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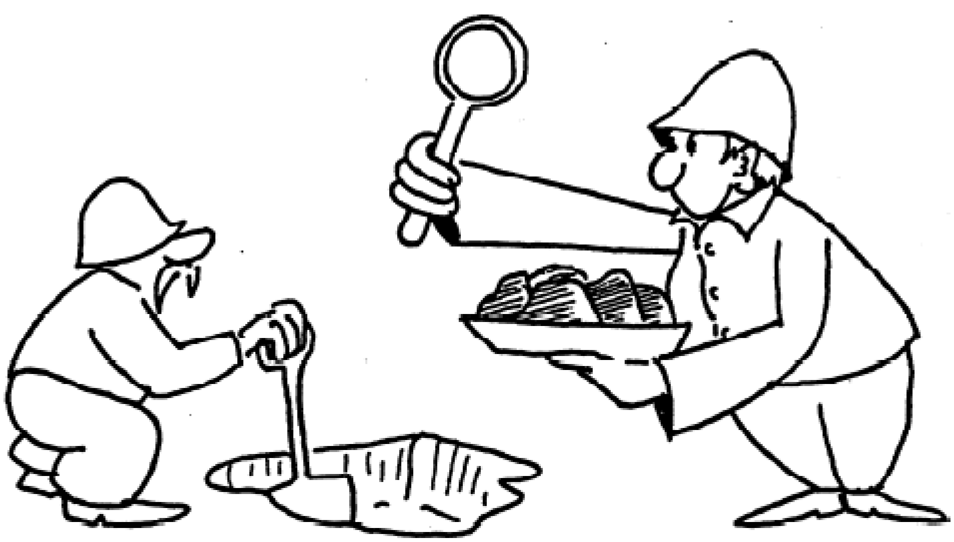
CHAPTER 3

SOILS



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Chapter 3: Soils

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3-1 Introduction

To verify the adequacy of a shoring system in soil, it is necessary to be familiar with the properties and expected behaviors of the types of soil in which the excavation is to be made. The lateral earth pressure exerted on a shoring system depends on the soil type, its density or consistency, and other factors such as external loads, the type of retaining system used, and the construction procedure. For most projects, the geotechnical investigation and geotechnical report(s), issued by the Division of Engineering Services - Geotechnical Services, should present sufficient information for the Engineer to perform shoring design and analyses. Contact Geotechnical Services for guidance when additional soil properties are needed for the design review. When the material encountered during the installation of the shoring system differs from the material that was anticipated, contact the shoring system designer. This chapter discusses the Department’s resources for soil information and provides guidance on how to use this information to determine parameters necessary for the design or verification of a shoring system.

3-2 Soil Identification, Classification, Description, and Presentation

The Contractor can obtain soil classification characteristics from the information provided in the *Geotechnical Design Report* or *Foundation Report* and corresponding Log of Test Borings, by performing independent sampling and analysis of the soil, or by having a competent person classify the soil per Cal/OSHA Construction Safety Orders, § 1541.1, *Requirements for Protective Systems*, Appendix A, *Soil Classification*. Note that the Construction Safety Orders are found in the California Code of Regulations (CCR) Title 8, Chapter 4, Subchapter 4.

The Cal/OSHA soil classification methods include a series of visual methods as well as a series of manual tests. The Construction Safety Orders, § 1541.1, Appendix A (c), *Requirements*, requires that the classification of soil deposits must be made based on the results of at least one visual and at least one manual analysis as described in paragraph (d), or in other approved methods of soil classification and testing. Some of the acceptable manual tests described in paragraph (d) are similar to those used in the Caltrans *Soil and Rock Logging, Classification, and Presentation Manual*, 2022 Edition *(Soil and Rock Logging Manual)*, including the dry strength and pocket penetrometer tests. The competent person will use the quantitative and qualitative information obtained from the visual and manual tests to classify the soils as either stable rock, Type A, Type B, or Type C soil. Depending on the type of soil classified, an unconfined compressive strength value is assigned. Unconfined compressive strength is defined in the Cal/OSHA standard as “the load per unit area at which a soil will fail in compression.”

It is the Engineer's responsibility to verify that the soil properties used by the Contractor's engineer in their shoring design submittal are appropriate. It is recommended that the Engineer contact the author of the Caltrans *Foundation Report* or *Geotechnical Design Report* to discuss and verify. The *Foundation Report* provides geotechnical information for structure items, while the *Geotechnical Design Report* is geared towards roadway items and provides geotechnical information for the entire project footprint.

Caltrans uses geotechnical reports, Log of Test Boring (LOTB) sheets and boring records to present the results of its geotechnical and borehole investigations. LOTB sheets are included in the contract plans for structures. They present the boring logs that both graphically and descriptively convey the soil descriptions and sampling information. The Standard Plans, Sheets A10F and A10G, *Legend – Soil*, provide additional information on soil classification, and Sheet A10H, *Legend – Rock*, provides additional information on rock classification. The *Soil and Rock Logging Manual*, maintained by Geotechnical Services, presents in further detail the Department's practice for identification, classification, description, and presentation of soil and rock for all investigations after December 7, 2009.

Correct interpretation of LOTB sheets, boring records, and related discussions in geotechnical reports requires familiarity with this manual. The following is an overview of the Department's soil presentation practice.

The descriptive sequence for a soil consists of a *group name* and *group symbol*, followed by descriptive components such as density or consistency, color, moisture, etc. The group name and group symbol of a soil, "SANDY lean CLAY (CL)" for example, are determined using one of the following standards:

- ASTM D2488, *Standard Practice for Description and Identification of Soils* (Visual-Manual Procedures), if laboratory testing is not performed.
- ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes* (Unified Soil Classification System), if laboratory particle size analysis and plasticity index tests are performed.

The descriptive components following the group name and group symbol are defined in Section 2, *Field Procedures for Soil and Rock Logging, Description, and Identification,* of the *Soil and Rock Logging Manual.* This section provides details of the Department's practice for identifying and describing soil in the field following the group name and group symbol which are defined therein. Section 3, *Procedures for Soil and Rock Description and/or Classification Using Laboratory Test Results,* presents the practice of soil classification and description based on laboratory test results.

Soils are identified or classified as either *coarse-grained* (gravel and sand) or *fine-grained* (silts and clays). Natural soil consists of one or any combination of gravel, sand, silt, or clay, and may also contain boulders, cobbles, and organics.

Coarse-grained soils retain more than 50 percent of material on or above the No. 200 sieve (0.075mm). GRAVEL (G) and SAND (S) are further identified or classified according to their gradation as well-graded (W) or poorly graded (P), SILT content (M), or CLAY content (C). Examples of these are *Well-graded SAND (SW)* or *SILTY SAND (SM)*.

Fine-grained soils pass more than 50 percent of material through the No. 200 sieve. SILT (M), CLAY (C), and ORGANIC SOIL (O) are further identified by visual methods or classified by laboratory plasticity tests as low plasticity (L) or high plasticity (H). Examples of these are *lean CLAY (CL)* or *SANDY SILT (ML).*

3-3 Soil Properties and Strength

Characteristics or properties that help predict the effect of a soil on a shoring system include the particle distribution (% gravel, % sand, % fines [silt & clay]), particle angularity, apparent density or consistency (strength), moisture, and unit weight. The *Soil and Rock Logging Manual* presents the Department's standards of measuring or determining these properties either visually (Section 2) or with laboratory testing (Section 3).

Typically, the Department uses one or more of the following investigative methods to determine a soil's identification, classification, description, and strength:

- Standard Penetration Test (SPT) with visual/manual methods
- Cone Penetration Test (CPT)
- Laboratory testing.

3-4 Standard Penetration Test (SPT)

The Standard Penetration Test (SPT) obtains a disturbed sample of soil for visual identification and description, and/or laboratory testing (particle size analysis, plasticity index). The number of hammer blows required to drive the split-spoon sampler a distance of 12 inches into the ground, is referred to as the **N** value. When corrected for the SPT hammer's energy efficiency, it becomes $\mathbf{N_{60}}$. This can be used to determine the apparent density of a granular soil. Empirical relationships to approximate the soil friction angle (ϕ) and density (unit weight), γ, are shown in Table 3-1.

Table 3-1. Properties of Granular Soils

Apparent Density	Relative Density (%)	SPT, N_{60} (blows/ft)	Friction Angle, ϕ (deg)	Unit Weight, γ (pcf)	
				Moist	Submerged
Very Loose	0-15	$N_{60} < 5$	<28	<100	<60
Loose	16-35	$5 \le N_{60} < 10$	28-30	95-125	55-65
Medium Dense	36-65	$10 \le N_{60} < 30$	31-36	110-130	60-70
Dense	66-85	$30 \le N_{60} < 50$	37-41	110-140	65-85
Very Dense	86-100	$N_{60} \ge 50$	>41	>130	>75

Note: Both the LOTB and boring records report the SPT blow count observed in the field as the **N** value, not **N_{60}** as used above, to determine the apparent density descriptor. The reader is encouraged to read the *Soil and Rock Logging Manual* on apparent density and Appendix A, *Field Test Procedures*, Section A.8, *Standard Penetration Test,* prior to using Table 3-1. There are a variety of correction factors that can be applied to the **N** value such as for overburden pressure. It is important to know what, if any, correction factors have been applied to the **N** value for the correct interpretation of Table 3-1.

The Division of Engineering Services, Geotechnical Services, has prepared a summary of "simplified typical soil values." For average trench conditions, the Engineer will find the data very useful to establish basic properties or evaluate data submitted by the Contractor; Table 3-2 lists approximate values.

Table 3-2. Simplified Typical Soil Values

Soil Classification	ϕ Friction Angle of the Soil	Density or Consistency	γ Soil Unit Weight (pcf)	K_a Coefficient of Active Earth Pressure	$K_w = K_a\gamma$ Equiv. Fluid Wt. (pcf)
Gravel, Gravel-Sand Mixture, Coarse Sand	41 34 29	Dense Medium Dense Loose	130 120 90	0.21 0.28 0.35	27 34 32
Medium Sand	36 31 27	Dense Medium Dense Loose	117 110 90	0.26 0.32 0.38	30 35 34
Fine Sand	31 27 25	Dense Medium Dense Loose	117 100 85	0.32 0.38 0.41	37 38 34
Fine Silty Sand, Sandy Silt	29 27 25	Dense Medium Dense Loose	117 100 85	0.35 0.38 0.41	41 38 34
Silt	27 25 23	Dense Medium Dense Loose	120 110 85	0.38 0.41 0.44	45 45 37

For active pressure conditions, use a unit weight value of γ = 115 pcf (pounds per cubic feet) minimum when insufficient soils data is known.

It is not the Department’s practice to use the SPT test as a means of estimating the shear strength of cohesive soil. Field tests on relatively undisturbed samples, including the pocket penetrometer, Torvane, and laboratory tests such as triaxial, unconfined compression, and direct shear, are considered more accurate and are discussed in the *Soil and Rock Logging Manual*. Field and/or laboratory test results are typically available in the *Foundation Report* and/or *Geotechnical Design Report* issued by Geotechnical Services staff, and it is recommended that the Engineer use those results in their shoring analyses. In the absence of any field or laboratory test results for cohesive soil, the consistency descriptor can be roughly correlated to shear strength and unit weight as shown in Table 3-3.

Table 3-3. Simplified Typical Properties of Cohesive Soils

Consistency	Unconfined Compressive Strength (psf)	Moist Unit Weight (pcf)
Very Soft	0-500	<100-110
Soft	500-1,000	100-120
Medium Stiff	1,000-2,000	110-125
Stiff	2,000-4,000	115-130
Very Stiff	4,000-8,000	120-140
Hard	>8,000	>132

3-5 Cone Penetration Test (CPT)

The Cone Penetration Test (CPT) is used by the Department to determine the in-situ properties of soil. The CPT consists of pushing a conically tipped, cylindrical probe into the ground at a constant rate. The probe is instrumented with strain gauges to measure resisting force against the tip and along the side while the probe is advancing downward. A computer controls the advance of the probe and the acquisition of data, and a continuous record of subsurface information is collected. The results of a CPT are presented on either a LOTB plan sheet or on 8 1/2 x 11 sheets as presented in Figure 3-1 and Figure 3-2.

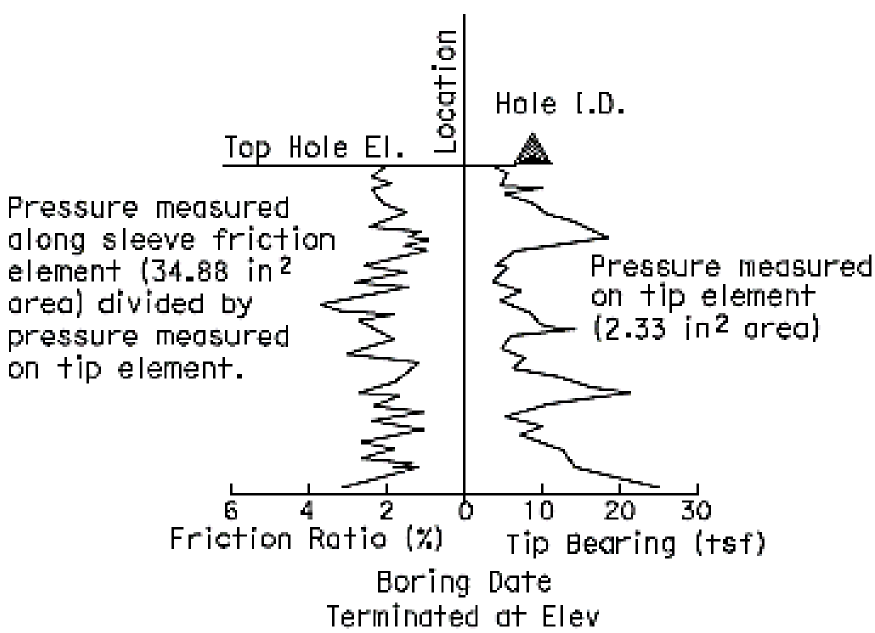

Figure 3-1. Cone Penetration Test (CPT) Boring

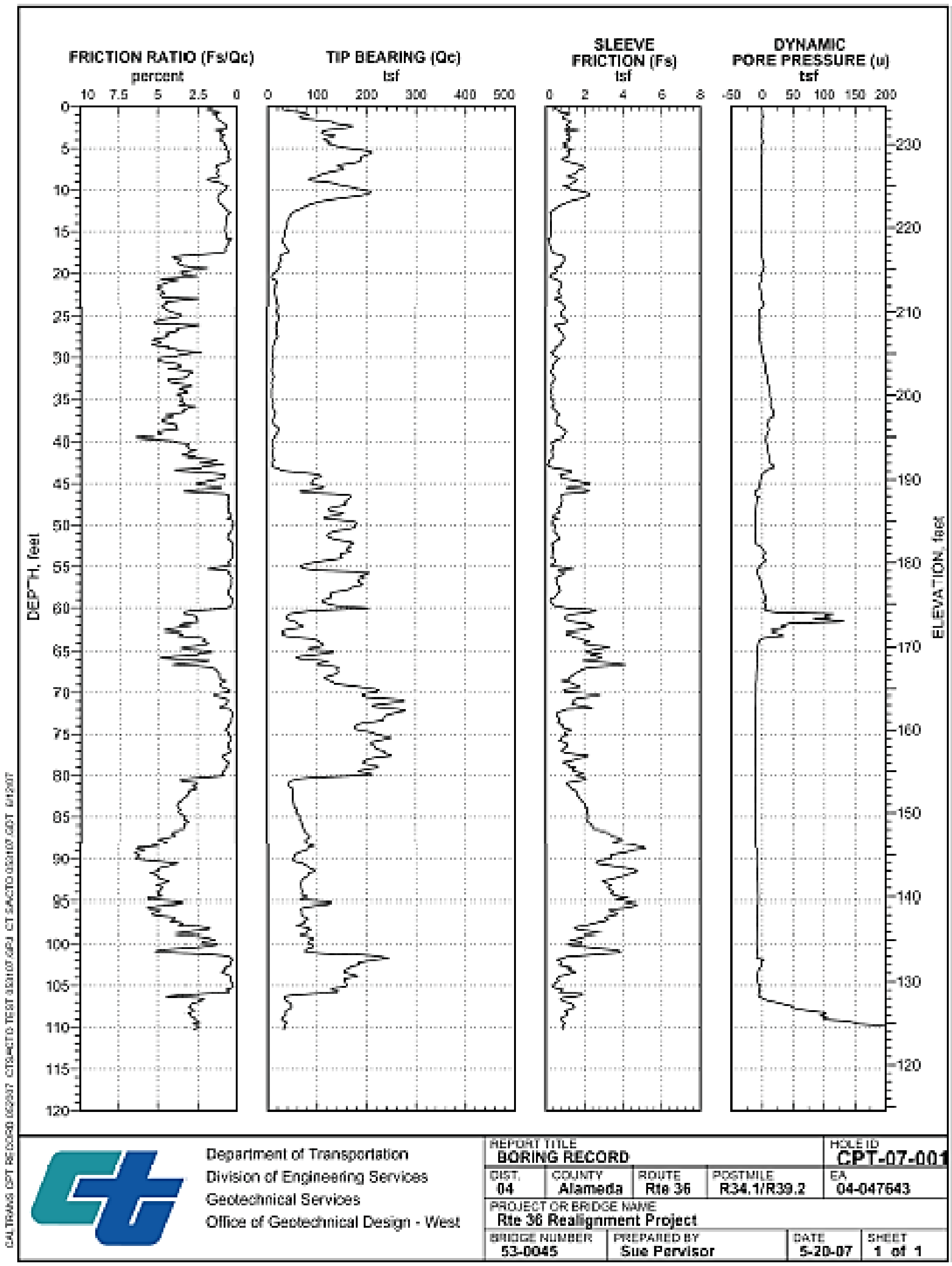

Figure 3-2. Typical CPT Plot

The CPT cannot recover soil samples, so visual/manual soil identification is not possible. However, it is possible to obtain approximate soil identification, relative density for granular soils, and undrained shear strength (**S_u**) for fine-grained soils by using several published relationships. The Engineer should review the appropriate project geotechnical report(s) for discussions relative to soil identification and strength from CPT investigations or contact Geotechnical Services for guidance on the interpretation of CPT data relating to shoring analysis and design.

3-6 Field and Laboratory Tests

Not all methods of evaluating soil shear strength are equally accurate. Therefore, the source of the shear strength data must be considered when evaluating a proposed trenching or shoring system. Table 3-4 presents a list of field and laboratory tests that are used to measure or estimate soil shear strength and an indication of their reliability.

Table 3-4. Field and Laboratory Test Reliability of Soil Shear Strength Measurements

Test Method	Coarse-grained Soil	Fine-grained Soil
Standard Penetration Test (SPT) (ASTM D1586)	Good	Poor
Cone Penetration Test (CPT) (ASTM D3441)	Good	Fair
Pocket Penetrometer	Not applicable	Fair
Torvane (shearvane)	Not applicable	Fair
Vane Shear (ASTM D2573)	Not applicable	Very good
Triaxial Compression (UU,CU) (ASTM D2850)	Very good*	Very good
Unconfined Compression (ASTM D2166)	Not applicable	Very good
Direct Shear (ASTM D3080)	Good*	Fair

*Recovery of undisturbed samples can be difficult

The Torvane and pocket penetrometer tests are field tests you may see noted on the LOTB of the plans. The Department uses these tests to aid in determining the uniformity of the cohesive soil encountered. The Contractor may perform their own tests while excavating. The Contractor may overly emphasize these field tests, but the tests need to be used in conjunction with all the materials information in the logs and geotechnical reports. The pocket penetrometer provides a value for a cohesive soils' unconfined compressive strength, $\mathbf{q_u}$, in tons per square foot. The Torvane (or shearvane) is a soil-testing tool utilized for determination of cohesive soils' undrained shear strength ($\mathbf{S_u}$). The use of a Torvane is an acceptable practice, meeting the requirements of Cal/OSHA *CSO,* § 1541.1, *Requirements for Protective Systems,* Appendix A, *Soil Classification*, subsection (d)(2)(D), *Acceptable Visual and Manual Tests*. In situations where the Contractor is proposing to use a Torvane, consult the SC Falsework Engineer in Structure Construction Headquarters[1] for assistance.

[1] Caltrans internal use only

For projects utilizing a cohesion value, **c**, it is recommended the following conditions be included and addressed with each shoring submittal:

1. Methods used to prevent tension cracks from developing at the top of the excavation.
2. Methods used to prevent water from ponding at the top of and the toe of the slope.
3. Verification that the soil is consistent and homogeneous throughout the excavation.

Additional information on the tests listed in Table 3-4 is in the *Soil and Rock Logging Manual*, Sections 2.5.3, *Consistency of Cohesive Soil*, and Appendix A, *Field Test Procedures*, Section A.2, *Torvane*.

3-7 Shear Strength

The shear strength of soil is measured by two parameters, the angle of internal friction ϕ, which is the resistance to interparticle slip, and the soil cohesion, which is the interparticle attraction of the soil particles. The design of most geotechnical structures requires a quantitative determination of the soil shear strength. One of the fundamental relationships governing soil shear strength is:

$$\tau_f = c + \sigma \tan \phi \qquad (3\text{-}7\text{-}1)$$

Where:

τ_f = Soil Shear Strength at Failure
ϕ = Internal Friction Angle
σ = Normal Stress
c = Soil Cohesion

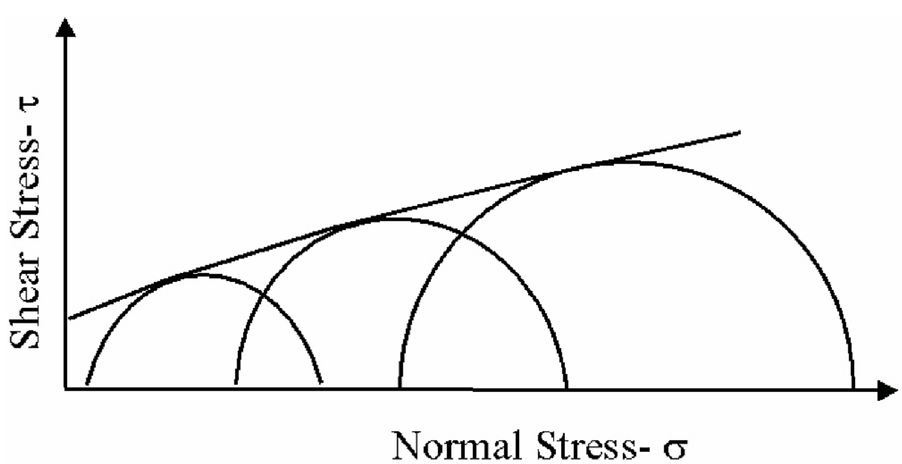

Figure 3-3. Mohr-Coulomb Criteria

In general, the relationship between shear strength and normal stress is not linear for large stress ranges. The strength envelope is a curve that is tangent to the Mohr circles as shown in Figure 3-3. The point of tangency to the Mohr circles represents the stress conditions on the failure plane of the sample.

In fine-grained (cohesive) soils, shear strength is initially insensitive to confining pressure since the strength is derived through cohesion (interparticle attraction). For cohesive soils, the failure criterion simplifies to:

$$\tau_f = S_u \qquad (3\text{-}7\text{-}2)$$

Where S_u is the undrained shear strength.

Cohesive soils will consolidate or swell over time depending on whether the soil has been loaded or unloaded, respectively. Trenching and shoring work often creates situations where soil loading is reduced, such as in an excavation. A fine-grained soil subjected to unloading will then expand and has the potential to lose shear strength over time.

3-8 Contractor Soil Investigations

The Contractor may elect to have a soils investigation performed to support their shoring design. In this case, the soils information or report will be furnished to the Engineer as part of the supporting data accompanying the shoring plans. Soil test results need to be used with caution. Soil test reports from many soils laboratories or similar sources may or may not include safety factors incorporated in the reported results.

Factors that the Engineer will consider when assigning strength parameters to a soil include:

1. The method with which the soil shear strength was determined (Table 3-4),
2. The variability of the subsurface profile, and
3. The number and distribution of shear strength tests.

3-9 Special Ground Conditions

Occasionally, excavations are made into soil or rock with properties that require special consideration in the design of the shoring system. The special condition must be defined, and the expected behavior of the material during and after excavation and installation of the shoring system, must be understood. Typically, the geotechnical report would identify and discuss the presence of special soil or rock conditions and it is recommended that Geotechnical Services be contacted for assistance with these situations.

Examples of special ground conditions are:

1. Fractured rock: Adversely oriented bedding or fracturing, which would allow toppling or wedge failure into the excavation, should be identified and accounted for in the design of the shoring system.
2. Organic soil: Organic soils, such as peat, are compressible and subject to decomposition, which can lead to significant volume changes.
3. Clay and shale: Subject to cracking and spalling upon exposure to the atmosphere, swelling and slaking when exposed to water, and weakening when unloaded. Excavating such materials might require protection of the shoring system to help retain natural moisture content to prevent cracking and spalling. Design analyses need to account for the expected disturbed strength of the retained material, which might be weaker than in-situ.
4. Running soil: A soil that cannot stand by itself even for a short term. Running soil will have little shear strength and will flow with virtually no angle of repose in an unsupported condition. The cohesive value (**c**) is equal to zero.
5. Quick condition: Occurs when the upward flow of water through a soil is sufficient to make the soil buoyant and thereby prevent grain interlocking. The soil grains are suspended in the water. A quick condition can be created in an excavation when the water level in the excavation is lower than the level outside, in the surrounding soil. It may best be stabilized by equalizing the water levels. Quick conditions can occur in some silts as well as in sand. For additional information on this topic, refer to Section 10-4, *Piping*, of Chapter 10, *Special Conditions*.