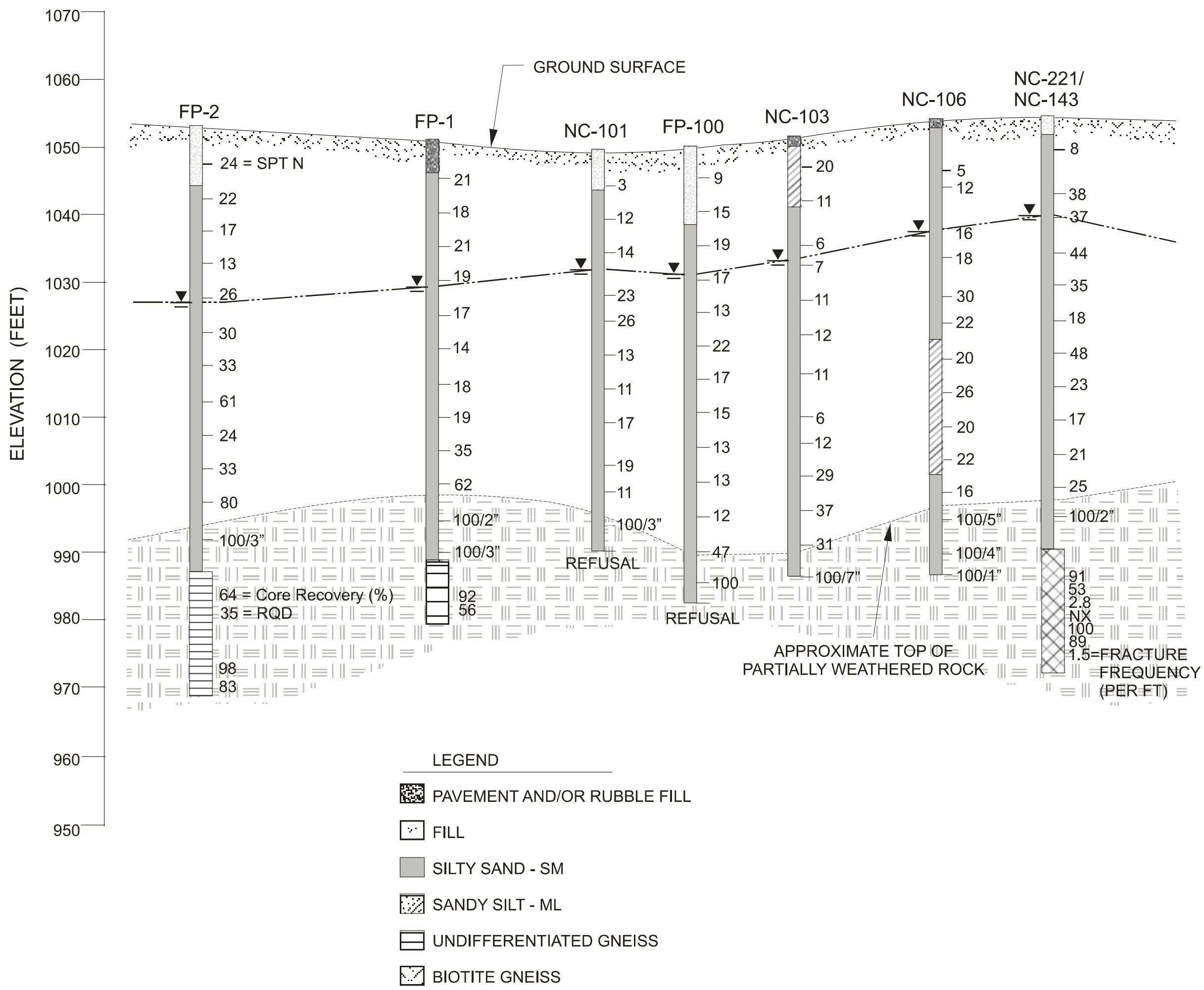


Figure 4-9. Example interpreted subsurface profile (FHWA, 2002a).

4.7.1 Use of Historical Data in Development of Subsurface Profile

Data from historical boring logs from the area can be used to supplement data provided by the current boring logs in developing a subsurface profile, however, such historical logs need to be reviewed carefully well in advance of drilling activities to ensure that the data are accurate. In some cases, boring log locations are referenced to the center alignment of a roadway without the location of the borehole having been actually surveyed. It is imperative to ensure that a consistent coordinate system is used to establish the correct relative location of all borings. Since borings would have likely been performed over an extended period of time or for different contracts along a roadway alignment (i.e., project centerlines are commonly changed during project development), it is possible that coordinate systems will not be consistent. Simply stated, if a historical boring cannot be located confidently on a site plan, then the boring has limited usefulness for establishing stratigraphy. Also, it is likely that different drill rigs with different operators and different energy efficiencies were used in the collection of SPT data on historical boring logs. This factor must also be recognized when an attempt is made to correlate engineering properties to SPT blow count values. However, the geotechnical specialist should realize that while there may be potential limitations in the use of historical borings, it is necessary to review these borings relative to the design under consideration. As an example, a historical boring may indicate a thick layer of very soft clay as evidenced by the description "weight of rod/weight of hammer" in the SPT recording box of the log at a large number of test depths. While shear strength and consolidation properties cannot be reliably estimated based on SPT blow count values, the historical boring may provide useful information concerning the depth to a firm stratum.

Most DOTs have collected large amounts of subsurface data from previous investigations within their states. Unfortunately, much of these data are archived with related project data once the project has been completed, and thus may not be readily available or accessible for use during future projects. Additionally, the subsurface data may not be fully utilized if the locations of the borings are not identified properly or if the plan drawing of the project site is not maintained with the boring logs. To overcome this problem, many DOTs currently use longitude and latitude to identify the boring locations, in lieu of or in conjunction with the conventional positioning format that uses station and offset. Unfortunately, the vast majority of the historical subsurface boring information is available only on paper. Therefore, a considerable amount of work is required to convert that data into electronic form before it can be fully appreciated and used to establish an electronic database of the subsurface information.

Several DOTs have recently commenced using electronic boring records for their projects. Not only does the use of electronic boring records provide a redundancy to compliment the paper copy, but it also preserves data in a way that has the potential for automated electronic data management. One method of electronic data management increasingly used by DOTs involves the use of a centralized electronic database in conjunction with Geographic Information System (GIS) techniques to locate and identify borings on a plan. In its most simplistic form, the electronically stored data are managed and assessed visually by using GIS software, where each boring location is identified on a plan map. An appropriately developed database and GIS can be used to great advantage by the DOT. Specifically, in addition to the previously mentioned advantages of having electronic data records compliment paper logs, it is possible to:

1. catalog borings that were conducted previously;
2. inventory data regarding specific problematic formations across the state; and

3. develop cross sections that depict subsurface conditions across a site or within a region.

This type of application of electronic boring records and data base accessibility can facilitate the development of subsequent subsurface investigations that are appropriately focused and that optimize the utility of existing data.