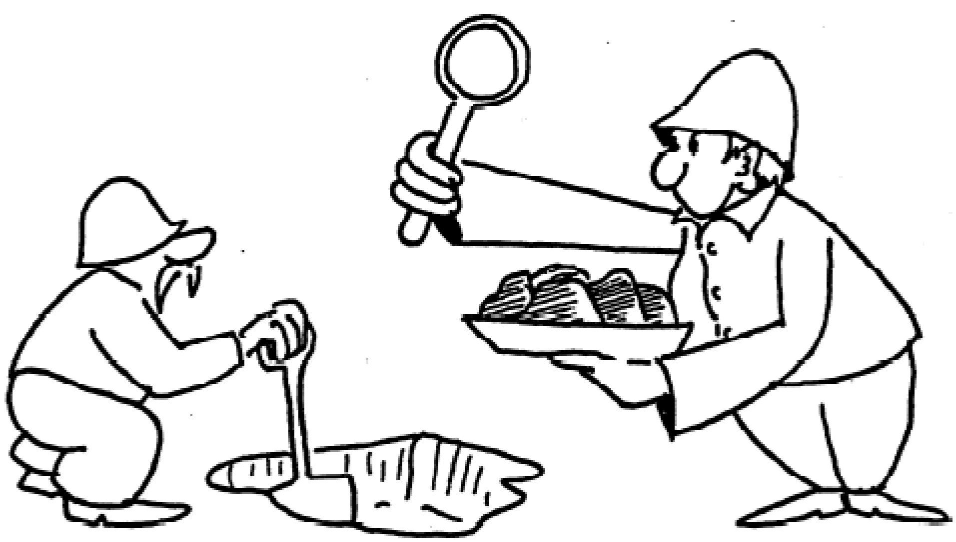
# CHAPTER 3

# SOILS



## 3.0 *INTRODUCTION*

To verify the adequacy of a shoring system in soil, it is necessary to be familiar with the types of soil in which the excavation is to be made, their properties, and expected behavior. 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 Geotechnical Services should present sufficient information for the Engineer to perform shoring design and analyses. The Engineer must contact Geotechnical Services for guidance when additional soil properties are needed for the design review or when the material encountered during the installation or construction of the shoring system differs from that assumed by 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.

## 3.1 *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 having a 'competent person' classify the soil as per Cal/OSHA Excavation Standard Appendix A to Section 1541.1 – Soil Classification.

As per the Cal/OSHA Appendix A, a competent person is "one who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them." That person must have had specific training in and be knowledgeable about soils analysis, the use of protective systems, and the requirements of the Standard (Cal/OSHA).

The Cal/OSHA soil classification methods include a series of visual analysis as well as a series of manual tests. As per Cal/OSHA Section 1541.1(c) in Appendix A, the classification of soil deposits shall be made based on the results of at least one visual and at least one manual analysis.

Some of the acceptable manual tests are similar to those used in the Caltrans Soil and Rock Logging, Classification, and Presentation Manual, including Dry Strength and Pocket Penetrometer methods. The competent person will use the quantitative and qualitative information obtained from the visual and manual tests to classify the soils as either Type A (stable rock), 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 Foundation Report or Geotechnical Design Report to discuss and verify.

Caltrans uses geotechnical reports, Log of Test Boring (LOTB) sheets and Boring Records (BR) to present the results of its geotechnical and borehole investigations. LOTB sheets are included in the contract plans for structures and present the boring logs, including soil descriptions and sampling information, whereas a BR is an 8½ x 11 sheet attached to a geotechnical report pertaining to roadway facilities (cuts, fills, grading, drainage). The Caltrans *Soil and Rock Logging, Classification, and Presentation Manual*, maintained by Geotechnical Services, presents the Department's practice for identification, classification, description and presentation of soil and rock for all investigations after August 1, 2007. The Manual is available through the Division of Engineering Services/Geotechnical Services at the following website:

http://www.dot.ca.gov/hq/esc/geotech/requests/logging_manual/logging_manual.html

Correct interpretation of LOTB sheets, BR, and related discussions in geotechnical reports requires familiarity with the 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, is determined using one of the following standards:

- ASTM D 2488-06, "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), if laboratory testing is not performed

- ASTM D 2487-06, “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 the Logging Manual. Section 2 of the Logging Manual presents the Department’s practice for identifying and describing soil in the field whereas Section 3 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)*.

## 3.2 *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 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

## 3.3 *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 $12^k$ sampler, is referred to as N value. When corrected for the SPT hammer's energy efficiency, it becomes $N_{60}$. This can be used to determine the apparent density of a granular soil. Empirical relationships to approximate the soil friction angle (ϕ) and density are shown in Table 3-1.

Table 3-1. Properties Granular Soils

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

Note that both the LOTB and BR 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 Logging Manual on Apparent Density and Appendix A.8 on SPT prior to using Table 3-1. Note: 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, Office of 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 | $\phi$ Friction Angle of the Soil | Density or Consistency | $\gamma$ 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<br>34<br>29 | Dense<br>Medium Dense<br>Loose | 130<br>120<br>90 | 0.21<br>0.28<br>0.35 | 27<br>34<br>32 |
| Medium Sand | 36<br>31<br>27 | Dense<br>Medium Dense<br>Loose | 117<br>110<br>90 | 0.26<br>0.32<br>0.38 | 30<br>35<br>34 |
| Fine Sand | 31<br>27<br>25 | Dense<br>Medium Dense<br>Loose | 117<br>100<br>85 | 0.32<br>0.38<br>0.41 | 37<br>38<br>34 |
| Fine Silty Sand, Sandy Silt | 29<br>27<br>25 | Dense<br>Medium Dense<br>Loose | 117<br>100<br>85 | 0.35<br>0.38<br>0.41 | 41<br>38<br>34 |
| Silt | 27<br>25<br>23 | Dense<br>Medium Dense<br>Loose | 120<br>110<br>85 | 0.38<br>0.41<br>0.44 | 45<br>45<br>37 |

For active pressure conditions, use a unit weight value of $\gamma$ = 115 pcf 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 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 density as shown in Table 3-3.

Table 3-3. Properties 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 |

## 3.4 *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 gages 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 nearly continuous record of subsurface information collected. The results of a CPT are presented on either a LOTB plan sheet or on an 8 ½ x 11 sheets as presented in Figure 3-1 and Figure 3-2..

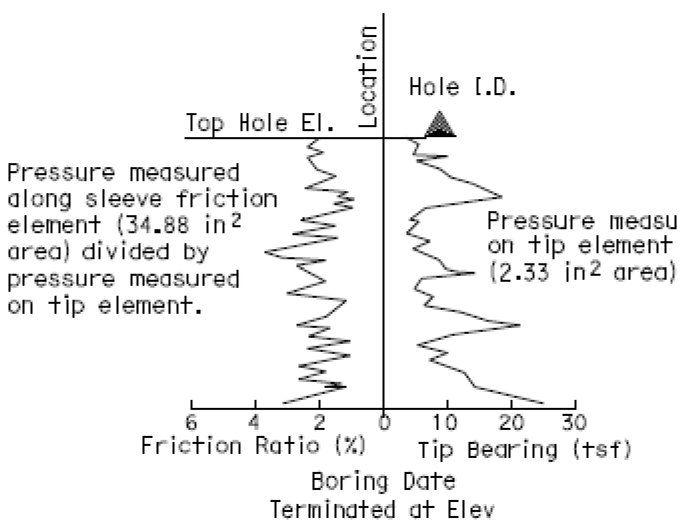



Figure 3-1. Cone Penetration Test (CPT) Boring

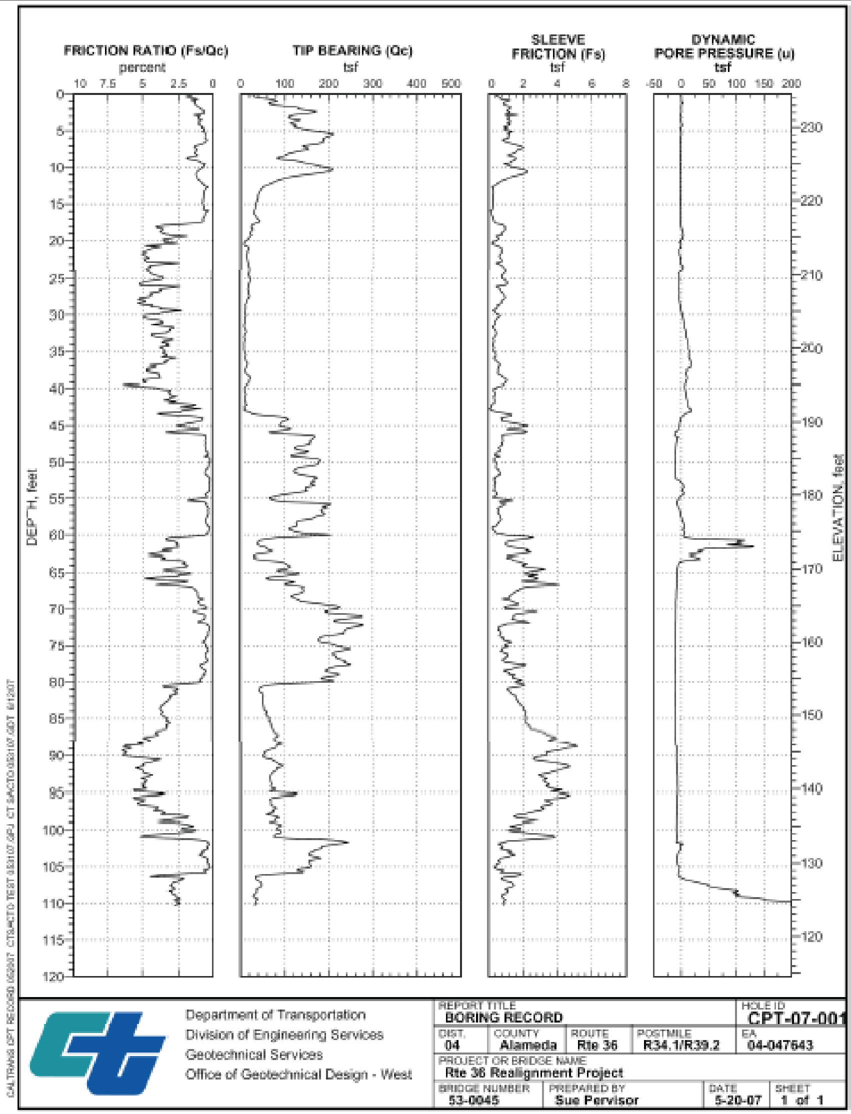



Figure 3-2. Typical CPT Plot

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 to contact Geotechnical Services for guidance on the interpretation of CPT data relating to shoring analysis and design.

## 3.5 *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 D 1588) | Good | Poor |
| Cone Penetration Test (CPT) (ASTM D 3441) | Good | Fair |
| Pocket Penetrometer | Not applicable | Fair |
| Vane Shear (ASTM D 2573) | Not applicable | Very good |
| Triaxial Compression (UU,CU) (ASTM D 2850) | Very good* | Very Good |
| Unconfined Compression (ASTM D 2166) | Not applicable | Very good |
| Direct Shear (ASTM D 3080) | Good* | Fair |

*Recovery of undisturbed samples can be difficult

## 3.6 *SHEAR STRENGTH*

The shear strength of soil is measured by two parameters, the angle of internal friction $\phi$, 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:

$$\tau_f = c + \sigma \tan\phi \qquad \text{Eq. 3-1}$$

Where:

$\tau_f$ = Soil Shear Strength at Failure.

$\phi$ = Internal Friction Angle.

$\sigma$ = Normal Stress.

$c$ = Soil Cohesion.

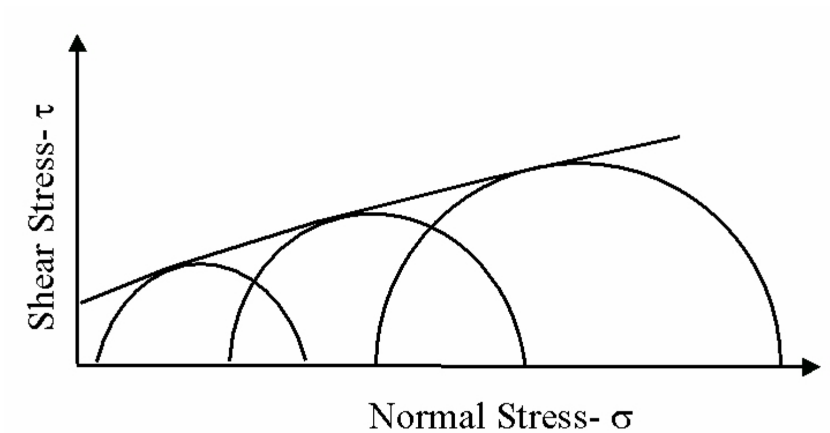



Figure 3-3. Mohr-Coulomb Criteria

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, and derive their strength through cohesion (interparticle attraction). For cohesive soils, the failure criterion simplifies to:

$$\tau_f = S_u \qquad \text{Eq. 3-2}$$

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.

## 3.7 *CONTRACTOR SOIL INVESTIGATIONS*

The Contractor may elect to have a soils investigation performed to support his 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:

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

## 3.8 *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 understood of the material during and after excavation and installation of the shoring system. 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:

- 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.
- Organic soil: Organic soils, such as peat, are compressible and subject to decomposition which can lead to significant volume changes.
- 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 insitu.
- 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. For running soil conditions, the full dry weight or the saturated unit weight of material has to be resisted. The angle of friction ($\phi$) and the cohesive value (c) are both zero.
- 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 developed by adverse water flow. It may best be stabilized when the trench is dewatered. Quick conditions can occur in some silt as well as in sand.