CHAPTER 3.0
BASIC SOIL PROPERTIES FOR FOUNDATION DESIGN

The foundation engineer is usually concerned with the construction of some type of engineering structure on or in the earth. For engineering purposes, we shall consider the earth to be made up of rock and soil. Rock is that naturally occurring material composed of mineral particles so firmly bonded together that relatively great effort is required to separate the particles (i.e., blasting or heavy crushing forces). Soil will be defined as naturally occurring mineral particles which are fairly readily separated into relatively small pieces, and in which the mass may contain air, water, or organic materials (derived from decay of vegetation, etc.). The mineral particles of the soil mass are formed from decomposition of the rock by weathering (by air, ice, wind, and water) and chemical processes. Classification of soils by particle size according to various standards is shown in Figure 3 – 1.

MAIN SOIL GROUPS	**SOIL TYPES**
Granular Soils	Sands and Gravels
Fine-Grained Soils	Silts and Clays
Organic Soils	Peat, Organic Clays, and Organic Silts

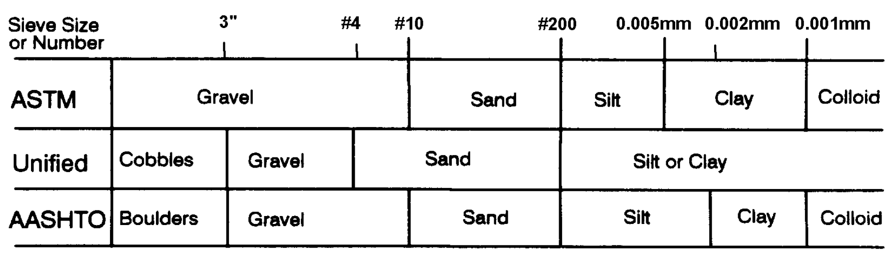


Figure 3 – 1: Particle Size Limit by Different Classifications Systems

3.1 ENGINEERING PROPERTIES OF SOILS

The major engineering properties of the main soil groups as related to foundation design are summarized as follows:

3.1.1 Engineering Properties of Granular Soils

- Excellent foundation material for supporting structures and roads.
- The best embankment material.
- The best backfill material for retaining walls.
- Might settle under vibratory loads or blasts.
- Dewatering can be difficult due to high permeability.

- If free draining not frost susceptible.

3.1.2 Engineering Properties of Cohesive Soils

- Very often possess low shear strength.
- Plastic and compressible.
- Loses part of shear strength upon wetting.
- Loses part of shear strength upon disturbance.
- Shrinks upon drying and expands upon wetting.
- Very poor material for backfill.
- Poor material for embankments.
- Practically impervious.
- Clay slopes are prone to landslides.

3.1.3 Engineering Properties of Silt

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

Engineering Properties of Silt as Compared to Clay

- Better load sustaining qualities
- Less compressible
- More permeable
- Exhibits less volume change

3.1.4 Engineering Properties of Organic Soils

Any soil containing a sufficient amount of organic matter to influence its engineering properties is called an organic soil. The term organic designates those soils containing an appreciable amount of decayed animal and/or vegetative matter in various states of decomposition.

The organic matter is objectionable for three main reasons:

1. Reduces load-carrying capacity of soil.

2. Increases compressibility considerably.

3. Frequently contains toxic gasses that are released during the excavation process.

All organic soils, whether peat, organic clays, organic silts, or even organic sands, should be viewed with suspicion as foundation and construction materials.

3.2 GRANULAR MATERIAL PROPERTIES

Grain size distribution is the single most important element in the design of granular material items. Grain size distribution is determined by sieving a soil sample of known weight through U.S. Standard mesh opening sizes. The percentages of total sample are recorded and plotted on a semi-log sheet (Figure 3 – 2). The resulting curves represent the grain size distribution in the soil sample.

Much can be learned about a sample's engineering properties from the shape and location of the curve. For instance, the well-graded curve represents a soil sample with a wide range of particle sizes that are evenly distributed. Densification of a well-graded sample causes the small particles to move into the voids between larger particles. As the voids in the sample are reduced, the density and strength of the sample increase. Specifications for select structural fill should contain required ranges of different particle sizes so that a dense, non-compressible backfill can be achieved with minimal compactive effort. For example, the well-graded material shown in Figure 3-2 could be specified by providing the following gradation limits:

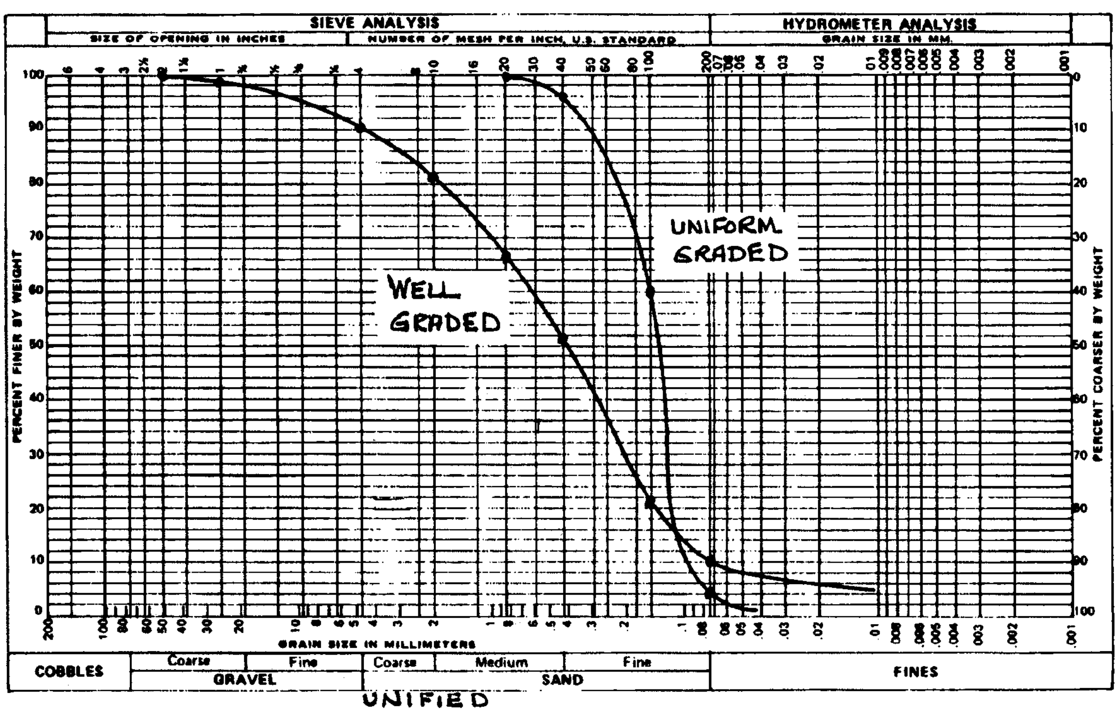


Figure 3 – 2: Grain Size Distribution

TABLE 3 – 1
TYPICAL GRADATION LIMITS OF WELL-GRADED GRANULAR MATERIAL

Sieve Size	Percent Passing by Weight
2″	100
#10	75-90
#40	40-60
#200	less than 15

A uniform graded material is composed of a narrow range of particle sizes. When compaction is attempted, inadequate distribution of particle sizes prevents reduction of the volume of voids in the soil. Such uniform materials should be avoided as select fill material. However, uniform graded materials do have an important use as drainage material. The relatively large void spaces act as conduits to carry water. Obviously, the larger the average particle size, the larger the void space. The early "French" drain was an example of the use of a coarse uniform graded soil. Typical specifications for drainage materials would show a narrow band of particle sizes:

TABLE 3 – 2
TYPICAL GRADATION LIMITS OF DRAINAGE MATERIALS

Sieve Size	Percent Passing by Weight
2″	100
1 ½ ″	90-100
1″	0-15

The durability of aggregates is also an important item in specifications. Non-durable materials tend to breakdown which causes a change in the grain size distribution. Smaller grains will tend to reduce the size of the mass and result in surface settlement or in the case of drainage material, clogging of the drainage paths. Infiltration of fines into drainage aggregate also causes clogging. Typically modern drainage aggregate systems are wrapped in a suitable geotextile to prevent contamination of the aggregate.

3.3 FINE-GRAINED MATERIAL PROPERTIES

Another important concept is that of plasticity of soils. During a visual examination of soil samples containing fine-grained materials, a judgment is made that the soil is plastic, or non-plastic but no relative value is assigned. Arbitrary indices have been chosen to define the plasticity of cohesive (clay) soils (Table 3 - 3). These are liquid limit (LL), plastic limit (PL), and plasticity index (PI). These limits quantitatively describe the effect of varying water content on the consistency of fine-grained soils. With increasing water content, fine-grained soils pass consecutively from the solid to semi-solid to plastic to liquid states. These limits and the applicable standard AASHTO test numbers are shown in Figure 3 - 3 and Table 3 – 3.

TABLE 3 – 3
SOIL PLASTICITY CHARACTERISTICS

Plasticity Characteristics	Symbol	Units′	How Obtained	Application
Liquid limit	LL	D	Directly from test AASHTO T89	Classification & properties correlation.
Plastic limit	PL	D	Directly from test AASHTO T89	Classification.
Plastic index	PI	D	LL-PL	Classification & properties correlation
Shrinkage limit	SL	D	Directly from test AASHTO T89	Classification computation of swell
Shrinking index	SI	D	PL-SL	
Activity	Ac	D	$\frac{PI}{\%\ \text{"Clay Size"}}$	Identification of clay mineral
Liquidity index	LI	D	$\frac{W - PL}{PI}$	Estimating degree of preconsolidation

Units′: D = Dimensionless

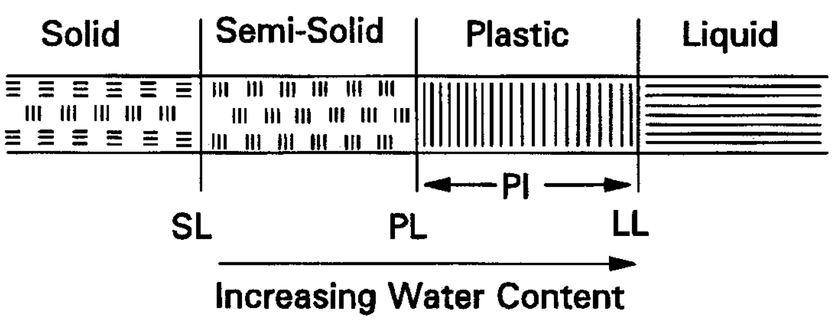


Figure 3 - 3: Relationship between Soil State and Atterberg Limit

The plasticity index (PI) represents the range of water content in which the soil remains plastic. In general, the plasticity index represents the relative amount of clay particles in the soil. The higher the PI, the greater the amount of clay particles present, and the more plastic the soil. A more plastic soil will:

1. Be more compressible.

2. Have higher shrink-swell potential.

3. Be less permeable.

Atterberg limits are a <u>cheap</u> method of obtaining a lot of useful data.

3.4 SOIL IDENTIFICATION, DESCRIPTION AND CLASSIFICATION

Three terms, which are used in the site exploration process, are: IDENTIFY, DESCRIBE, and CLASSIFY. Identification is the process of determining which components exist in a particular soil sample, i.e., gravel, sand, silt, clay, etc. Description is the process of estimating the relative percentage of each component and preparing a word picture of the sample (ASTM D2488). Identification and description are accomplished primarily by both a visual examination and the feel of the sample.

Classification is the process of grouping soils with similar engineering properties into categories. For example, the Unified Soil Classification System (ASTM D2487), which is the most commonly used system in geotechnical work, is based on grain size, gradation, and plasticity. The AASHTO system (M145), which is also of interest to highway engineers, groups soils into categories having similar load carrying capacity and service characteristics for pavement subgrade design.

The important distinction between classification and both identification and description is that standard AASHTO or ASTM laboratory tests must be performed to determine a soil's classification. Highway agencies typically do not need to perform the laboratory tests necessary to classify every soil sample. Instead soil technicians are trained to accurately identify and describe soil samples to an accuracy which is acceptable for highway engineering work.

During progression of a boring, the field drilling personnel should only roughly identify and describe the soils encountered. Unfortunately the drillers are usually delegated the task of exactly identifying and describing the soil samples. This is unfair, as drillers must be concerned with many other tasks involving mechanical operation of the rig and preparation of pertinent data for the subsurface log. ln addition, the visual identification test should not be done outdoors in an atmosphere subjected to the elements, as this single operation will provide the basis for later testing and soil profile development. Instead, the soil samples should be sent to a laboratory and visually identified by a technician experienced in soils work. This is of great importance where no laboratory testing is to be performed and design values are estimated on the visual description and SPT results.

The identification system used should permit the engineer to easily relate the soil description to its appearance and behavior characteristics. Density of granular soils or consistency of cohesive soils may be estimated from SPT N-values as previously described in Table 2 – 3. Classification tests, except for moisture content, may be performed on typical samples to verify identification. If possible, the moisture content of every sample should be determined. A typical soil description procedure, known as the Modified Unified Description (MUD), is shown in Appendix A. The Unified Classification System is shown in Appendix B.

3.5 ROCK CLASSIFICATION*

Rock is classified with respect to its geological origin as follows:

- Igneous rocks – such as granite, diorite and basalt, are those formed by the solidification of molten material, either by intrusion at depth in the earth's crust or by extrusion at the earth's surface.

- Sedimentary rocks – such as sandstone, limestone and shale, are those rocks formed by deposition, usually under water, of products derived by the disaggregation of pre-existing rocks.

* Based on: Canadian Foundation Engineering Manual (March, 1978).

- Metamorphic rocks – such as quartzite, schist and gneiss, may be either igneous or sedimentary rocks which have been altered physically and sometimes chemically by the application of intense heat and pressure at some time in their geological history

3.5.1 Structural Features of Rock Masses

Geological structures generally have a significant influence on the rock mass properties. Some of the important features are described as follows:

- Rock mass – means an aggregate of blocks of solid rock material containing structural features, which constitute mechanical discontinuities. Rock mass refers to any in situ rock with all inherent geomechanical discontinuities.

- Rock material – or intact rock means the consolidated aggregate of mineral particles forming solid material between structural discontinuities. Properties attributed to it refer to rock material free of geomechanical discontinuities.
- Geomechanical or structural discontinuities – means all geological features which separate solid blocks of the rock mass, such as joints, faults, bedding planes, cleavage planes, shear zones, and solution cavities. These features constitute planes of weakness which reduce the strength of the rock mass appreciably.

- Major discontinuities or major structures – means those geological features constituting structural discontinuities which are sufficiently well developed and continuous that shear failure along them would involve little or no shearing of intact rock material.

3.5.2 Engineering Properties of Rock Masses

The quality of a rock mass for foundation purposes depends mainly upon the strength of rock material and on the spacing, the nature (width, roughness, waviness, weathering, etc.) and the orientation of discontinuities. Classification of rock according to some of those properties is given in Table 3-3 and 3-4.

TABLE 3 - 4
CLASSIFICATION OF ROCK WITH RESPECT TO STRENGTH

Classification of Rock with Respect to Strength	Unconfined Compressive Strength - PSI
Very high strength	greater than 32,000
High strength	8,000 to 32,000
Medium strength	2,000 to 8,000
Low strength	500 to 2,000
Very low strength	125 to 500

Note: Rocks with compressive strengths lower than 125-lb/sq. in. should be treated as soils.

TABLE 3 - 5
CLASSIFICATION OF ROCK MASS WITH RESPECT TO THE SPACING OF DISCONTINUITIES

Classification of Rock Mass with Respect to the Spacing of Discontinuities	Average Spacing
Very wide	greater than 10 ft
Wide	3 ft. to 10 ft.
Moderately close	1 ft. to 3 ft.
Close	2 in. to 1 ft.
Very close	smaller than 2 in.

3.5.3 Nature and Orientation of Rock Discontinuities

For foundation purposes, the nature of rock discontinuities may be expressed in terms of their width, the degree of weathering of rock contact faces, and the character of infilling materials.

In addition to the strength of rock material, and the spacing and nature of discontinuities, the quality of a rock mass for foundation purposes is affected by the orientation of discontinuities with respect to the applied load. A rock mass is said to contain adversely oriented discontinuities, if under the action of the resultant foundation load the minimum resistance to sliding occurs when the sliding surface is considered to be along these discontinuities.

3.5.4 Rock Quality Designation (RQD)

This is a general method by which the quality of the rock at a site, is obtained based on the relative amount of fracturing and alteration.

The Rock Quality Designation (RQD) is based on a modified core recovery procedure which, in turn, is based indirectly on the number of fractures (except those due directly to drilling operations) and the amount of softening or alteration in the rock mass as observed in the rock cores from a drill hole. Instead of counting the fractures, an indirect measure is obtained by summing the total length of core recovered by counting only those pieces of hard and sound core which are 4 inches or greater in length. The ratio of this modified core recovery length to the total core run length is known as the RQD.

An example is given below from a core run of 60 inches. For this particular case the total core recovery is 50 inches yielding a core recovery of 83 percent. On the modified basis, only 38 inches are counted and the RQD is 63 percent.

CORE RECOVERY, in	MODIFIED CORE RECOVERY, in
10	10
2	
2	
3	
4	4
5	5
3	
4	4
6	6
4	4
2	
5	5
Total = 50	Total = 38

Therefore, Percentage Core Recovery = 50/60 = 83%; RQD= 38/60 = 63%

A general description of the rock quality can be made from the RQD Value (Table 3-5).

TABLE 3 - 6
RQD DESCRIPTION

RQD (ROCK QUALITY DESIGNATION)	DESCRIPTION OF ROCK QUALITY
0 – 25	Very poor
26 – 50	Poor
51 – 75	Fair
76 – 90	Good
91 – 100	Excellent

3.6 SOIL PROFILE DEVELOPMENT

The mark of successfully accomplishing a subsurface investigation is the ability to draw a soil profile of the project site complete with soil types and necessary design properties. The soil profile is a visual display of subsurface conditions as interpreted from all foregoing explorations and testing. Uncertainties in its development usually indicate additional explorations or testing are required.

In the optimum situation the soil profile is developed in stages. First, a rough profile is established from the drillers' logs by the soils engineer or geologist. The object is to discover any obvious gaps or question marks while the drill crew is still at the site so that additional work can be performed immediately. Once a crew has left the site, a delay of months may occur before their schedule permits reoccupying the site (not to mention the additional cost to the highway agency, and aggravation to the drill crew to reoccupy a remote site). The drilling inspector or crew chief should be required to call the soils engineer when progression of the last scheduled boring has begun, to request further instructions for supplemental borings.

When all borings are completed and laboratory visuals and moisture content data received, the initial soil profile should be revised. Definite soil layer boundaries and accurate soil descriptions should be established for soil deposits. Too often the engineer will over-complicate a simple profile by noting minute variations between adjacent soil samples. This can be avoided by:

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

2. Remembering that the soil samples examined are only a minute portion of the soil underlying the site and must be considered in relation to not only adjacent samples, but also adjacent borings.

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

1. Review the U.S.D.A. County Soil Map and determine major deposits expected at the site.

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

3. Personally review representative soil samples to check laboratory identification and to calibrate your interpretation with the laboratory technicians who performed the visual.

4. Establish rational mechanics for drawing the soil profile.

    a. Use a vertical scale of 1-inch equals 10 feet or 20 feet; generally, any smaller scale tends to squeeze data and prevent interpretation.

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

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

The final soil profile is the foundation engineer's best interpretation of all available subsurface data. The final soil profile should include the average physical properties of the soil deposits, i.e., unit weight, shear strength, etc., in addition to a visual description of each deposit observed water level, and special items such as boulders or artesian pressure. Successful development of this subsurface profile will allow the foundation engineer to advance his design with confidence.

3.7 APPLE FREEWAY DESIGN EXAMPLE – BASIC SOIL PROPERTIES

In this chapter the process of establishing the basic soil properties based on visual description (logs), classification test (laboratory) and construction a soil profile are illustrated with reference to this Apple Freeway Example Design. The boring logs (Exhibit D of Chapter 2 Apple Freeway Example) and hypothetical moisture content tests data are used to illustrate how a preliminary soil profile is established for analysis and design.

Given: Boring logs and soil test data (Chapter 2 Apple Freeway Design Example)

Required: Determine preliminary soil profile

Solution:

Step 1: **Locate the borings in plan and elevation**

Step 2: **Plot the variation of field SPT value and classification test data (moisture content W) with depth.**

Step 3: **Plot the observed water levels in the borings and the date observed.**

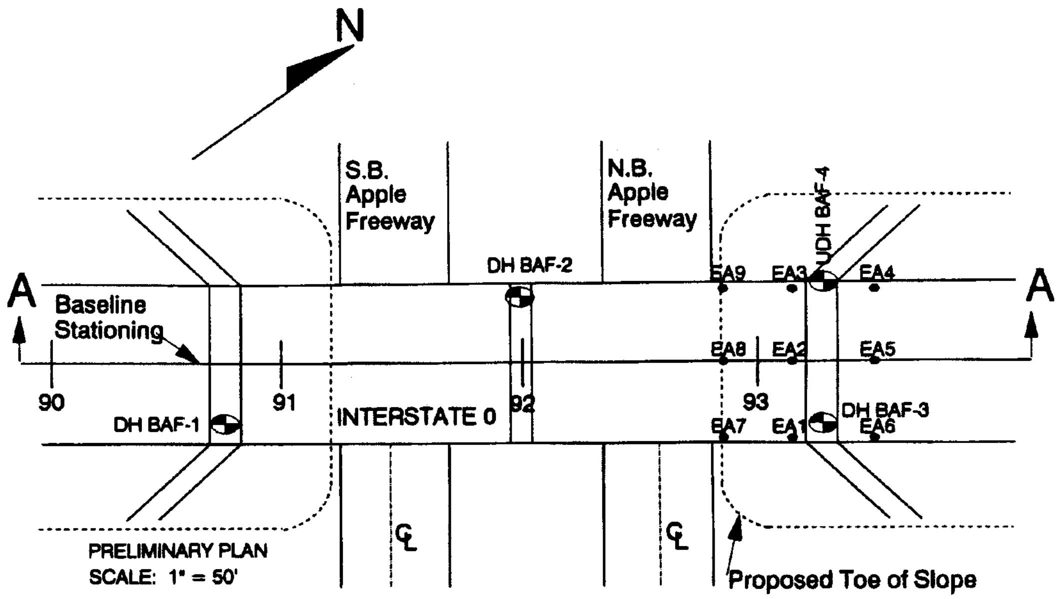
Step 4: **Extrapolate between zones of similar properties based on site reconnaissance in formation, visual description and classification tests to establish preliminary soil profile.**

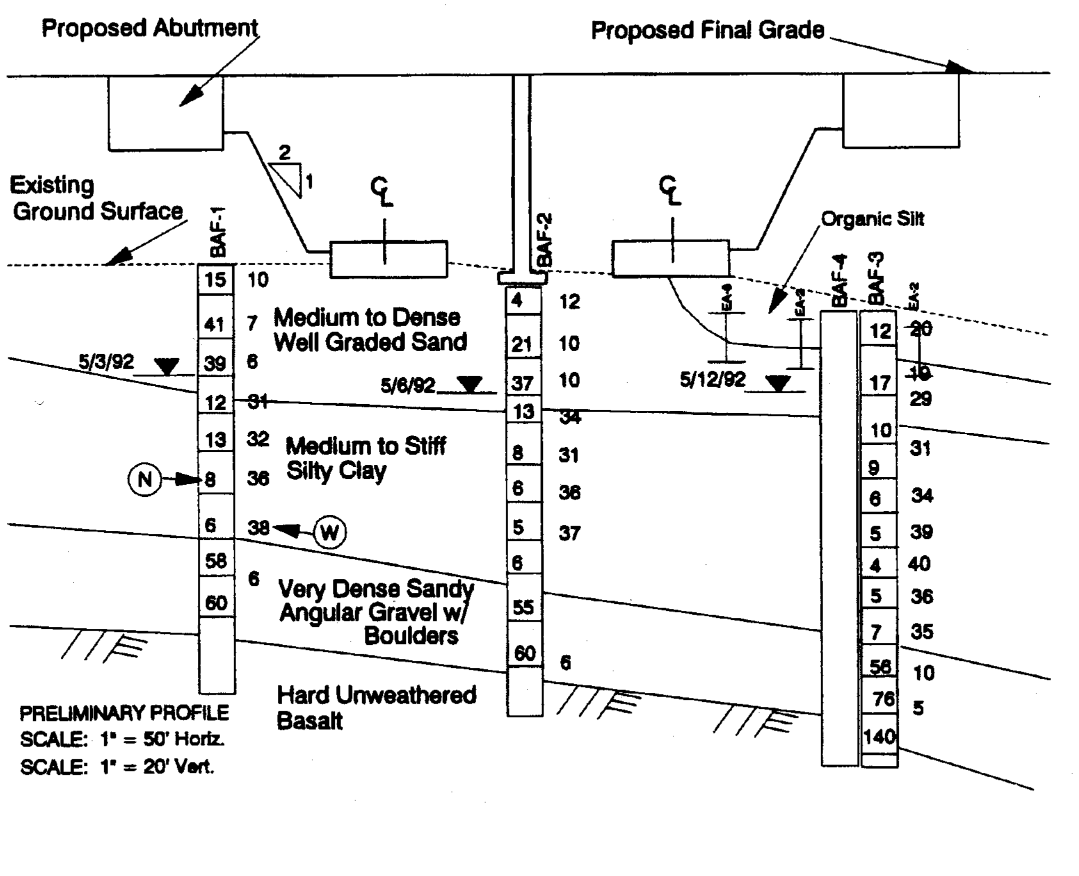
Site Exploration	Terrain Reconnaissance Site Inspection Subsurface Borings	
	Basic Soil Properties	Visual Description Classification Tests Soil Profile
Laboratory Testing	P_o Diagram Test Request Consolidation Results Strength Results	
Slope Stability	Design Soil Profile Circular Arc Analysis Sliding Block Analysis Lateral Squeeze	
Embankment Settlement	Design Soil Profile Settlement Time – Rate Surcharge Vertical Drains	
Spread Footing Design	Design Soil Profile Pier Bearing Capacity Pier Settlement Abutment Settlement Vertical Drains Surcharge	

Pile Design	Design Soil Profile
	Static Analysis – Pier
	    Pipe Pile
	    H – Pile
	Static Analysis – abutment
	    Pipe Pile
	    H – Pile
	Driving Resistance
	Abutment Lateral Movement	

Construction Monitoring	Wave Equation Hammer Approval Embankment Instrumentation	

Apple Freeway Design Example – Basic Soil Properties
Exhibit A





Apple Freeway Design Example – Basic Soil Properties
Exhibit B – Workshop Design Problem Preliminary Soil Profile

<u>Summary of the Basic Soil Properties Phase for Apple Freeway Design Problem</u>

- <u>Visual Description</u>

  Predominant soil types are sand, silty clay and sandy gravel.

- <u>Classification Tests</u>

  Moisture content and unit weight determined.

- <u>Soil Profile</u>

  Subsurface variation of soil layers and ground water estimated.