FLORIDA A&M UNIVERISTY – FLORIDA STATE UNIVERSITY
COLLEGE Of ENGINEERING

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

GEOTECHNICAL INVESTIGATION

FOR CIVIL AND ENVIRONMENTAL ENGINEERING PROJECTS

By

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INTRODUCTION

Lecture 1

Session 1

Introduction to Geotechnical Investigation

Objectives:
1. To learn how to conduct geotechnical investigation for foundation projects
2. To review soil and rock properties needed for foundation analysis and design

Outcomes:

To apply fundamental knowledge of soil mechanics and geotechnical engineering to geotechnical investigation

Learning Tasks:
1. Assignments
2. Online quizzes

INTRODUCTION

Before we investigate the feasibility of any foundation project one should understand

1. the interaction between the human activities & the geologic environment

INTRODUCTION

Human Activities
&
Geologic Environment

Geometrical Changes

External Stresses

Altering Stresses in Soil Layers

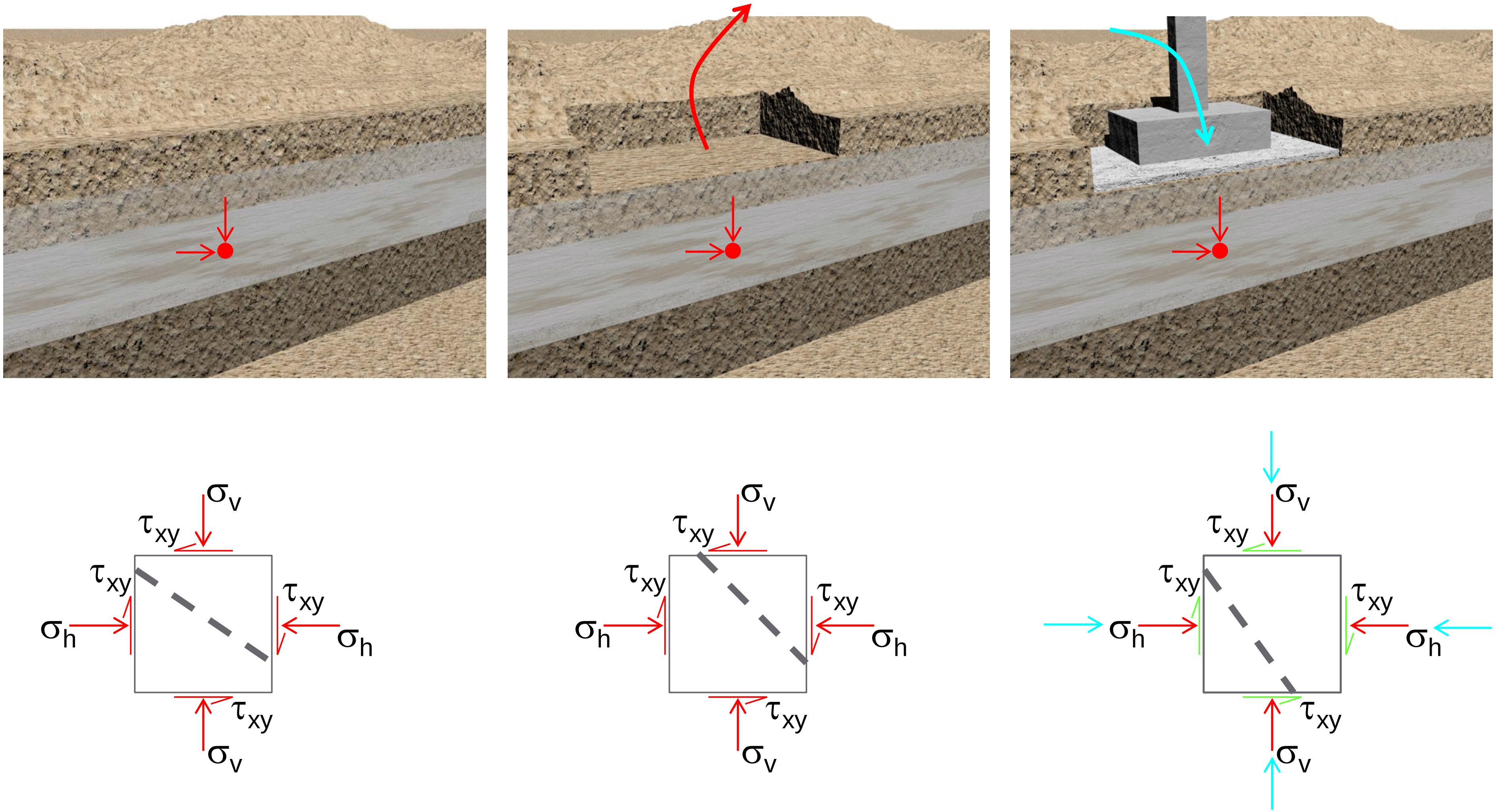
Active Impact

1. Building Construction
2. Dams
3. Embankments
4. Roadways/ Railways
5. Underground Construction
6. Waterways
7. Earth Retaining Structures
8. Dewatering Facilities
9. Airports
10. Hydraulic Structures
11. Towers/Silos
12. Pipelines
13. Bridges

Passive Impact

1. Slope Failure
2. Flow / Landslides
3. Erosion
4. Flooding
5. Ground Subsidence
6. Settlement
7. Ground Failure
8. Piping
9. Heave
10. Earthquake

Altering Stresses in Soil Layers



INTRODUCTION

An adequate assessment of the site should be done through

Geotechnical Investigation

INTRODUCTION

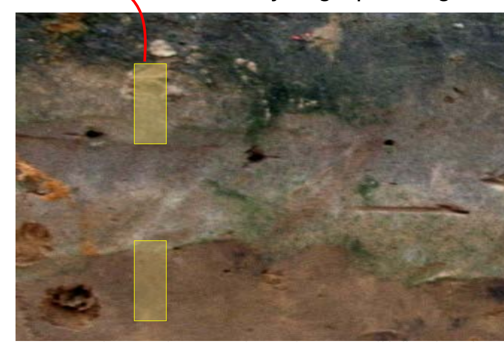
2. Conduct a thorough geotechnical investigation

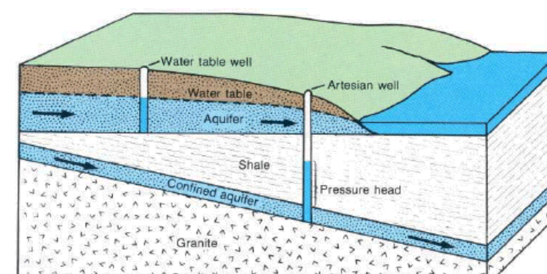
This requires the skill and the knowledge to

1. Identify and describe rock & soil formations
2. Identify geologic hazards
3. Identify and describe rock & soil types
4. Define groundwater conditions
5. Procure samples
6. Perform field and laboratory testing

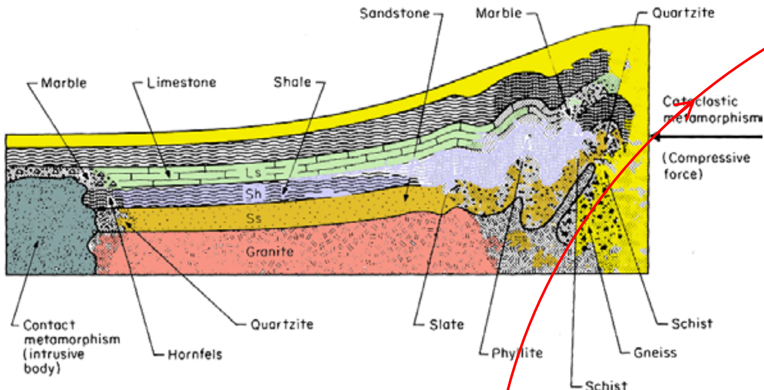
Continental United States Physiographic regions

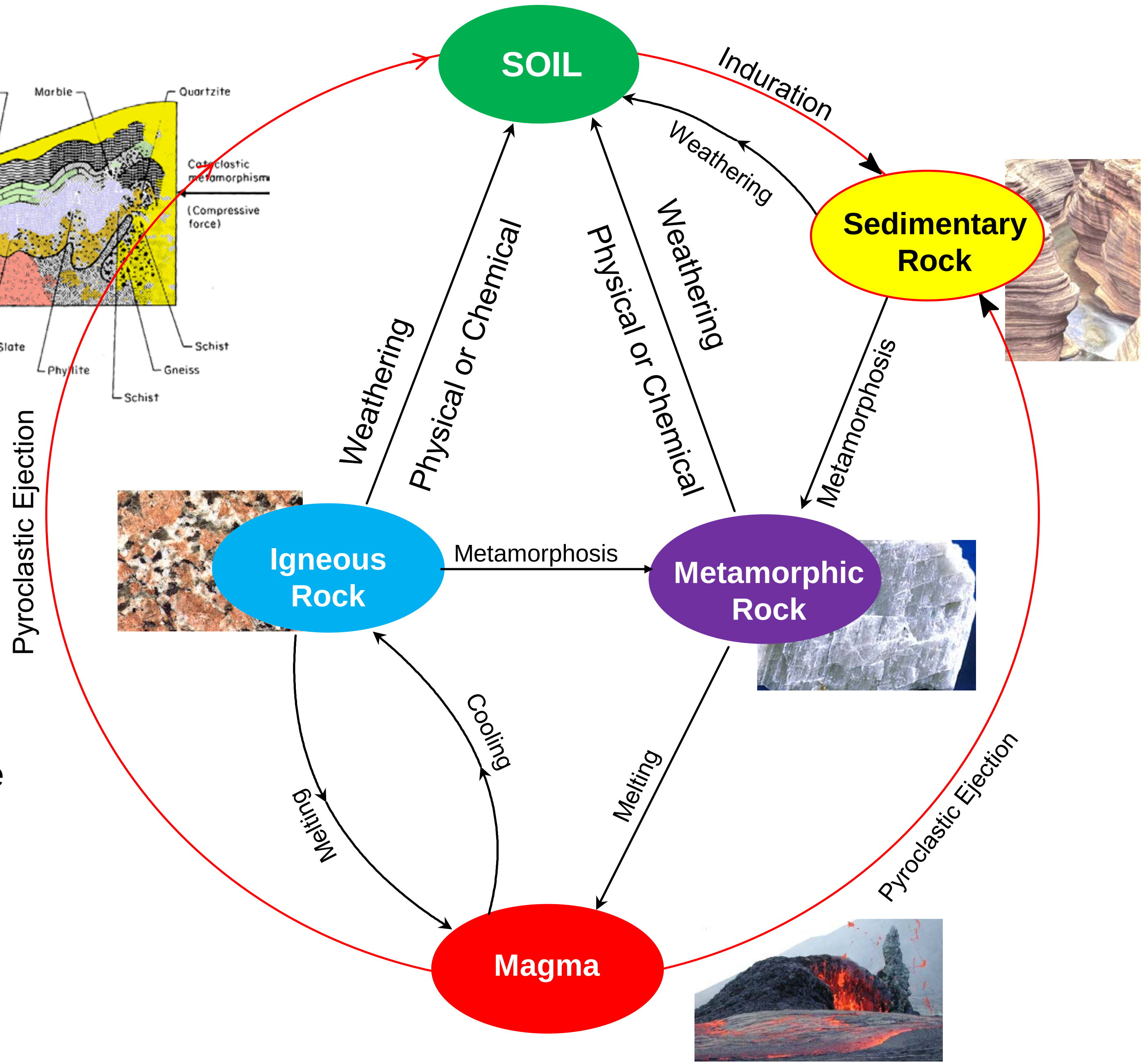
Samples





1. Identify and describe rock & soil formations





Primary processes in the geologic cycle

1. Identify and describe rock & soil formations

Soil Formation

* Soil material is the product of rock

* The geological process that produce soil is **WEATHERING** → Chemical and Physical

* Variation in Particle size and shape depends on:

1 - Weathering Process

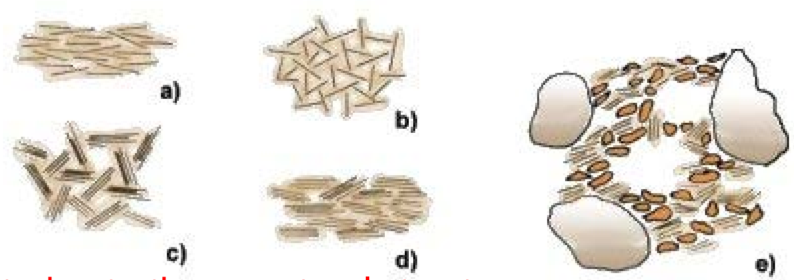
2 - Transportation Process

* Variation in Soil structure depends on:

1 - Soil Minerals

2 - Deposition Process

flocculated   bookhouse



turbostratic   natural structure

Soil Formation

* Transportation and Deposition

Four forces are usually cause the transportation (water, wind, ice, gravity) and deposition of soils

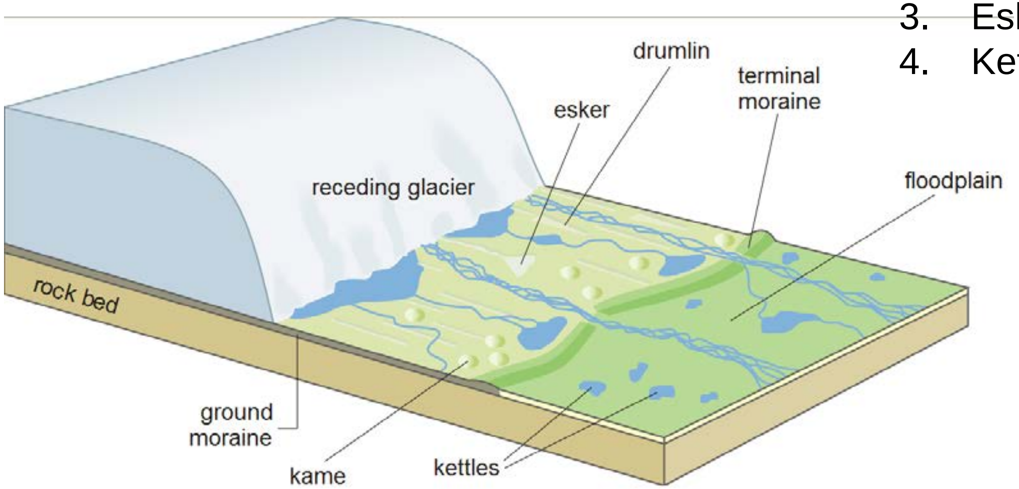
1-Water → Alluvial Soil

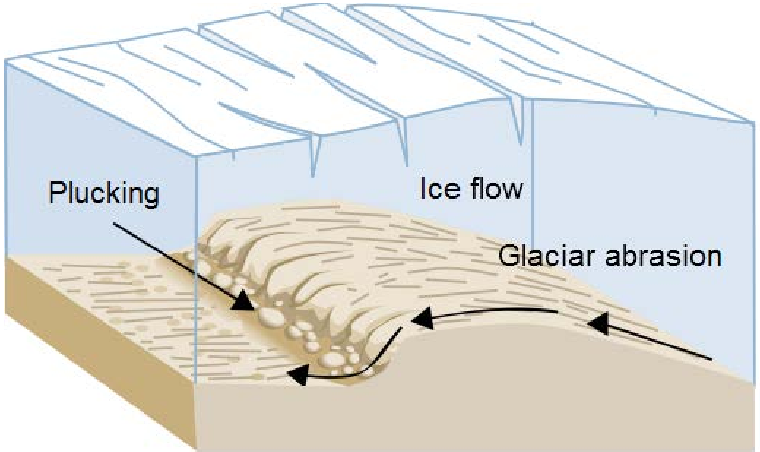
1- Fluvial
2- Estuarine
3- Lacustrine
4- Coastal
5- Marine

1. Identify and describe rock & soil formations

2- Ice → Glacial Soils

1. Hard Pan
2. Terminal Moraine
3. Esker
4. Kettles





1. Identify and describe rock & soil formations

3- Wind → Aeolian Soils

1. Sand Dunes
2. Loess

4- Gravity → Colluvial Soil

1-Talus

1. Identify and describe rock & soil formations 6/6

Continental United States **Physiographic Regions** Include

- 8 regions,
- 25 provinces, and
- 85 sections

3. Identify and describe rock & soil types

Rock Type

1. Igneous Rock
2. Sedimentary Rock
3. Metamorphic Rock

Soil Type

1. Residual Soil
2. Transported Soil

Question

What type of soils are usually produced in nature by the different weathering & Transportation processes?

- *Boulders*
- *Gravel*
- *Sand*
- *Silt*
- *Clay*

---

* These soils can be
  - Dry
  - Saturated -Fully
  - Partially

•Also they have different **shapes , textures , structures**

Shapes .... Elongated
Rounded
Plated
Angular

Texture .... Coarse
Medium
Fine

Structures..... Loose
Dense
Honeycombed
Dispersed
Flocculated

Geotechnical Investigation

Steps of Geotechnical Investigation

1. Data Collection
2. Terrain Analysis
3. Site Exploration
4. Subsurface Sectioning
5. Sample Recovery
6. Soil Testing

Geotechnical Investigation

1. Data Collection

1.1 Type of structure

1.2 General use of the structure

1.3 Column load

1.4 Column spacing

1.5 Building code

1.6 Basement requirements

1.7 Topography maps

1.8 Geological maps

1.9 Soil Maps

1.10 Groundwater maps

1.11 Report, Ariel photographs, satellite images, etc.

Geotechnical Investigation

2 Terrain Analysis

Using remote sensing and landform interpretation techniques to determine:

2.1 Geomorphic characteristics on the site (Landform)

2.2 Relief amplitudes

2.3 Drainage basins

2.4 Vegetation

2.5 Climate conditions, weathering, frost action, erosion, and mass wasting

Geotechnical Investigation

3. Site Exploration

It is a field trip to inspect:

3.1 General topography, existing drainage, ditches, etc.

3.2 General conditions of the soil

3.3 Type of vegetation

3.4 Surface water condition

3.5 Accessibility of the site

Geotechnical Investigation

4. Subsurface Sectioning

This includes the following

- *4.1 Test Pits (for shallow depths)*
- *4.2 Auger Boring (Manual, Mechanical)*
- *4.3 Wash Boring*
- *4.4 Core boring*
- *4.5 Special Methods - Seismic refraction*
  GPR
  Electric Resistivity

The depth and the interval of the subsurface sectioning is governed by:

- *Type of construction*
- *Column Load*
- *Column spacing*

Test boring is the most usable method.

In planning and executing the test boring you need to know:

- *Equipment Selection*
- *Boring Spacing*
- *Boring Depths*

Equipment Selection for Subsurface Sectioning

This depends on:

1- Terrain features
2- Accessibility
3- Geological conditions
4- Boring Depths
5- Sample types
6- Nature of the project

Boring Spacing:
Depending on the area under study, a grid systems may be appropriate in uniform conditions.
The spacing usually ranges from 30 ft to 1600 ft. The following spacing may be adopted for wide range of construction:

1- Multistory Buildings	*30 ft to 100 ft*
2- Residential Subdivision	*800 ft to 1600 ft*
3- Warehouses, Industrial plants	*60 ft to 200 ft*
4- Dams and Dikes	*130 ft to 260 ft*
5- Highways and Railways	*800 ft to 1600 ft*

** In general spacing may vary depending on the irregularity of the site geology.

Depth of Boring:
1- Boring should be extended through any unsuitable foundation strata (unconsolidated fill, organic soils, compressible layers until soil of acceptable bearing capacity is reached.
2- In general, boring should be extended to at least 1.5 to 2 times the minimum width of the loaded area.
3- In the case of very heavy structures (bridges), boring in most cases are extended to bedrock, or at least one boring should be extended to bedrock.
4- The following empirical equations can be used to estimate the minimum depth of borings in office buildings:

$D_b = 3\,S^{0.7}$ *(for light steel or narrow concrete buildings)*

$D_b = 6\,S^{0.7}$ *(for heavy steel or wide concrete buildings)*

Where S = number of stories in meters

Geotechnical Investigation

4. Subsurface Sectioning

Areas of investigation	Boring depth
Large structure with separate closely space footings	Extend to depth where increase in vertical stress for combined foundations is less than 10 percent of effective overburden stress. Generally all boring should extend to no less than 9 m (30 ft) below lowest part of foundation unless rock is encountered at shallower depth.
Isolated rigid foundations	Extend to depth where vertical stress decreases to 10 percent of bearing pressure. Generally all borings should extend no less than 9 m (30 ft) below lowest part of foundation unless rock is encountered at shallower depth.
Long bulkhead or wharf wall	Extend to depth below dredge line between 0.75 and 1.5 times unbalanced height of wall. Where stratification indicates possible deep stability problem, selected borings should reach top of hard stratum.
Deep cuts	Extend to depth between 0.75 and 1 times base width of narrow cuts. Where cut is above groundwater in stable materials, depth of 1.2 to 2.4 m (4 to 8 ft) below base may suffice. Where base is below groundwater, determine extent of previous strata below base.
Dams and water retention structures	Extend to depth of 0.5 base width of earth dams or 1 to 1.5 times height of small concrete dams in relatively homogeneous foundations. Borings may terminate after penetration of 3 to 6 m (10 to 20 ft) in hard and impervious stratum if continuity of this stratum is known from reconnaissance.
High embankments	Extend to depth between 0.5 to 1.25 times horizontal length of side slope in relatively homogeneous foundation. Where soft strata are encountered, borings should reach hard materials.

From NAVFAC DM-7.1, 1982.

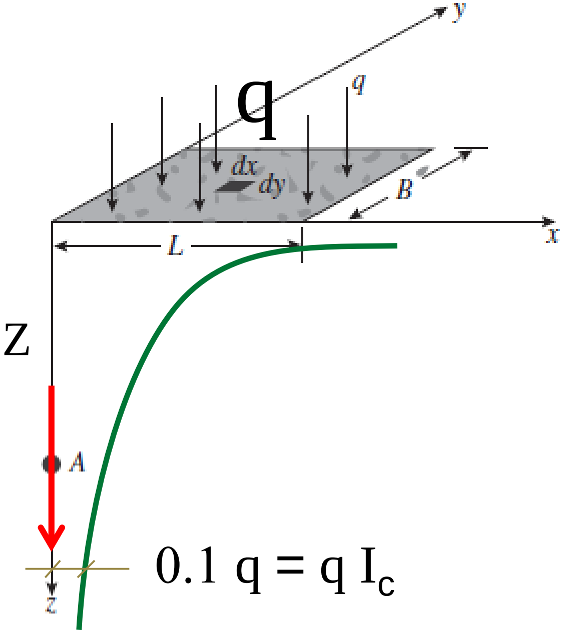
4. Subsurface Sectioning

Boussinesq’s Equation for Vertical Stress Caused by a Rectangularly Loaded Area

$$\Delta\sigma_c = q\, I_c$$

0.1 q

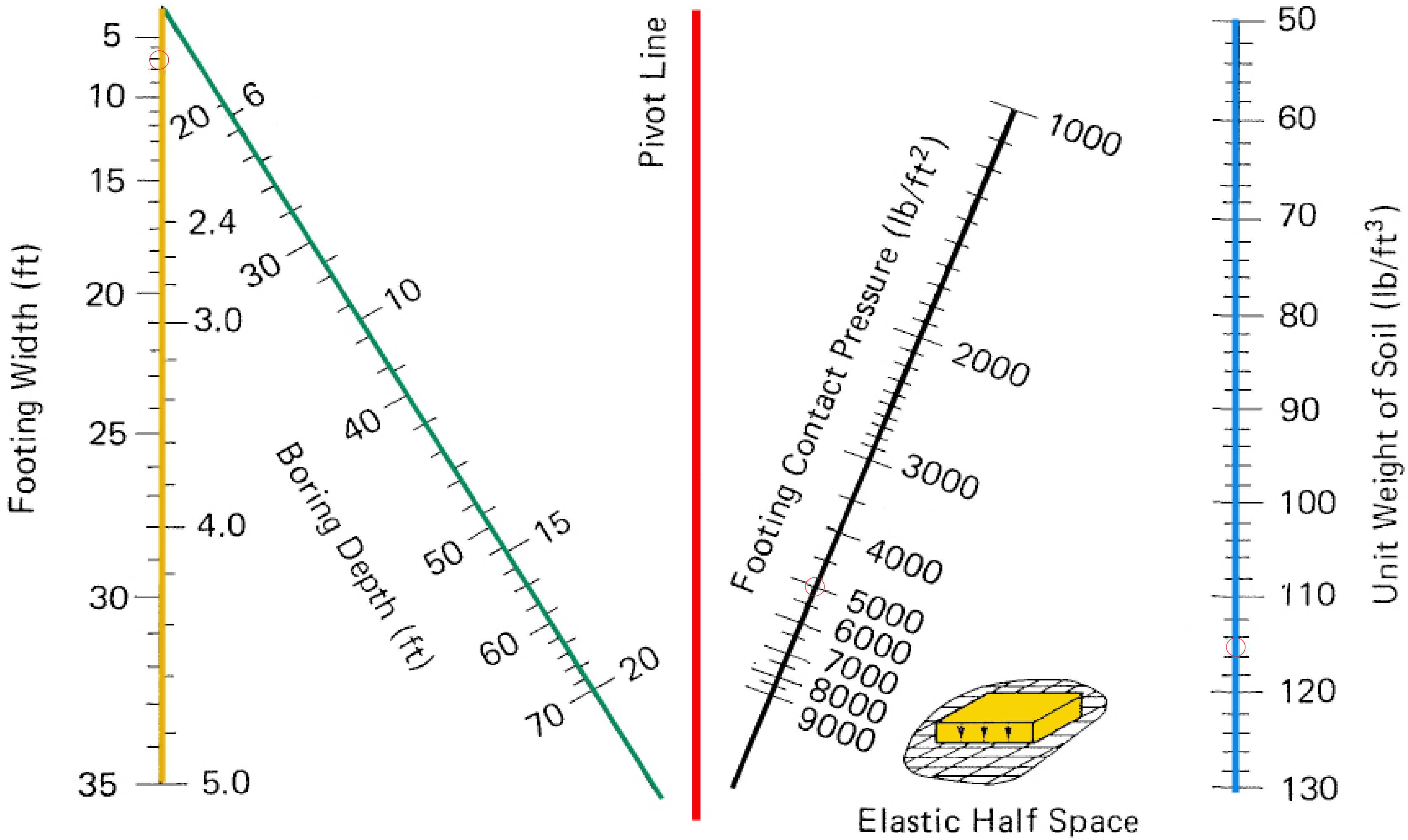
$$I_5 = \frac{1}{4\pi}\left[\frac{2m'n'\sqrt{m^{2\prime} + n^{2\prime} + 1}}{m^{2\prime} + n^{2\prime} + m^{2\prime}n^{2\prime} + 1}\left(\frac{m^{2\prime} + n^{2\prime} + 2}{m^{2\prime} + n^{2\prime} + 1}\right) + \tan^{-1}\left(\frac{2m'n'\sqrt{m^{2\prime} + n^{2\prime} + 1}}{m^{2\prime} + n^{2\prime} - m^{2\prime}n^{2\prime} + 1}\right)\right]$$



$$m' = B/Z \qquad n' = L/Z$$

4. Subsurface Sectioning

Boring depth using Richard et al. 1979 Chart



Boring Depth Using Boussinesq's Equation for Square loading

(RICHARD D. BARKSDALE AND MILTON O. SCHREIBER, 1979)

4. Subsurface Sectioning

Boring depth

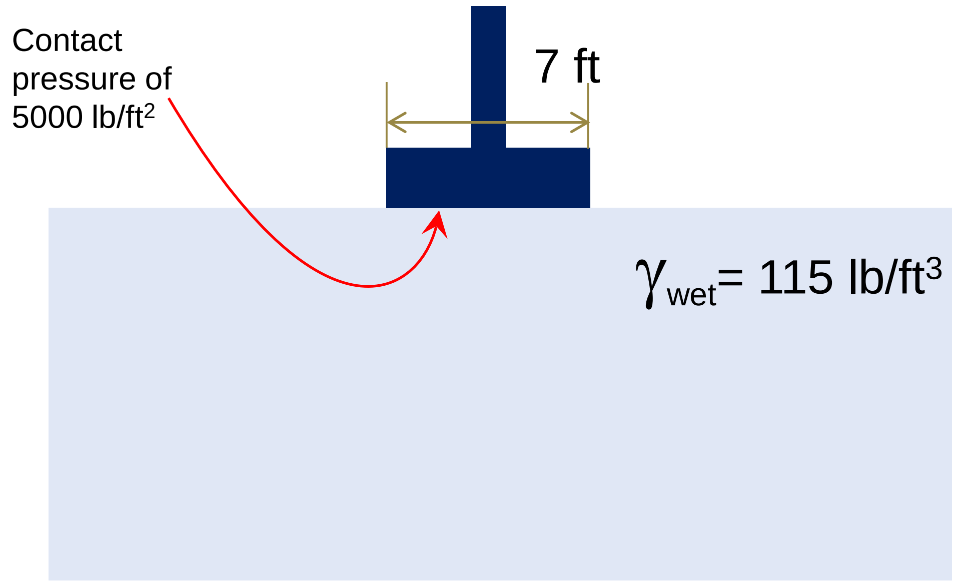
EXAMPLE

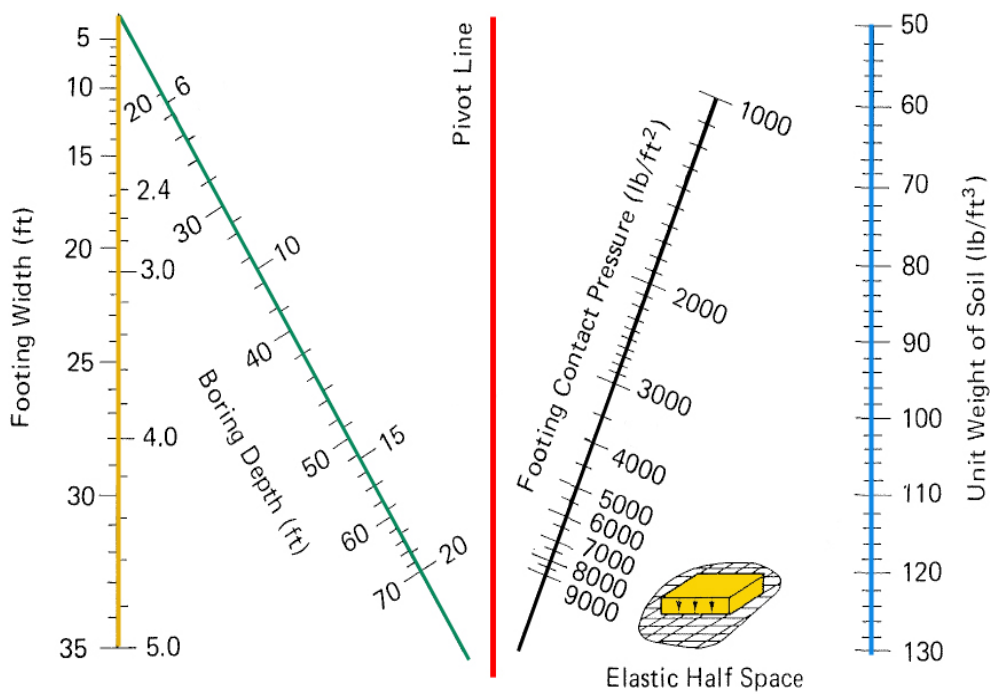
Given

7 ft square footing
Contact pressure of 5000 lb/ft^2
Wet unit weight of the soil = 115 lb/ft^3
Water table is estimated to be 40 ft beneath the footing.

Find

The minimum depth of test boring D_b

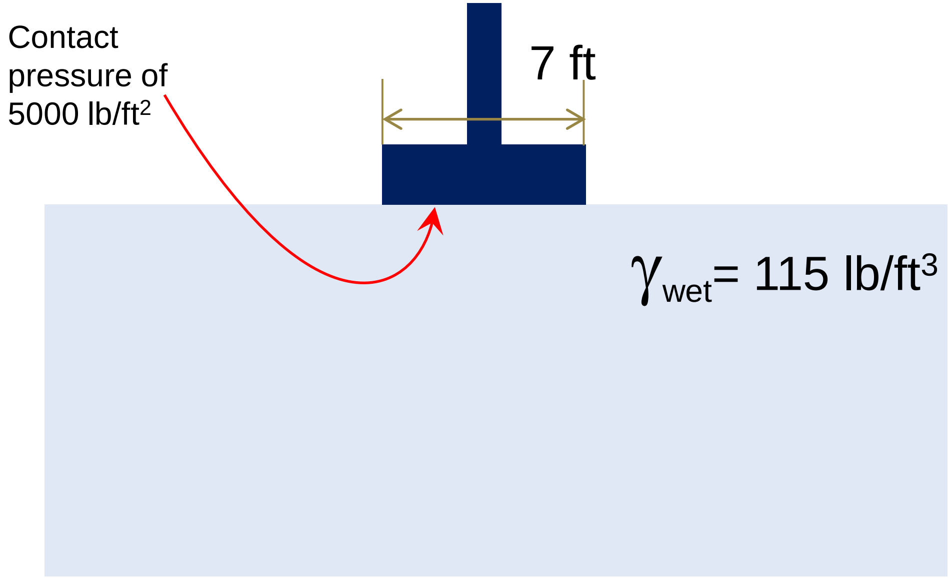




4. Subsurface Sectioning

Boring depth

EXAMPLE

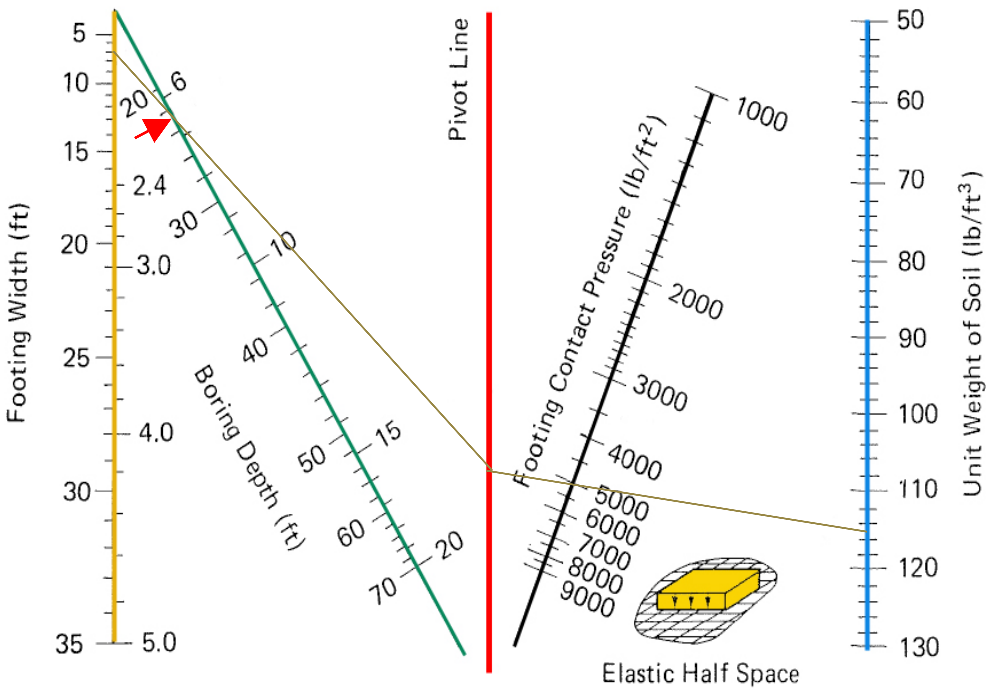


Solution

Since the water table is estimated to be 40 ft beneath the footing and the footing's width is 7 ft, the soil's wet unit weight should be used

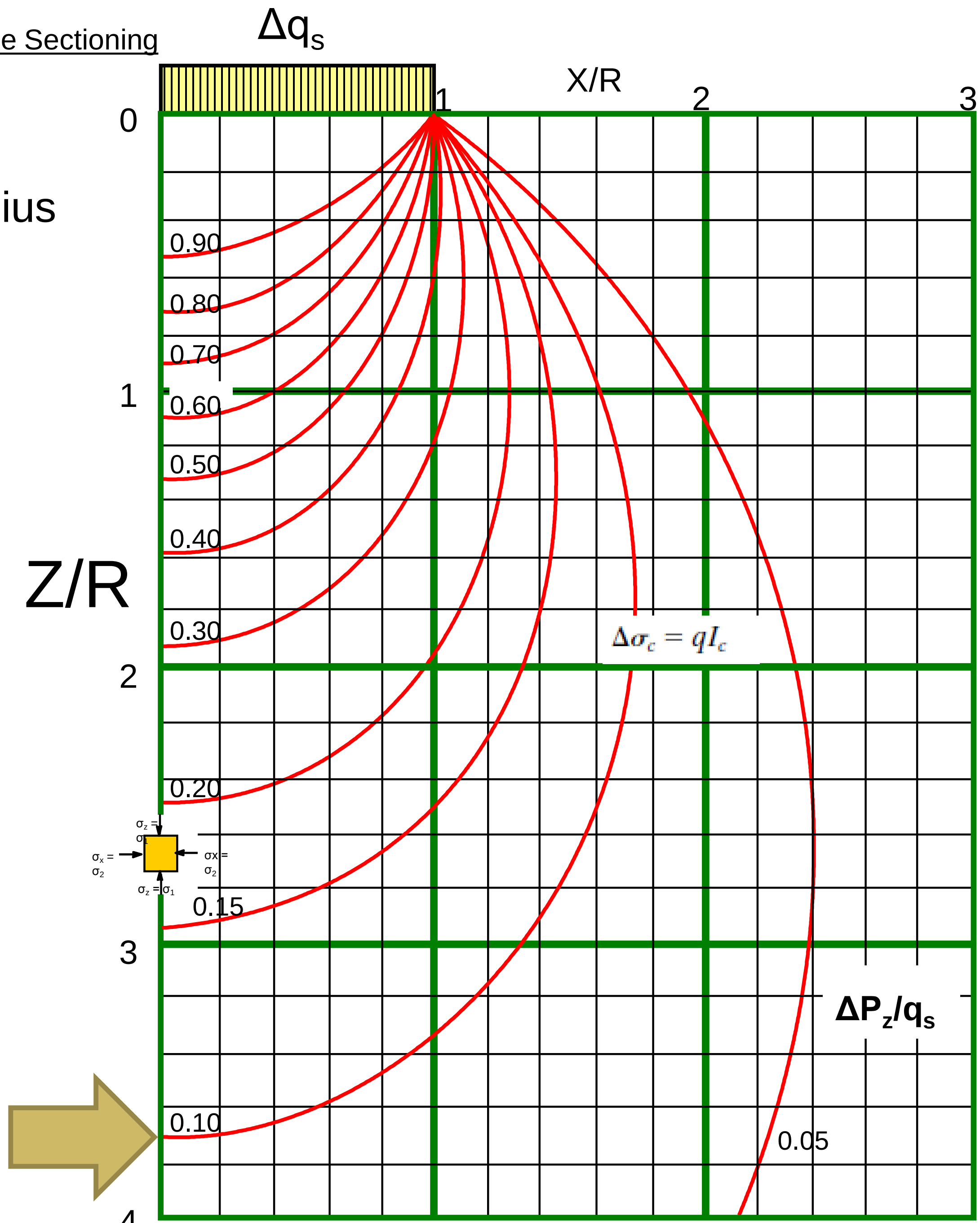
Using γ_{wet} =115 lb/ft^3,
Contact pressure = 5000 lb/ft^2, and
Width of footing =7 ft,

D_b ~ 21.5 ft. use 22 ft.

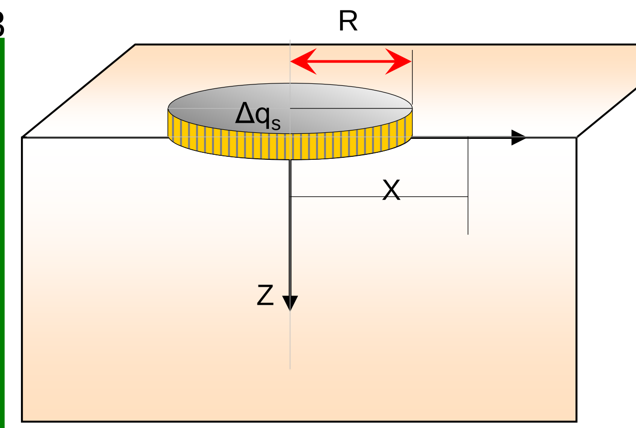


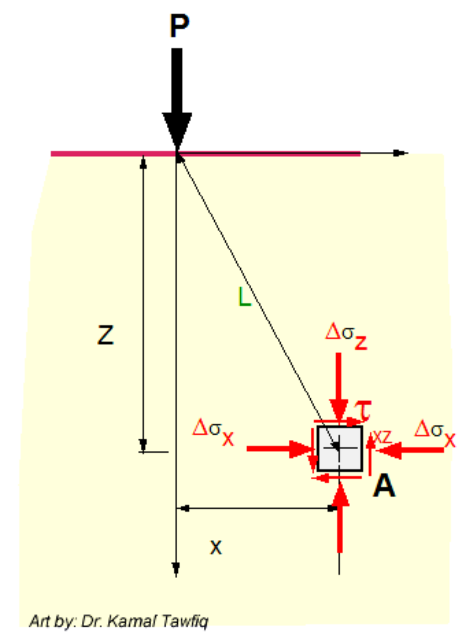
4. Subsurface Sectioning

R = Radius



Circular Load: (Vertical Stress)/(Surface Stress)





Geotechnical Investigation

5. Sample Recovery

5.1 Methods of Sample Recovery

1. *Hand auger*
2. *Split spoon*
3. *Backhoe*
4. *Thin wall tube (Shelby tube)*

5.2 Soil samples obtained during sectioning are either:

1. ***Disturbed***
2. ***Undisturbed***

Disturbed soil samples are used for
1. *Grain size analysis*
2. *Determination of index properties*
3. *Organic content*
4. *Specific gravity*

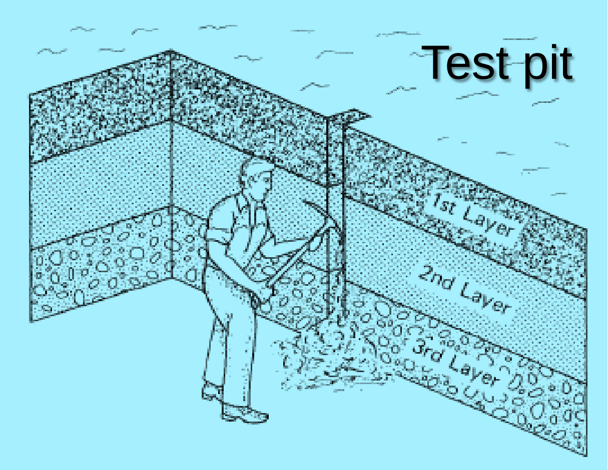
Undisturbed samples are used for
1. *As for disturbed sample*
2. *Determining mechanical properties*
3. *Determining hydraulic properties*

Geotechnical Investigation

Methods of Sample Recovery

1. *Hand auger*

The practical depth of investigation using a hand auger depends upon the soil properties and depth of investigation.



Geotechnical Investigation

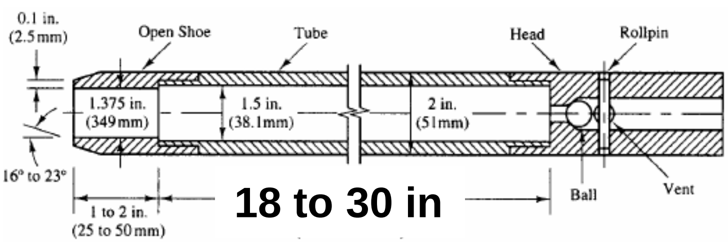
Methods of Sample Recovery

2. Split spoon

- Split spoon sampling methods are used primarily to collect shallow and deep subsurface soil samples.
- All split spoon samplers, regardless of size, are basically split cylindrical barrels that are threaded on each end.
- Split spoon sampling method is used to obtain **<u>disturbed</u>** and **<u>undisturbed</u>** **<u>samples.</u>**
  - *The sampler is driven in into the soil by a hammer*
  - *The weight of the hammer is 140 lb*
  - *The number of blows (N) required to penetrate the spoon of three 6 in. intervals are added and recorded.*

This procedure is called the Standard Penetration Test (SPT)

Actually, the Standard Penetration Number N is the number of blows of the last two intervals (12 in.) The first interval (6 in.) is usually discarded (why?????????)



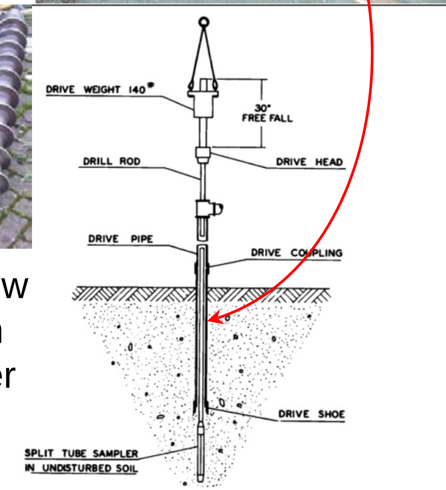
Geotechnical Investigation

THE STANDARD PENETRATION TEST (SPT)   ASTM D1586

- The SPT is one of the most popular and economical means to obtain subsurface information.

- The testing method was standardized in 1958 as ASTM D1568

Hollow Stem Auger



Driving sample

The test consists of:

* A 140 lb driving mass falling from a height of 30 in.

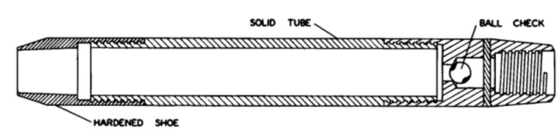
* Drive the standard split spoon sampler a distance of 18 in. into the soil

* Counting the number of blows (N) to drive the sampler 12 in. (6 in. + 6 in.)

* The boring log should show "refusal" and should be halted if:

a- 50 blows are required for any 150 mm increment
b- 100 blows are obtained
c- 10 successful blows produce no advance

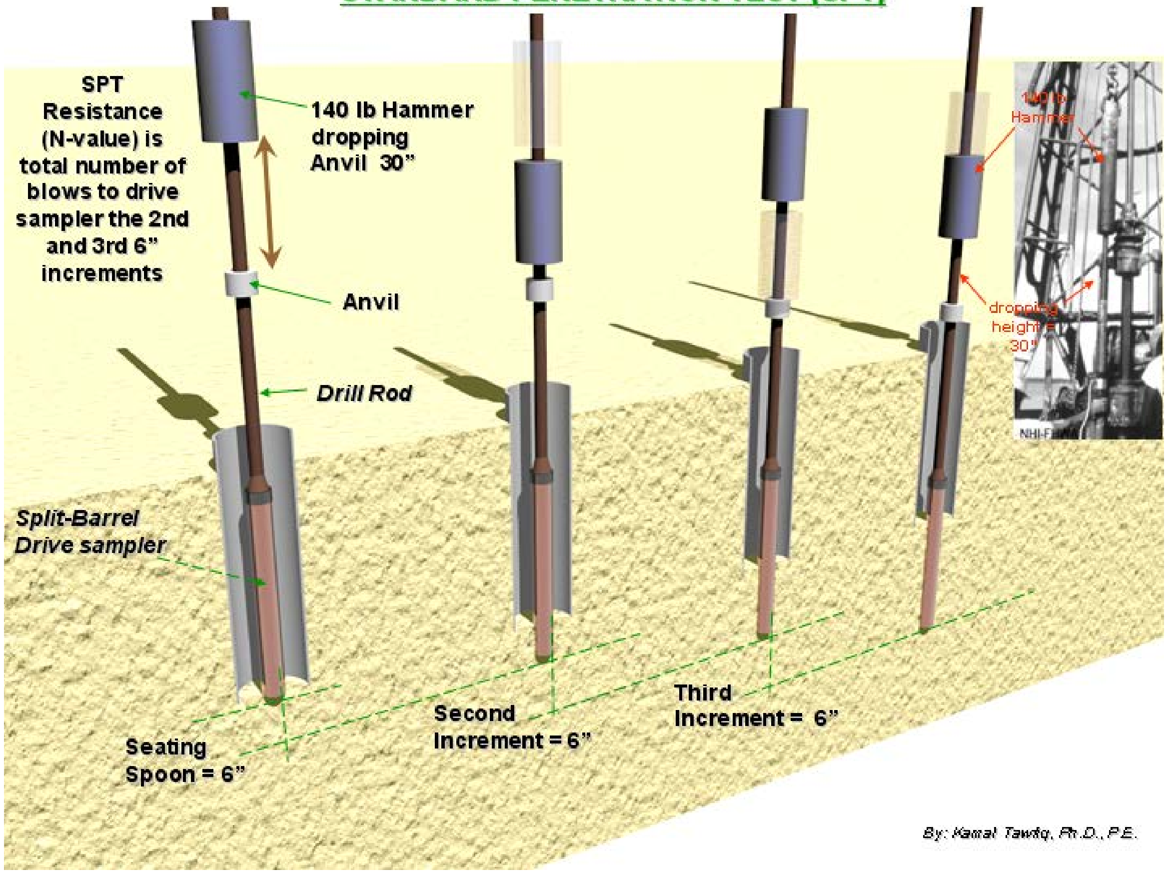
* N should be corrected for the increase of the overburden pressure



Solid tube sampler

THE STANDARD PENETRATION TEST (SPT) ASTM D1586

STANDARD PENETRATION TEST (SPT)



STANDARD PENETRATION TEST (SPT)

SPT vs. Relative Density of Sand — Meyerhoff (1956)

State of Packing	Relative Density	Standard Penetration Resistance (N)	Static Cone Resistance (q_c)	Angle of Internal Friction (ϕ')
	Percent	Blows / ft	Tsf or kgf/cm^2	Degrees
Very Loose	< 20	< 4	< 20	< 30
Loose	20 – 40	4 – 10	20 – 40	30 – 35
Compact	40 – 60	10 – 30	40 – 120	35 – 40
Dense	60 – 80	30 – 50	120 – 200	40 – 45
Very Dense	> 80	> 50	> 200	> 45

SPT vs. Undrained Shear Strength

Soil Consistency	SPT N	S_u (psf)	S_u (kPa)
Very Soft	< 4	< 250	< 12
Soft	2 – 4	250 – 500	12 – 25
Medium	4 - 8	500 – 1000	25 – 50
Stiff	8 – 15	1000 – 2000	50 – 100
Very Stiff	15 – 30	2000 – 4000	100 – 200
Hard	> 30	> 4000	> 200

Terzaghi et al. (1996)

See attached SPT video

Corrections for SPT Field Blow-count (N_{Field})

1- Peck & Bazaraa (1969) suggested

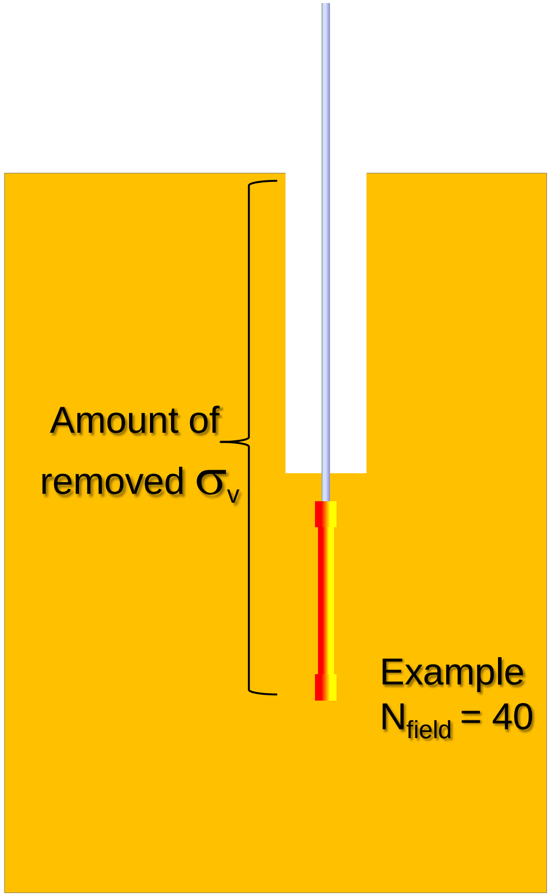
$$N_{cor} = \frac{4\ N_f}{1 + 2\ \sigma_v} \qquad \text{For } (\sigma_v < 1.5 \text{ kips/ft}^2)$$

$$N_{cor} = \frac{4\ N_f}{3.25 + 0.5\ \sigma_v} \qquad \text{For } (\sigma_v > 1.5 \text{ kips/ft}^2)$$

σ_v = Vertical effective stress at the sampling depth (kips/ft^2)

2- Peck, Hanson, and Thornburn (1974) proposed

$$N_{cor} = \left(0.77 \log \frac{20}{\sigma_v}\right) (N_f) \qquad \text{For } (\sigma_v \text{ in tons/ft}^2)$$



1 kip = kilopound = 1000 lb = 4448.2216 Newtons (N) = 4.4482216 kilonewtons (kN)

1 US ton = 2000 lb

Corrections for SPT Field Blow-count (N_{Field})

Example 1:

Given:

SPT = 40 at 20' in sand

$\gamma_{sand} = 115$ lb/ft^3

Find:

N_{cor} = ??

Solution:

Using Peck, Hanson, and Thornburn (1974) equation

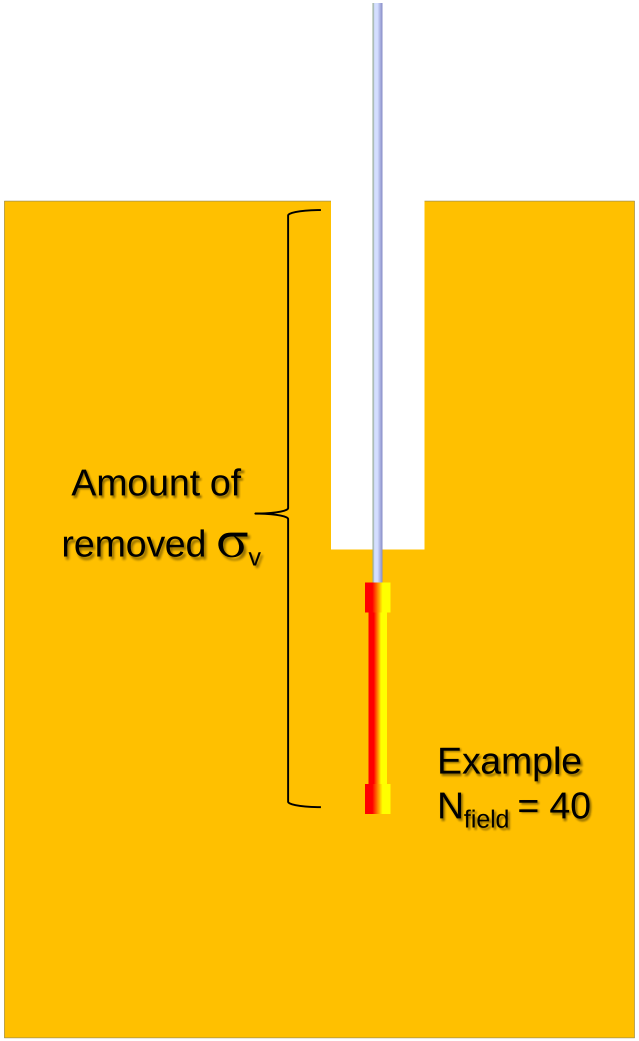
$$N_{cor} = \left(0.77 \log \frac{20}{\sigma_v} \right) (N_f) \quad \text{For } (\sigma_v \text{ in tons/ft}^2)$$

$C_N = 0.77 \log (20/\sigma_v)$

σ_v = (20) (115)/ 2000(lb/ton) = 1.15 tons/ft^2

$C_N = 0.77 \log (20/1.15) = 0.955$

N_{cor} = (0.955) (40) = 38



Corrections for SPT Field Blow-count (N_{Field})

Example 2:

Given:

SPT = 40 at 20' in sand

γ_{sand} = 115 lb/ft^3

Find:

N_{cor} = ??

Solution:

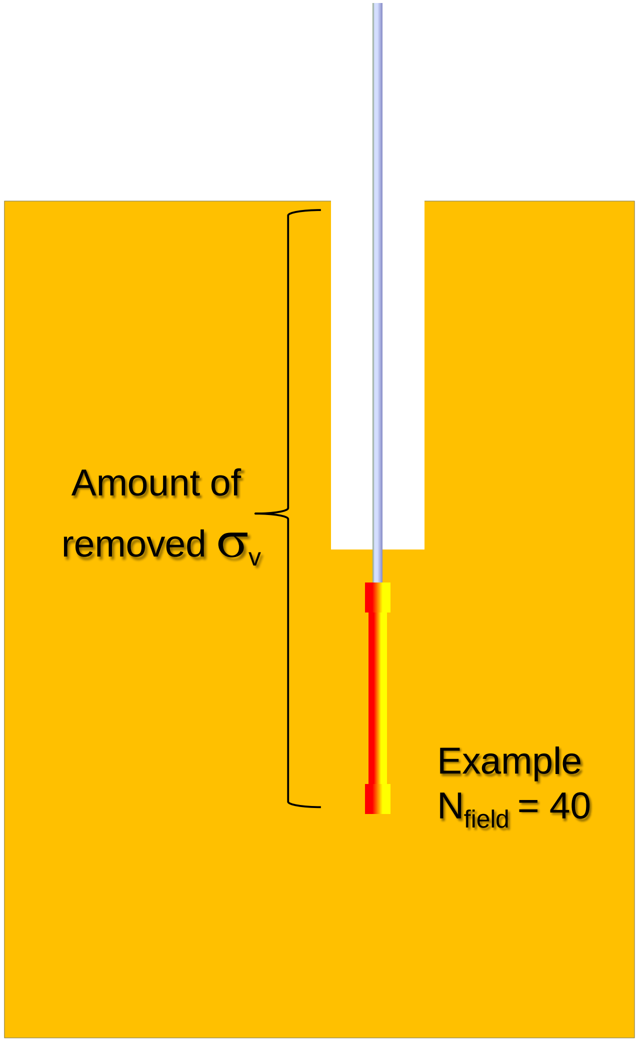
Using Peck & Bazaraa (1969) equation

σ_v = [(20)(115) / 1000 (lb/kip)] = 2.3 kips/ft^2

Since σ_v is > 1.5 kips/ft^2 use

$$N_{cor} = \frac{4\ N_f}{3.25 + 0.5\ \sigma_v} \qquad \text{For } (\sigma_v > 1.5 \text{ kips/ft}^2)$$

N_{cor} = 4 (40) / [3.25+(0.5)(2.3)] = 36



Corrections for SPT Field Blow-count (N_{Field})

Skempton (1986) suggested the following correction for the SPT field blow-coun
N_f

$$N_{60} = \frac{E_m\, C_b\, C_r\, N_f}{60}$$

Assuming 60% hammer efficiency

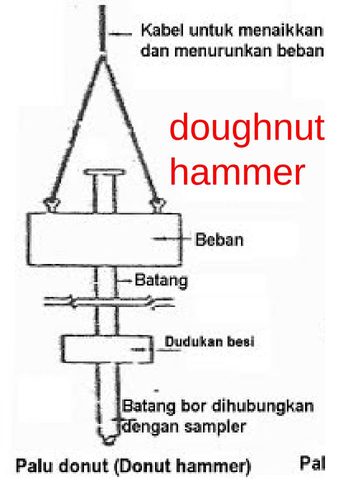
Where:

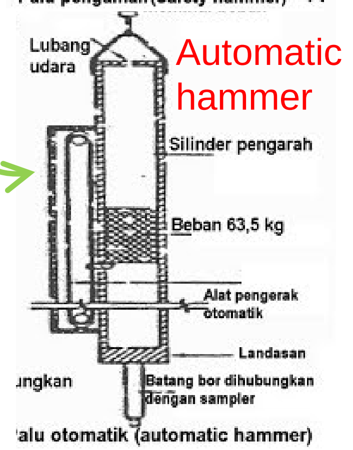
E_m = Hammer efficiency **(for U.S. equipment, E_m= 0.6 for a <u>safety hammer</u>, and 0.45 for a <u>doughnut hammer</u>).** For **<u>automatic systems</u>** that lift the hammer and allow it to drop unimpeded can deliver higher energy to the drill rods with values of **<u>E_m as high as 95</u> percent** (ASTM D 6066-96, 2004).

C_b = Borehole diameter correction (**C_b = <u>1.0</u>** for borehole = 65 to 115 mm diameter, **<u>1.05</u>** for 150 mm diameter, and **<u>1.15</u>** for 200 mm diameter)

C_r = Rod length correction (**C_r = <u>0.75</u>** for up to 4 m for drill rods, **<u>0.85</u>** for 4 to m drill rods, **<u>0.95</u>** for 6 to 10 m drill rods, and **<u>1.00</u>** for rods in excess of 10 m)

As an average value N_{60} = 0.5 to 0.67N_f





Correction of N Value for foundations in an earthquake zone

engineering, such as liquefaction analyses, the standard penetration test N_{60} value is corrected for the overburden soil pressure, also known as the effective overburden pressure or the vertical effective stress (σ_v).

$$(N_1)_{60} = C_N \; N_{60} = \left[\frac{100}{\sigma_v}\right]^{0.5} N_{60}$$

$$N_{60} = \frac{E_m \, C_b \, C_r \, N_f}{60}$$

Where:

$(N_1)_{60}$ = *standard penetration test N value corrected for both field testing procedures and overburden pressure*

C_N = *correction factor to account for the overburden pressure, and it is approximately equal to* $(100/\sigma_v)^{0.5}$ *where* σ_v *is the vertical effective stress, in kPa.*

Suggested maximum values of C_N *range from* **1.7 to 2.0** *(Youd and Idriss, 1997, 2001).*

N_{60} = *standard penetration test N value corrected for field testing procedures. The* N_{60} *is calculated by using Skempton's equation.*

Relationship between bearing capacity factors, ϕ, and SPT

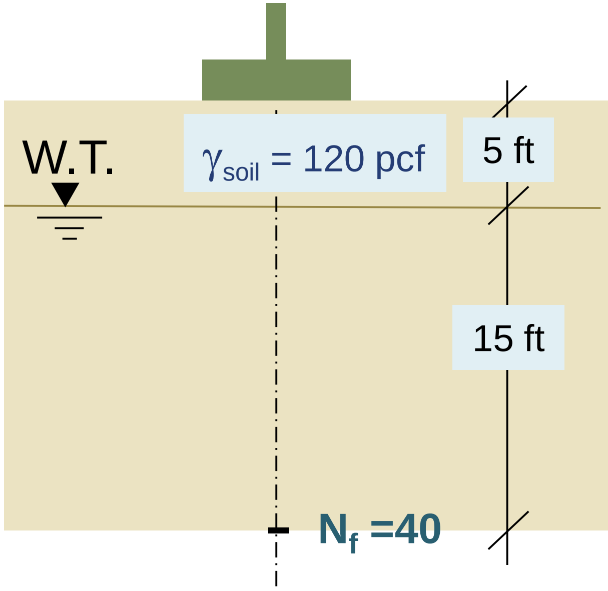
Example

Given:

$N_f = 40$

Water Table = 5'

γ_{soil} = 120 pcf



Find:

N_q, N_γ and ϕ

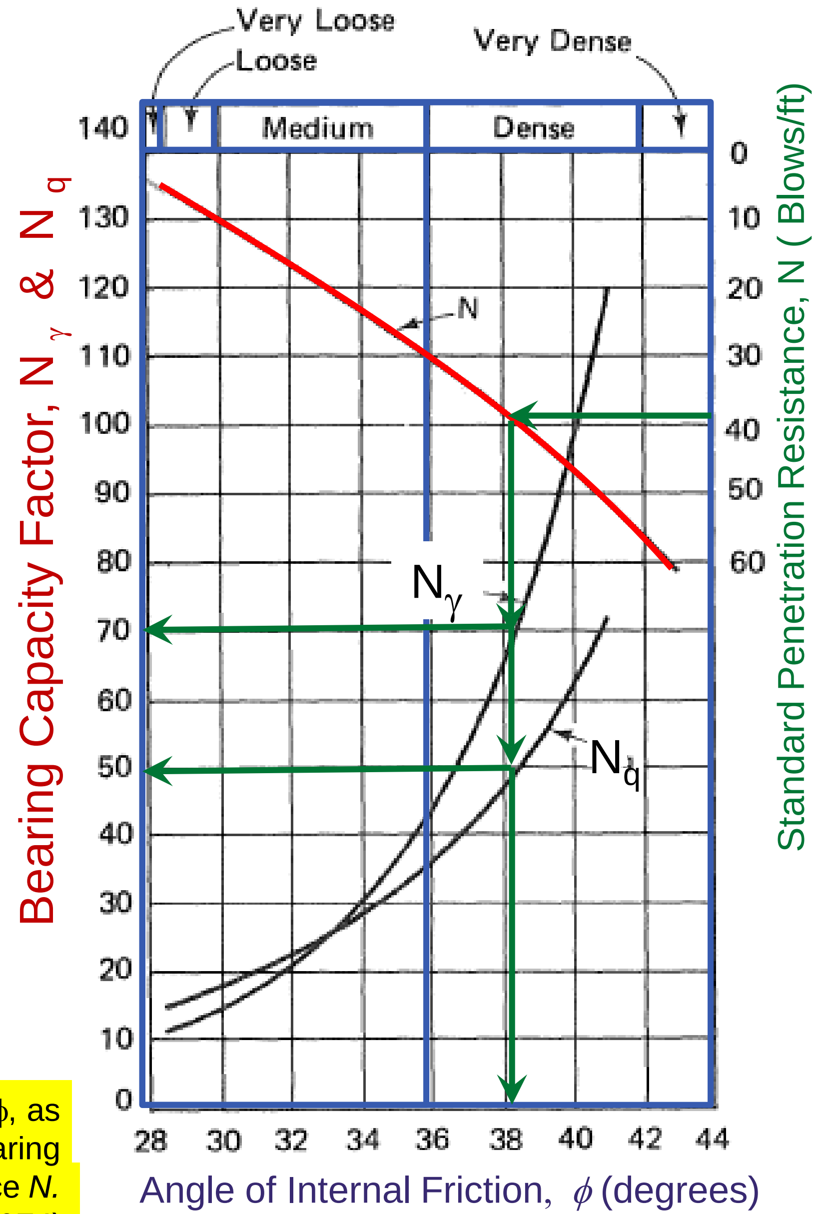
Solution:

$\sigma_v = \{(5)(120)+[15(120-62.4)]\}/2000$ lb/ton =

= ton/ft^2

$N_{cor} = C_N N_f = 0.77 \log (20/\quad) =$

N_q, = N_γ = ϕ =



Curves showing the relationship between bearing capacity factors and ϕ, as determined by theory, and rough empirical relationship between bearing capacity factors or ϕ and values of standard penetration resistance *N.* *Peck et al. (1974)*

Geotechnical Investigation

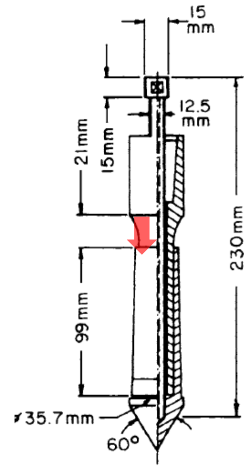
Cone Penetration Test (CPT)

The most common type of mechanical penetrometer is **the Dutch mantle cone** and is abbreviated CPT.

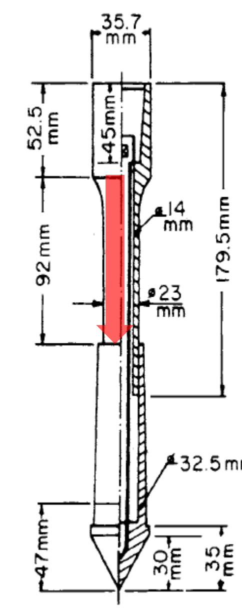
The cone is pushed into the soil to the desired depth (initial position) and then force is applied to the inner rod, which moves the cone downward into the extended position.

The cone is pushed into the soil at a rate of about 2 to 4 ft/min (10 to 20 mm/sec). The required force to move the cone into the extended position divided by the horizontally projected area (10 cm^2) of the cone is defined as the cone resistance q_c *, also known as the cone bearing or the* end bearing resistance.

By continually repeating the two-step process shown in the figure, the cone resistance q_c *is obtained at increments that ordinarily do not exceed 8 in. (20 cm).*



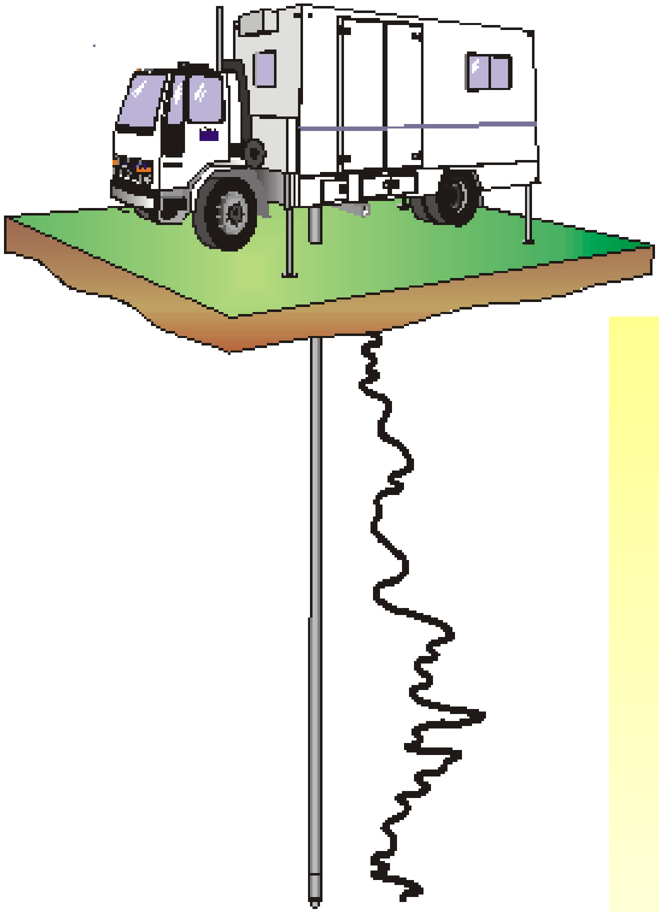
INITIAL POSITION

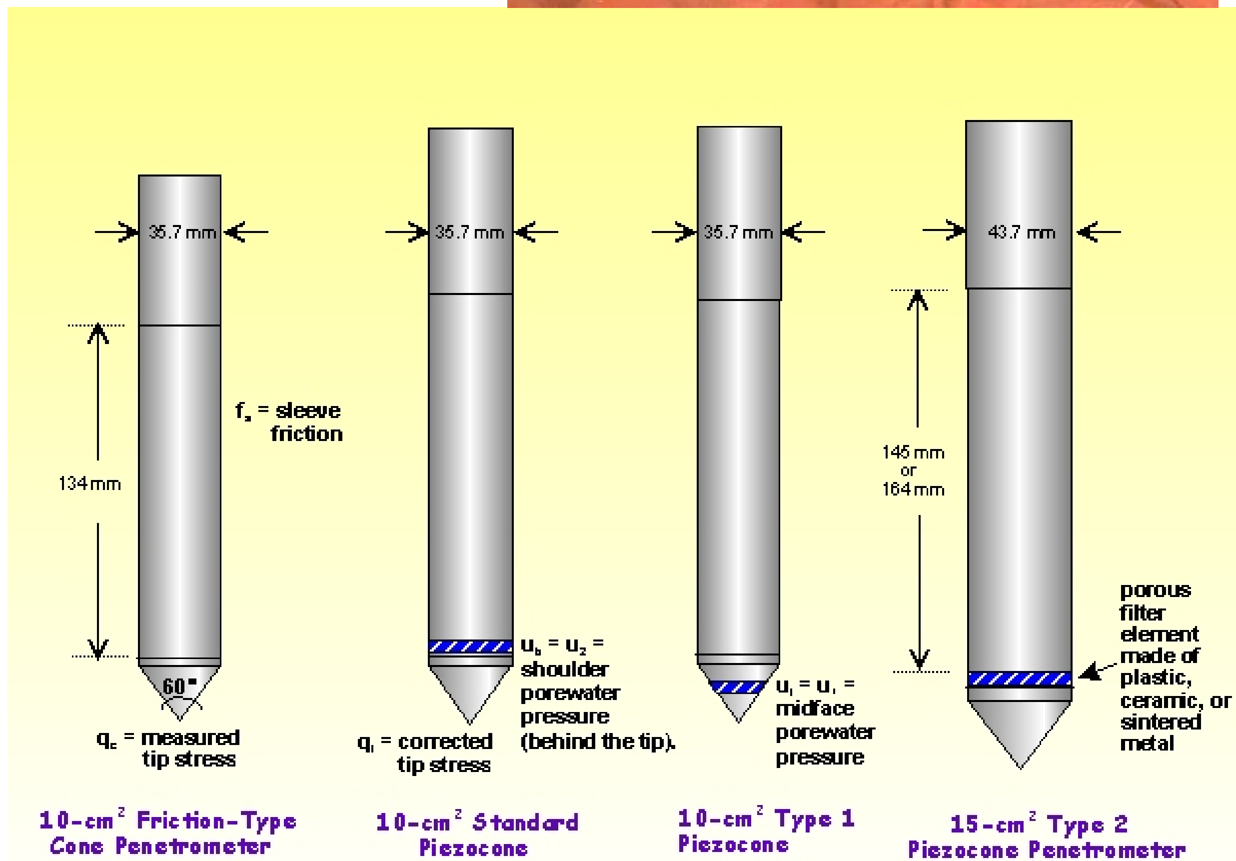


EXTENDED POSITION

2 to
4 ft/min

Cone Penetration Test (CPT)





Friction CPT | Standard Piezocone | Type 1 Piezocone | Type 2 Piezocone

Cone Penetration Test (CPT)

Special features of the cone penetration test are as follows:

1. Cone resistance versus depth.

A considerable amount of work has been performed in correlating cone resistance q_c *with subsurface conditions. Figure1 presents four examples,* where the cone resistance q_c has been plotted versus depth below ground surface. The shape of the cone resistance q_c *plots versus depth can be used to identify sands, clays, cavities, or rock.*

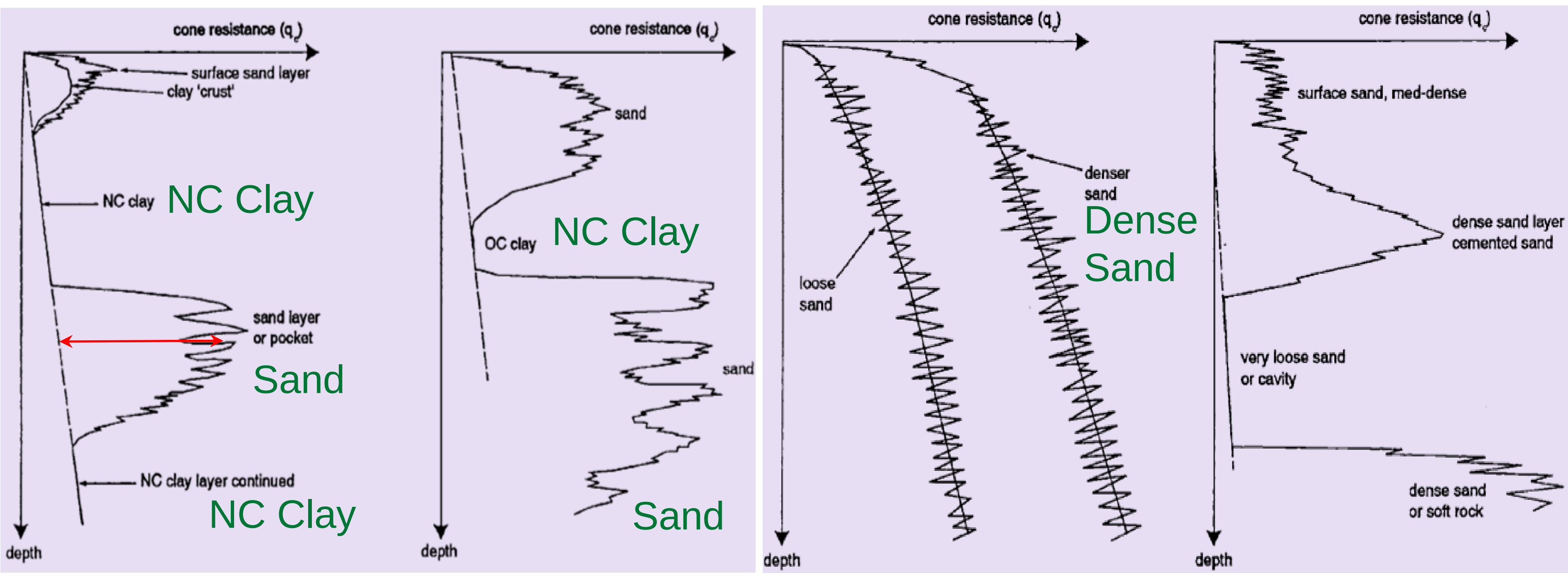


Figure1: Simplified examples of CPT cone resistance qc versus depth, showing possible interpretations of soil types and conditions. (From Schmertmann, 1977.)

Cone Penetration Test (CPT)

Special features of the cone penetration test are as follows:

2. *Friction ratio.*

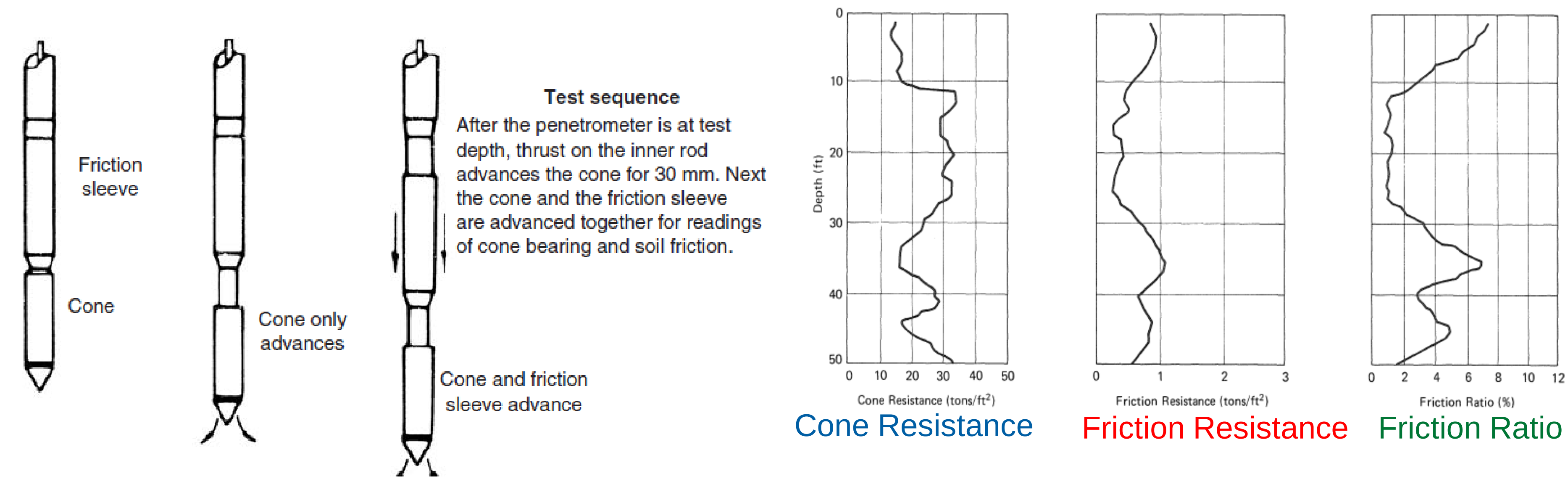
The figure below illustrates the two-step process that can be used to obtain the soil friction along a side sleeve f_s.

1- In the **first step**, the cone resistance is obtained (q_c) = 1000 psi

2- in the **second step**, the cone plus sleeve friction is determined (q_c + f_s) = 1440 psi

3- Subtraction gives **the sleeve friction (**f_s) = 440 psi

The friction ratio **(FR)** can then be calculated, defined as **FR** = sleeve friction (f_s) divided by cone resistance = (f_s/q_c)x100. By knowing the friction ratio (**FR**) and cone resistance q_c, **the type of soil** can be estimated by using Fig. 2.



Test sequence for obtaining the sleeve friction from the Dutch cone penetrometer and an example of the test data plotted versus depth.

Cone Penetration Test (CPT)

Figure 2: Guide for estimating soil type from Dutch mantle cone

Steps:

1- Enter chart with cone resistance q_c *and friction ratio*

2- FR = sleeve friction divided by cone resistance = $(f_s / q_c)x100.$

(From Schmertmann, 1977)

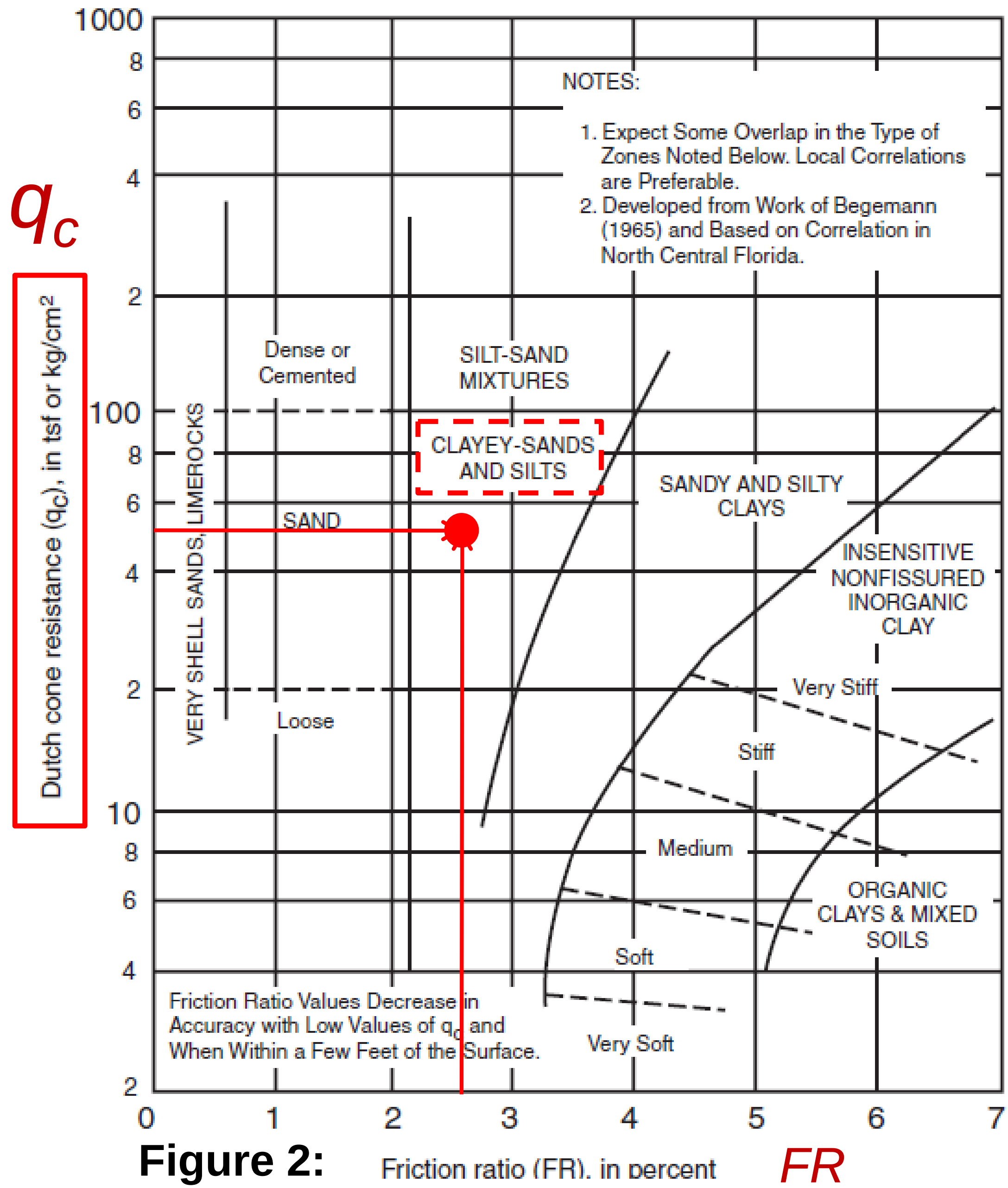
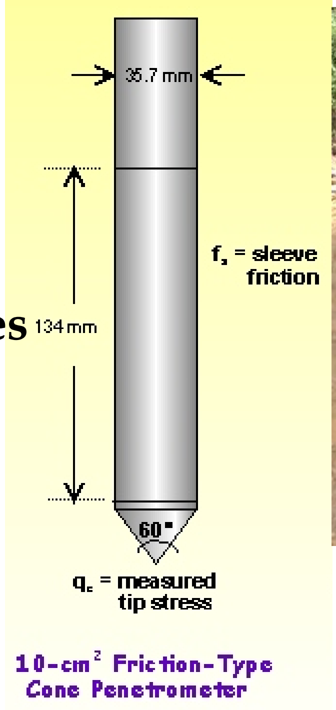
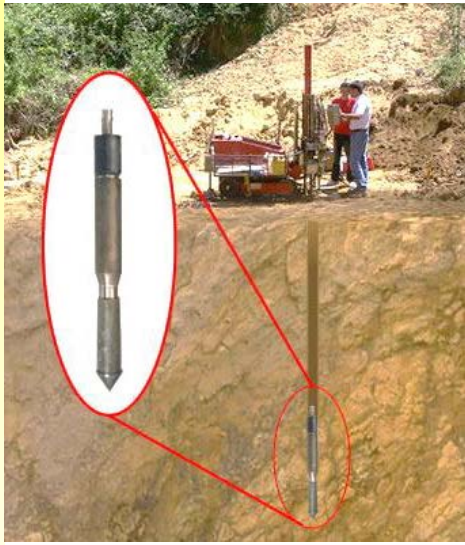


Figure 2:

Cone Penetration Test (CPT)



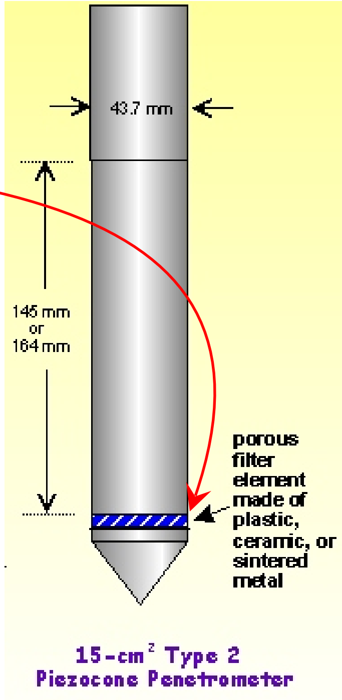


Other Cone Penetrometers.

Besides the mechanical cone, there are other types of cone penetrometers, such as:

Electric cone. A cone penetrometer that uses electric-force transducers built into the apparatus for measuring cone resistance and friction resistance.

Piezocone. A cone penetrometer with the additional capability **of measuring pore water pressure** generated during the penetration of the cone.



Special devices. The cone can even be equipped with a video camera to enable the type of soil to be viewed during the test (Raschke and Hryciw, 1997).

Cone Penetration Test (CPT)

A major advantage of the cone penetration test (CPT)

- It provides almost a continuous subsurface record of the cone resistance q_c and f_s

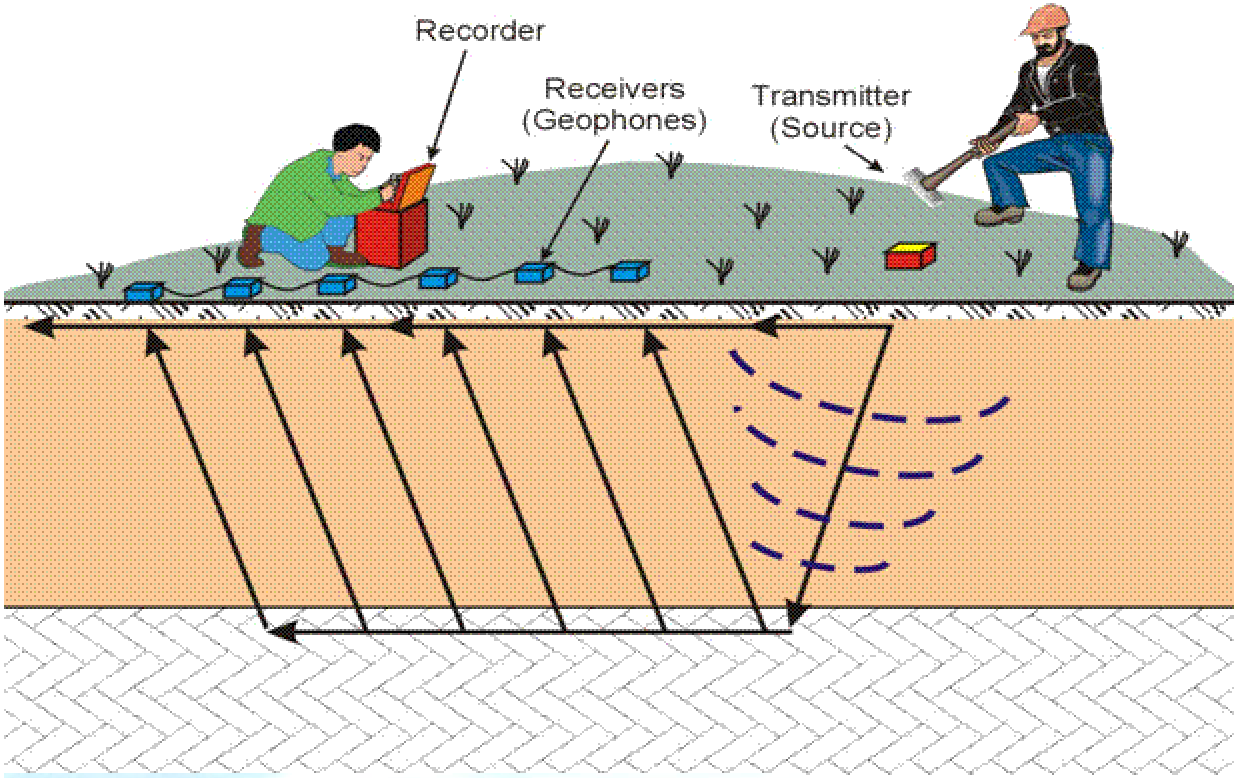
This is in contrast to the **SPT**, which obtains data at much larger intervals in the soil deposit.

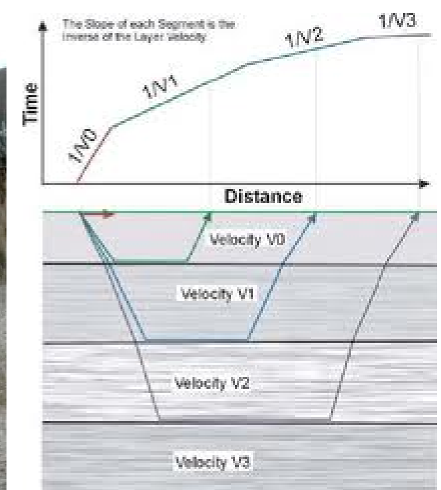
Disadvantages of the **CPT** are that soil samples cannot be recovered and special equipment is required to produce a steady and slow penetration of the cone.

Unlike the SPT, the ability to obtain a steady and slow penetration of the cone is not included as part of conventional drilling rigs.

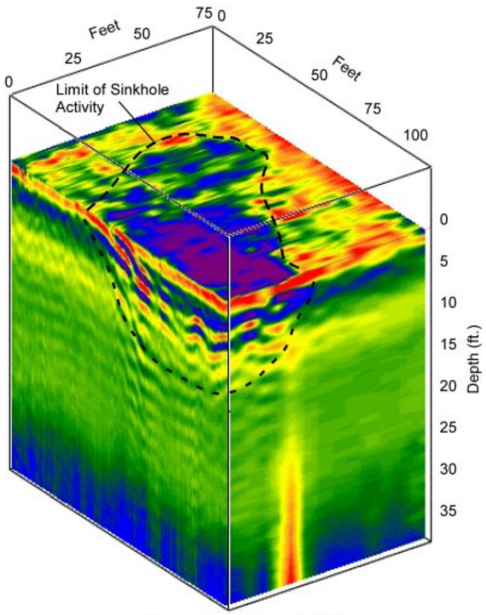
Because of these factors, in the United States, the CPT is used less frequently than the SPT.

Seismic refraction (for large areas)

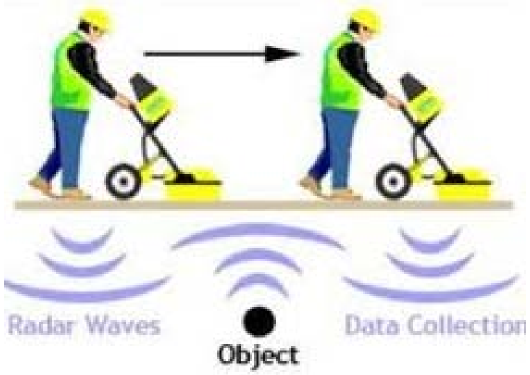


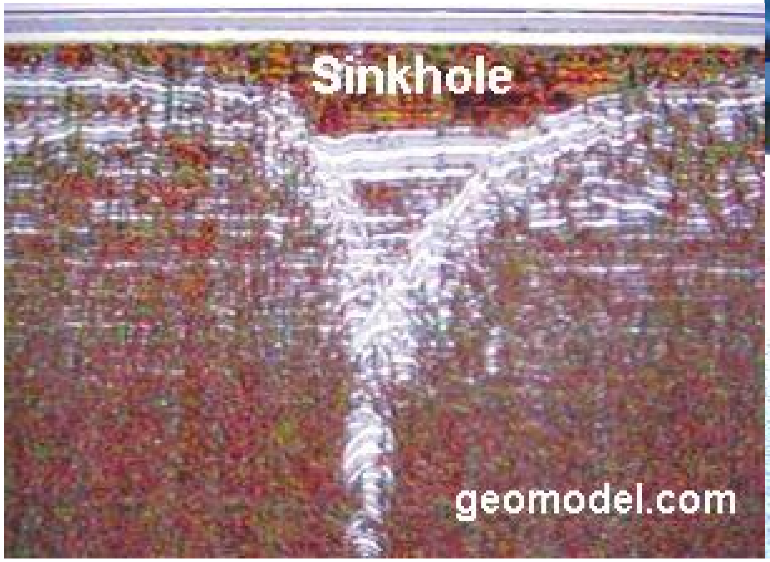


Ground Penetration Radar (GPR)

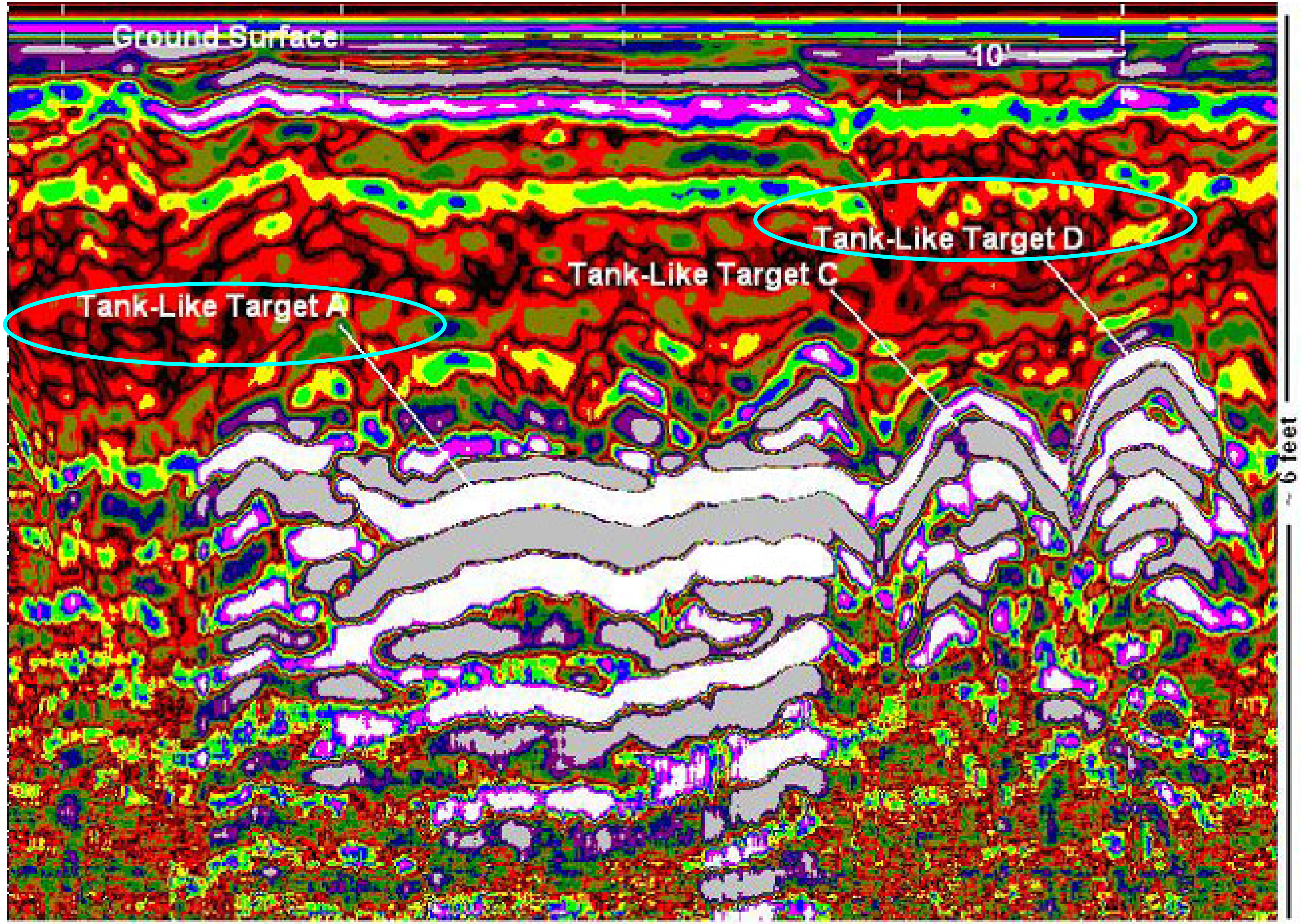


Three Dimensional View of GPR Profiles Over Sinkhole



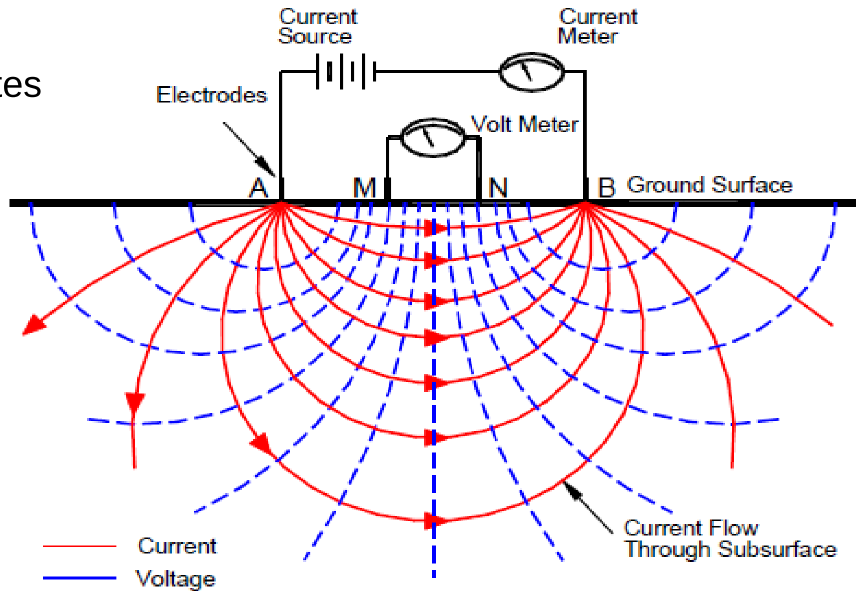


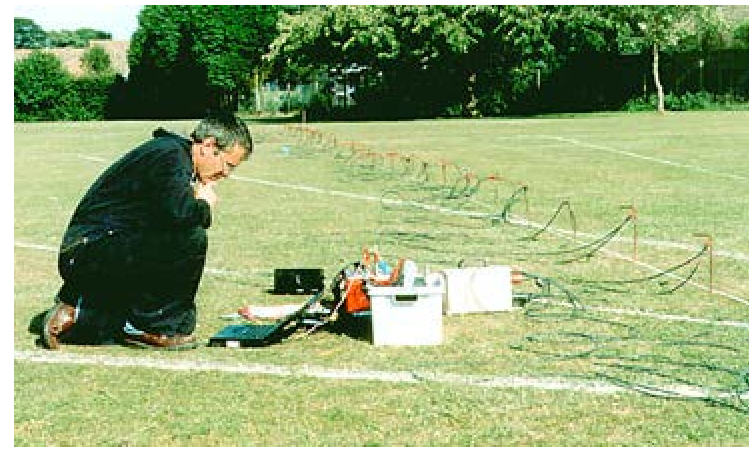
Ground Penetration Radar (GPR)



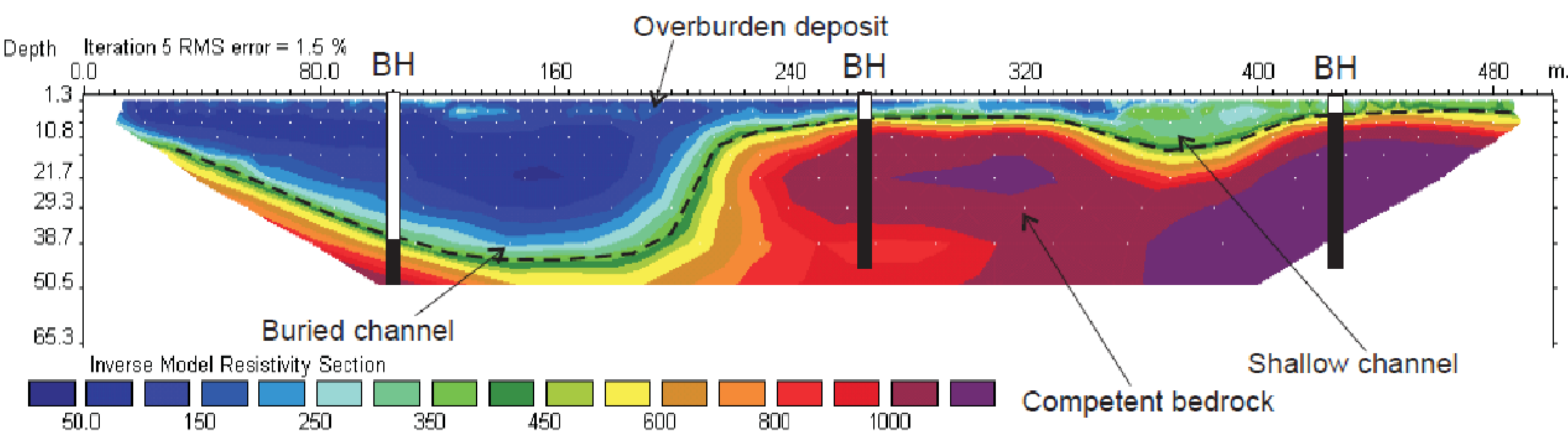
Geo-electrical Profiling using Electrical resistivity or D.C. Resistivity Method

Good for sensing buried wastes and waste migration

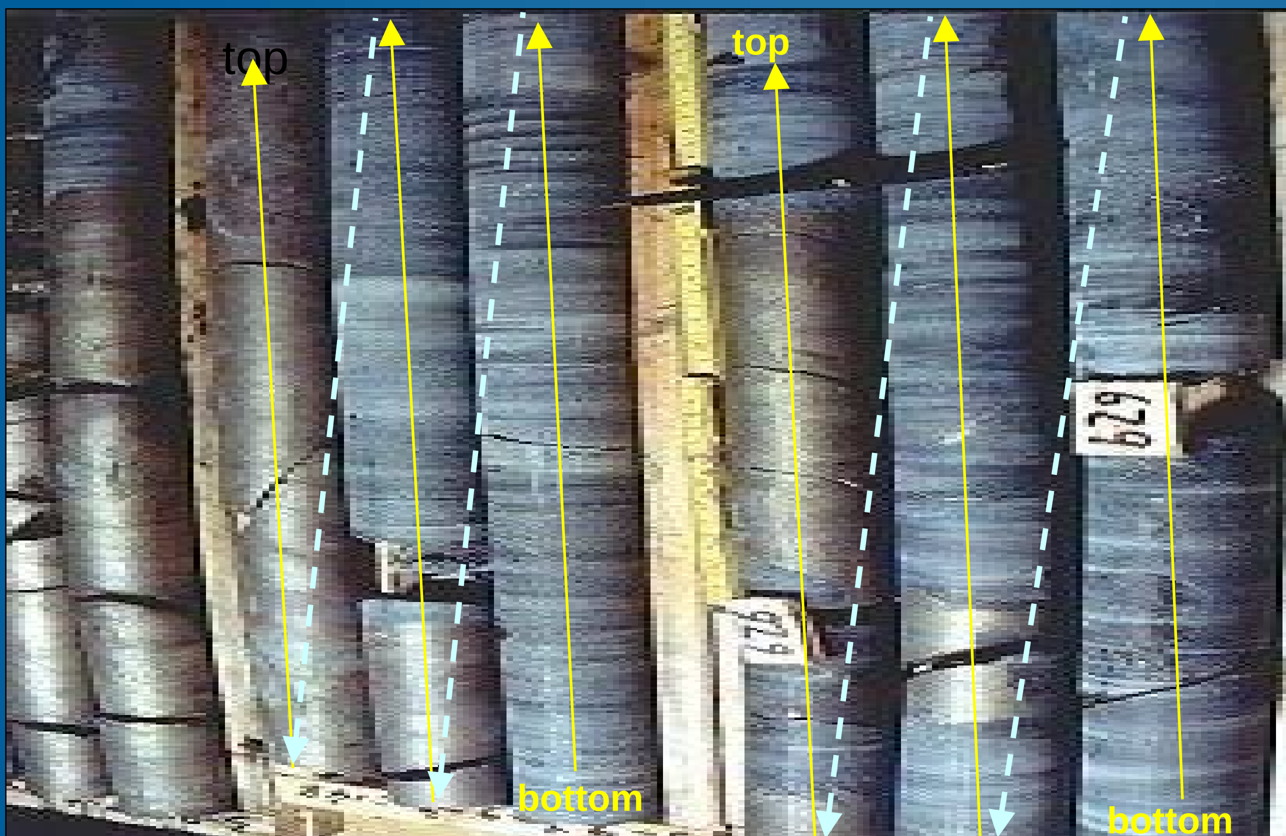




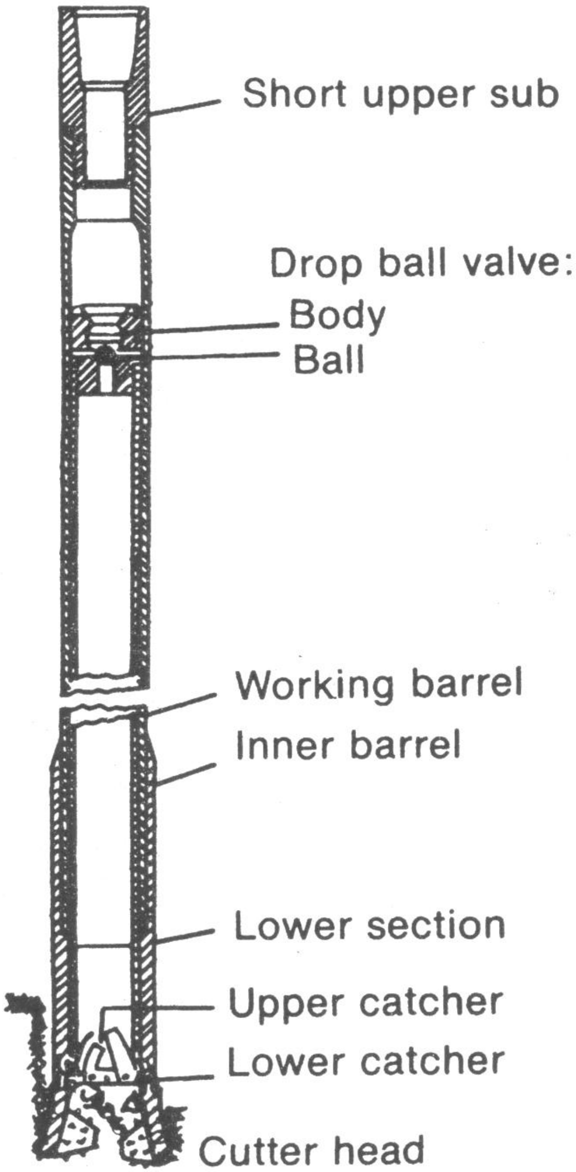
Schematic Illustrating Basic Concept of
D.C. Resistivity Crew In Operation Electrical Resistivity Measurement

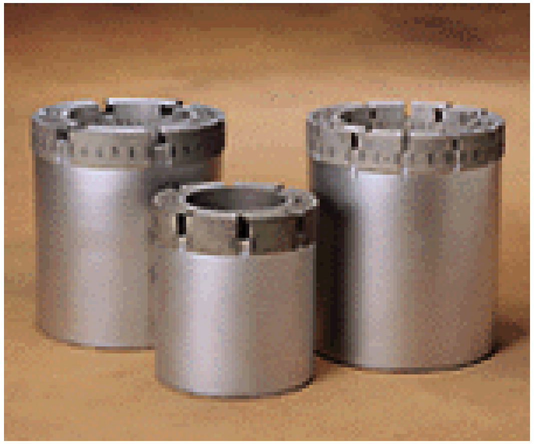


Geotechnical Investigation



Rotary core barrel





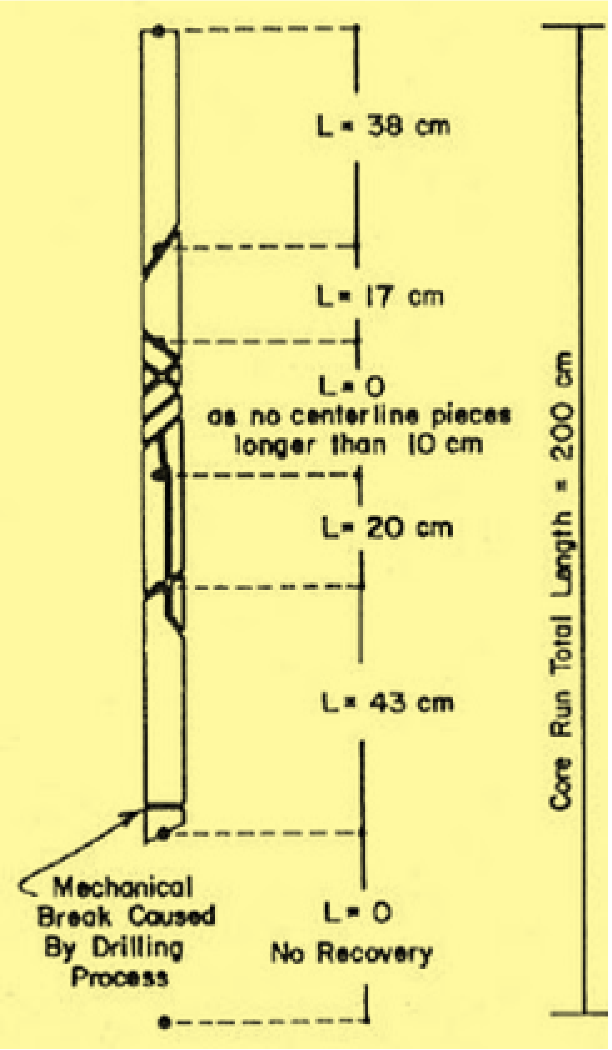
Coring bits are commonly 1.75 to 5.25 inches in diameter.

Diamond or Tungsten carbide insets on rotary coring bit.

Core recovery parameters describe the quality of core recovered from a borehole.

Total core recovery (TCR)

TCR is the borehole core recovery percentage.



TCR is defined as the quotient:

$$\% \; TCR = \left(\frac{\sum L_{\text{sum of pieces}}}{L_{\text{total core run}}} \right) \times 100$$

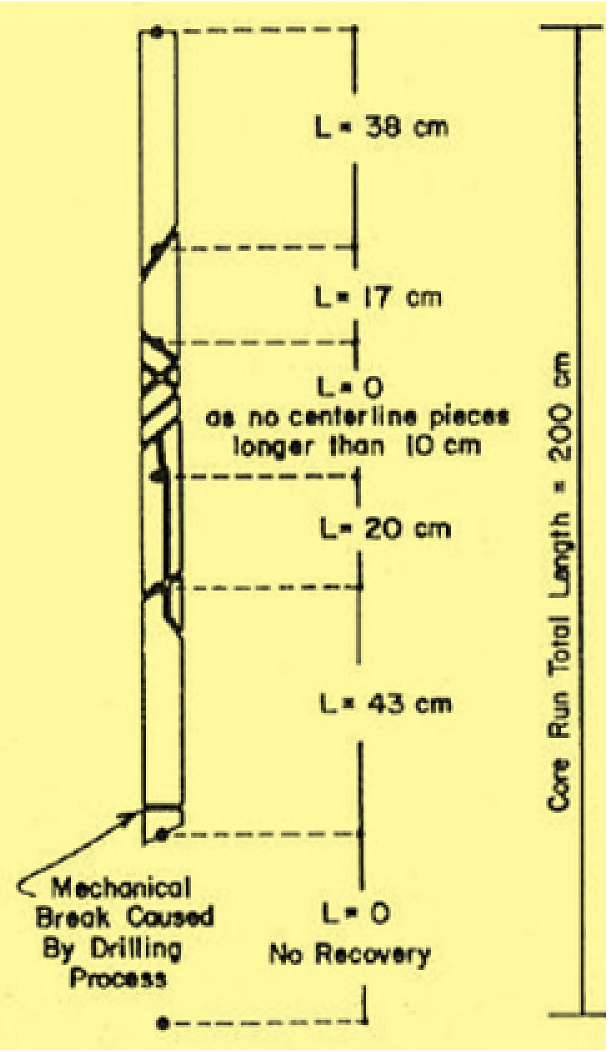
$L_{\text{sum of pieces}}$ = Sum of length of core pieces

$L_{\text{total core run}}$ = Total length of core run

Core recovery parameters describe the quality of core recovered from a borehole.

Solid core recovery (SCR)

Solid core recovery (SCR) is the borehole core recovery p
cylindrical, pieces of rock core.



SCR is defined as the quotient:

$$SCR = \left(\frac{L_{\text{sum of solid core pieces}}}{L_{\text{total core run}}}\right) \times 100$$

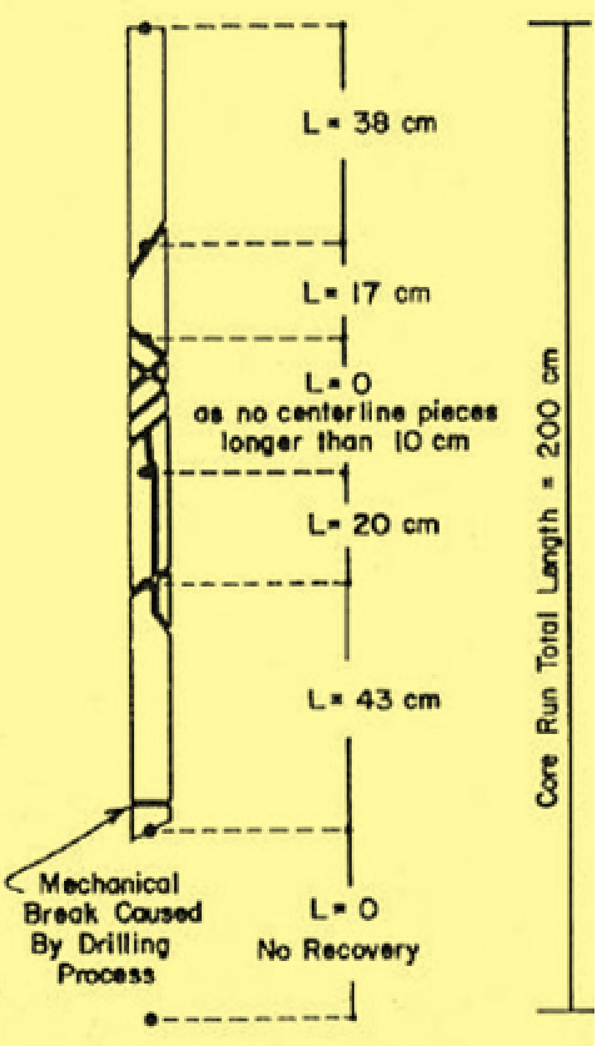
Rock Quality Designation (RQD) Factor

Developed in 1964 by Deere

Rock-Quality Designation (RQD) is a rough measure of the degree of jointing or fracture in a rock mass, measured as a percentage of the drill core in lengths of 10 cm or more.

$$\mathbf{RQD} = \frac{\sum L_{\text{sum of 10cm}}}{L_{\text{total core run}}} \mathbf{\times 100}$$

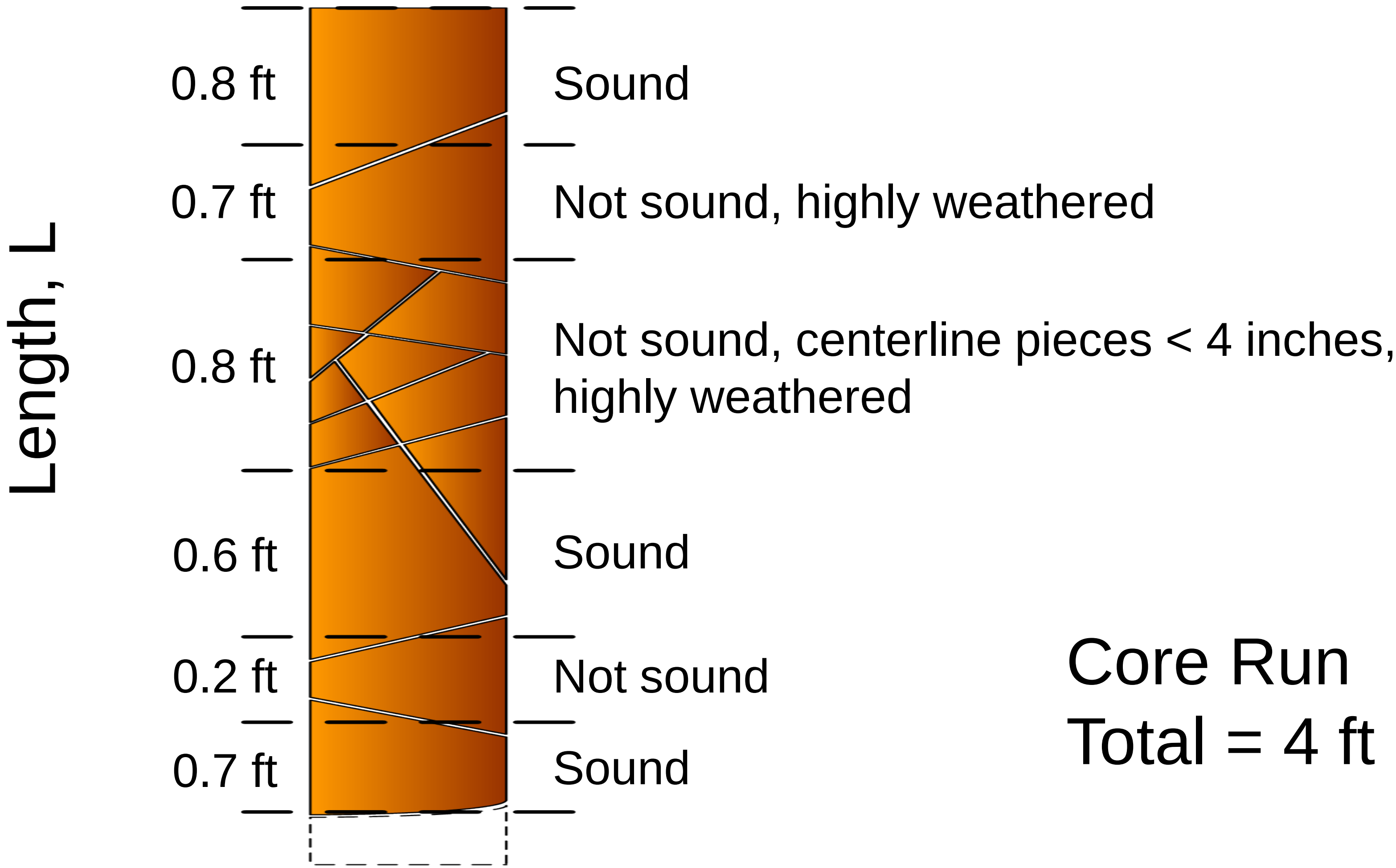
$L_{\text{sum of 10cm}}$ = Sum of length of core sticks longer than 10 cm measured along the center line of the core



From the RQD index the rock mass can be classified as follows:

RQD	Rock mass quality
<25%	very poor
25-50%	poor
50-75%	fair
75-90%	good
90-100%	excellent

Rock Quality



Core Run
Total = 4 ft

$CR = 95\%$ $RQD = 53\%$

NEW SECTION

Geotechnical Investigation

MEASUREMENTS OF MATERIAL PROPERTIES

Soil Properties

1. **Physical properties**
2. **Index Properties**
3. **Hydraulic Properties**
4. **Mechanical Properties**

MEASUREMENTS OF MATERIAL PROPERTIES

Methods of Measurement

1- Laboratory Testing Methods

2- In-Situ Testing Methods

3- Empirical Correlation's

Terzaghi & Peck (1948): Cc = 0.009 (w_c – 10%)

Skempton (1944): Cc 0.007 (w_c – 7%)

MEASUREMENTS OF MATERIAL PROPERTIES

Methods of Measurement

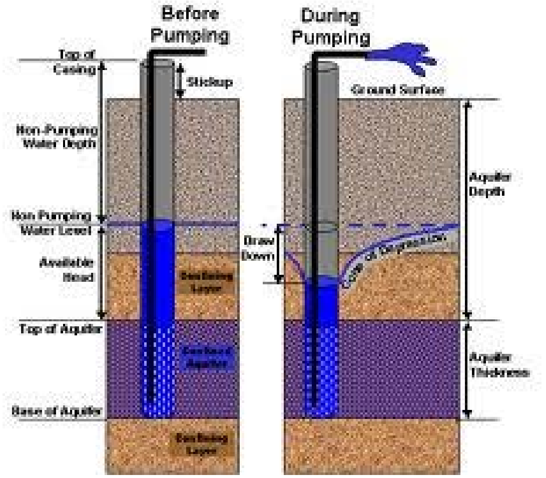
1- Laboratory Testing Methods

- Provide better control over the boundary conditions
- Different parameters can be determined individually or in combination
- Results can be produced

MEASUREMENTS OF MATERIAL PROPERTIES

Methods of Measurement

2- In-Situ Testing Methods



1. Measurements of properties for large soil masses
2. Less disturbance
3. Measurements under real field conditions
4. Can be performed during site exploration (SPT & CPT)

In-Situ testing methods are used to determine:

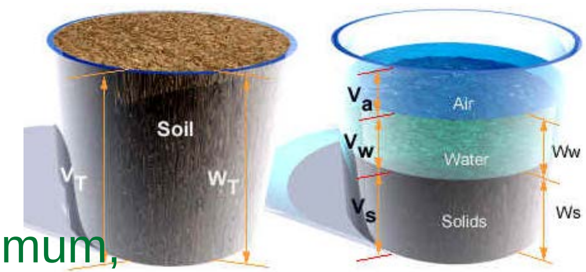
1- *Hydraulic properties (Wells)*

2- *Mechanical properties (SPT, CPT, Vane Shear Test, Pressuremeters, CBR) (See Table 3.20)*

<u>MEASUREMENTS OF MATERIAL PROPERTIES</u>

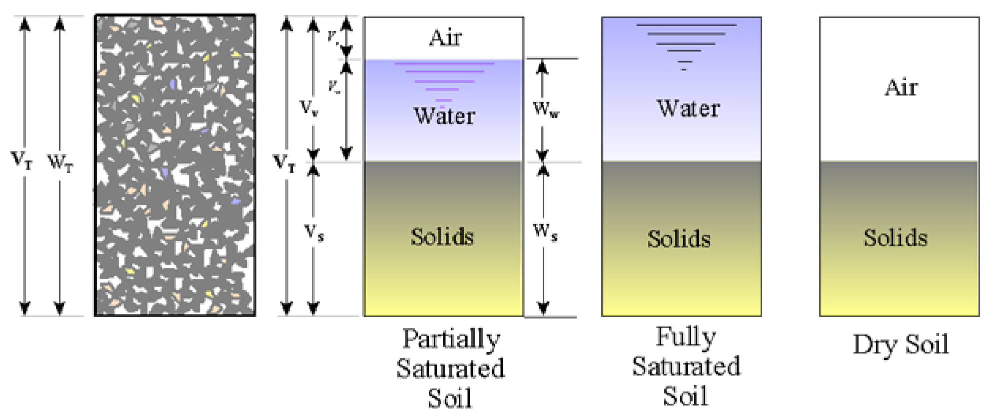
<u>Soil Properties</u>

1- Physical properties: Used to describe the soil. These properties are incorporated with the soil <u>classification</u> systems, and in some cases they are related to the <u>mechanical properties</u>



Phase Diagram

- Specific gravity
- Grain size
- Density (Saturated, Partially saturated, submerged, minimum, maximum, relative, optimum moisture content)
- Porosity
- Degree of saturation
- Void ratio
- Moisture content
- Hardness (for rocks)
- Durability (for rocks)
- Reactivity (for rocks)



<u>MEASUREMENTS OF MATERIAL PROPERTIES</u>

Soil Properties

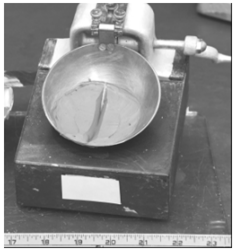
2- Index Properties: Used to <u>classify</u> the soil or to <u>correlate</u> with the mechanical properties.

- Atterberg Limits or Consistency Limits (LL, PL SL)
- Moisture Content vs. Unit Weight Relationship (Compaction)
- Grain Size Distribution
- Relative Density D_r

Relative Density D_r

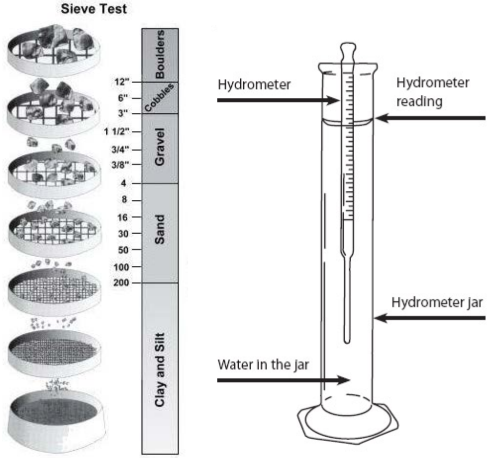
PL

LL



Proctor Test

Grain Size Distribution

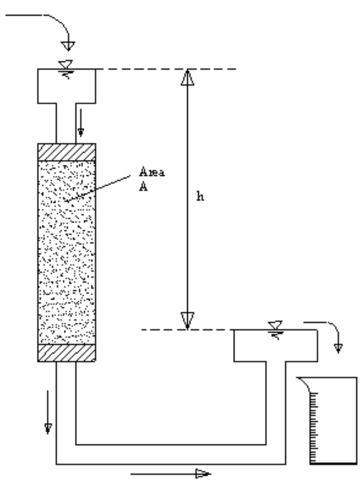


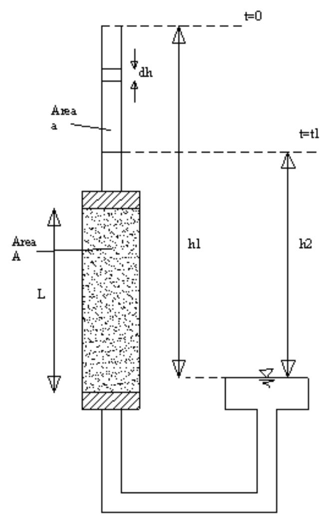
MEASUREMENTS OF MATERIAL PROPERTIES

Soil Properties

3- Hydraulic Properties

- Permeability or Hydraulic Conductivity (k)
- Infiltration Rate





Double Ring Infiltrometer

MEASUREMENTS OF MATERIAL PROPERTIES

Soil Properties

4- Mechanical Properties: To describe the behavior of the soil under different types of stresses

-Deformation Moduli – Young's Modulus (E) & Shear Modulus (G)

-Consolidation (C_c, C_s, C_v, P_c, m_v, K)

-Strength (c, ϕ) Unconfined Compression
Direct Shear,
Triaxial Compression

-California Bearing Ratio (CBR) or

-Lime Rock Bearing Ration (LBR)
used for pavement design

Consolidation Test

MEASUREMENTS OF MATERIAL PROPERTIES

Methods of Measurement

3- Empirical Correlations

- Correlations are usually based on **basic or index properties**
- These properties are correlated with the **mechanical & hydraulic properties**
- Used to provide basis for all engineering analysis
- Reduce the cost of geotechnical investigation
- Presented as ----- Tables, Charts, and Equations

For example Beyer formula for coefficient of permeability (k)

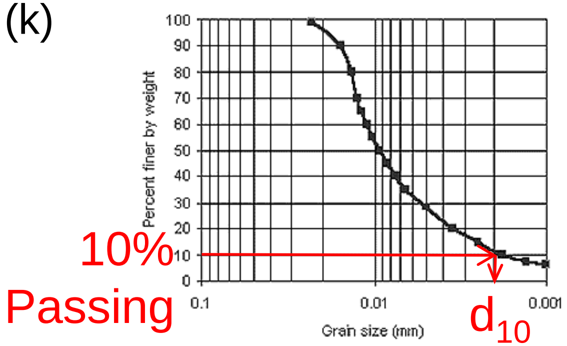
$K = C \cdot (d_{10})^2$

Where :

C = $4.5\times10^{-3} \, \log \dfrac{500}{U}$

U = Uniformity coefficient = d_{60}/d_{10}

d_{10} = Effective diameter (mm)



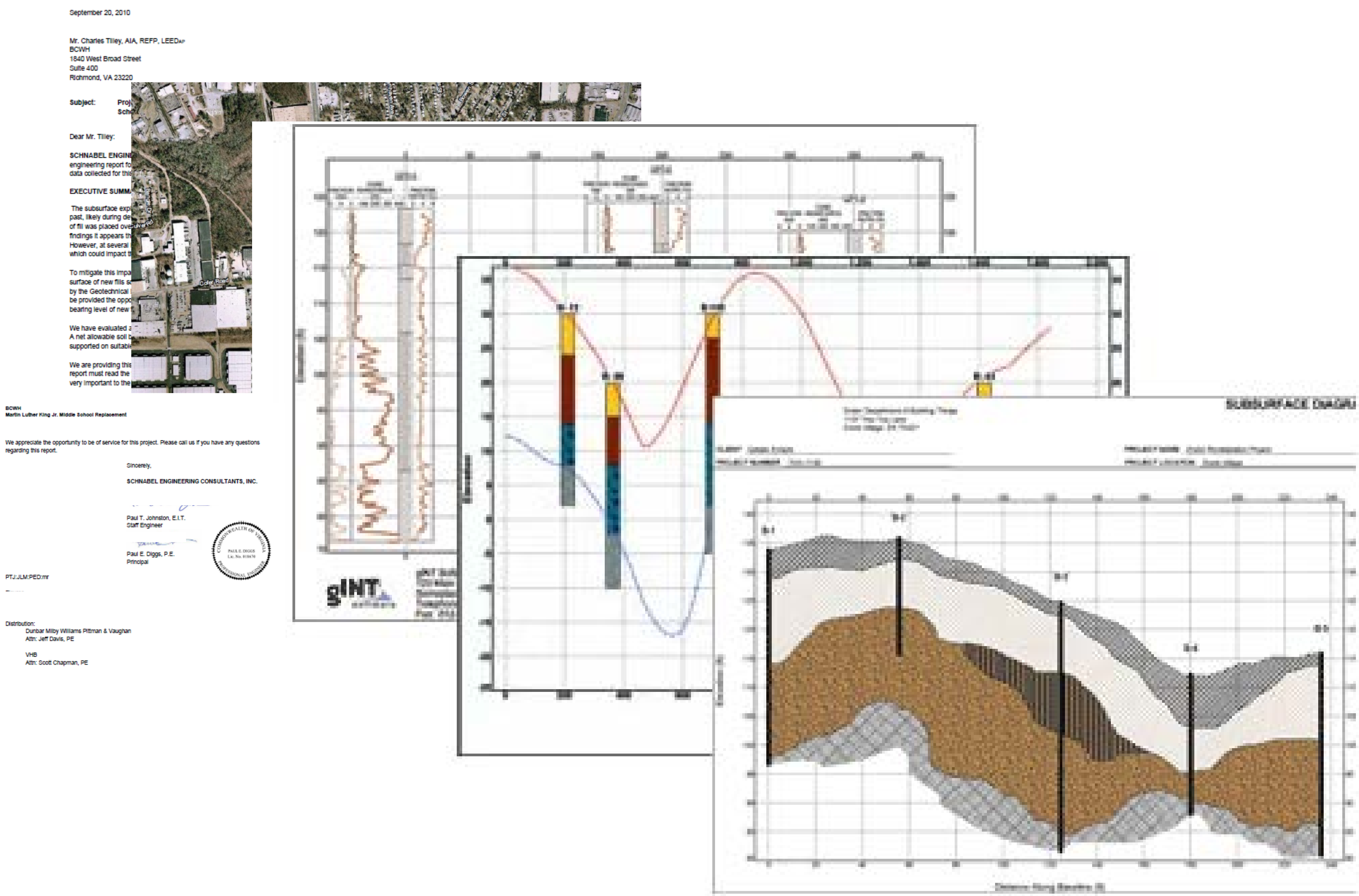
Reporting Geotechnical Investigation

Both an adequate geotechnical investigation and a comprehensive geotechnical report are necessary to construct a safe, cost-effective project.

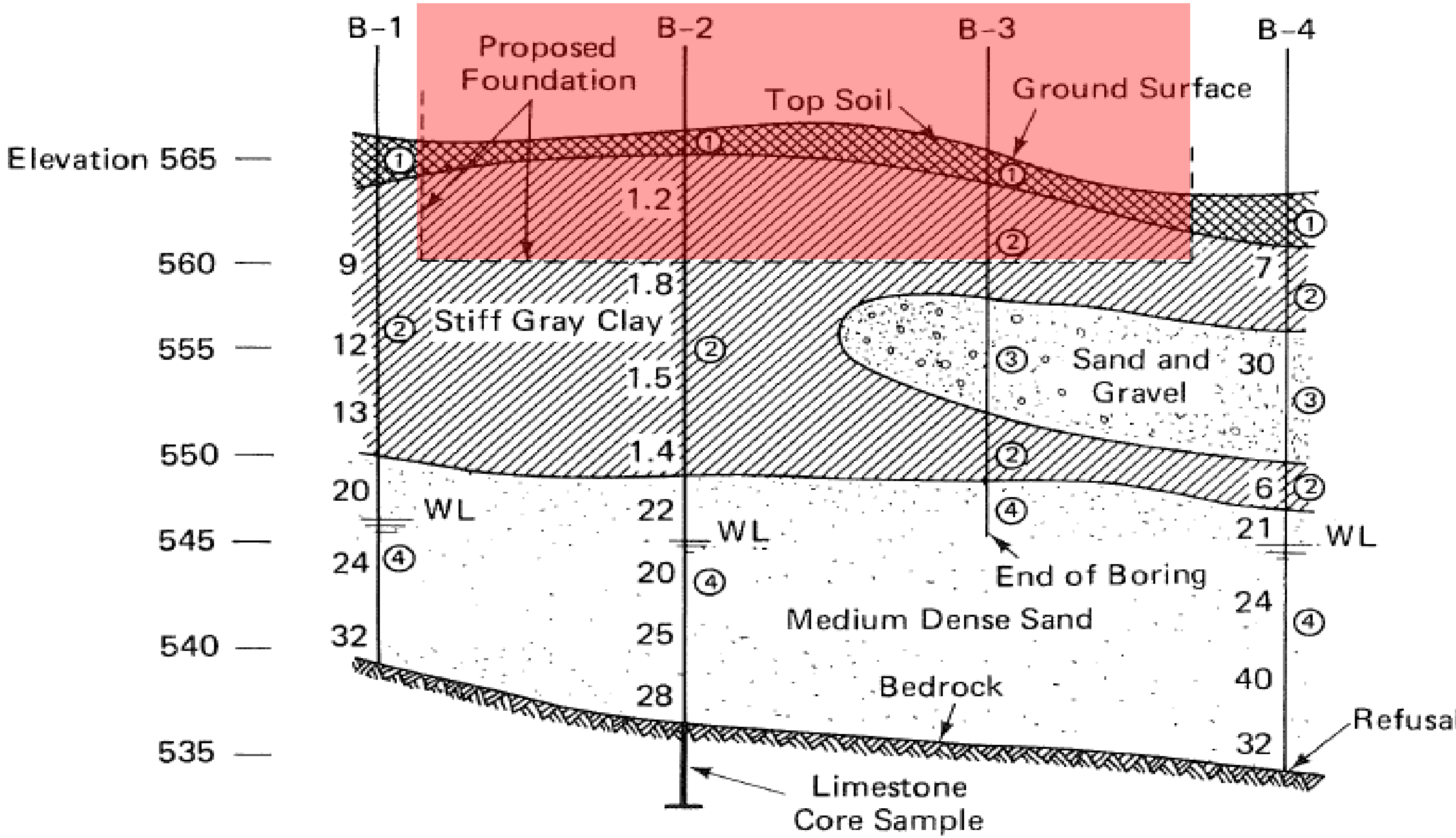
While the geotechnical report content and format will vary by project size and highway agency, all geotechnical reports should contain certain **basic** essential information, including:

1. *Cover letter and Executive summery*
2. *Scope of the Project*
3. *Site Description*
4. *Proposed Construction*
5. *Summary of all subsurface exploration data, including subsurface soil profile, exploration logs, laboratory or in situ test results, and ground water information;*
6. *Interpretation and analysis of the subsurface data; Specific engineering recommendations for design;*
7. *Discussion of conditions for solution of anticipated problems; and Recommended geotechnical special provisions.*

Geotechnical Report Production



Geotechnical Report Production



Note: ① ②, . . . = Top Soil, Stiff Gray Clay, . . .

9, 12 , . . . = Standard Penetration Resistance (Number of Blows/ft)

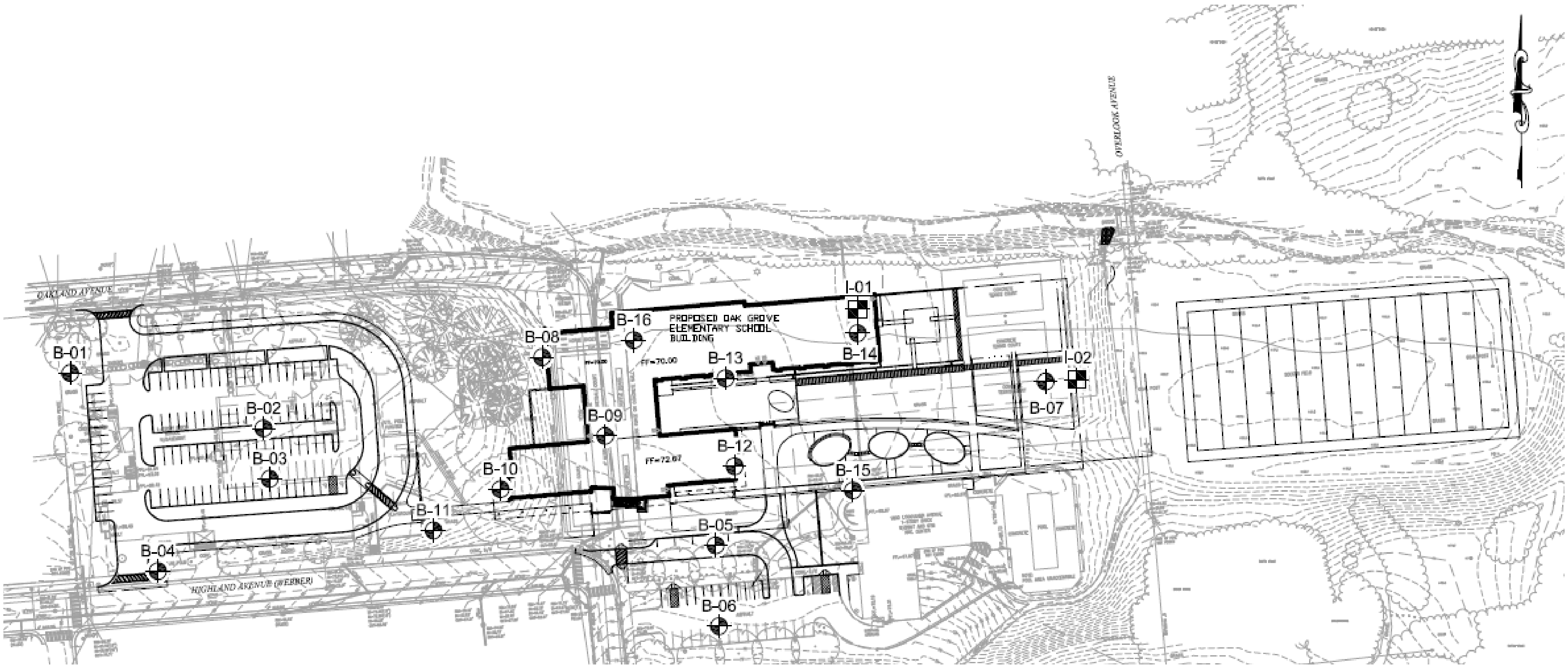
1.2, 1.8, . . . = Unconfined Comp. Strength (tons/ft^2)

Geotechnical Report Production

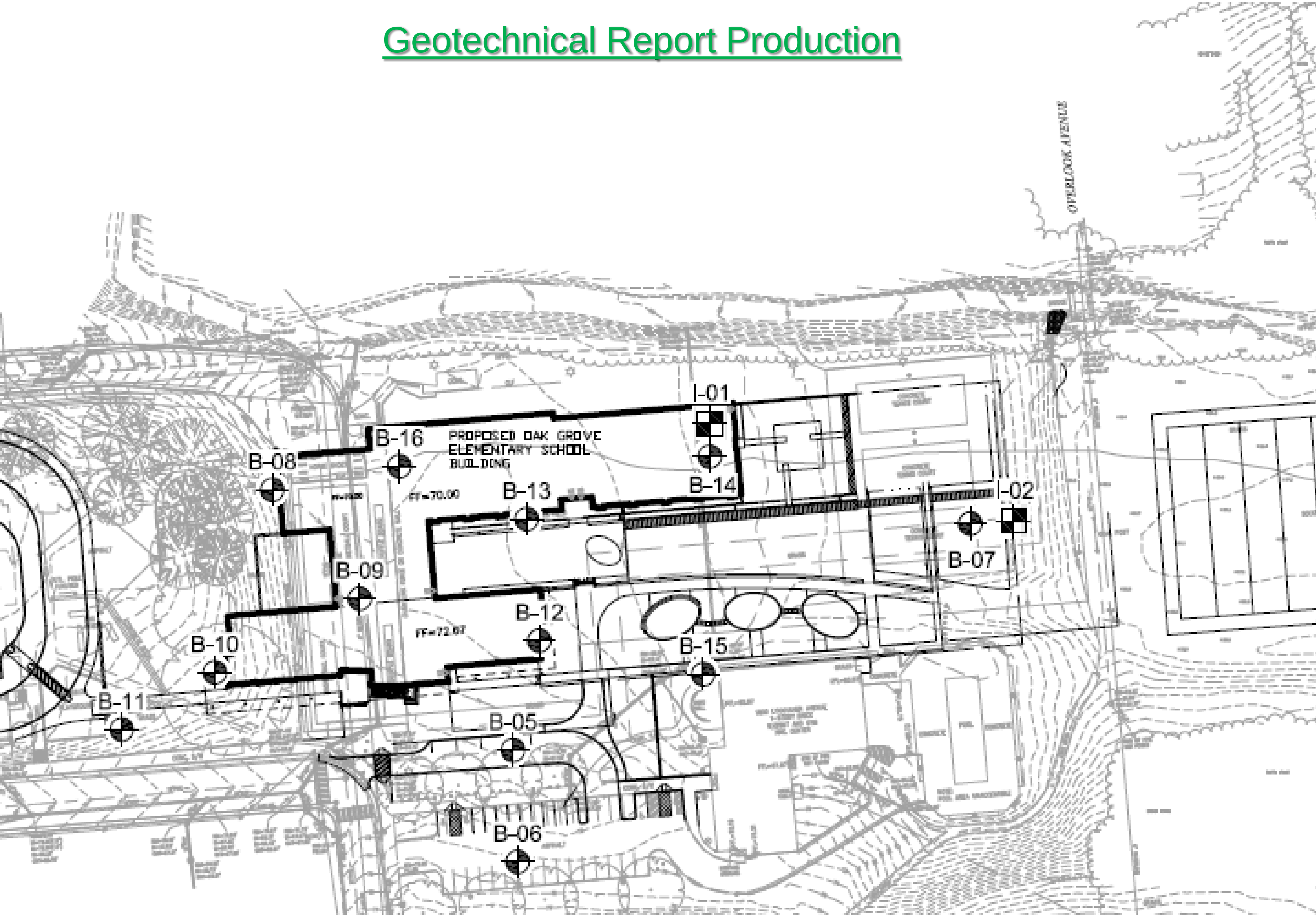
1- Map of the Project Location

Geotechnical Report Production

2- Boring Locations



Geotechnical Report Production



Geotechnical Report Production

3- Boring Log:

Soil description and classification

Sample depth

SPT field value

Water Table

ENGINEERING SOIL TEST BORING RECORD

Elevation (ft-msl) +182.2	Stratum Depth (ft)	Visual Soil Description	Sample Depth (ft)	Sample Recovery (in)	Soil Sym. K	Penetration N 60 (blows/ft)	Remarks and raw SPT data
+180	0.3	Top soil, grass, and roots					
	7.0	Loose gray-brown clayey fine SAND (SC)	6.0	16		7	(2+3+4)
+170	14.5	Soft blue-tan clayey SILT (MH)	12.0	16		3	(0+2+1) Groundwater z_w = 15.5 feet (Nov. 8, 2001)
+160	21.5	Firm yellow-tan clean to slightly silty fine SAND (SP to SP-SM)	20.5	18		32	(11+14+18)
	30.0	Firm yellow-tan clean fine to medium SAND (SP)	28.0	11		28	(+13+15+13)
+150	39.0	Loose white to yellow slightly silty medium to coarse SAND (SP)	36.0	11		5	(+2+3+2)
+140	45.5	Very stiff green fine-medium sandy CLAY (CL)	43.5	16		20	(+10+10+10)
+130	60.2	Stiff green-gray silty to sandy CLAY (CL)	52.5	18		15	(+6+7+8)
+120	64.0	Dense white medium SAND (SP) with shells	63.5	10		42	(+20+22+20)
		REFUSAL at 64 feet					

Soil Symbols K (Unified Soil Classification System): Top Soil, CL, MH, CH, SP

Other Symbols: Water Level

Driller:	
Boring Number:	AGB-1
Date Drilled:	Oct/29/2001
Job Number:	32335
Site Location:	Florida
Test Method:	ASTM D 1586
Hammer Type:	Diedrich Automatic (ER =82%)
Sampler:	Drive (split-barrel)
Drilling Method:	Hollow Stem Augers
Make of Drilling Rig:	CME-850 (truck mounted)

Notes:

N = Penetration in blows per foot (ASTM D-1586)

$N_{60} = (E_f/60) * N_{measured}$ = Energy-Corrected N-value

E_f = Energy Efficiency of Hammer Used

ER = energy ratio per ASTM D-4633

3- Boring Log:

Soil description and classification

Sample

SPT field value

[redacted] ENGINEERING TEST BORING LOG	Project: Oak Grove Elementary School Replacement, 2406 Webber Avenue, Richmond, Virginia	Boring Number: B-16 Contract Number: 10613074 Sheet: 1 of 1

Contractor: Ayers & Ayers, Inc.
Powhatan, Virginia

Contractor Foreman: J. Ayers

Schnabel Representative: P. Johnston

Equipment: CME-45B (Truck)

Method: 2-1/4" I.D. Hollow Stem Auger

Hammer Type: Safety Hammer (140 lb)

Dates Started: 8/25/10 Finished: 8/25/10

Location: See Location Plan

Ground Surface Elevation: 67± (ft) Total Depth: 15.5 ft

Groundwater Observations

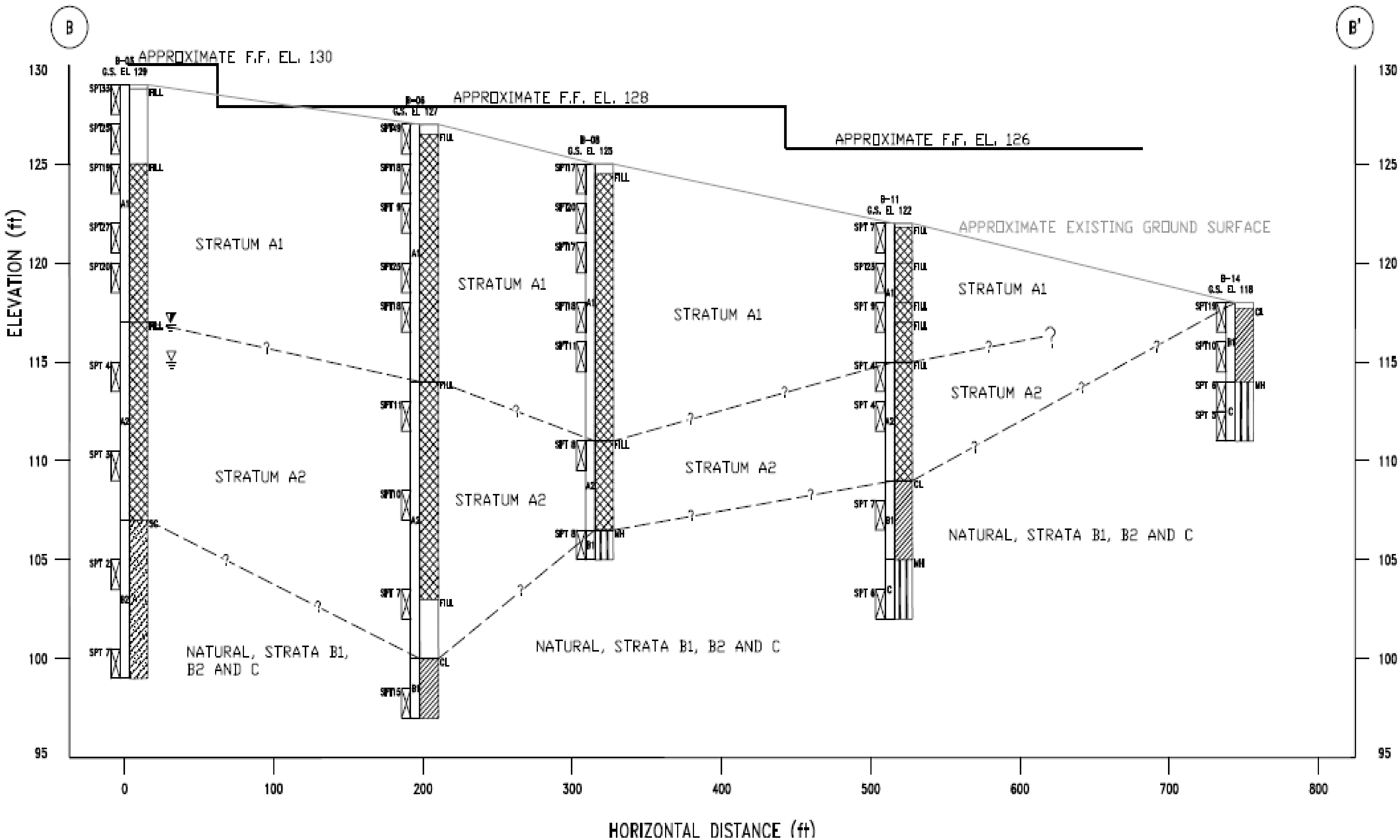
	Date	Time	Depth	Casing	Caved
Encountered	8/25	---	Dry	---	---
Completion	8/25	9:13 AM	Dry	---	---
Casing Pulled	8/25	9:15 AM	Dry	---	8.0'

DEPTH (ft)	MATERIAL DESCRIPTION	SYMBOL	ELEV (ft)	STRATUM	SAMPLING DEPTH	SAMPLING DATA	TESTS	REMARKS
	FILL, sampled as sandy lean clay; moist, orange	FILL		A		S-1, SPT 8+6+11	MC = 12.6%	FILL
	Change: contains crushed stone					S-2, SPT 4+6+40	LL = 32 PL = 16 MC = 13.5% % Passing #200 = 63.5	
	Change: contains concrete				5	S-3, SPT 11+2+2		
7.0	CLAYEY SAND WITH GRAVEL, fine to coarse grained sand; moist, gray	SC	60.0	B2		S-4, SPT 16+6+7		PLEISTOCENE TERRACE
9.0	SILTY SAND, fine to coarse grained sand; moist, orange and black, estimated 10-15% rock fragments	SM	58.0	C	10	S-5, SPT 5+5+8		RESIDUAL
	Change: orange							
15.5			51.5		15	S-6, SPT 15+18+28		

13 (5+5+8)

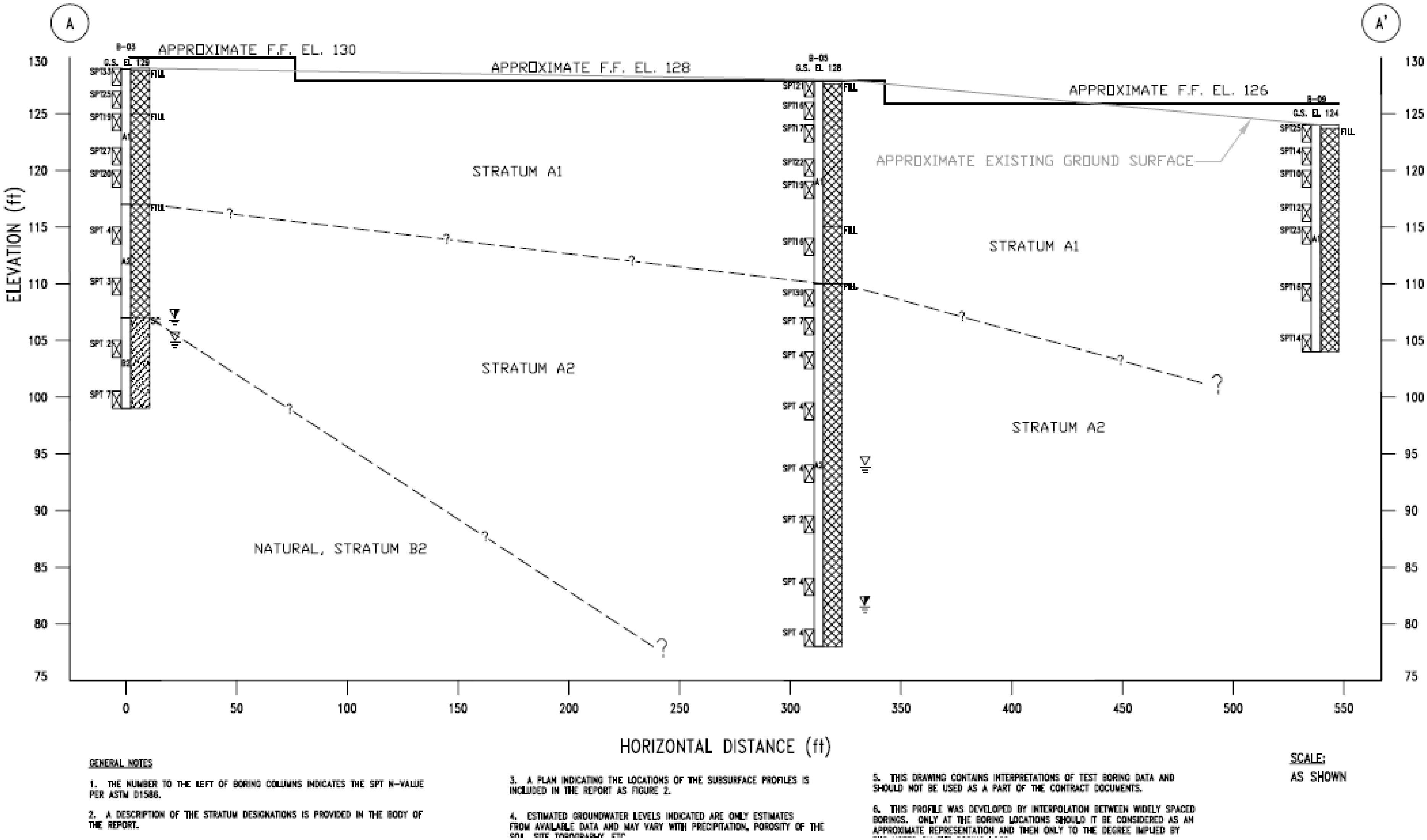
Bottom of Boring at 15.5 ft.
Auger refusal at 15.5 ft.
Boring backfilled with cuttings upon completion.

4- Profile of Soil Layers:

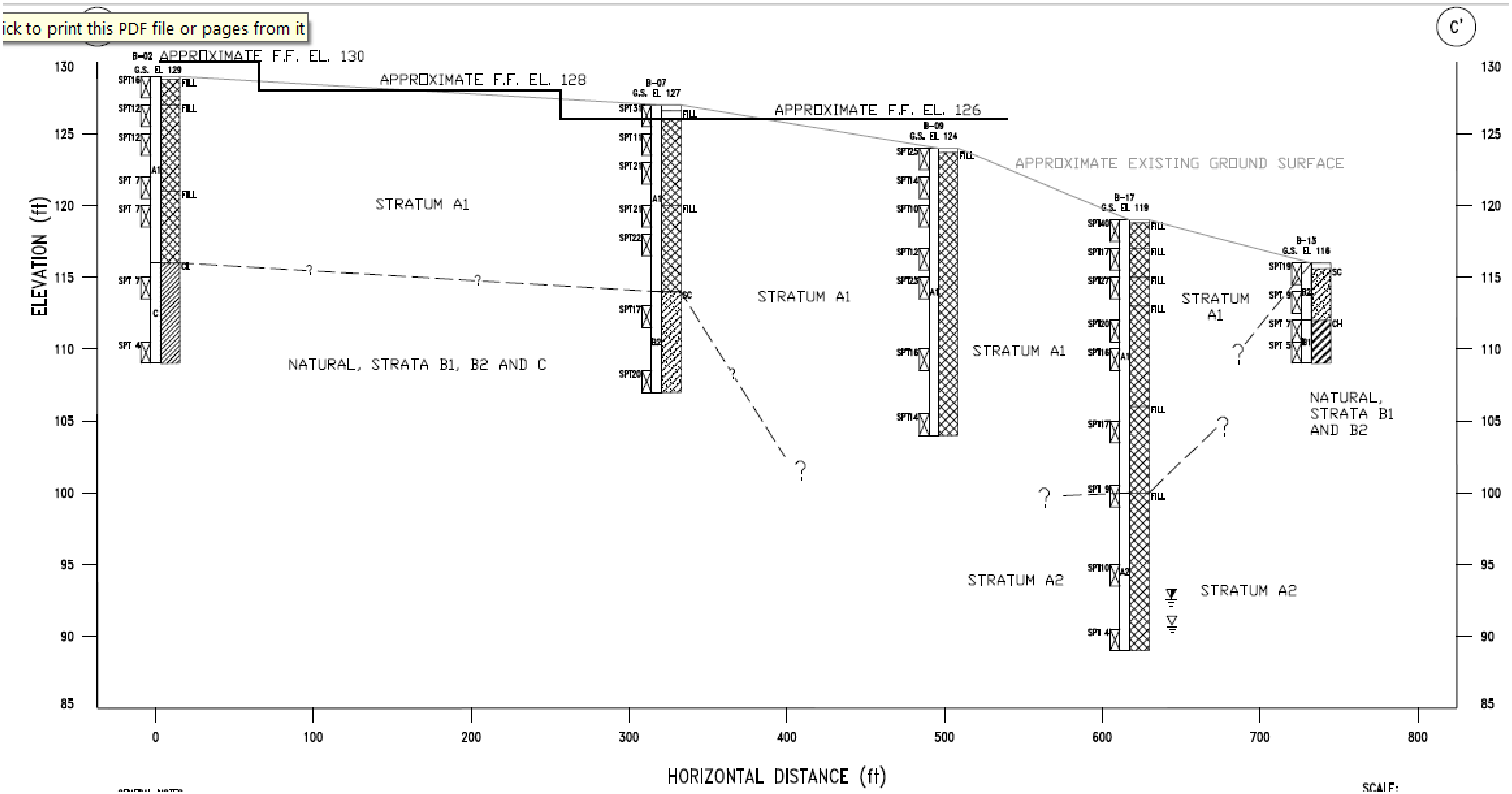


Geotechnical Report Production

4- Profile of Soil Layers:



4- Profile of Soil Layers:



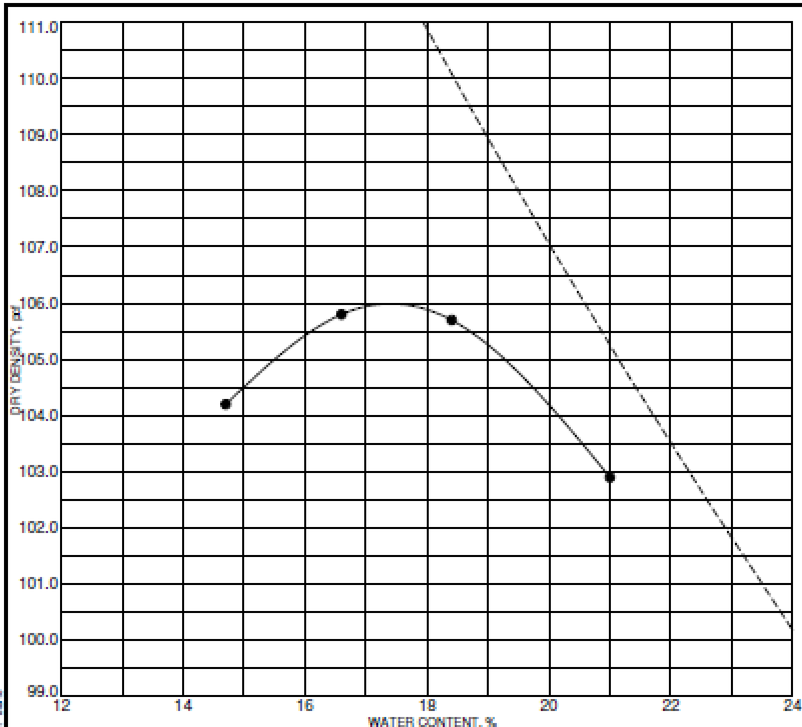
6- Soil Testing Results

Summary Of Laboratory Tests

Appendix
Sheet 1 of 1
Project Number: 10613077

Boring No.	Sample Depth ft / Elevation ft	Sample Type	Description of Soil Specimen	Stratum	Natural Moisture (%)	Liquid Limit	Plastic Limit	Plasticity Index	% Passing No. 200 Sieve	% Passing No. 40 Sieve	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	CBR Dry Density At Compaction (pcf)	CBR Moisture Content (%)	CBR Percent Swell	CBR Value
B-03	2.0 - 3.5 / 127.0 - 125.5	Jar	SILTY, CLAYEY SAND (SC-SM), fine to coarse grained sand, brown	A1	9.4	22	18	4	21.2	77.0	--	--	--	--	--	--
B-05	2.0 - 3.5 / 126.0 - 124.5	Jar	CLAYEY SAND WITH GRAVEL (SC), fine to coarse grained sand, brown	A1	12.1	44	19	25	34.1	57.9	--	--	--	--	--	--
B-11	0.0 - 1.5 / 122.0 - 120.5	Jar	SANDY LEAN CLAY (CL), brown	A1	19.8	49	23	26	59.4	89.2	--	--	--	--	--	--
B-14	0.0 - 7.0 / 118.0 - 111.0	Bulk	SANDY LEAN CLAY (CL, A-7-6), brown	B1	18.9	40	21	19	59.0	98.5	109.4	15.8	110.0	15.4	0.7	13.1
B-16	0.0 - 7.0 / 132.0 - 125.0	Bulk	SANDY LEAN CLAY (CL, A-7-6), brown and gray	A1	13.9	41	21	20	53.9	99.3	106.0	17.3	105.8	17.7	1.2	8.1

5- Soil Testing Summery



Sample Description: SANDY LEAN CLAY (CL, A-7-6), brown and gray

Sample Source: B-16, 0.0 ft

Test Methods: VTM1

Assumed Specific Gravity: 2.61

Max. Dry Density (pcf): 106.0

Opt. Moisture (%): 17.3

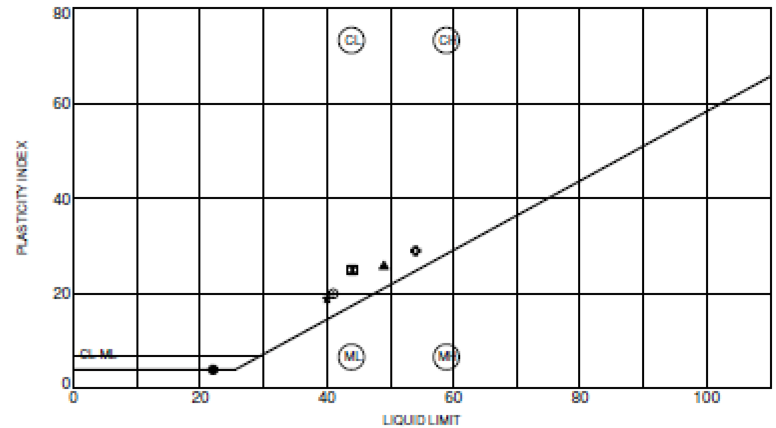
Liquid Limit (LL): 41

Plasticity Index (PI): 20

% Retained #4 Sieve:

% Passing # 200 Sieve: 53.9

Comments: Bulk sample off augers from 0 to 7 ft.



PLOTTED DATA REPRESENTS SOIL PASSING NO. 40 SIEVE

Specimen		LL	PL	PI	Fines	Description
B-03	2.0 ft	22	18	4	21	SILTY, CLAYEY SAND (SC-SM), fine to coarse grained sand, brown
B-05	2.0 ft	44	19	25	34	CLAYEY SAND WITH GRAVEL (SC), fine to coarse grained sand, brown
B-11	0.0 ft	49	23	26	59	SANDY LEAN CLAY (CL), brown
B-14	0.0 ft	40	21	19	59	SANDY LEAN CLAY (CL, A-7-6), brown
B-16	0.0 ft	41	21	20	54	SANDY LEAN CLAY (CL, A-7-6), brown and gray
B-16	2.0 ft	54	25	29	53	SANDY FAT CLAY (CH), brown and gray