Boring Log Interpretation

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Reference Manual






National Highway Institute

CHAPTER 4.0

BORING LOG PREPARATION

4.1 GENERAL

The boring log is the basic record of almost every geotechnical exploration and provides a detailed record of the work performed and the findings of the investigation. The field log should be written or printed legibly, and should be kept as clean as is practical. All appropriate portions of the logs should be completed in the field prior to completion of the field exploration.

A wide variety of drilling forms are used by various agencies. The specific forms to be used for a given type of boring will depend on local practice. Typical boring log, core boring log and test pit log forms endorsed by the ASCE Soil Mechanics & Foundations Engineering Committee are presented in Figures 4-1 through 4-3, respectively. A proposed legend for soil boring logs is given in Figure 4-4 and for core boring logs in Figure 4-5. This chapter presents guidelines for completion of the boring log forms, preparation of soil descriptions and classifications, and preparation of rock descriptions and classifications.

A boring log is a description of exploration procedures and subsurface conditions encountered during drilling, sampling and coring. Following is a brief list of items which should be included in the logs. These items are discussed in detail in subsequent sections:

- Topographic survey data including boring location and surface elevation, and bench mark location and datum, if available.
- An accurate record of any deviation in the planned boring locations.
- Identification of the subsoils and bedrock including density, consistency, color, moisture, structure, geologic origin.
- The depths of the various generalized soil and rock strata encountered.
- Sampler type, depth, penetration, and recovery.
- Sampling resistance in terms of hydraulic pressure or blows per depth of sampler penetration. Size and type of hammer. Height of drop.
- Soil sampling interval and recovery.
- Rock core run numbers, depths & lengths, core recovery, and Rock Quality Designation (RQD)
- Type of drilling operation used to advance and stabilize the hole.
- Comparative resistance to drilling.
- Loss of drilling fluid.
- Water level observations with remarks on possible variations due to tides and river levels.

Project: Project Location: Project Number:	**Log of Boring ___** Sheet 1 of ____

Date(s) Drilled	Logged By	Checked By
Drilling Method	Drill Bit Size/Type	Total Depth Drilled (meters)
Drill Rig Type	Drilled By	Hammer Weight/ Drop (N/m)
Apparent Groundwater Depth ____ m ATD ____ m after ___ hrs ____ m after ____ hrs		Surface Elevation (meters)
Comments	Borehole Backfill	Elevation Datum

Depth, meters	SAMPLES				MATERIAL DESCRIPTION and other remarks	Elevation, meters	Pocket Pen., kPa	Water Content, %	Liquid Limit	Plasticity Index	Other Tests
	Location	Type	Number	Sampling Resistance							
0											
1											
2											
3											
4											

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Figure 4-1. Representative Boring Log Form.

Project: **Project Location:** **Project Number:**	**Log of Core Boring** ___ Sheet 1 of ___

Date(s) Drilled	Logged By	Checked By
Drilling Method	Drill Bit Size/Type	Total Depth Drilled (meters)
Drill Rig Type	Drilled By	Inclination from Vertical/Bearing
Apparent Groundwater Depth ___ m ATD ___ m after ___ hrs ___ m after ___ hrs		Approx. Surface Elevation (meters)
Comments		Borehole Backfill

Depth, meters	Elevation, meters	ROCK CORE							MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES
		Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/ Number	Lithology					
0													
1													

Template: Proj ID: Printed:

Figure 4-2. Representative Core Boring Log.

Project: Project Location: Project Number:	**Log of Exploration Pit ___**

Date(s) Excavated	Logged By	Checked By
Approximate Length (meters)	Approximate Width (meters)	Approximate Depth (meters)
Excavation Equipment	Excavation Contractor	Approximate Pit Trend
Groundwater Level (meters)	Date Measured	Approx. Surface Elevation (meters)
Comments		

Depth, meters	Elevation, meters	Sample Type and Number	Pocket Pen., kPa	Graphic Log	MATERIAL DESCRIPTION and other remarks	Water Content, %	Other Tests
0							
1							
2							
3							
4							

Template: Proj ID: Printed:

Figure 4-3. Representative Exploration Pit Log.

Project:
Project Location:
Project Number:

Key to Soil Symbols and Terms

Sheet 1 of 2

Depth, meters	SAMPLES: Location	SAMPLES: Type	SAMPLES: Number	SAMPLES: Sampling Resistance	MATERIAL DESCRIPTION and other remarks	Elevation, meters	Pocket Pen., kPa	Water Content, %	Liquid Limit	Plasticity Index	Other Tests
0					**DESCRIPTIONS OF SAMPLER AND FIELD TEST CODES**						
1		S	1	15	The number of blows (15) of a 63.6 Kgr hammer falling 750 mm used to drive a 50 mm O.D. split-barrel sampler for the last 300 mm of penetration.						
		S	2	50/150	Number of blows (50) used to drive the split-barrel a certain number of millimeters (150).						
2		P	3	1724	Thin-wall tube pushed hydraulically, using a certain pressure (1,724 kPa) to push the last 150 mm.						
3		A	4		**SAMPLER CODES** P - Thin-wall tube sample. C - Denison or Pitcher-type core-barrel sample. Ps - Piston sample. A - Auger sample. BS - Bulk sample. SS - Standard spoon sample. CL - California liner sample.						
4–5		NX - 65	5	40	BX - Rock cored with BX core barrel, which obtains a 41 mm-diameter core. NX - Rock cored with NX core barrel, which obtains a 53 mm-diameter core. 65 - Percentage (65) of rock core recovered. 40 - Rock Quality Designation (RQD) percentage (40).						
		S			Sample recovered: indicated by blackened box in "Location" column.						
6		NR			Sample not recovered: indicated by vertical bar in "Location" column and "NR" (no recovery) in "Type" column.						
7					**OTHER FIELD TEST DESIGNATIONS** FV - Field vane shear test. PMT - Pressuremeter test. DMT - Dilatometer test. BHS - Borehole shear test.						

ABBREVIATIONS FOR "OTHER TESTS" COLUMN

- C - Consolidation and specific gravity tests.
- D - Maximum and minimum density.
- DS - Direct shear test.
- G - Specific gravity test.
- K - Permeability test.
- M - Mechanical (sieve or hydrometer) analysis.
- T - Triaxial compression test.
- TV - Torvane shear test.
- U - Unconfined compression test.
- W - Unit weight and natural moisture content.
- X - Special tests performed - see laboratory test results.

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Figure 4-4. Proposed Key to Boring Log (Continued on Page 4-6).

Project:	Key to Soil Symbols and Terms
Project Location:	Sheet 2 of 2
Project Number:	

TERMS DESCRIBING CONSISTENCY OR CONDITION

COARSE-GRAINED SOILS (major portion retained on No. 200 sieve): includes (1) clean gravels and sands and (2) silty or clayey gravels and sands. Condition is rated according to relative density as determined by laboratory tests or standard penetration resistance tests.

Descriptive Term	Relative Density	SPT Blow Count
Very loose	0 to 15%	< 4
Loose	15 to 35%	4 to 10
Medium dense	35 to 65%	10 to 30
Dense	65 to 85%	30 to 50
Very dense	85 to 100%	> 50

FINE-GRAINED SOILS (major portion passing on No. 200 sieve): includes (1) inorganic and organic silts and clays, (2) gravelly, sandy, or silty clays, and (3) clayey silts. Consistency is rated according to shearing strength, as indicated by penetrometer readings, SPT blow count, or unconfined compression tests.

Descriptive Term	Unconfined Compressive Strength, kPa	SPT Blow Count
Very soft	< 25	< 2
Soft	25 to 50	2 to 4
Medium stiff	50 to 100	4 to 8
Stiff	100 to 200	8 to 15
Very stiff	200 to 400	15 to 30
Hard	> 400	> 30

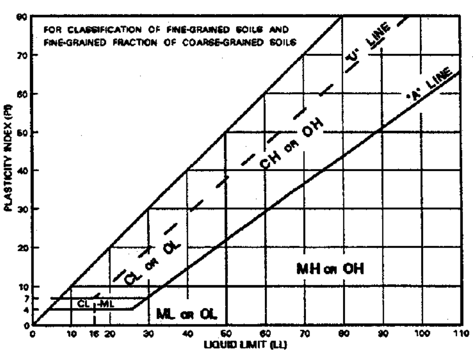
GENERAL NOTES

1. Classifications are based on the Unified Soil Classification System and include consistency, moisture, and color. Field descriptions have been modified to reflect results of laboratory tests where deemed appropriate.

2. Surface elevations are based on topographic maps and estimated locations.

3. Descriptions on these boring logs apply only at the specific boring locations and at the time the borings were made. They are not warranted to be representative of subsurface conditions at other locations or times.

Major Divisions			Group Symbols		Typical Names	Laboratory Classification Criteria		
Coarse-Grained Soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve) coarse-grained soils are classified as follows: Less than 5 percent . . . . . . GW, GP, SW, SP; More than 12 percent . . . . . . GM, GC, SM, SC; 5 to 12 percent . . . . Borderline cases requiring dual symbols **	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly-graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM*	d / u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols
			GC		Clayey gravels, gravel-sand-silt mixtures		Atterberg limits above "A" line or P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly-graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM*	d / u	Silty sands, sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols
			SC		Clayey sands, sand-clay mixtures		Atterberg limits above "A" line or P.I. greater than 7	
Fine-Grained Soils (More than half of material is smaller than No. 200 sieve size)	Silts and Clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Plasticity Chart (see below)		
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and Clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly Organic Soils		Pt		Peat and other highly organic soils			



Plasticity Chart

Material		Particle Size: mm	Particle Size: Sieve size
Silt or clay		< 0.074	< #200
Sand	Fine	0.074 to 0.42	#200 to #40
	Medium	0.42 to 2.00	#40 to #10
	Coarse	2.00 to 4.76	#10 to #4

Material		Particle Size: mm	Particle Size: Sieve
Gravel	Fine	4.76 to 19.1	#4 to 3/4 in.
	Coarse	19.1 to 76.2	3/4 in. to 3 in.
Cobbles		76.2 to 304.8	3 in. to 12 in.
Boulders		304.8 to 914.4	12 in. to 36 in.

* Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg Limits: suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

** Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

Figure 4-4. Proposed Key for Final Boring Log (continued).

Project: Project Location: Project Number:	**Key to Rock Core Log** Sheet 1 of 2

Depth, meters	Elevation, meters	ROCK CORE: Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/	Number	Lithology	MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES
0														
1	2	3	4	5	6	7	8	9	10	11 META-ARKOSE, light gray, moderately weathered, moderately strong.	13	14	15	16
2		1	1	100	1	80				12 a b c d e f g h				Slow drilling
					0			1		1: 75, J, VN, Fe, Su, Pl, S, VC				
4								M		M: Mechanical Breakage				

1 **Depth:** Distance (in meters) from the collar of the borehole.

2 **Elevation:** Elevation (in meters) from the collar of the borehole.

3 **Run No.:** Number of the individual coring interval, starting at the top of bedrock.

4 **Box No.:** Number of the core box which contains core from the corresponding run.

5 **Recovery:** Amount (in percent) of core recovered from the coring interval; calculated as the length of core recovered divided by the length of the run.

6 **Frac. Freq.:** (Fracture Frequency) The number of naturally occurring fractures in each foot of core; does not include mechanical breaks, which are considered to be induced by drilling.

7 **R Q D:** (Rock Quality Designation) Amount (in percent) of intact core (pieces of sound core greater than 100 mm in length) in each coring interval; calculated as the sum of the lengths of intact core divided by the length of the core run.

8 **Fracture Drawing:** Sketch of the naturally occurring fractures and mechanical breaks, showing the angle of the fractures relative to the cross-sectional axis of the core. "NR" indicates no recovery.

9 **Fracture Number:** Location of each naturally occurring fracture (numbered) and mechanical break (labeled "M"). Naturally occurring fractures are described in Column 11 (keyed by number) using descriptive terms defined on the following page (Items a - h).

10 **Lithology:** A graphic log presentation using symbols to represent differing rock types.

11 **Description:** Lithologic description in this order: rock type, color, texture, grain size, foliation, weathering, strength, and other features; descriptive terms are defined on the following page. A detailed descriptive log of overburden materials is not necessarily provided.

12 **Discontinuity Description:** Abbreviated description of fracture corresponding to number of naturally occurring fracture in Column 9 using terms defined on the following page (Items a - h).

13 **Packer Tests:** A vertical line depicts the interval over which a packer test is performed.

14 **Laboratory Tests:** A vertical line depicts the interval over which core has been removed for laboratory testing. Laboratory tests performed are indicated in Column 16.

15 **Drill Rate:** Rate (in meters per hour) of penetration of drilling. "N/O" indicates rate not observed.

16 **Field Notes:** Comments on drilling, including water loss, reasons for core loss, and use of drilling mud; also, laboratory tests performed on core.

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Figure 4-5. Proposed Key to Core Boring Log (Continued on Page 4-8).

Project: Project Location: Project Number:	Key to Rock Core Log Sheet 2 of 2

Depth, meters	Elevation, meters	ROCK CORE: Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/ Number	Lithology	MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES

KEY TO DESCRIPTIVE TERMS USED ON CORE LOGS

DISCONTINUITY DESCRIPTORS

a Dip of fracture surface measured relative to horizontal

b Discontinuity Type:

- F - Fault
- J - Joint
- Sh - Shear
- Fo - Foliation
- V - Vein
- B - Bedding

c Discontinuity Width (millimeters):

- W - Wide (12.5-50)
- MW - Moderately Wide (2.5-12.5)
- N - Narrow (1.25-2.5)
- VN - Very Narrow (<1.25)
- T - Tight (0)

d Type of Infilling:

- Cl - Clay
- Ca - Calcite
- Ch - Chlorite
- Fe - Iron Oxide
- Gy - Gypsum/Talc
- H - Healed
- No - None
- Py - Pyrite
- Qz - Quartz
- Sd - Sand

e Amount of Infilling:

- Su - Surface Stain
- Sp - Spotty
- Pa - Partially Filled
- Fi - Filled
- No - None

f Surface Shape of Joint:

- Wa - Wavy
- Pl - Planar
- St - Stepped
- Ir - Irregular

g Roughness of Surface:

- Slk - Slickensided [surface has smooth, glassy finish with visual evidence of striations]
- S - Smooth [surface appears smooth and feels so to the touch]
- SR - Slightly Rough [asperities on the discontinuity surfaces are distinguishable and can be felt]
- R - Rough [some ridges and side-angle steps are evident; asperities are clearly visible, and discontinuity surface feels very abrasive]
- VR - Very Rough [near-vertical steps and ridges occur on the discontinuity surface]

h Discontinuity Spacing (meters):

- EW - Extremely Wide (>20)
- W - Wide (7-20)
- M - Moderate (2.5-7)
- C - Close (0.7-2.5)
- VC - Very Close (<0.7)

ROCK WEATHERING / ALTERATION

Description	Recognition
Residual Soil	Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is not apparent; material can be easily broken by hand
Completely Weathered/Altered	Original minerals of rock have been almost entirely decomposed to secondary minerals, minerals, although original fabric may be intact; material can be granulated by hand
Highly Weathered/Altered	More than half of the rock is decomposed; rock is weakened so that a minimum 50-mm-diameter sample can be broken readily by hand across rock fabric
Moderately Weathered/Altered	Rock is discolored and noticeably weakened, but less than half is decomposed; a minimum 50-mm-diameter sample cannot be broken readily by hand across rock fabric
Slightly Weathered/Altered	Rock is slightly discolored, but not noticeably lower in strength than fresh rock
Fresh	Rock shows no discoloration, loss of strength, or other effect of weathering/alteration

ROCK STRENGTH

Description	Recognition	Approximate Uniaxial Compressive Strength (kPa)
Extremely Weak Rock	Can be indented by thumbnail	250 - 1,000
Very Weak Rock	Can be peeled by pocket knife	1,000 - 5,000
Weak Rock	Can be peeled with difficulty by pocket knife	5,000 - 25,000
Medium Strong Rock	Can be indented 5 mm with sharp end of pick	25,000 - 50,000
Strong Rock	Requires one hammer blow to fracture	50,000 - 100,000
Very Strong Rock	Requires many hammer blows to fracture	100,000 - 250,000
Extremely Strong Rock	Can only be chipped with hammer blows	> 250,000

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Figure 4-5. Proposed Key to Core Boring (continued).

- The date and time that the borings are started, completed, and of water level measurements.
- Closure of borings.

Boring logs provide the basic information for the selection of test specimens. They provide background data on the natural condition of the formation, on the ground water elevation, appearance of the samples, and the soil or rock stratigraphy at the boring location, as well as areal extent of various deposits or formations. Data from the boring logs are combined with laboratory test results to identify subgrade profiles showing the extent and depth of various materials at the subject site. Soil profiles showing the depth and the location of various types of materials and ground water elevations are plotted for inclusion in the geotechnical engineer's final report and in the plans and specifications. Detailed boring logs including the results of laboratory tests are included in the text of the report.

4.2 PROJECT INFORMATION

The top of each boring log provides a space for project specific information: name or number of the project, location of the project, drilling contractor (if drilling is contracted out), type of drilling equipment, date and time of work, drilling methods, hammer weight and fall, name of personnel logging the boring, and weather information. All information should be provided on the first sheet of each boring log.

4.3 BORING LOCATIONS AND ELEVATIONS

The boring location (coordinates and/or station and offset) and ground surface elevation (with datum) must be recorded on each boring log. Procedures discussed in Section 2.5.3 should be used for determining the location and elevation for each boring site.

4.4 STRATIGRAPHY IDENTIFICATION

The subsurface conditions observed in the soil samples and drill cuttings or perceived through the performance of the drill rig (for example, rig chatter in gravel, or sampler rebounding on a cobble during driving) should be described in the wide central column on the log labeled "Material Description", or in the remarks column, if available. The driller's comments are valuable and should be considered as the boring log is prepared. In addition to the description of individual samples, the boring log should also describe various strata. The record should include a description of each soil layer, with solid horizontal lines drawn to separate adjacent layers. It is important that a detailed description of subsurface conditions be provided on the field logs at the time of drilling. Completing descriptions in the laboratory is not an acceptable practice. Stratification lines should be drawn where two or more items in the description change, i.e., change from firm to stiff and low to high plasticity. Minor variations can be described using the term 'becoming'. A stratification line should be drawn where the geological origin of the material changes and the origin (if determined) should be designated in the material description or remarks column of the log. Dashed lines should be avoided.

The stratigraphy observations should include identification of existing fill, topsoil, and pavement sections. Careful observation and special sampling intervals may be needed to identify the presence and thickness of these strata. The presence of these materials can have a significant impact on the conclusions and recommendations of the geotechnical studies.

Individual strata should be marked midway between samples unless the boundary is encountered in a sample or special measurements are available to better define the position of the boundary.

4.5 SAMPLE INFORMATION

Information regarding the sampler types, date & time of sampling, sample type, sample depth, and recovery should be shown on each log form using notations and a graphical system or an abbreviation system as designated in Figures 4-4 and 4-5. Each sample attempt should be given a sequential number marked in the sample number column. If the sampler is driven, the driving resistance should be recorded at the specified intervals and marked in the sampling resistance column. The percent recovery should be designated as the length of the recovered sample referenced to the length of the sample attempt (example 550/610 mm).

4.6 SOIL DESCRIPTION AND SOIL CLASSIFICATION

Soil description/identification is the systematic, precise, and complete naming of individual soils in both written and spoken forms (ASTM D-2488, AASHTO M 145), while soil classification is the grouping of the soil with similar engineering properties into a category based on index test results; e.g., group name and symbol (ASTM D-2487, AASHTO M 145). It is important to distinguish between visual identification and classification to minimize conflicts between general visual evaluation of soil samples in the field verses a more precise laboratory evaluation supported by index tests. During progression of a boring, the field personnel should only describe the soils encountered. Group symbols associated with classification should not be used in the field. Visual descriptions in the field is often subjected to outdoor elements, which may influence results. It is important to send the soil samples to a laboratory for accurate visual identification by a technician experienced in soils work, as this single operation will provide the basis for later testing and soil profile development. Classification tests can be performed by the laboratory on representative samples to verify identification and assign appropriate group symbols. If possible, the moisture content of every sample should be performed.

4.6.1 Soil Description

The soil's description should include as a minimum:

- Apparent consistency (for fine-grained soils) or density adjective (for coarse-grained soils)
- Water content condition adjective (e.g., dry, damp, moist, wet)
- Color description
- Minor soil type name with "y" added if fine-grained minor component is less than 30 percent but greater than 12 percent or coarse-grained minor component is 30 percent or more.
- Descriptive adjective for main soil type
- Particle-size distribution adjective for gravel and sand
- Plasticity adjective and soil texture (silty or clayey) for inorganic and organic silts or clays
- Main soil type name (all capital letters)

- Descriptive adjective "with" for the fine-grained minor soil type if 5 to 12 percent or for the coarse-grained minor soil type if less than 30 percent but 15 percent or more (note some practices use the descriptive adjectives "some" and "trace" for minor components).
- Descriptive term for minor type(s) of soil
- 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 should generally be stated in the order given above. For example:

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 changes occur within the same soil layer, such as change in apparent density, the log should indicate a description of the change, such as "same, except very dense".

Consistency and Apparent Density

The consistency of fine-grained soils and apparent density of coarse-grained soils are estimated from the blow count (*N*-value) obtained from Standard Penetration Tests (AASHTO T-206, ASTM D 1586). The consistency of clays and silts varies from soft to firm to stiff to hard. The apparent density of coarse-grained soil ranges from very loose to firm to dense and very dense Suggested guidelines in Tables 4-1 and 4-2 are given for estimating the in-place consistency or apparent density of soils from N-values.

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. Mechanical tools such as the pocket (hand) penetrometer, and field index tests (smear test, dried strength test, thread test) 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; realizing that the sampler begins to reflect the presence of the lower layer before it reaches it.

The N-values in all soil types should be corrected for energy efficiency, if possible (ASTM D 4633). An energy efficiency of 60% is considered the reference in the U.S. In certain geotechnical evaluations of coarse-grained soil behavior (relative density, friction angle, liquefaction potential), the blow count (N-value) should be normalized to a reference stress of one atmosphere, as discussed in Chapters 5 and 9.
Note that N-values should <u>not</u> be used to determine the design strength of fine grained soils.

Water Content (Moisture)

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

Color

The color should be described when the sample is first retrieved at the soil's as-sampled water content (the color will change with 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. Note that some agencies may require Munsell color and carry no inferences of texture designations. When the soil is marked with spots of color, the term "mottled" can be applied. Soils with a homogeneous texture but having color patterns which change and are not considered mottled can be described as "streaked".

TABLE 4-1.

EVALUATION OF THE APPARENT DENSITY OF COARSE-GRAINED SOILS

Measured N-value	Apparent Density	Behavior of 13 mm Diameter Probe Rod	Relative Density, %
0 - 4	Very loose	Easily penetrated by hand	0 - 20
> 4 - 10	Loose	Firmly penetrated when pushed by hand	20 - 40
>10 - 30	Firm	Easily penetrated when driven with 2 kg. hammer	40 - 70
>30 - 50	Dense	A few centimeters penetration by 2 kg. hammer	70 - 85
>50	Very Dense	Only a few millimeters penetration when driven with 2 kg. hammer	85 - 100

TABLE 4-2.

EVALUATION OF THE CONSISTENCY OF FINE-GRAINED SOILS

Uncorrected N-value	Consistency	Unconfined Compressive Strength, q_u, kPa	Results Of Manual Manipulation
<2	Very soft	<25	Specimen (height = twice the diameter) sags under its own weight; extrudes between fingers when squeezed.
2 - 4	Soft	25 - 50	Specimen can be pinched in two between the thumb and forefinger; remolded by light finger pressure.
4 - 8	Firm	50 - 100	Can be imprinted easily with fingers; remolded by strong finger pressure.
8 - 15	Stiff	100 - 200	Can be imprinted with considerable pressure from fingers or indented by thumbnail.
15 - 30	Very stiff	200 - 400	Can barely be imprinted by pressure from fingers or indented by thumbnail.
>30	Hard	>400	Cannot be imprinted by fingers or difficult to indent by thumbnail.

TABLE 4-3.
ADJECTIVES TO DESCRIBE WATER CONTENT OF SOILS

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 wet to touch; granular soil exhibits some free water when densified

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 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 of the particles finer than the No. 200 sieve 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 follow ASTM D 2487; i.e., gravel, sand, clay, silt, organic clay, organic silt, and peat.

Coarse-Grained Soils (Gravel and Sand)

Coarse-grained soils consist of gravel, sand, and fine-grained soil, whether separately or in combination, and in which more than 50 percent of the soil is retained on the No. 200 sieve. 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. Poorly graded coarse-grained soil is uniformly graded with most particles about the same size or lacking one or more intermediate sizes.

Gravels and sands may be described by adding particle-size distribution adjectives in front of the soil type following 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.

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

- Coarse- to medium-grained sand typically exhibits a very harsh and gritty feel and smear.
- Coarse- to fine-grained sand has a less harsh feel, but exhibits a very gritty smear.
- Medium- to fine-grained sand exhibits a less gritty feel and smear which becomes softer 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 the 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 100 mm is about 1/2 minute for particle sizes coarser than silt. About 50 minutes would be required for particles of .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, it masks almost entirely the sand component from visual separation. Note that gray fine-grained sand visually appears siltier than the actual silt content.

TABLE 4-4.

PARTICLE SIZE DEFINITION FOR GRAVELS AND SANDS

Soil Component	Grain Size	Determination
Boulders*	300 mm +	Measurable
Cobbles*	300 mm to 75 mm	Measurable
Gravel		
Coarse	75 mm to 19 mm	Measurable
Fine	19 mm to #4 sieve (4.75 mm)	Measurable
Sand		
Coarse	#4 to #10 sieve	Measurable and visible to eye
Medium	#10 to #40 sieve	Measurable and visible to eye
Fine	#40 to #200 sieve	Measurable and 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

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.

Fine-Grained Soils

Fine-grained soils are those in which 50 percent or more pass the No. 200 sieve (fines) and the fines are inorganic or organic silts and clays. To describe the fine-grained soil types, plasticity adjectives, and soil types as adjectives should be used to further define the soil type's texture and plasticity. Based on correlations and laboratory tests, the following simple field identification tests can be used to estimate the degree of plasticity of fine-grained soils.

Shaking (Dilatancy) Test: Water is dropped or sprayed on a part of basically fine-grained soil 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 soil pat between the thumb and forefinger and releasing it alternatively to observe its reaction and the speed of the response. Soils which are predominantly silty (nonplastic to low plasticity) will show a dull dry surface upon squeezing and a glassy wet surface immediately upon releasing of the pressure. With increasing fineness (plasticity) and the related decreasing dilatancy, this phenomenon becomes less and less pronounced.

Dry Strength Test: A 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, materials with great dry strength are clays of high plasticity and those with little dry strength are predominantly silts.

Thread Test: (After Burmister, 1970) Moisture is added or worked out of a small ball (about 40 mm diameter) and the ball kneaded until its consistency approaches medium stiff to stiff (compressive strength of about 100 KPa), it breaks, or crumbles. A thread is then rolled out to the smallest diameter possible before disintegration. The smaller the thread achieved, the higher the plasticity of the soil. Fine-grained soils of high plasticity will have threads smaller than 3/4 mm in diameter. Soils with low plasticity will have threads larger than 3 mm in diameter.

Smear Test: 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.

Highly Organic Soils

Colloidal and amorphous organic materials finer than the No. 200 sieve are identified and classified in accordance with their drop in plasticity upon oven drying (ASTM D 2487). Additional 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;

TABLE 4-6.

FIELD METHODS TO DESCRIBE PLASTICITY

Plasticity Range	Adjective	Dry Strength	Smear Test	Thread Smallest Diameter, 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	6 to 3
>10 - 20	medium plasticity	medium - breaks into pieces or crumbles with considerable finger pressure	smooth and dull	1-1/2
>20 - 40	high plasticity	high - cannot be broken with finger pressure; spec. will break into pieces between thumb and a hard surface	shiny	3/4
>40	very plastic	very high - can't be broken between thumb and a hard surface	very shiny and waxy	½

3. fresh organic soils usually have a characteristic odor which can be recognized, particularly when the soil is heated;
4. compared to non-organic 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. their workability at the plastic limit is weaker and spongier than an equivalent non-organic soil;
6. the smear, although generally smooth, is usually duller and appears more silty; and
7. the organic content of these soils can also be determined by 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 higher than 50 percent by volume it should be described as peat. The engineering behavior of soils below and above the 50 percent dividing line presented here 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 thin layer of deposit found on the surface composed of partially decomposed organic materials, such as leaves, grass, small roots etc. It contains many nutrients that sustain plant and insect life. These should not be classified as organic soils or peat and should not be used in engineered structures.

Minor Soil Type(s)

In many soil formations, two or more soil types are present. 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 (i.e., f. gravelly, c-f. sandy, silty, clayey, organic). 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 if 5 to 12 percent or for the coarse-grained minor soil type if 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 use the descriptive adjectives “some” and “trace” for minor components.
- "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.

Inclusions

Additional inclusions or characteristics of the sample can be described by using "with" and the descriptions described above. Examples are given below:

- 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 soils complete description)

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 nonlayered soil using the sequence for soil descriptions discussed above. The thickness and shape of layers and the geological type of layering are noted using the descriptive terms presented in Table 4-7. Place the thickness designation before the type of layer, or at the end of each description and in parentheses, whichever is more appropriate.

Examples of descriptions for layered soils are:

- Medium stiff, moist to wet 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 (5 to 20 mm); and nonplastic SILT, trace f. sand (10 to 15 mm); (Alluvium).

TABLE 4-7.

DESCRIPTIVE TERMS FOR LAYERED SOILS

Type Of Layer	Thickness	Occurrence
Parting	< 1.5 mm	
Seam	10 to 1.5 mm	
Layer	300 to 10 mm	
Stratum	>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 0.3 m of thickness or laboratory sample inspected
Frequent		More than one per 0.3 m of thickness or laboratory

Geological Name

The soil description should include the field supervisor's assessment of the origin of the soil unit and the geologic name, if known, 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 bpf:
Very hard gray-blue silty CLAY (CH), damp **[Potomac Group Formation]**

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

4.6.2 Soil Classification

As previously indicated, final identification with classification is best performed in the laboratory. This 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, 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 4.6.3) is used and is also based on grain size and plasticity.

The Unified Classification System

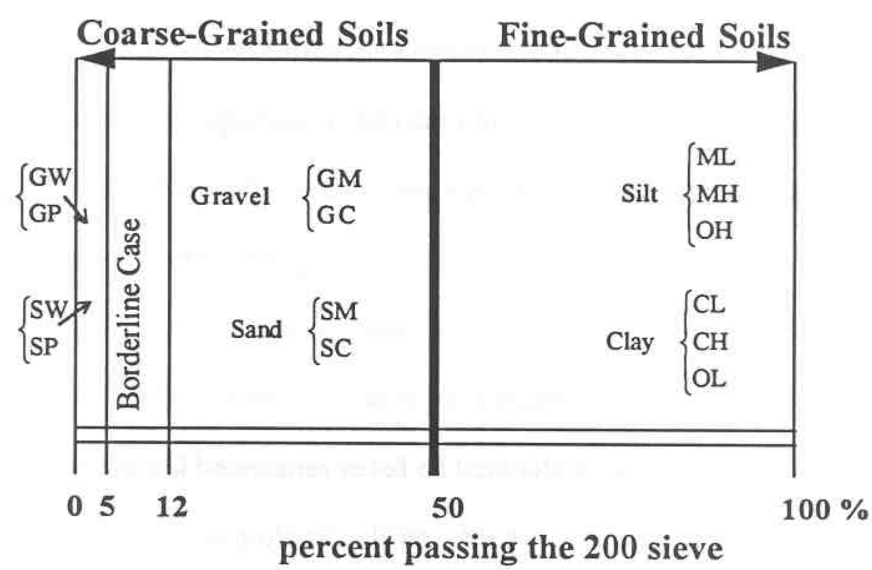
The Unified Classification System (ASTM D 2487) groups soils with similar engineering properties into categories base on grain size, gradation and plasticity. Table 4-8 provides a simplification of the group breakdown and Table 4-9 provides an outline of the complete laboratory classification method. Following are the procedures along with charts and tables for classifying coarse-grained and fine-grained soils.

Classification of Coarse-Grained Soils

The flow chart to determine the group symbol and group name for coarse-grained soils, those in which 50 percent or more are retained on the No. 200 sieve (0.075 mm) is given in Figure 4-6. This figure is identical to that of Figure 2 in ASTM D 2487 except for the recommendation to capitalize the primary soil type; i.e., GRAVEL.

TABLE 4-8.

THE UNIFIED CLASSIFICATION SYSTEM



Soil Type: G = Gravel S = Sand M = Silt
C = Clay O = Organics

Soil Gradation: determined on dis-aggregated specimen forced through nested sieves
W = Well Graded P = Poorly Graded
$C_u > 4$ (GW) to 6 (SW) $C_u < 4$ (GP) to 6(SP)

Plasticity: determined on remolded specimens
H = High Plasticity L = Low Plasticity
LL > 50 LL< 50

TABLE 4-9.

SOIL CLASSIFICATION CHART (LABORATORY METHOD)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[a]			Soil Classification	
			Group Symbol	Group Name[b]
GRAVELS More than 50% of coarse Fraction retained on No. 4 Sieve	CLEAN GRAVELS Less than 5% fines	$C_U \$4$ and $1\#C_C \#3$[e]	GW	Well-graded Gravel
		$C_U \#4$ and $1\$C_C \$3$[e]	GP	Poorly-graded Gravel[f]
	GRAVELS WITH FINES More than 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 retained on No. 4 Sieve	CLEAN SANDS Less than 5% fines[d]	$C_U \$6$ and $1\#C_C \#3$[e]	SW	Well-graded Sand[i]
		$C_U \#6$ and $1\$C_C \$3$[e]	SP	Poorly-graded Sand[i]
	SANDS WITH FINES More than 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	$\frac{\text{Liquid limit} - \text{ovendried}}{\text{Liquid limit} - \text{not dried}} < 0.75$	OL	Organic Clay[k,l,m,n] Organic Silt[k,l,m,o]
SILTS AND CLAYS Liquid limit more than 50%	Inorganic	Pl plots on or above "A" line	CH	Fat Clay[k,l,m]
		Pl plots below "A" line	MH	Elastic Silt[k,l,m]
	Organic	$\frac{\text{Liquid limit} - \text{ovendried}}{\text{Liquid limit} - \text{not dried}} < 0.75$	OH	Organic Silt[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 and Muskeg

TABLE 4-9. (Continued)

SOIL CLASSIFICATION CHART (LABORATORY METHOD)

NOTES:

a Based on the material passing the 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 $$C_U = \frac{D_{60}}{D_{10}} = Uniformity\ Coefficient\ (also\ UC)$$

$$C_C = \frac{(D_{30})^2}{(D_{10})(D_{60})} = Coefficient\ of\ Curvature$$

f If soil contains $\geq$ 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 $\geq$ 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, add "with sand" or "with gravel", whichever is predominant.

l If soil contains $\geq$ 30% plus No. 200, predominantly sand, add "sandy" to group name.

m If soil contains $\geq$ 30% plus No. 200, predominantly gravel, add "gravelly" to group name.

n Pl $\geq$ 4 and plots on or above "A" line.

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

p Pl plots on or above "A" line.

q Pl plots below "A" line.

FINE-GRAINED SOILS (clays & silts): 50% or more passes the No. 200 sieve

COARSE-GRAINED SOILS (sands & gravels): more than 50% retained on No. 200 sieve

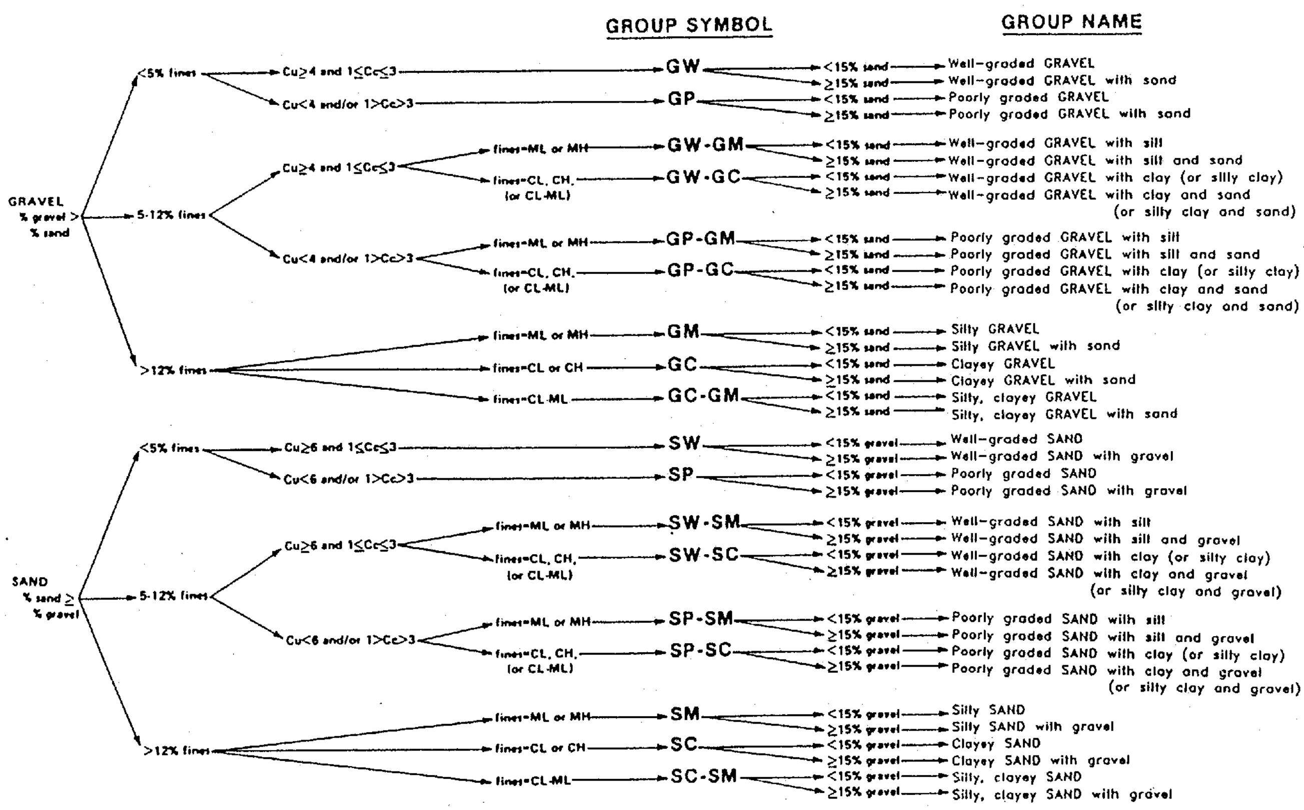


Figure 4-6. Flow Chart to Determine the Group Symbol and Group Name for Coarse-grained Soils. (From U.S. Bureau of Reclamation Soil Classification Handbook, 1960)

Classification of Fine-Grained Soils

Fine-grained soils, those in which 50 percent or more pass the No. 200 sieve (fines), are defined by the plasticity chart (Figure 4-7) and, for organic soils, the decrease in liquid limit (LL) upon oven drying (Table 4-9). Inorganic silts and clays are those which do not meet the organic criteria as given in Table 4-9. The flow charts to determine the group symbol and group name for fine-grained soils are given in Figure 4-8a and b. These figures are identical to Figures 1a and 1b in ASTM D 2487 except that they are modified to show the soil type capitalized; i.e., CLAY. Dual symbols are used to indicate the organic silts and clays that are above the "A"-line. For example, CL/OL instead of OL and CH/OH instead of OH. To describe the fine-grained soil types, plasticity adjectives, and soil types as adjectives should be used to further define the soil type's texture , plasticity, and location on the plasticity chart; see Table 4-10. Examples using Table 4-10 are given in Table 4-11.

As an example, the group name and symbol has been added to the example descriptions given in the previous section:

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

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

Some local practices omit the USCS group symbol (e.g., CL, ML, etc.) but include the group symbol at the end of the description.

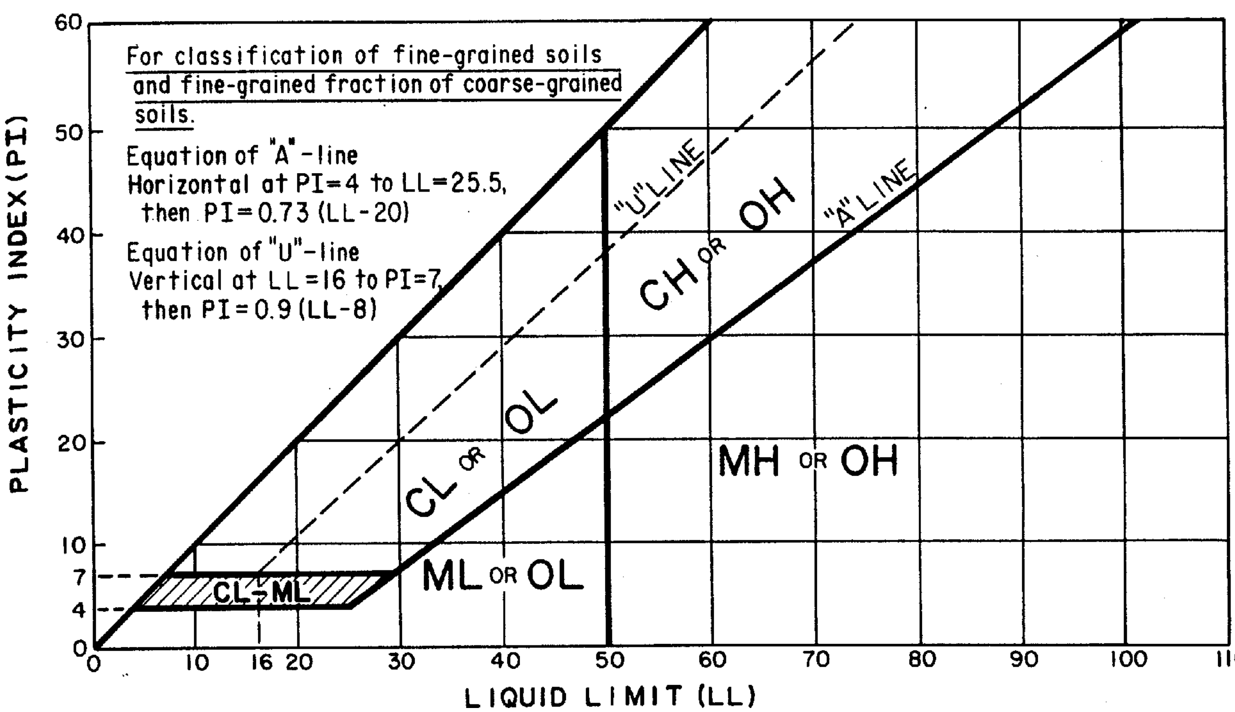


Figure 4-7. Plasticity Chart for Unified Soil Classification System (ASTM D 2488).

TABLE 4-10.

SOIL PLASTICITY DESCRIPTIONS

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

[1] 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 4-11.

EXAMPLES OF DESCRIPTION OF FINE-GRAINED SOILS

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

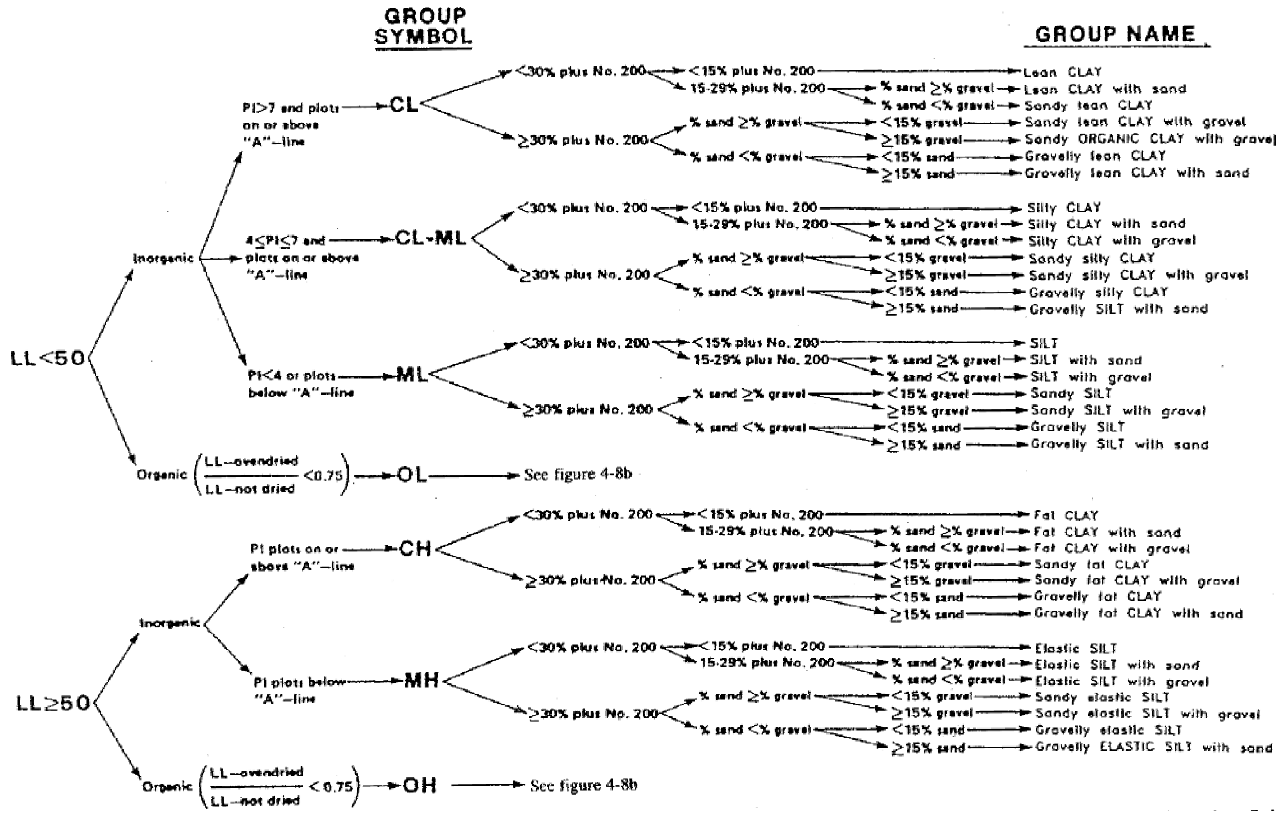


Figure 4-8a. Flow Chart to Determine the Group Symbol and Group Name for Fine-Grained Soils.

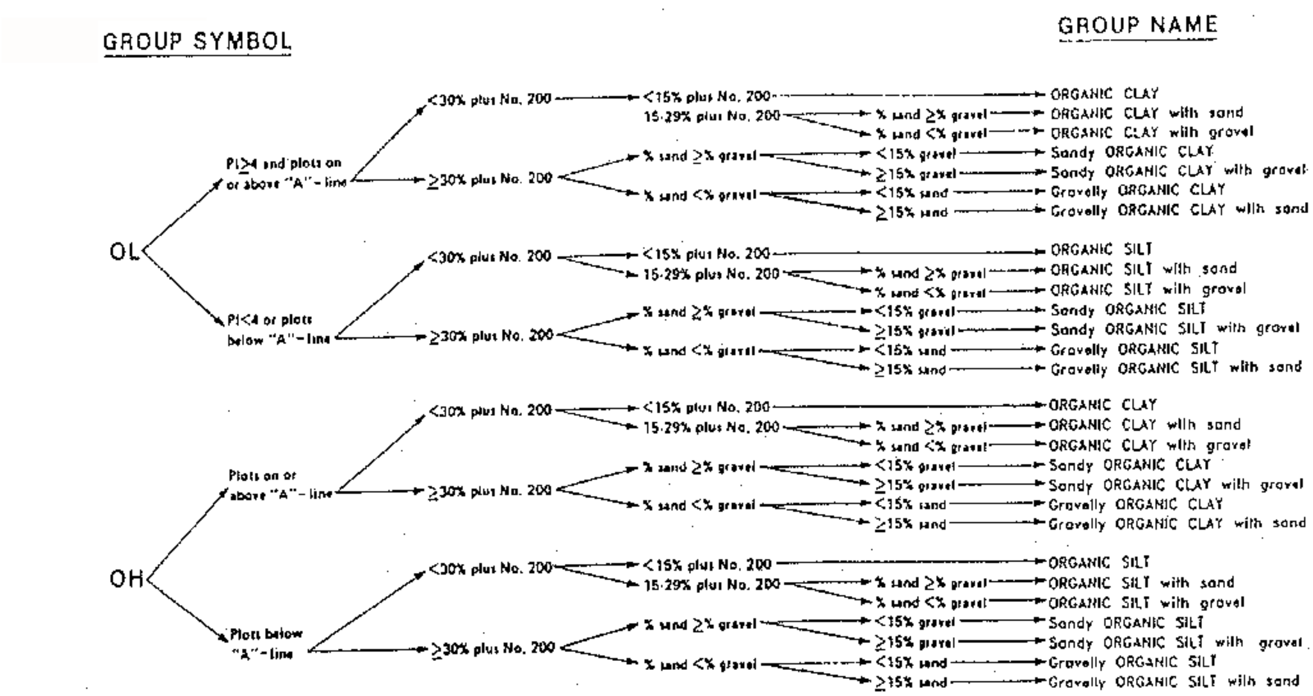


Figure 4-8b. Flow Chart to Determine the Group Symbol and Group Name for Organic Soils.

4.6.3 AASHTO Soil Classification System

The AASHTO soil classification system is shown in Table 4-12. This 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. Soils where more than 35% pass the No. 200 sieve are classified under groups A-4, A-5, A-6 and A-7. These are mostly silt and clay-type materials. The classification procedure is shown in Table 4-12. 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 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* is applied when the fine fractions of the soil have a plasticity index of 10 or less. The term *clayey* is applied when the fine fractions have a plasticity index of 11 or more.

iii. If cobbles and boulders (size larger than 75 mm) are encountered they are excluded from the portion of the soil sample on which 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. This is written in parenthesis after the group or subgroup designation. The group index is given by the equation

Group Index: $GI=(F-35)[0.2+0.005(LL-40)] + 0.01(F-15)(PI-10)$ (4-1)

where F is the percent passing No. 200 sieve, LL is the liquid limit and PI is the plasticity index. The first term of Eq. 4-1 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 Eq. 4-1 yields a negative value for GI, it is taken as zero.
- The group index calculated from Eq. 4-1 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 calculating the group index for soils belonging to groups A-2-6 and A-2-7, the partial group index for PI should be used, or

$$GI=0.01(F-15)(PI-10) \quad (4-2)$$

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

TABLE 4-12.

AASHTO SOIL CLASSIFICATION SYSTEM (AASHTO M 145, 1995)

GENERAL CLASSIFICATION	GRANULAR MATERIALS (35 percent or less of total sample passing No. 200)							SILT-CLAY MATERIALS (More than 35 percent of total sample passing No. 200)			
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:											
2 mm (No. 10)	50 max.										
0.425 mm (No. 40)	30 max.	50 max.	51 min.								
0.075 mm (No. 200)	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 0.425 mm (No. 40)											
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.

Classification procedure: 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 4-9).

**See group index formula (Eq. 4-1) Group index should be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc.

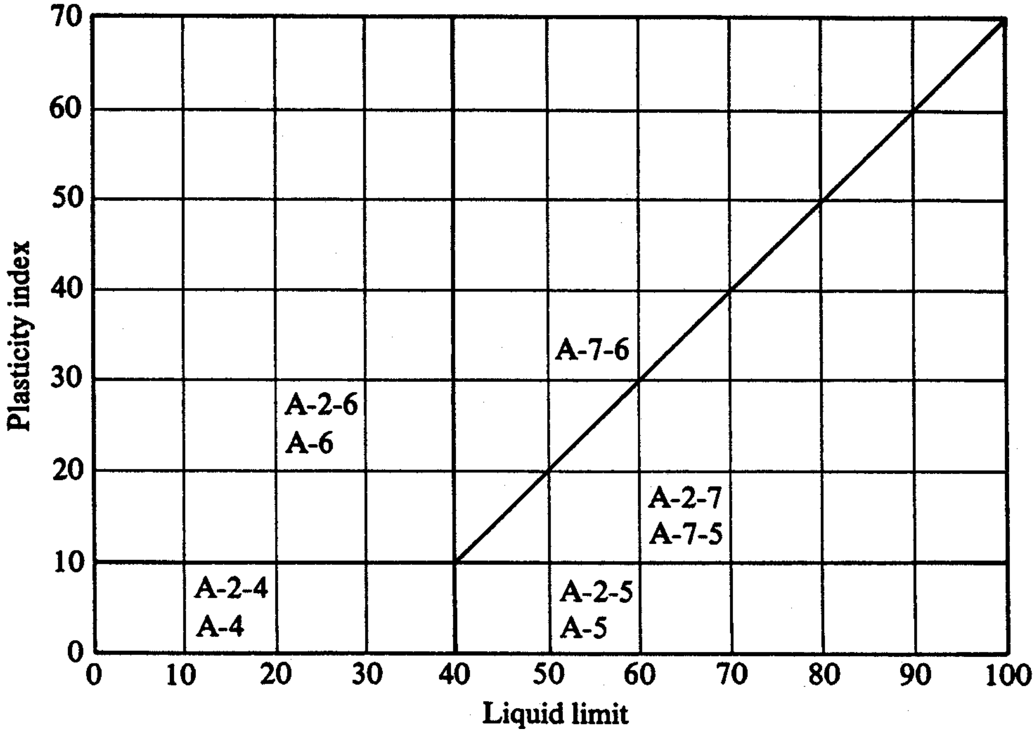


Figure 4-9. Range of Liquid Limit and Plasticity Indices for Soils in Soil Classification Groups A-2, A-4, A-5, A-6 and A-7 (AASHTO Standard M 145, 1995).

4.7 LOGGING PROCEDURES FOR CORE DRILLING

As with soil boring logs, rock or core boring logs should be as comprehensive as possible under field conditions, yet be terse and precise. The level of detail should be keyed to the purpose of the exploration as well as to the intended user of the prepared logs. Although the same basic information should be presented on all rock boring logs, the appropriate level of detail should be determined by the geotechnical engineer and/or the geologist based on project needs. Borings for a bridge foundation may require more detail concerning degree of weathering than rock structure features. For a proposed tunnel excavation, the opposite might be true. Extremely detailed descriptions of rock mineralogy may mask features significant to an engineer, but may be critical for a geologist.

4.7.1 Description of Rock

Rock descriptions should use technically correct geological terms, although local terms in common use may be acceptable if they help describe distinctive characteristics. Rock cores should be logged when wet for consistency of color description and greater visibility of rock features. The guidelines presented in the "International Society for Rock Mechanics Commission on Standardization of Laboratory and Field Tests" (1978, 1981), should be reviewed for additional information regarding logging procedures for core drilling.

The rock's lithologic description should include as a minimum the following items:

- Rock type
- Color
- Grain size and shape
- Texture (stratification/foliation)
- Mineral composition
- Weathering and alteration
- Strength
- Other relevant notes

The various elements of the rock's description should be stated in the order listed above. For example:

"Limestone, light gray, very fine-grained, thin-bedded, unweathered, strong"

The rock description should include identification of discontinuities and fractures. The description should include a drawing of the naturally occurring fractures and mechanical breaks.

4.7.2 Rock Type

Rocks are classified according to origin into three major divisions: igneous, sedimentary, and metamorphic, see Table 4-13. These three groups are subdivided into types according to mineral and chemical composition, texture, and internal structure. For some projects a library of hand samples and photographs representing lithologic rock types present in the project area should be maintained.

4.7.3 Color

Colors should be consistent with a Munsell Color Chart and recorded for both wet and dry conditions as appropriate.

4.7.4 Grain Size and Shape

The grain size description should be classified using the terms presented in Table 4-14. Table 4-15 is used to further classify the shape of the grains.

4.7.5 Stratification/Foliation

Significant nonfracture structural features should be described. The thickness should be described using the terms in Table 4-16. The orientation of the bedding/foliation should be measured from the horizontal with a protractor.

TABLE 4-13.

ROCK GROUPS AND TYPES

IGNEOUS

Intrusive (Coarse Grained)	*Extrusive (Fine Grained)*	*Pyroclastic*
Granite	Rhyolite	Obsidian
Syenite	Trachyte	Pumice
Diorite	Andesite	Tuff
Diabase	Basalt	
Gabbro		
Peridotite		
Pegmatite		

SEDIMENTARY

Clastic (Sediment)	*Chemically Formed*	*Organic Remains*
Shale	Limestone	Chalk
Mudstone	Dolomite	Coquina
Claystone	Gypsum	Lignite
Siltstone	Halite	Coal
Sandstone		
Conglomerate		
Limestone, oolitic		

METAMORPHIC

Foliated	*Nonfoliated*
Slate	Quartzite
Phyllite	Amphibolite
Schist	Marble
Gneiss	Hornfels

TABLE 4-14.

TERMS TO DESCRIBE GRAIN SIZE OF (TYPICALLY FOR) SEDIMENTARY ROCKS

Description	Diameter (mm)	Characteristic
Very coarse grained	> 4.75	Grains sizes are greater than popcorn kernels
Coarse grained	2.00 -4.75	Individual grains can be easily distinguished by eye
Medium grained	0.425 -2.00	Individual grains can be distinguished by eye
Fine grained	0.075-0.425	Individual size grains can be distinguished with difficulty
Very fine grained	< 0.075	Individual grains cannot be distinguished by unaided eye

TABLE 4-15.

TERMS TO DESCRIBE GRAIN SHAPE (FOR SEDIMENTARY ROCKS)

Description	Characteristic
Angular	Showing very little evidence of wear. Grain edges and corners are sharp. Secondary corners are numerous and sharp.
Subangular	Showing definite effects of wear. Grain edges and corners are slightly rounded off. Secondary corners are slightly less numerous and slightly less sharp than in angular grains.
Subrounded	Showing considerable wear. Grain edges and corners are rounded to smooth curves. Secondary corners are reduced greatly in number and highly rounded.
Rounded	Showing extreme wear. Grain edges and corners are smoothed off to broad curves. Secondary corners are few in number and rounded.
Well-rounded	Completely worn. Grain edges or corners are not present. No secondary edges or corners are present.

TABLE 4-16.

TERMS TO DESCRIBE STRATUM THICKNESS

Descriptive Term	Stratum Thickness
Very Thickly bedded	> 1 m
Thickly bedded	0.5 to 1.0 m
Thinly bedded	50 mm to 500 mm
Very Thinly bedded	10 mm to 50 mm
Laminated	2.5 mm to 10 mm
Thinly Laminated	< 2.5 mm

4.7.6 Mineral Composition

The mineral composition should be identified by a geologist based on experience and the use of appropriate references. The most abundant mineral should be listed first, followed by minerals in decreasing order of abundance. For some common rock types, mineral composition need not be specified (e.g. dolomite, limestone).

4.7.7 Weathering and Alteration

Weathering as defined here is due to physical disintegration of the minerals in the rock by atmospheric processes while alteration is defined here as due to geothermal processes. Terms and abbreviations used to describe weathering or alteration are presented in Figure 4-5.

4.7.8 Strength

The point load test, described in Section 8.2.1, is recommended for the measurement of sample strength in the field. The point-load index (I_s) may be converted to an equivalent uniaxial compressive strength and noted as such on the records. Various categories and terminology recommended for describing rock strength based on the point load test are presented in Figure 4-5. Figure 4-5 also presents guidelines for common qualitative assessment of strength while mapping or during primary logging of core at the rig site by using a geological hammer and pocket knife. The field estimates should be confirmed where appropriate by comparison with selected laboratory tests.

4.7.9 Hardness

Hardness is commonly assessed by the scratch test. Descriptions and abbreviations used to describe rock hardness are presented in Table 4-17.

TABLE 4-17.

TERMS TO DESCRIBE ROCK HARDNESS

Description (Abbr)	Characteristic
Soft (S)	Reserved for plastic material alone.
Friable (F)	Easily crumbled by hand, pulverized or reduced to powder and is too soft to be cut with a pocket knife.
Low Hardness (LH)	Can be gouged deeply or carved with a pocket knife.
Moderately Hard (MH)	Can be readily scratched by a knife blade; scratch leaves a heavy trace of dust and scratch is readily visible after the powder has been blown away.
Hard (H)	Can be scratched with difficulty; scratch produces little powder and is often faintly visible; traces of the knife steel may be visible.
Very Hard (VH)	Cannot be scratched with pocket knife. Leave knife steel marks on surface.

4.7.10 Rock Discontinuity

Discontinuity is the general term for any mechanical crack or fissure in a rock mass having zero or low tensile strength. It is the collective term for most types of joints, weak bedding planes, weak schistosity planes, weakness zones, and faults. The symbols recommended for the type of rock mass discontinuities are listed in Figure 4-5.

The spacing of discontinuities is the perpendicular distance between adjacent discontinuities. The spacing should be measured in centimeters or millimeters, perpendicular to the planes in the set. Figure 4-5 presents guidelines to describe discontinuity spacing.

The discontinuities should be described as closed, open, or filled. Aperture is used to describe the perpendicular distance separating the adjacent rock walls of an open discontinuity in which the intervening space is air or water filled. Width is used to describe the distance separating the adjacent rock walls of filled discontinuities. The terms presented in Table 4-18 should be used to describe apertures.

Terms such as "wide", "narrow" and "tight" are used to describe the width of discontinuities such as thickness of veins, fault gouge filling, or joints openings. Guidelines for use of such terms are presented in Figure 4-5.

For the faults or shears that are not thick enough to be represented on the boring log, the measured thickness is recorded numerically in millimeters.

In addition to the above characterization, discontinuities are further characterized by the surface shape of the joint and the roughness of its surface. Refer to Figure 4-5 for guidelines to characterize these features.

Filling is the term for material separating the adjacent rock walls of discontinuities. Filling is characterized by its type, amount, width (i.e., perpendicular distance between adjacent rock walls) and strength. Figure 4-5 presents guidelines for characterizing the amount and width of filling. The strength of any filling material along discontinuity surfaces can be assessed by the guidelines for soil presented in the last three columns of Table 4-2. For non-cohesive fillings, then identify the filling qualitatively (e.g., fine sand).

TABLE 4-18.
TERMS TO CLASSIFY DISCONTINUITIES BASED ON APERTURE SIZE

Aperture	Description	
<0.1 mm	Very tight	"Closed Features"
0.1 - 0.25 mm	Tight	
0.25 - 0.5 mm	Partly open	
0.5 - 2.5 mm	Open	"Gapped Features"
2.5 - 10 mm	Moderately open	
> 10 mm	Wide	
1-10 cm	Very wide	"Open Features"
10-100 cm	Extremely wide	
>1 m	Cavernous	

4.7.11 Fracture Description

The location of each naturally occurring fracture and mechanical break is shown in the fracture column of the rock core log. The naturally occurring fractures are numbered and described using the terminology described above for discontinuities.

The naturally occurring fractures and mechanical breaks are sketched in the drawing column. Dip angles of fractures should be measured using a protractor and marked on the log. For nonvertical borings, the angle should be measured and marked as if the boring was vertical. If the rock is broken into many pieces less than 25 mm long, the log may be crosshatched in that interval, or the fracture may be shown schematically.

The number of naturally occurring fractures observed in each 0.5 m of core should be recorded in the fracture frequency column. Mechanical breaks, thought to have occurred due to drilling, are not counted. The following criteria can be used to identify natural breaks:

1. A rough brittle surface with fresh cleavage planes in individual rock minerals indicates an artificial fracture.
2. A generally smooth or somewhat weathered surface with soft coating or infilling materials, such as talc, gypsum, chlorite, mica, or calcite obviously indicates a natural discontinuity.
3. In rocks showing foliation, cleavage or bedding it may be difficult to distinguish between natural discontinuities and artificial fractures when these are parallel with the incipient weakness planes. If drilling has been carried out carefully then the questionable breaks should be counted as natural features, to be on the conservative side.
4. Depending upon the drilling equipment, part of the length of core being drilled may occasionally rotate with the inner barrels in such a way that grinding of the surfaces of discontinuities and fractures occurs. In weak rock types it may be very difficult to decide if the resulting rounded surfaces represent natural or artificial features. When in doubt, the conservative assumption should be made; i.e., assume that they are natural.

The results of core logging (frequency and RQD) can be strongly time dependent and moisture content dependent in the case of certain varieties of shales and mudstones having relatively weakly developed diagenetic bonds. A not infrequent problem is "discing", in which an initially intact core separates into discs on incipient planes, the process becoming noticeable perhaps within minutes of core recovery. The phenomena are experienced in several different forms:

1. Stress relief cracking (and swelling) by the initially rapid release of strain energy in cores recovered from areas of high stress, especially in the case of shaley rocks.
2. Dehydration cracking experienced in the weaker mudstones and shales which may reduce RQD from 100 percent to 0 percent in a matter of minutes, the initial integrity possibly being due to negative pore pressure.
3. Slaking cracking experienced by some of the weaker mudstones and shales when subjected to wetting and drying.

All these phenomena may make core logging of fracture frequency and RQD unreliable. Whenever such conditions are anticipated, core should be logged by an engineering geologist as it is recovered and at subsequent intervals until the phenomenon is predictable. An added advantage is that the engineering geologist can perform mechanical index tests, such as the point load index or Schmidt hammer test (see Chapter 8), while the core is still in a saturated state.