FOUNDATION ENGINEERING I

CEng 3204

Foundation Engineering I

- *Topics to be covered*
  1. *Site Exploration*
  2. *Types of Foundation and their Selection*
  3. *Design of Shallow Foundations*
  4. *Analysis and Design of Retaining Walls*

Chapter 1: Site Exploration

Chapter 1: Site Exploration

- Topics to be discussed:
  - Purpose and extent
  - Planning
  - Methods and evaluation
  - Soil exploration report

Chapter 1: Site Exploration

- Site Exploration
  - The investigation and testing of the surface, subsurface, and any obstruction at a **site** to obtain the full information necessary for designing a complete structure with its foundations.
  - It covers both field and laboratory investigations of a site for gathering information on the layers of deposits that underlain a proposed structure for economical and safe design of foundation.
  - Always a pre-requisite for foundation design.

Chapter 1: Site Exploration

- Purpose
  - Alternative sites
  - Type and depth of foundation
  - Load bearing capacity and probable settlement
  - Appropriate method of construction
  - Construction materials
  - Safety of existing structures
  - Ground water location

Chapter 1: Site Exploration

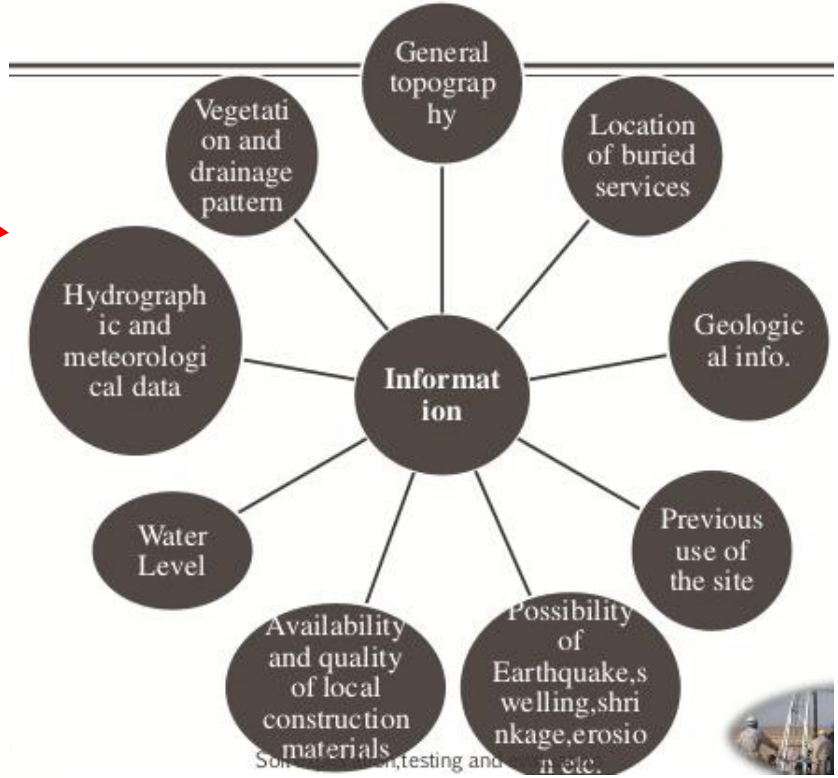
- Extent
  - Importance of structure
  - Complexity of soil conditions
  - Foundation arrangement
  - Availability of equipment and skill
  - Relative cost of exploration
  - Information available

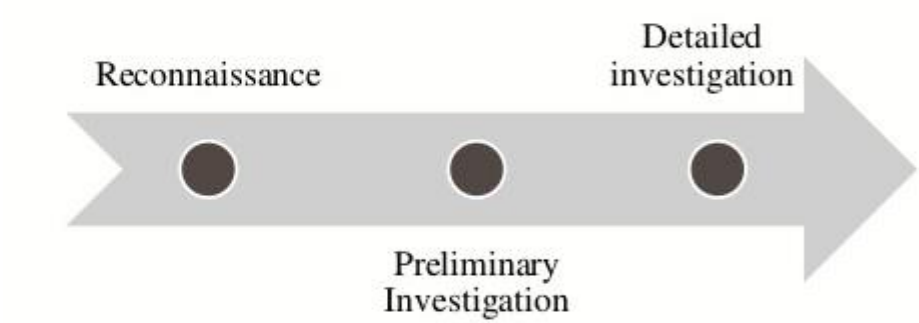
Chapter 1: Site Exploration

- Information obtained
  - General topography and accessibility of the site
  - Location of buried services
  - General geology of the site
  - Previous history and use of the site
  - Special features: erosion, earthquake, flooding, shrinkage…
  - Availability of construction materials
  - Detailed record of soil and rock strata
  - Location of ground water
  - Laboratory and field results of various strata

Chapter 1: Site Exploration

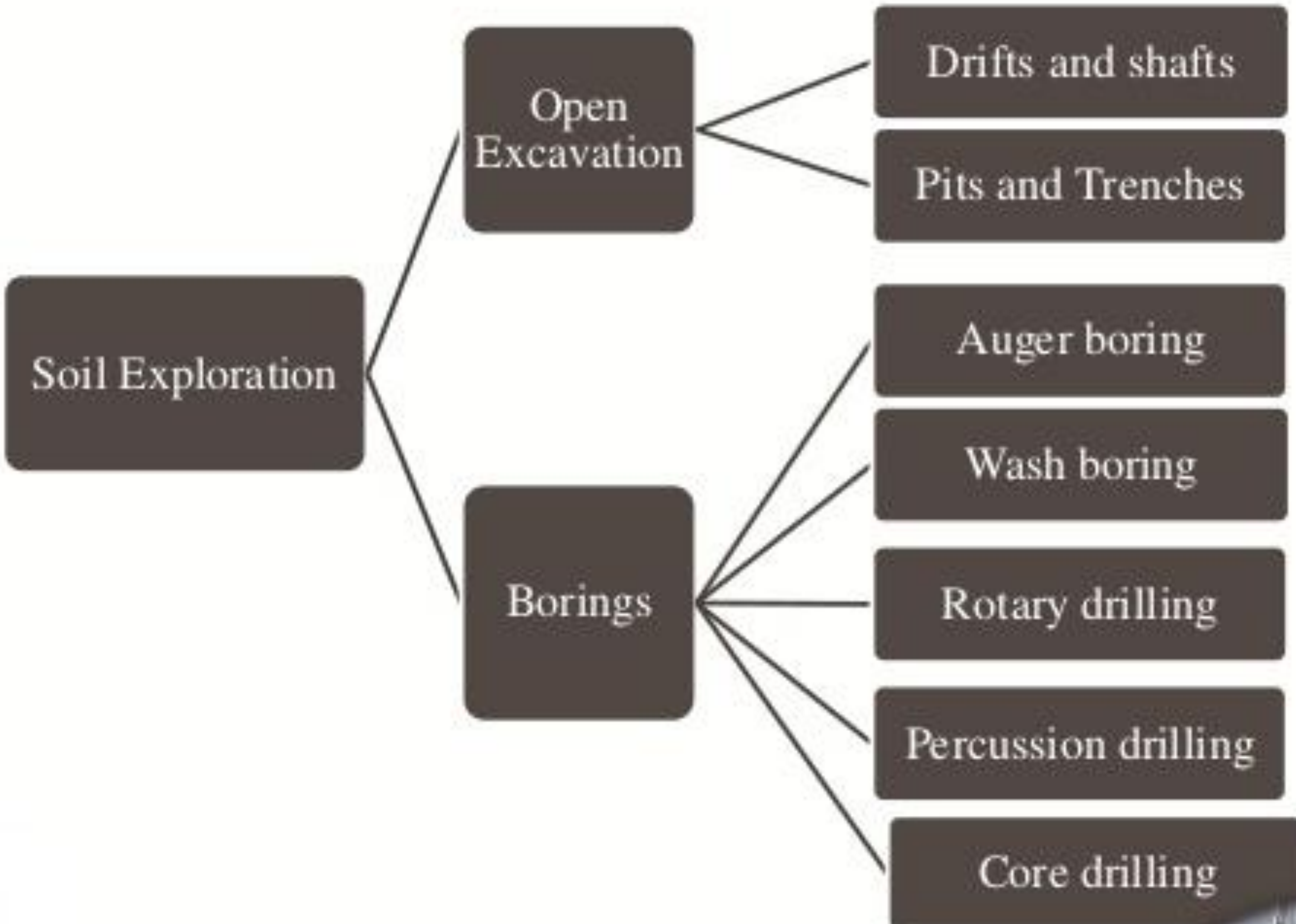
- Planning of site exploration
  - Assembly of available information
  - Reconnaissance survey
  - Preliminary ground investigation
  - Detailed ground investigation





Chapter 1: Site Exploration

- Exploration methods
  - Direct method
    - Test pit, trenches
  - Semi-direct method
    - Boring
  - Indirect methodical
    - Geophysical methods, sounding or penetration tests


Soil Exploration
Open Excavation
Drifts and shafts
Pits and Trenches
Borings
Auger boring
Wash boring
Rotary drilling
Percussion drilling
Core drilling

Chapter 1: Site Exploration

- Methods of site exploration
  1. Soil sampling
     - Obtain samples using different sampling techniques and conduct laboratory test.
     - Samples taken at some interval below round surface (-1m, -2m, …)
  2. Field tests
     - Conduct appropriate field tests in-situ

Chapter 1: Site Exploration

1. Soil sampling
   - Boring enables us to extract continues or discrete samples for visual inspection and testing to determine properties of soil.

   a. Test pits
      - Simplest, cheapest, man-made
      - Wide and shallow
      - Usual size is 2m X 2m and 5m deep
      - Block samples can be easily extracted (chunk sampling)
      - Not preferred if GWT is encountered near ground surface
      - Can not be dug in silts and sands below water table soft clays.

Chapter 1: Site Exploration

1. Soil sampling
   b. Boreholes
      - Usual size is 30 cm diameter and 50 m deep or more
      - Most common for deep investigation
      - Mostly done by **power driven machines**
      - Can be used in any type of soil
      - Expensive and less convenient
      - Harder to determine exact stratification of the ground

Chapter 1: Site Exploration

1. Soil sampling
   b. Boreholes

- Borehole drilling methods
  1. Auger boring
  2. Wash boring
  3. Rotary drilling
  4. Percussion drilling

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1. Soil sampling
   b. Boreholes
      1. Auger boring
      - Digs by screw like movement.

      Hand operated augers: helical types or post-hole auger
      - Up to 5m
      - Soft soil
      - Used for making subsoil explorations for highways, railways, runways,…

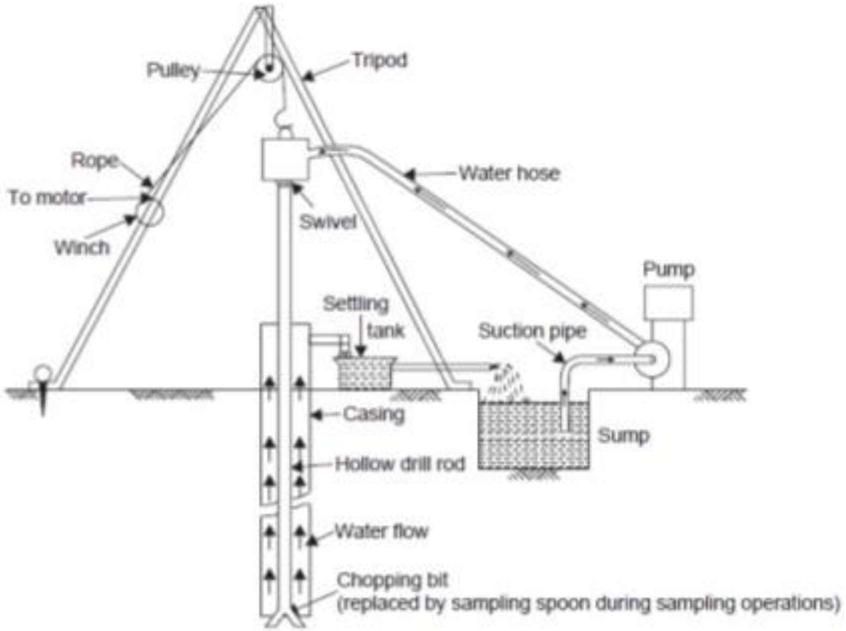
      Machine operated augers
      - Up to 50m
      - All type of soils


Hand auger-Helical


Post hole auger

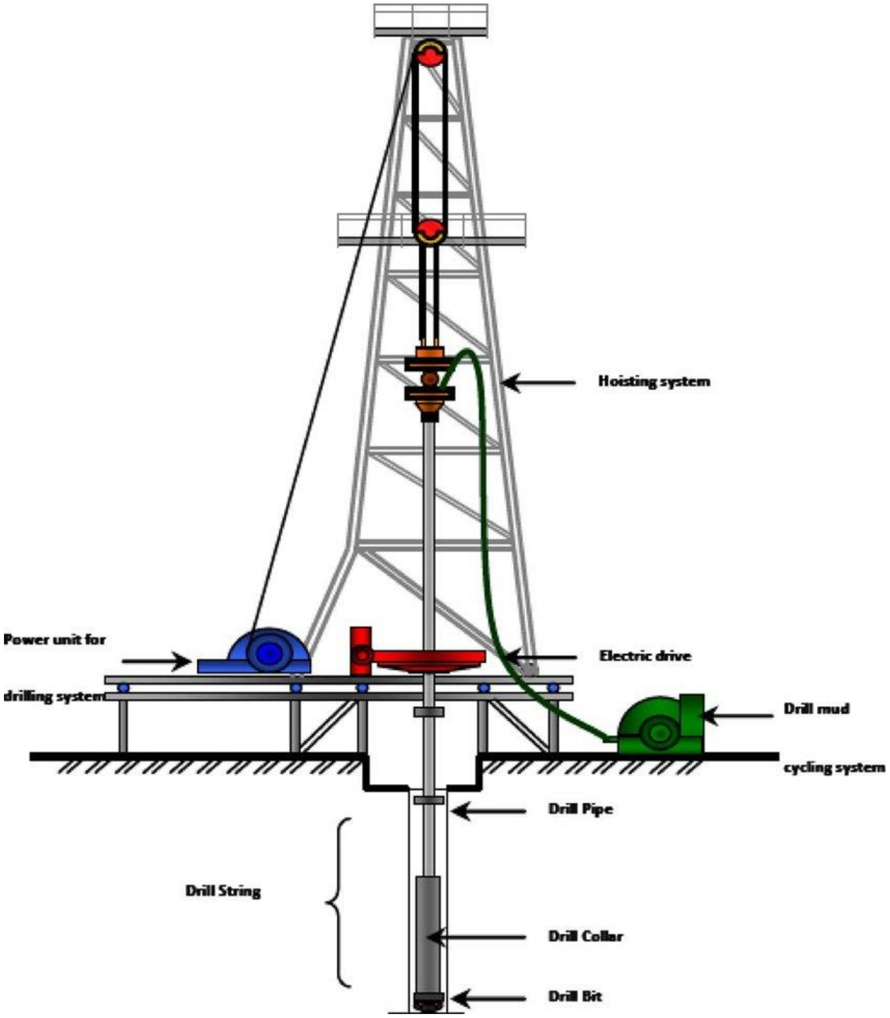
Chapter 1: Site Exploration

1. Soil sampling
   b. Boreholes
      2. Wash boring
         - Machine operated
         - Water is introduced by some means to the drilling process to aid in boring
         - Natural water content of the soil will be altered.
         - Faster than auger boring.
         - Machine is light thus easily transported.
         - Undisturbed samples can be easily extracted by samplers.



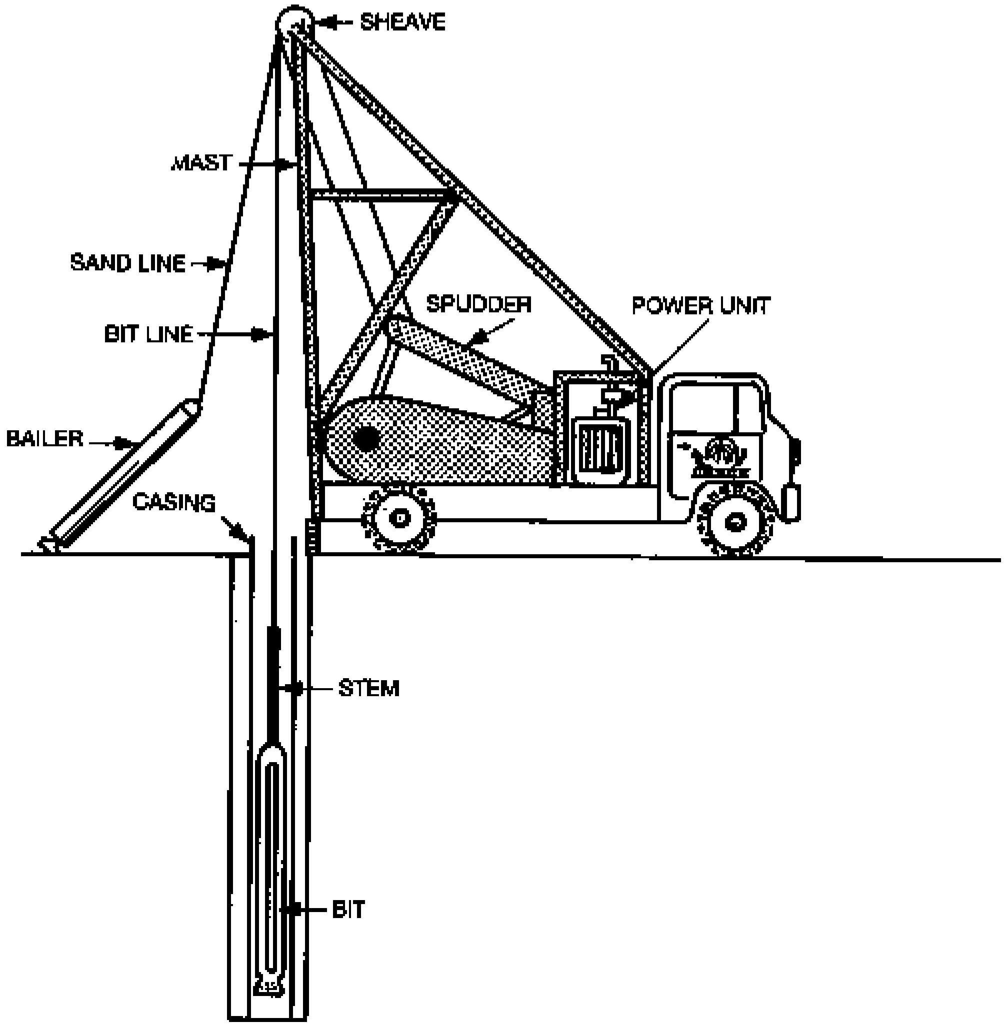
Chapter 1: Site Exploration

1. Soil sampling
   b. Boreholes
      3. Rotary drilling
         - Trailer or lorry mounted
         - Borehole is advanced by power rotated drilling bit (carbide or diamond)
         - The most rapid method in all soils.
         - Undisturbed sample can be obtained by a sampler.
         - Can be expensive
         - Not suitable for highly fissured rocks (gravelly soils)



Chapter 1: Site Exploration

1. Soil sampling
   b. Boreholes
      4. Percussion drilling
         - Involves rise and fall movement of a heavy chisel like bit.
         - Causes high disturbance in the underlying soil.
         - Used when very hard soil or rock is encountered.



Chapter 1: Site Exploration

1. Soil sampling
   - Layout, Number and Depth of Boreholes
     - Depends on:
       - Importance of structure
       - Soil uniformity on the site

Project	Distance b/n borings (m)			Minimum number of borings
	Horizontal stratification of soil			
	Uniform	Average	Erratic	
Multi storey building	50	25	10	2 if supplemented with sounding tests otherwise 4
One or two storey building	60	30	15	2
Bridge piers, abutments, towers, etc	-	30	7.5	1 to 2 for each foundation
High ways	300	150	30	

Table 1: Guidelines for preliminary exploration (EBCS 7, 1995)

Chapter 1: Site Exploration

1. Soil sampling
   - Depth of test pits/borehole
     - EBCS 7 recommends
       - For structures on footing: $D = 3B \geq 1.5$ m
       - For structures on mat: $D = 1.5B$
       - For structures on piles: $D \geq D' + 3m$
     - For preliminary investigation
       - $D = 3 * S^{0.7}$ for light steel and narrow concrete buildings
       - $D = 6 * S^{0.7}$ for heavy steel and wide concrete buildings

         - D' is pile length from surface
         - S is number of stories

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1. Soil sampling
   - Soil sample types:

   a. **Disturbed samples**
   - ***Non-representative sample***: helps in determining the depth at which major changes may be occurring in subsurface soil strata.
   - ***Representative sample***: can be use for identification of soil types, atterberg limits, grain size distribution, specific gravity, natural moisture content, compaction…

   b. **Undisturbed samples**
   - Particle size distribution, moisture content and soil structure is well preserved.
   - Used to determine the soils' shear strength, consolidation and permeability.

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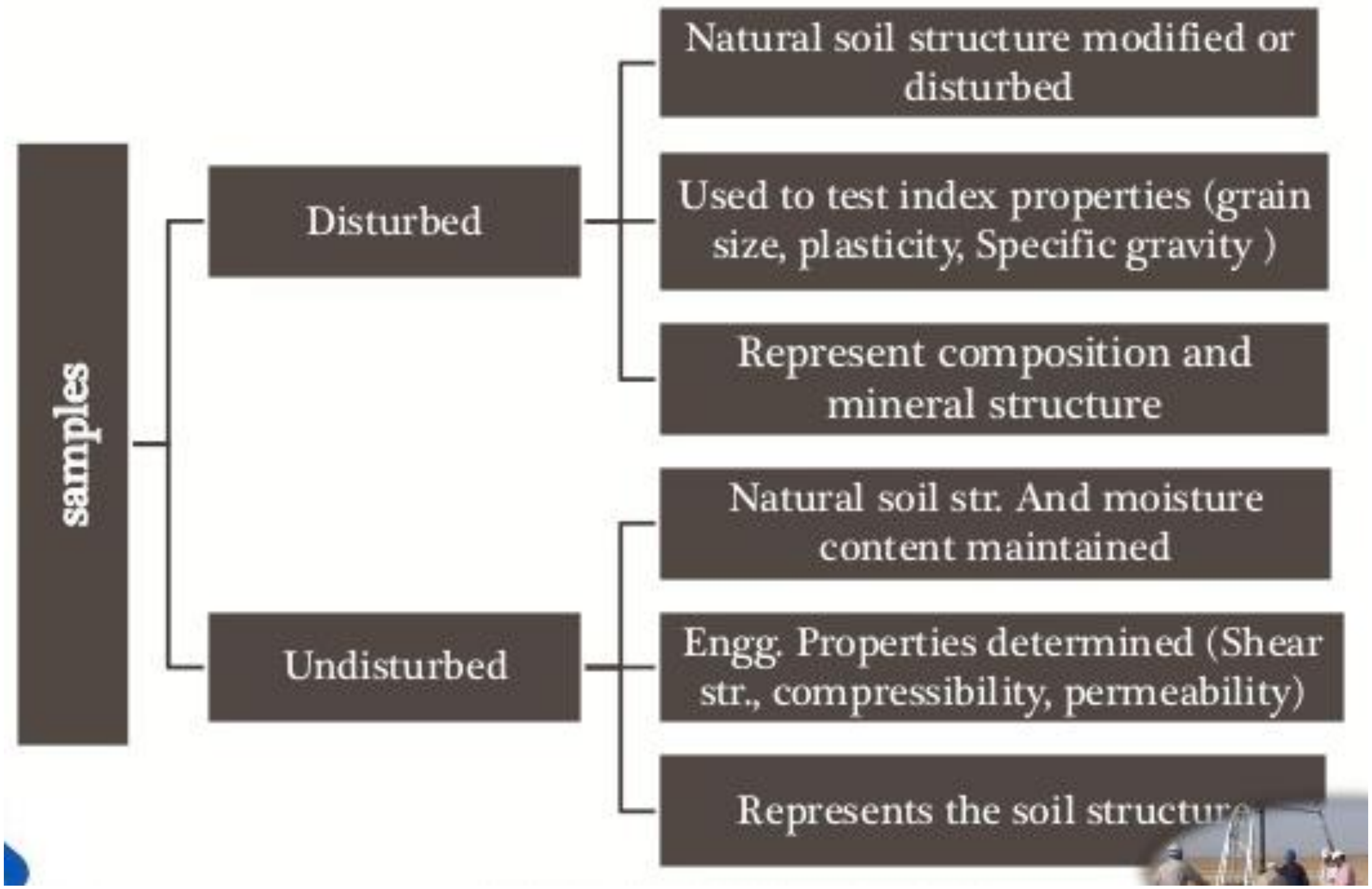
SAMPLING TOOLS AND SAMPLERS



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- Type of Samplers
  1. Split spoon sampler

- Disturbed samples of soft rock, cohesive and cohesionless soils are obtained.

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- Type of Samplers
  2. Thin-Walled Tube Sampler

- Undisturbed cohesive soils can be obtained.

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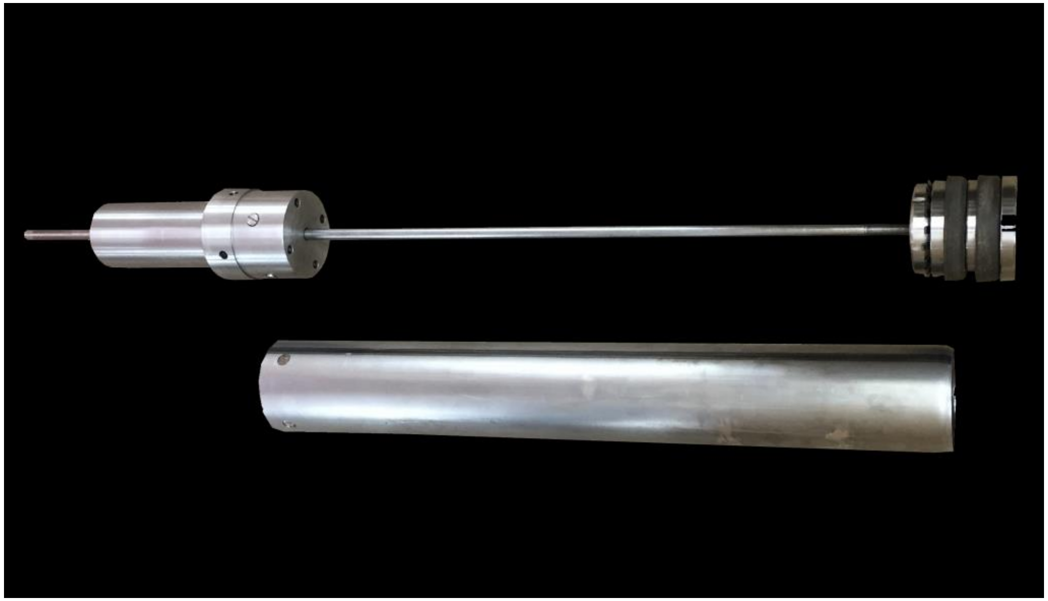
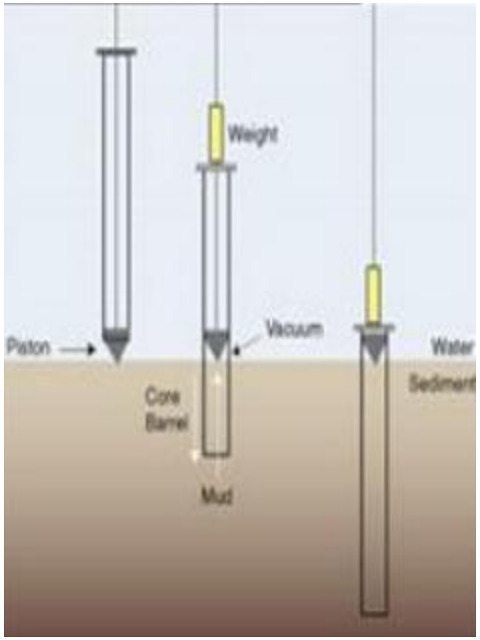
- Type of Samplers
  3. Piston Sampler





Provides the best undisturbed samples of cohesive soils.

Chapter 1: Site Exploration

- The degree of disturbance of a sample depends on:
  - Natural cause of removal of overburden while collecting samples.
  - Impact applied
  - Rate of penetration of the devices
  - Dimension of the sampler and inside wall friction
- If other conditions are kept constant the degree of disturbance of a sample is indicated by:

a) Area ratio:

$$A_r(\%) = \frac{D_o^2 - D_i^2}{D_i^2} * 100\%$$

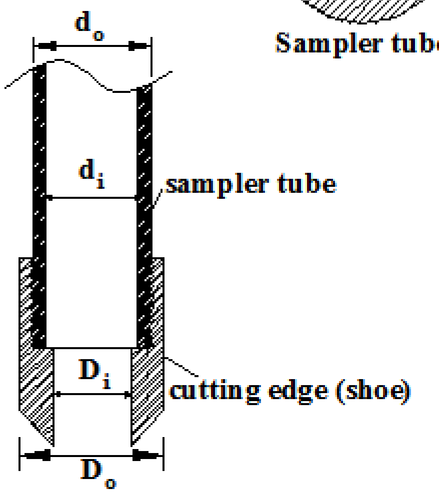
If $A_r \leq 10\%$, the sample disturbance can be considered as negligible.

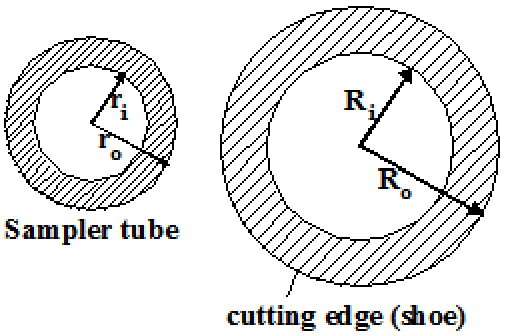
b) Inside clearance:

$$\text{Inside clearance}(\%) = \frac{d_i - D_i}{D_i} * 100\%$$

c) Out side clearance:

$$\text{Out side clearance}(\%) = \frac{D_o - d_o}{d_o} * 100\%$$





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2. Field Test

- Used to determine the relative densities, shear strengths and bearing capacities of soils directly without disturbing effects of boring and sampling.
- Most commonly used tests are:

A. Penetration or sounding tests
B. Vane shear test
C. Plate load test
D. Indirect Geophysical methods

Chapter 1: Site Exploration

2. Field Test

   A. Penetration Tests

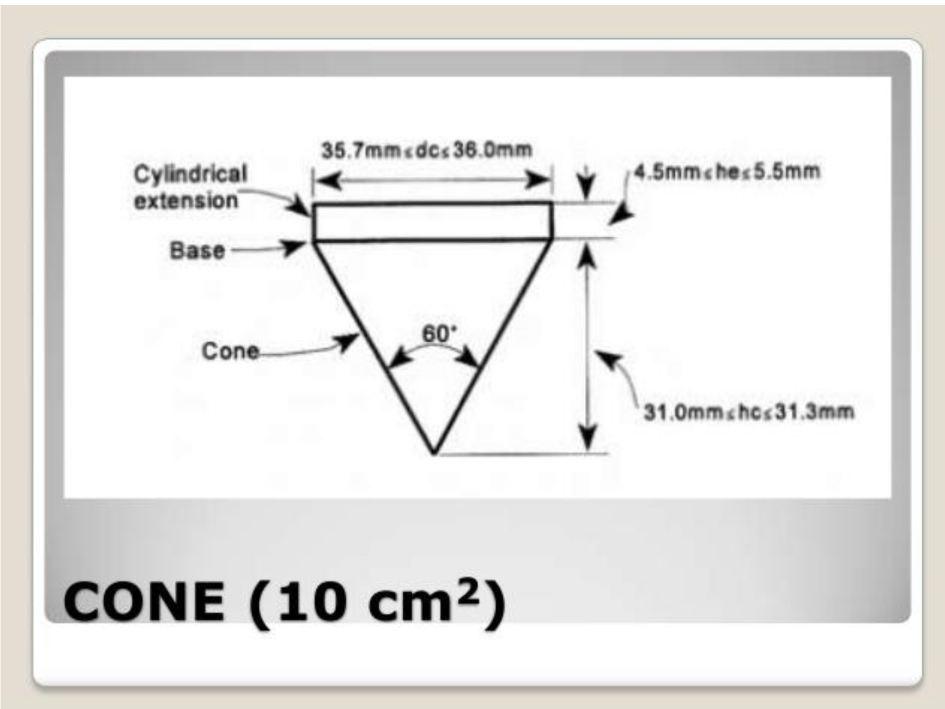
      - Conducted to get information on relative density of soils with little or no cohesion.
      - Based on the fact that the relative density of a soil stratum is directly proportional to the resistance of the soil against the penetration of the drive point.
      - Correlations between values of penetration resistance versus φ, bearing pressure, density and modulus of compressibility have been developed.
      - Classified as ***static*** and ***dynamic penetration tests.***

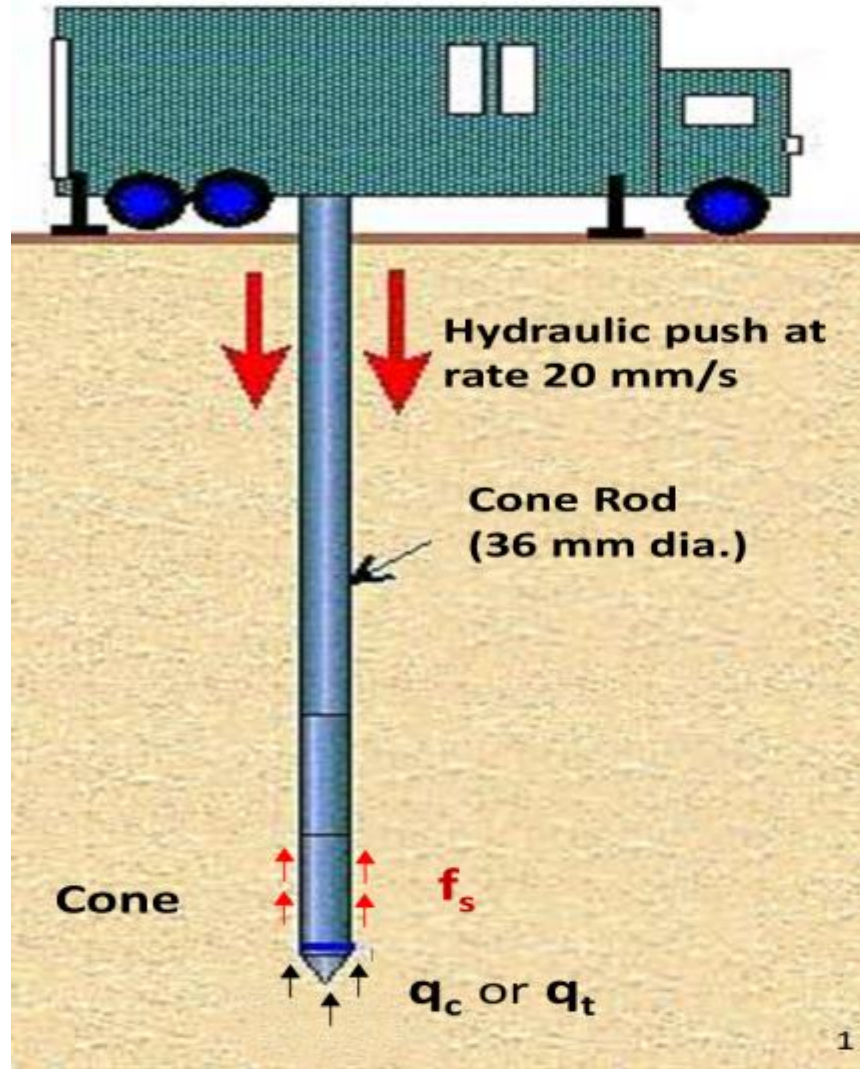
i.	Static Cone penetration test (CPT)	Static
ii.	Standard Penetration Test (SPT)	Dynamic
iii.	Dynamic cone penetration test (DCPT)	Dynamic

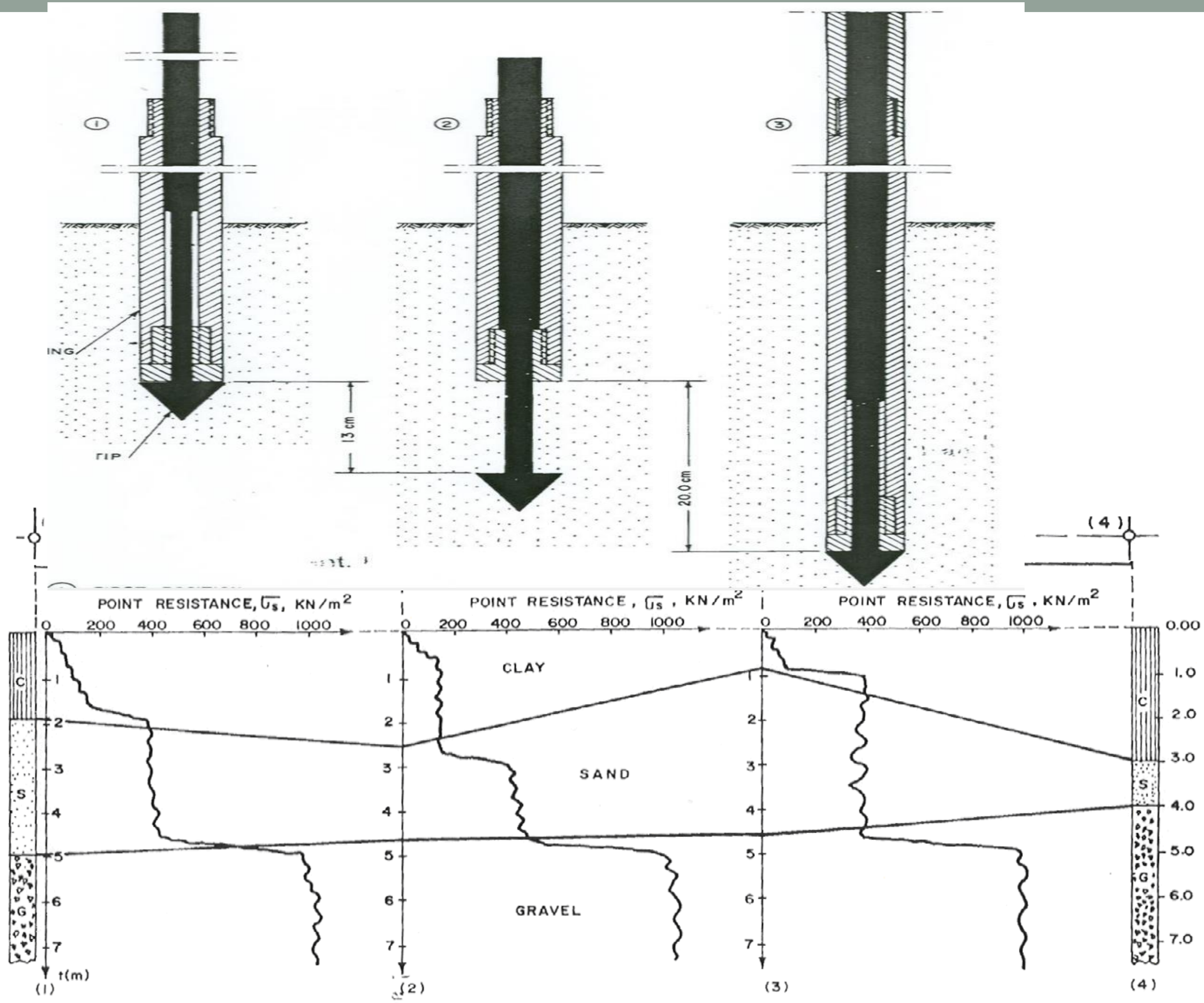
Chapter 1: Site Exploration

2. Field Test
   A. Penetration Tests
      i. Static Penetration Tests

- **Static Cone Penetration Test (Dutch Cone Penetrometer Test)**
  - Widely used in Europe.
  - Used to determine the relative resistance offered by the different soil layers.
  - Used in soft clays and fine to medium course sands.
  - The cone is driven into the ground at a rate of 10 to 20 mm/sec for a depth of 13cm and the force is measured.
  - The end resistance of the cone is called **cone penetration resistance (point resistance) –** q_c
  - q_c is calculated as the force required to advance the cone divided by the end area.
- Push cone alone = end res. (q_c)
- Push sleeve and cone together = total resistance($q_c' = q_c + q_s$)
- Now, skin fric. res. , $q_s = q_c' – q_c$


35.7mm≤dc≤36.0mm
4.5mm≤he≤5.5mm
Cylindrical extension
Base
Cone
60°
31.0mm≤hc≤31.3mm
CONE (10 cm^2)


Hydraulic push at rate 20 mm/s
Cone Rod (36 mm dia.)
Cone
f_s
q_c or q_t
1



①
②
③
ING
TIP
13 cm
20.0 cm
(4)
POINT RESISTANCE, σs, KN/m2
0 200 400 600 800 1000
CLAY
SAND
GRAVEL
C
S
G
t(m)
0.00
1.0
2.0
3.0
4.0
5.0
6.0
7.0
(1)
(2)
(3)
(4)

Chapter 1: Site Exploration

- **Static Cone Penetration Test (Dutch Cone Penetrometer Test)**
- Estimation φ and the stress strain modulus of compressibility- E_s of non cohesive soils

Average point resistance q_c (MPa)	compactness	ϕ^o	E_s (MPa)
<5	Very loose (weak)	30	15 - 30
5-10	Loose	32	30 – 50
10-15	Medium dense	35	50 – 80
15-20	Dense	37.5	80 - 100
>20	Very dense	40	100 - 120

- Mayne and kempler (1988) suggested for the undrained shear strength (c_u)

$$c_u = \frac{q_c - \sigma_v}{N_K}$$

$$N_K = \begin{cases} 15 & \text{for electric cone penetrometer} \\ 20 & \text{for mechanical cone penetrometer} \end{cases}$$

where q_c = point resistance (Kpa)

σ_v= the total vertical pressure (KPa),

Chapter 1: Site Exploration

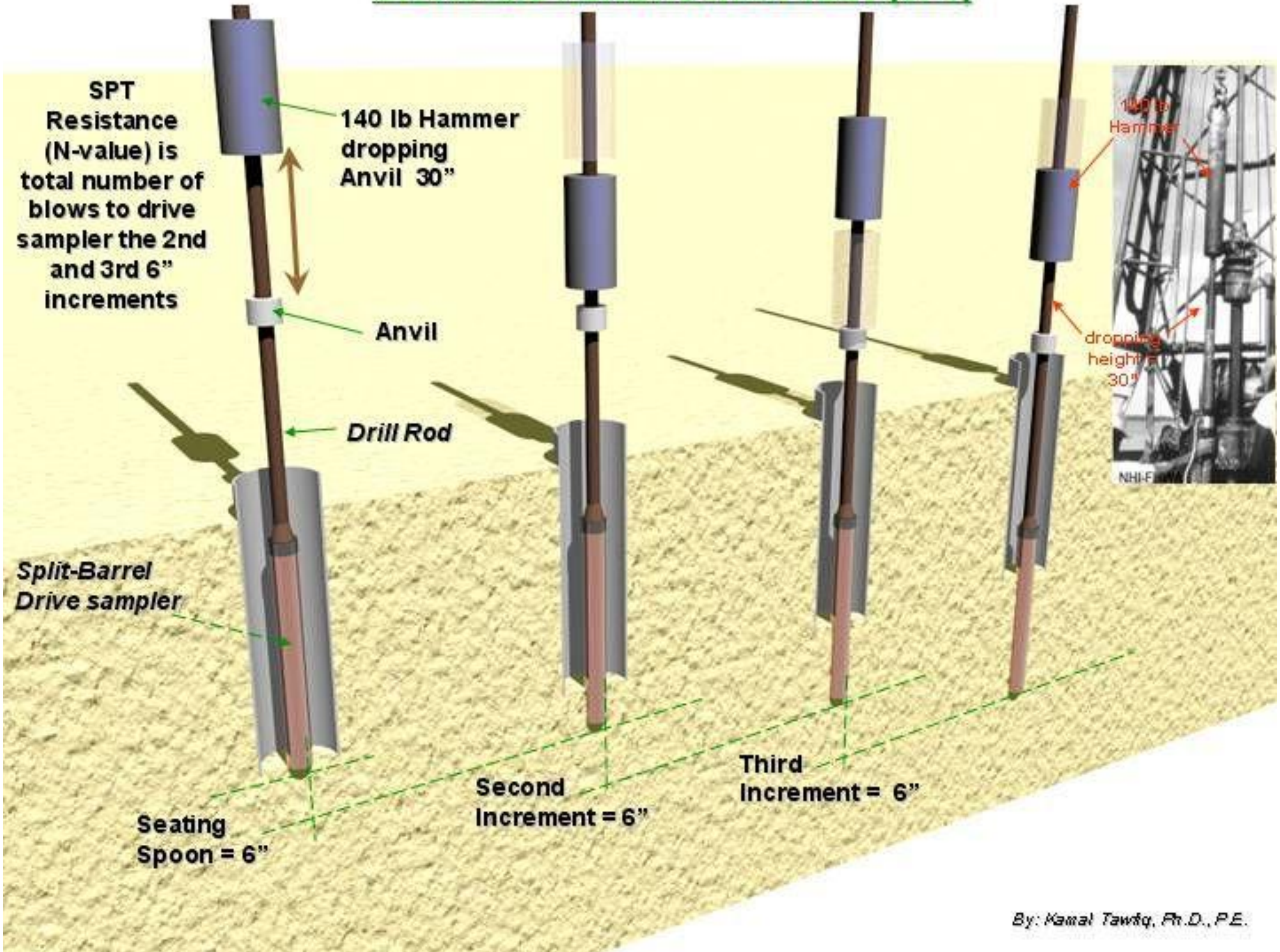
2. Field Test
   A. Penetration Tests
      ii. Dynamic Penetration Tests
         - **Standard Penetration Test (SPT)**
            - most commonly used filed test in a borehole. Economical.
            - Objective is to determine the resistance of a soil to penetration by a standard sampler, to obtain rough estimate of the properties of the soils in in-situ.

            - **Stop boring at a desired depth → Insert SPT equipment → Conduct test → take equipment out → Bore to a deeper depth → Do the same**

            - **Hammer down until tip goes in 15cm → Stop → Hammer down until tip goes in further 15 cm → Stop → Hammer down until tip goes in further yet another15 cm**

            - The number of blows required to drive the sampler the last two 15 cms is counted . This number is called the ***Standard Penetration Number, N.***
            - The test is halted if there is refusal (if 50 blows are required for any 15cm penetration) or if 10 successive blows produce no advance.

STANDARD PENETRATION TEST (SPT)



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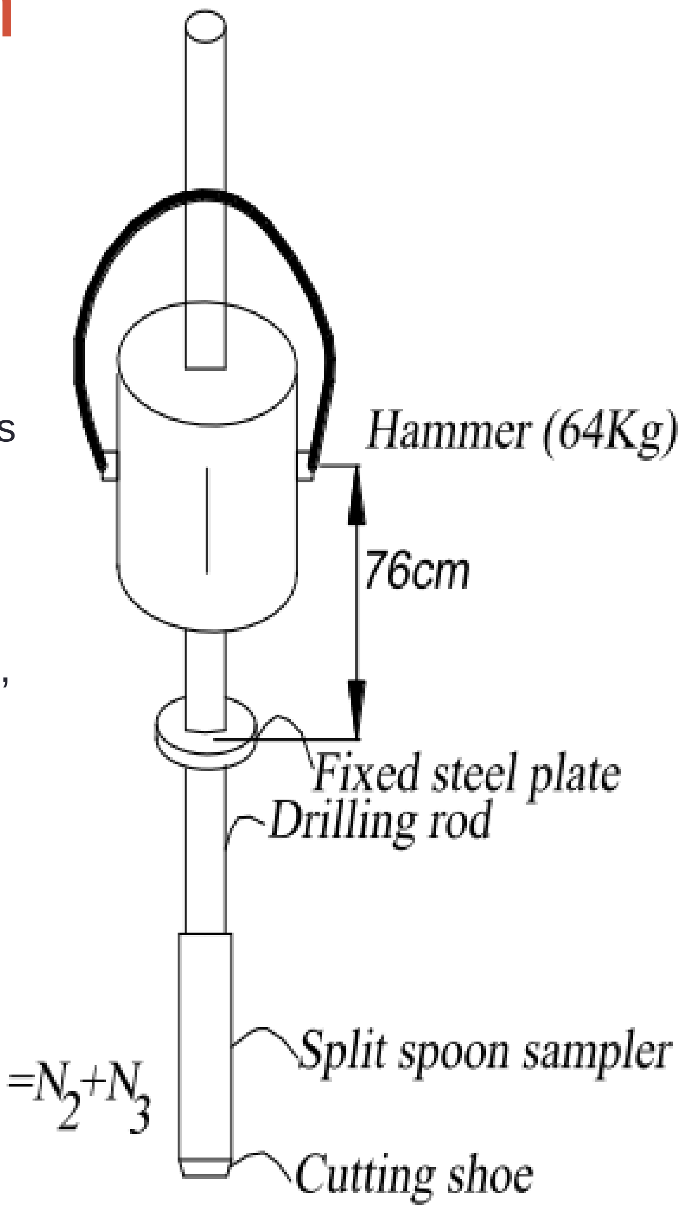
2. Field Test
   A. Penetration Tests
      ii. Dynamic Penetration Tests
         - **Standard Penetration Test (SPT)**
            - After applying some corrections, N value is correlated with important properties of the soil, for use in foundation design.

Why correct N value?

- Difference in some features of SPT equipments, drilling rigs, hammer and skill of operation.
- Drilling hammer configuration and the way hammer load is applied.
- Whether liner is employed or not.
- Amount of overburden pressure.
- Length of the drill rod.
- Borehole diameter.



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- **Standard Penetration Test (SPT)**
- *To get approximately the same value for a given soil type at a given depth it has been suggested to correct the N value;*

$$N'_{70} = C_N \eta_1 \eta_2 \eta_3 \eta_4 N$$

- N'_{70} = corrected or modified blow count
- C_N = adjustment for effective overburden pressure

$$C_N = \sqrt{\frac{95.76}{P'_o}}$$

- P'o= effective overburden pressure at the depth of interest (in KPa)

- η 1 = correction for equipment and hammer type

$$\eta_1 = \frac{E_{r\,(i)}}{E_{r\,(70)}} = \frac{E_{r\,(i)}}{70}$$

- Er (i) = equipment used for the test
- Note: Er* N = constant for all equipment

- i.e. N_{70}*70=N_{60}*60

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- **Standard Penetration Test (SPT)**

$$N'_{70} = C_N \eta_1 \eta_2 \eta_3 \eta_4 N$$

- η_2 = correction for rod length

$$\eta_2 = \begin{cases} 1.0; & for\ \ L > 10\,m \\ 0.95; & for\ \ 6 < L \le 10\,m \\ 0.85; & for\ \ 4 < L \le 6\,m \\ 0.95; & for\ \ L \le 4\,m \end{cases}$$

- η_3 = correction for sample liner

$$\eta_3 = \begin{cases} 1.0; & without\ \ liner \\ 0.8; & with\ \ liner\ in\ dense\ sand\ and\ clay \\ 0.9; & with\ \ liner\ in\ loose\ sand \end{cases}$$

- η_4 = correction for bore hole diameter

$$\eta_4 = \begin{cases} 1.0; & for\ 60 \le \phi \le 120mm \\ 1.05; & for\ \phi = 150mm \\ 1.15; & for\ \phi = 200mm \end{cases}$$

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- **Standard Penetration Test (SPT)**
  - Correlations of SPT Results
    - Cohensionless soils

The Japanese Railway Standard proposed

$$\phi = \sqrt{18N'_{70}} + 15 \qquad \textit{for roads and bridges}$$

$$\phi = 0.36N'_{70} + 27 \qquad \textit{for buildings}$$

Mayerhof (1959) suggested

$$\phi = 28 + 0.15D_r$$, where D_r = relative density in %

Yoshida et al (1988) suggested

$$D_r(\%) = 25(P'_o)^{-0.12}(N_{60})^{0.46}$$, where P'_o =effective pressure in KPa

Skempton (1986):

$$\frac{N'_{70}}{D_r^{\,2}} = 32 + 0.288P'_o$$; where P'_o in KPa

Chapter 1: Site Exploration

- **Standard Penetration Test (SPT)**
  - Correlations of SPT Results
    - *Cohensionless soils*

Terzaghi and Peck also gave the following correlation between SPT value, f and Dr.

Table 1.2 : Correlation between N, ϕ, and D_r for Sands

Condition	N'_{70}	ϕ (degree)	D_r(%)
Very loose	0-4	<20	0-15
Loose	4-10	28-30	15-35
Medium	10-30	30-36	35-65
Dense	30-50	36-42	65-85
Very dense	>50	>42	>85

Chapter 1: Site Exploration

- **Standard Penetration Test (SPT)**
  - Correlations of SPT Results
    - *Cohesive soils*

The common correlations of N-values with unconfined compressive strength of cohesive soils is:

$$q_u = K * N$$

Where K- is about 12 and - q_u In MPa

The following correlations are suggested by Bowels (1995)

Table 1.3 : Correlation between N and q_u for Clays

Consistency	N	q_u(KPa)	γ_{sat}(KN/m^3)
Very soft	0-2	<25	16-19
Soft	2-4	25-50	
Medium	4-8	50-100	17-20
Stiff	8-15	100-200	19-22
Very stiff	15-30	200-400	
Hard	>30	>400	

Chapter 1: Site Exploration

2. Field Test

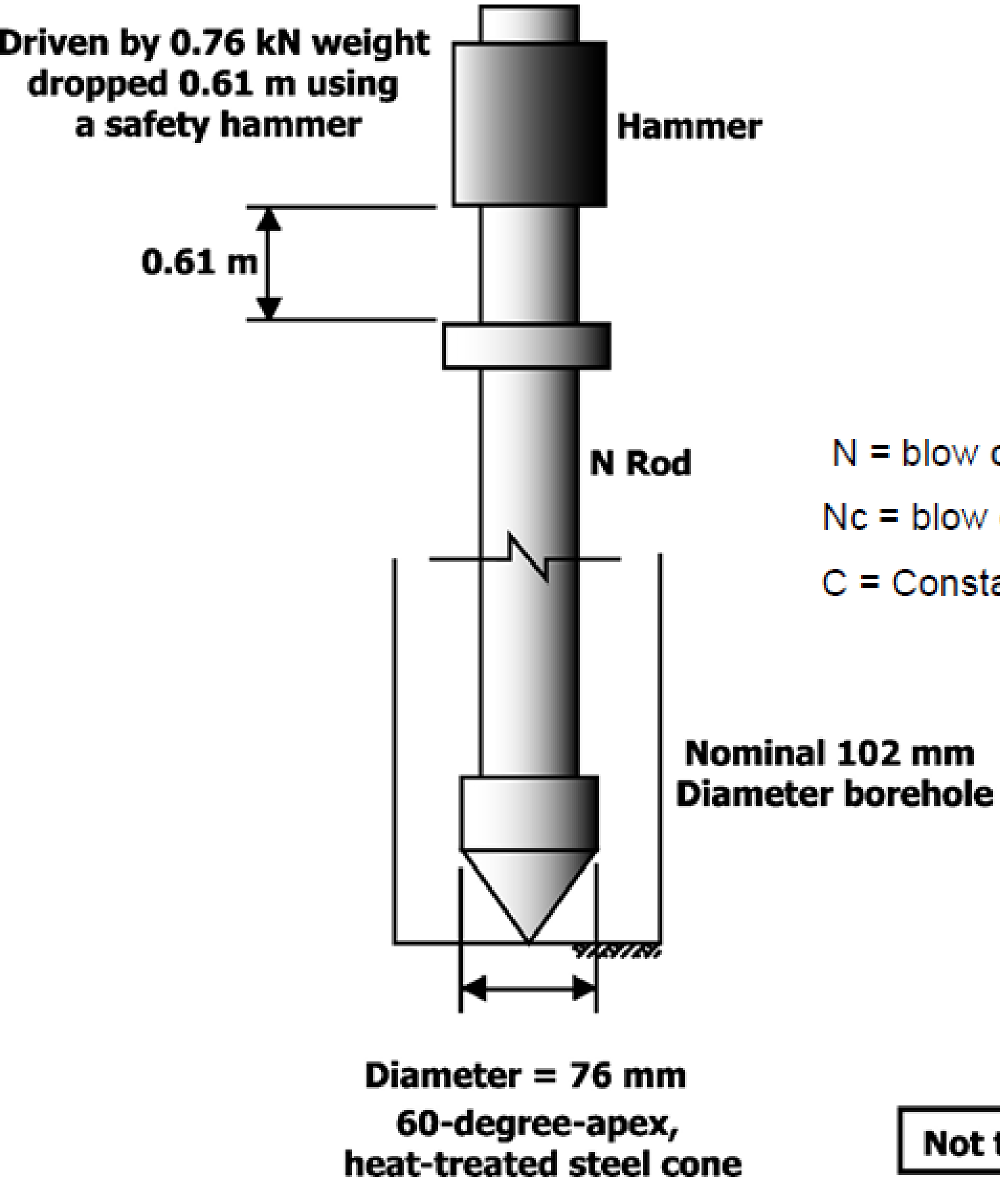
   A. Penetration Tests

      ii. Dynamic Penetration Tests

      - **Dynamic Cone Penetration Test**
        - **Used to determine the effort required to force a point through the soil and obtain resistance value.**
        - Used in cohesionless soils when static penetration test is difficult o perform or when dynamic properties of the soil are of special interest.
        - Can be ***dry or wet method.***
        - ***The cone attached to the drilling rod is driven into the soil by blows of 65 kg hammer falling from a height of 75 cm. The blow count for every 30 cm penetration is made to get a continuous record of the variation of the soil consistency with depth.***

Table 1.4: Proprties of sounding equipment

Type	Mass of hammer, m (Kg)	Drop height , h (cm)	Tip area (cm^2)
Light penetrometer	10	50	10
Medium penetrometer	30	50	10
Heavy penetrometer	50	50	15
SPT	63.5	76.2	tip open



$$N_c = N/C$$

N = blow count for SPT

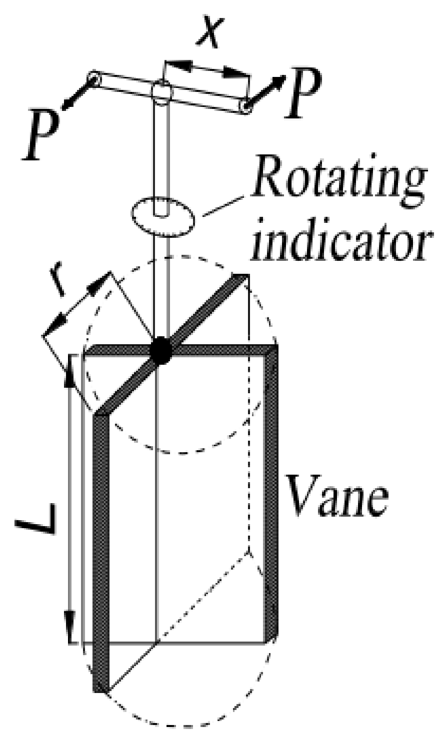
Nc = blow count for dynamic cone

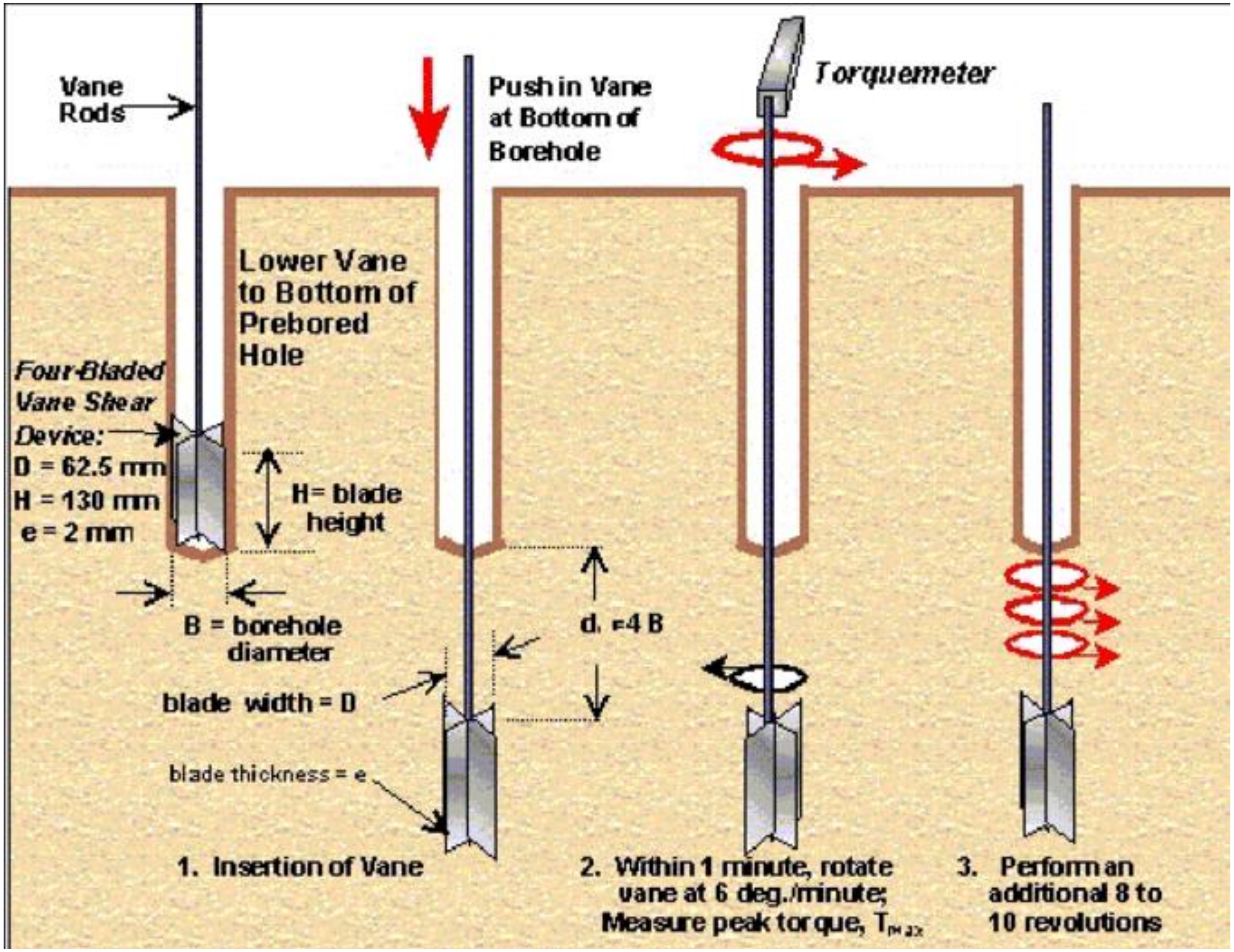
C = Constant, lies between 0.8 and 1.2 when bentonite is used.

Not to Scale

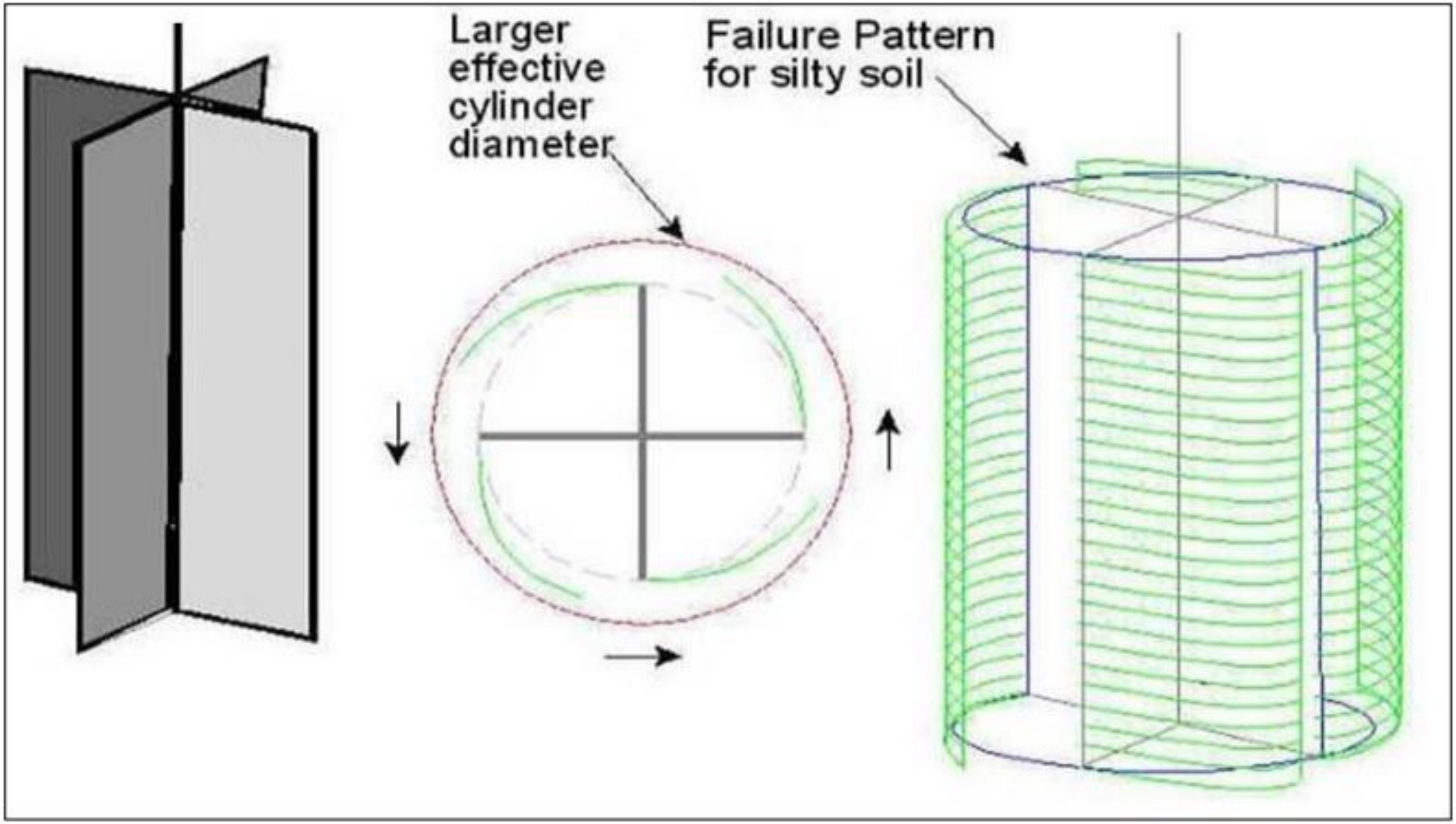
Chapter 1: Site Exploration

2. Field Test
   B. Vane Shear Test
      - Conducted inside a borehole or test pit at a desired depth.
      - Used for the determination of the undrained shear strength (Cu) of soft clays.
      - Standard rotation = 5˚/sec



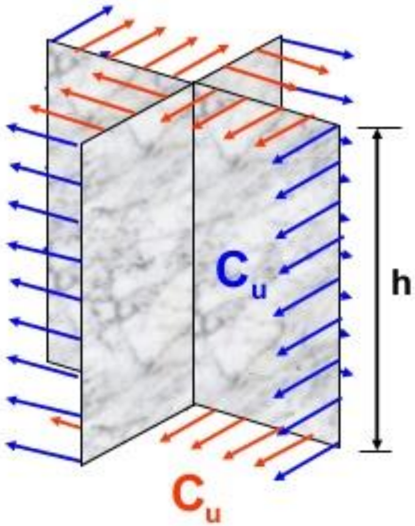


Vane Rods
Push in Vane at Bottom of Borehole
Torquemeter
Lower Vane to Bottom of Prebored Hole
Four-Bladed Vane Shear Device:
D = 62.5 mm
H = 130 mm
e = 2 mm
H= blade height
B = borehole diameter
blade width = D
blade thickness = e
1. Insertion of Vane
2. Within 1 minute, rotate vane at 6 deg./minute; Measure peak torque, T
3. Perform an additional 8 to 10 revolutions


Larger
effective
cylinder
diameter
Failure Pattern
for silty soil

Chapter 1: Site Exploration

Vane shear test



Since the test is very fast, Unconsolidated Undrained (UU) can be expected

$$T = M_s + M_e + M_e = M_s + 2M_e$$

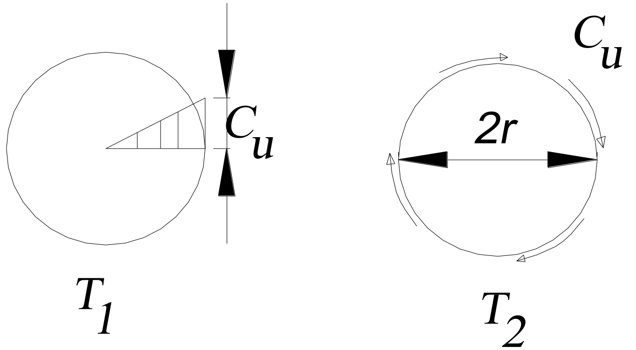
M_s – Shaft shear resistance along the circumference

$$M_s = \pi d h C_u \frac{d}{2} = \pi C_u \frac{d^2 h}{2}$$

$$T = \pi C_u \frac{d^2 h}{2} + \frac{\pi C_u d^3}{12} \times 2$$

$$T = \pi C_u \left(\frac{d^2 h}{2} + \frac{d^3}{6} \right)$$

$$C_u = \frac{T}{\pi \left(\frac{d^2 h}{2} + \frac{d^3}{6} \right)}$$



Vane dimension (mm)			Rod (mm) D_{rod}
L = 4r	r	S	D_{rod}
150	37.5	3	16
100	25	1.6	18

S = blade thickness

D_{rod} = rod diameter (mm)

Chapter 1: Site Exploration

B. Vane Shear Test

- correlation between consistency and C_u

	Undrained shear strength C_u(Kpa)	
Consistency	BS5930:1981	Terzaghi and Peck: 1967
Very soft	<20	<12
Soft	20-40	12-25
Firm	40-75	25-50
Medium	40-75	25-50
Stiff	75-150	50-100
Very stiff	>150	100-200
Hard		>200

- Field vane shear test overestimates the undrained shear strength thus reduction factor should be used to estimate the **design undrained shear strength**.
  - $c_{u,\ d} = \lambda\ c_{u,}$

Chapter 1: Site Exploration

B. Vane Shear Test

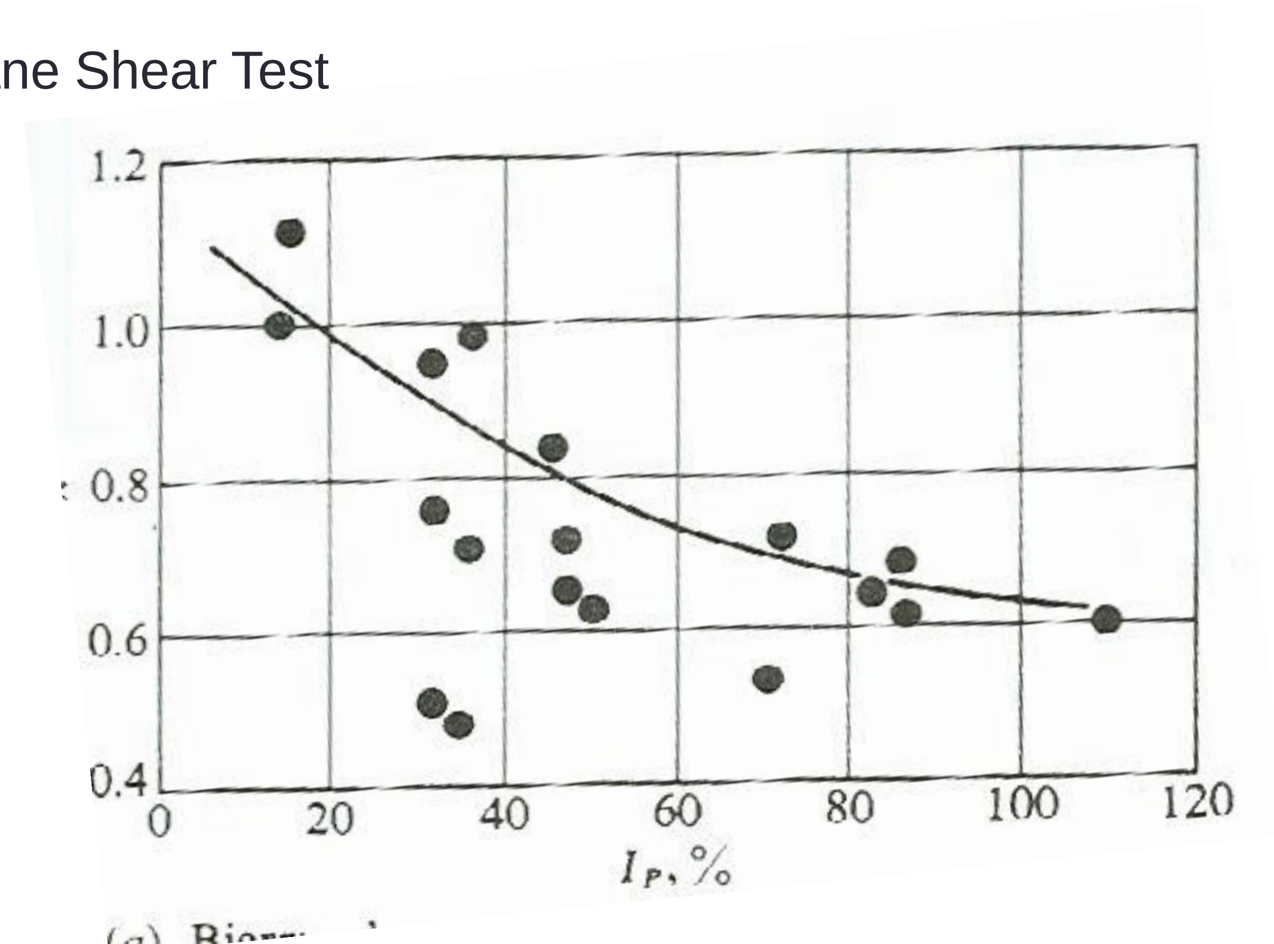
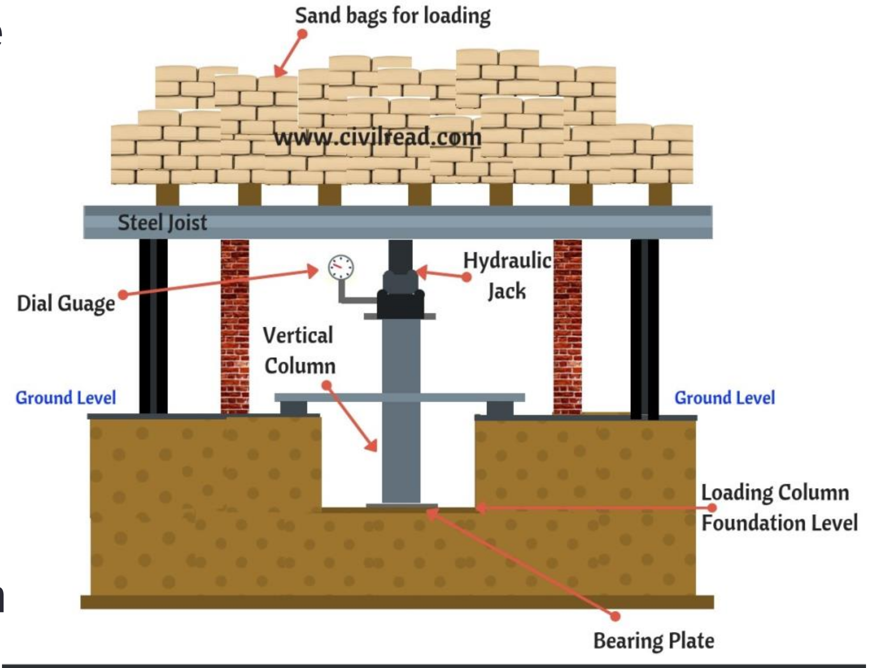


Figure 1.8: Bjerrum’s correction factor for vane shear test.

Chapter 1: Site Exploration

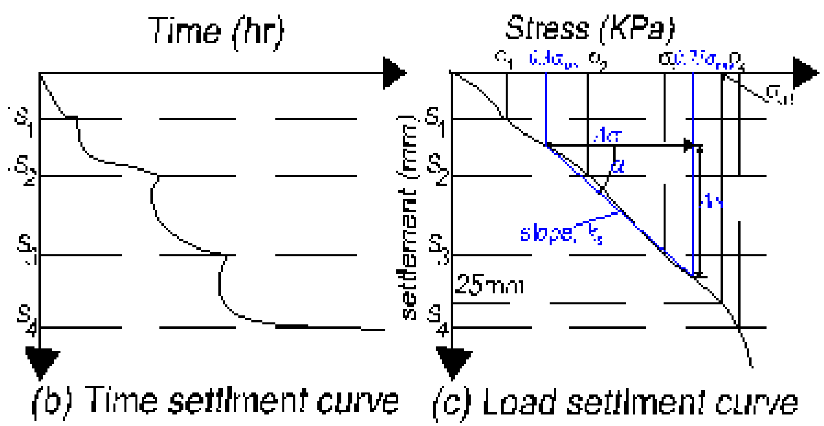
2. Field Test
   c. Plate Load Test
      - Most reliable method of obtaining the ultimate bearing capacity of a soil.
      - Also used in the design of highways and railways.
      - Probable settlement of a given loading at a given depth can also be determined.
      - Involves installing a prototype foundation (plate) at a desired depth.
      - The prototype foundation is loaded in increments and the corresponding settlement is measured.



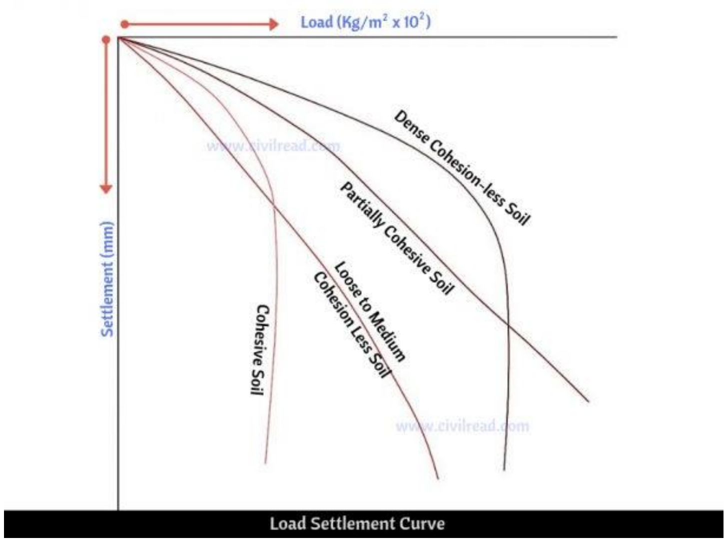
Gravity Loading - Plate Load Test

Chapter 1: Site Exploration

2. Field Test
   C. Plate Load Test
      - Round plate: 30 cm and 70 cm
      - Square plate: 0.3 m X 0.3 m and 60cm X 60cm
      - Excavate pit (at least 4B or 4R wide) and place plate
      - Load is applied on the plate with increment of $q_{ult, estimated}$ / 5
      - Settlement is recorded from a dial gauge for each load increment.



(b) Time settlment curve (c) Load settlment curve



Chapter 1: Site Exploration

2. Field Test

   C. Plate Load Test

- Test stops when:
  - Soil fail in shear
  - Total settlement reaches 25 mm
  - Capacity of the apparatus is reached

- Relationship between settlement of plate and footing (Terzaghi and Peck)

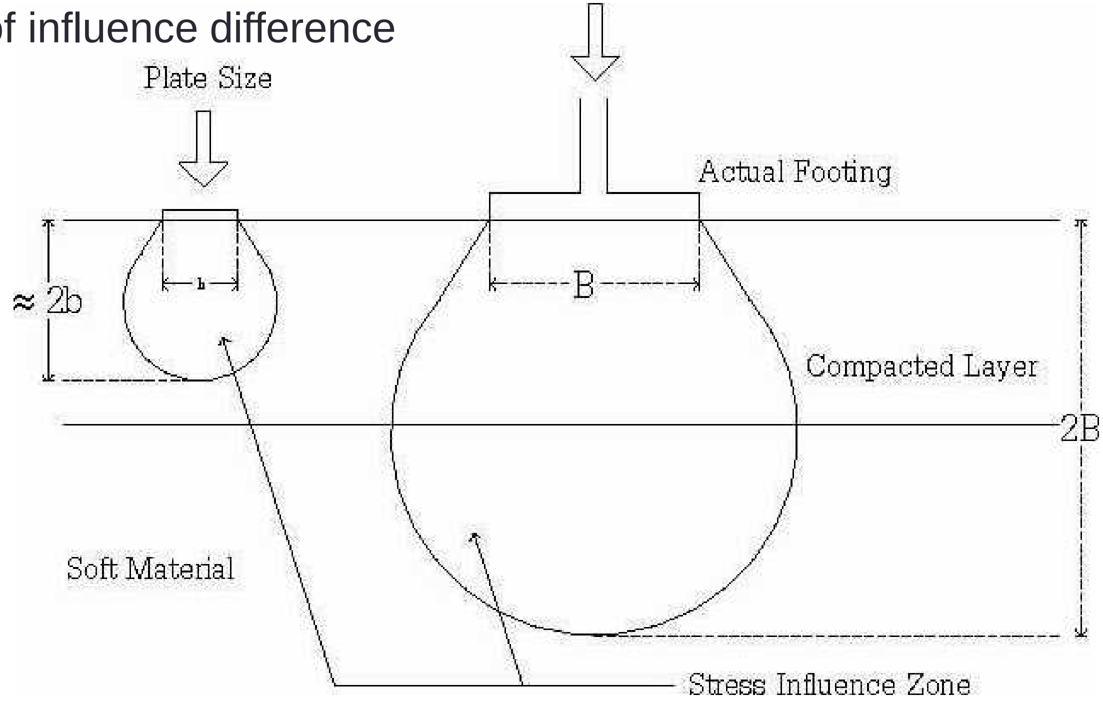
For sands $S_P = S_F\left[\frac{b_P(B+0.3)}{B(b_p+0.3)}\right]^2$ and $S_P = \frac{b_P}{B}S_F$ for clays

where: B= width of footing (least dimension) and b_p= width (diameter) of plate

For sandy soils $q_{ult,F} = \frac{B_F}{B_P}q_{ult,P}$ and for clays $q_{ult,F} = q_{ult,P}$

Chapter 1: Site Exploration

2. Field Test
   C. Plate Load Test
   - Limitations
     - Size difference
     - Short term test
     - Zone of influence difference



Chapter 1: Site Exploration

2. Field Test

   D. Indirect Geophysical Methods

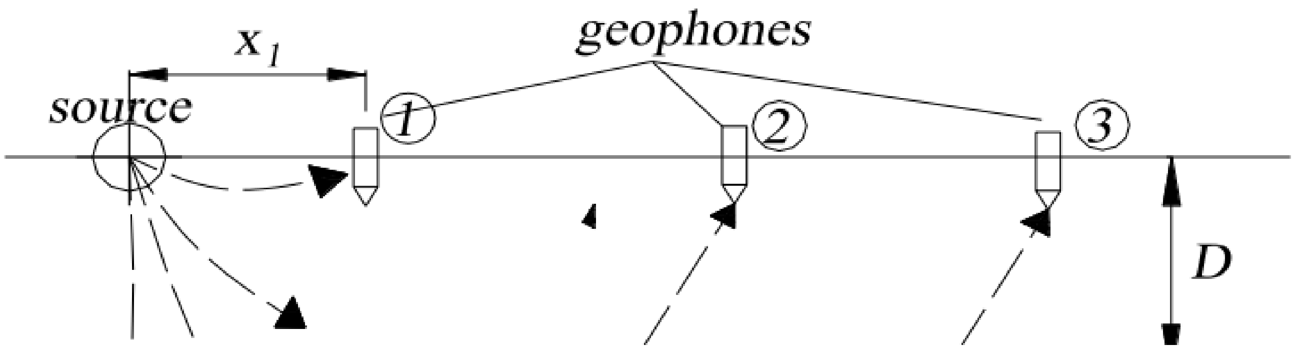
      - Correlates speed and condition of wave propagation in a soil media with soil properties.
      - Checks and supplements the soil test results.
      - Gives idea about the position of water table, strata boundaries, depth of bed rocks,…
      - Results must be confirmed from boreholes.

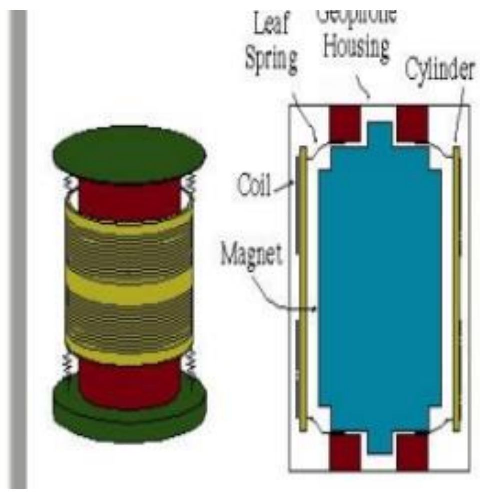
2. Field Test

    D. Indirect Geophysical Methods

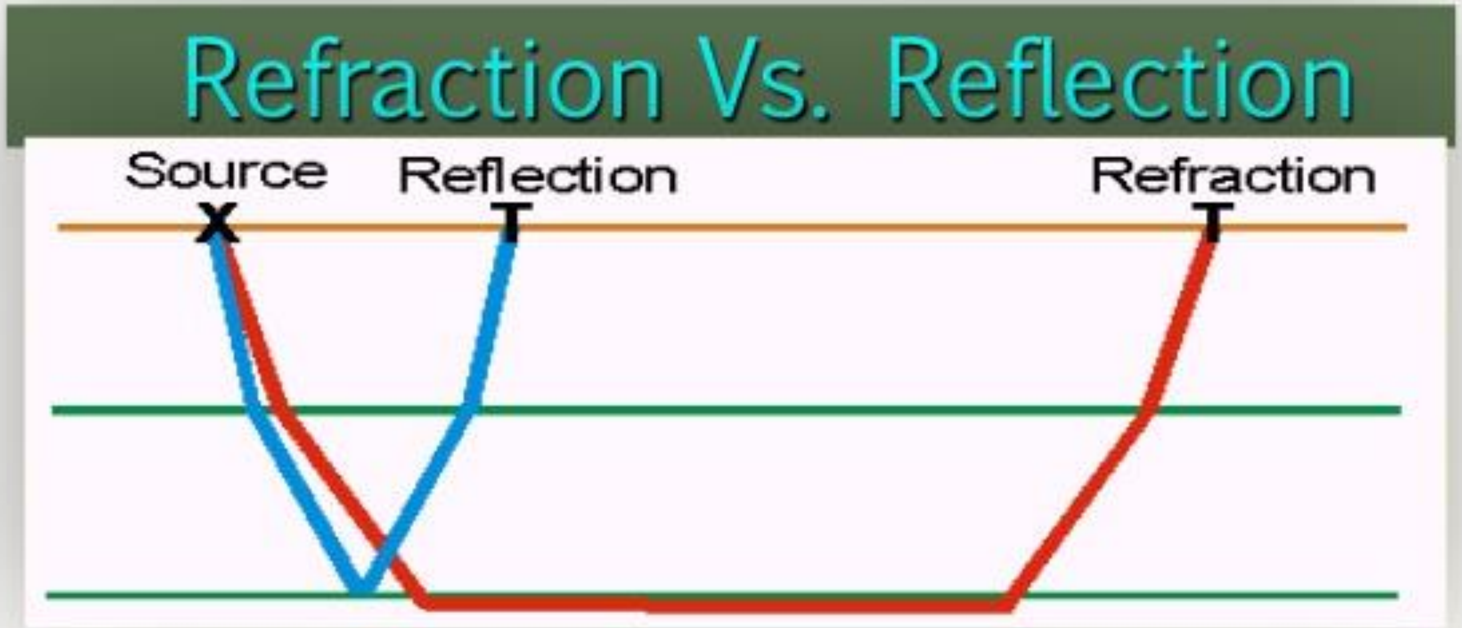
- **Seismic exploration**
  - Seismic waves move through different types of soils at different velocities.
    - Sound rocks 4000 to 7000 m/s
    - Clays 500-700 m/s
    - Loose weathered soil 30 m/s
  - Seismic waves are refracted when they cross the boundary between two different types of soils.
  - Shock waves are induced by producing an explosion at the surface
  - The waves are picked up through **geophones** placed at various point.
  - Helps in plotting soil profile.
  - Test would fail to detect a layer having velocity lesser than that of the upper layer.
  - Reliable for relatively thick and distinct layer.

- **Seismic exploration**



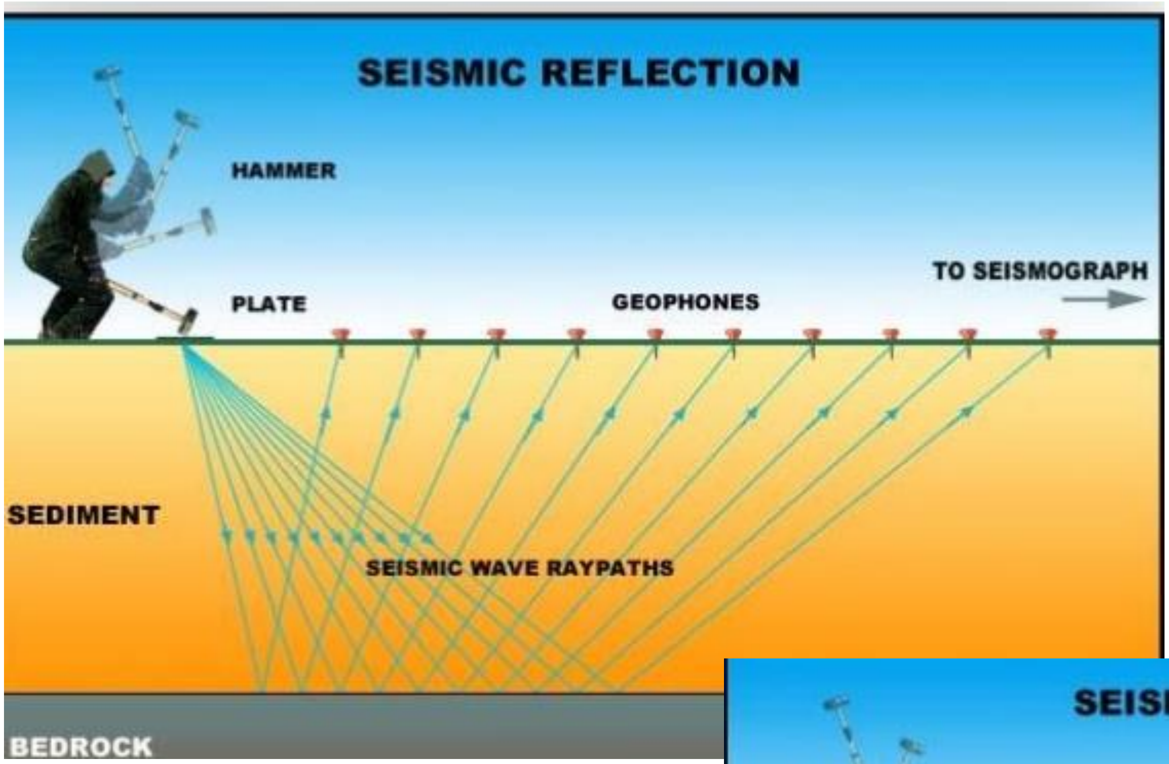


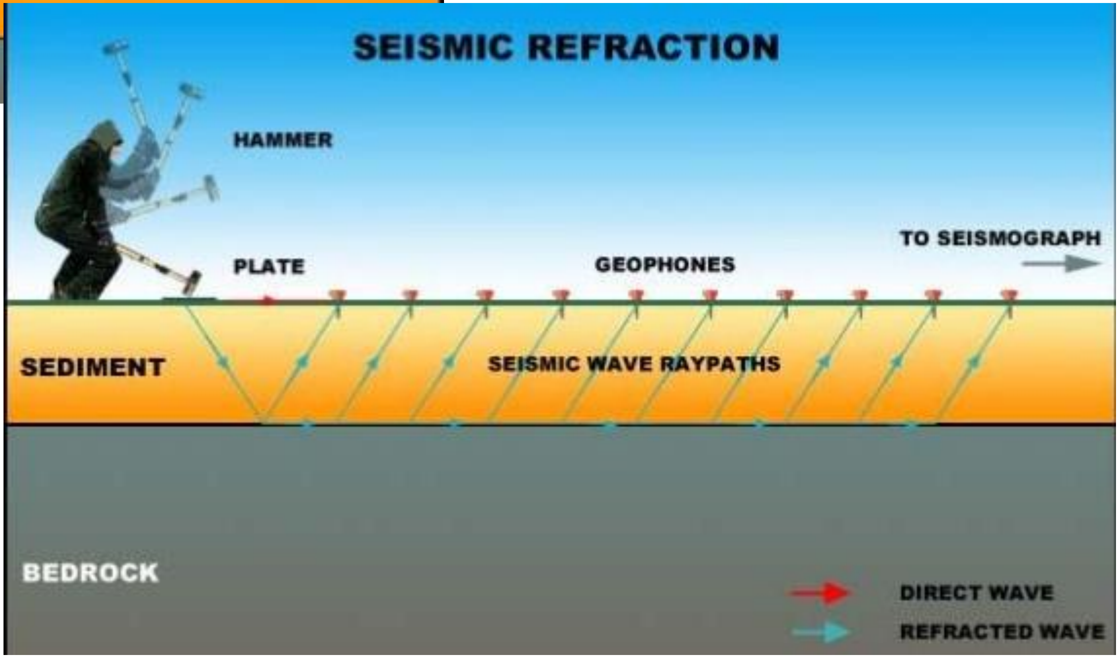
Soil type	Velocity of Longitudinal Waves V_l (m/s)
Non cohesive	200 – 1500
Soils with little cohesion	1000 – 1600
Cohesive soils	1600 – 2000
Rocks	2000 – 6000



- **Seismic Refraction**: the signal returns to the surface by refraction at subsurface interfaces, and is recorded at distances much greater than depth of investigation

- **Seismic Reflection**: the seismic signal is reflected back to the surface at layer interfaces, and is recorded at distances less than depth of investigation


SEISMIC REFLECTION
HAMMER
PLATE
GEOPHONES
TO SEISMOGRAPH
SEDIMENT
SEISMIC WAVE RAYPATHS
BEDROCK


SEISMIC REFRACTION
HAMMER
PLATE
GEOPHONES
TO SEISMOGRAPH
SEDIMENT
SEISMIC WAVE RAYPATHS
BEDROCK
DIRECT WAVE
REFRACTED WAVE

Advantages :

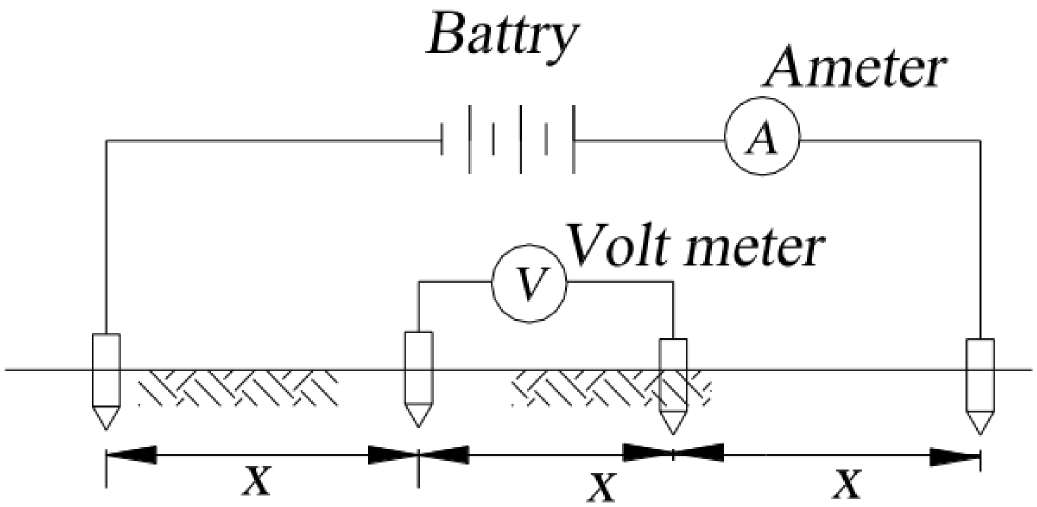
- Complete picture of stratification of layer upto 10m depth.
- **Simple equipments and easy** execution
- **Little processing** required
- Provides seismic velocity information for estimating material properties.
- Provides **greater vertical resolution** than electrical, magnetic, or gravity methods.
- Data acquistion requires very limited intrusive activity is **non-destructive.**

Disadvantages :

- Cannot be used when hard layer overlies soft layer
- Cannot be used in areas like concrete or bitumen
- Presence of buried conduits and services
- Cannot be used in frozen layers
- High cost
- Skilled labour

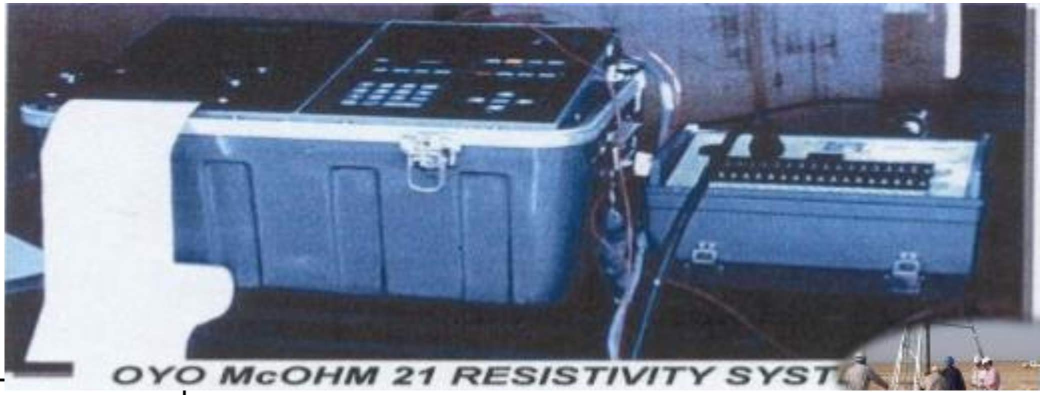
Chapter 1: Site Exploration

2. Field Test
   D. Indirect Geophysical Methods
      - **Electrical resistivity Method**
        - Different soils exhibits different resistivity.
        - Four electrode are inserted in the ground and current is made to flow. Resistance is then measured.
        - Requires good contrast in resistivity between the soil layers.
        - Wrong readings may be taken if difference between layers is not substantial or if soil is wet and contains considerable amount of dissolved salts.



$$\rho = 2\pi\, x \frac{E}{I}$$

where: ρ= apparent resistivity in Ohms/m
x = electrode spacing
E = potential drop
I = circuit current



Soil type	Resistivity Ohms/m
Clay and saturated silt	0 – 1000
Sandy clay	1000 – 2700
Clayey sand and saturated sand	2700 – 5400
sand	5400 – 16400
gravel	16,400 – 50,000

Electrical Resistivity method- Pros and Cons

Advantages

- It is a very rapid and economical method.
- It is good up to 30m depth.
- The instrumentation of this method is very simple.
- It is a non-destructive method.

Disadvantages of this method are:

- It can only detect absolutely different strata like rock and water.
- It provides no information about the sample.
- Cultural problems cause interference, e.g., power lines, pipelines, buried casings, fences.

Chapter 1: Site Exploration

- Rock Core Investigation
  - Sampling (usually used)
    - known as rock core sampling..
    - Bore up to rock layer → take a sample → conduct lab tests → determine bearing capacity of the rock
    - Sampling technique:
      - Normally obtained by rotary drilling.
      - Sampler consists of a tube with cutting bit at its lower end.
      - The depth of recovery of the sample should be recorded. For a general evaluation of the rock quality the following quantities can be calculated.

$$recovery\ ratio = \frac{length\ of\ core\ recovered}{theoretical\ length\ of\ rock\ cored}$$

(recovery ratio of 1 indicates the presence of intact rock , can be less than 0.5>

    - The recovery ratio depends on quality of rock mass, stability, skill of operator, choice of core barrel

$$RQD = \frac{\sum length\ of intact\ pieces\ of\ core > 100mm}{theoretical\ length\ of\ rock\ cored}$$

RQD (%)	Rock Quality
90-100	Excellent
75-90	Good
50-75	Fair
25-50	Poor
0-25	Very Poor

Chapter 1: Site Exploration

- Ground Water Measurement
  - Load bearing capacity of a foundation is highly affected by the presence of water table.
  - Establishing the highest and the lowest possible levels of water during the life of the project is necessary.
  - For soils with high coefficient of permeability water level may stabilize within a day.
  - For soils with low permeability, water level may stabilize within a week.
  - To measure seasonal GWT variation. Install piezometer in the borehole.

Steel Tape for measuring GWT

Chapter 1: Site Exploration

- Soil Exploration Report
  - Prepared for use in design offices and for future construction work.
  - The contents of the report should include:

1. **Scope** of the investigation
2. Proposed structure
3. **Location description** of the site → structures nearby, drainage conditions, vegetation and any other features unique to the site.
4. **Geological setting** of the site
5. **Details of field exploration** → no. of boring, depths of boring, types of boring involved, and so on
6. General description of **subsoil conditions** → from lab. And field test
7. **Water-table location**
8. **Recommendations** regarding the foundation, the allowable bearing pressure, and any special construction procedures that may be needed.
9. **Conclusions and limitations** of the investigations.

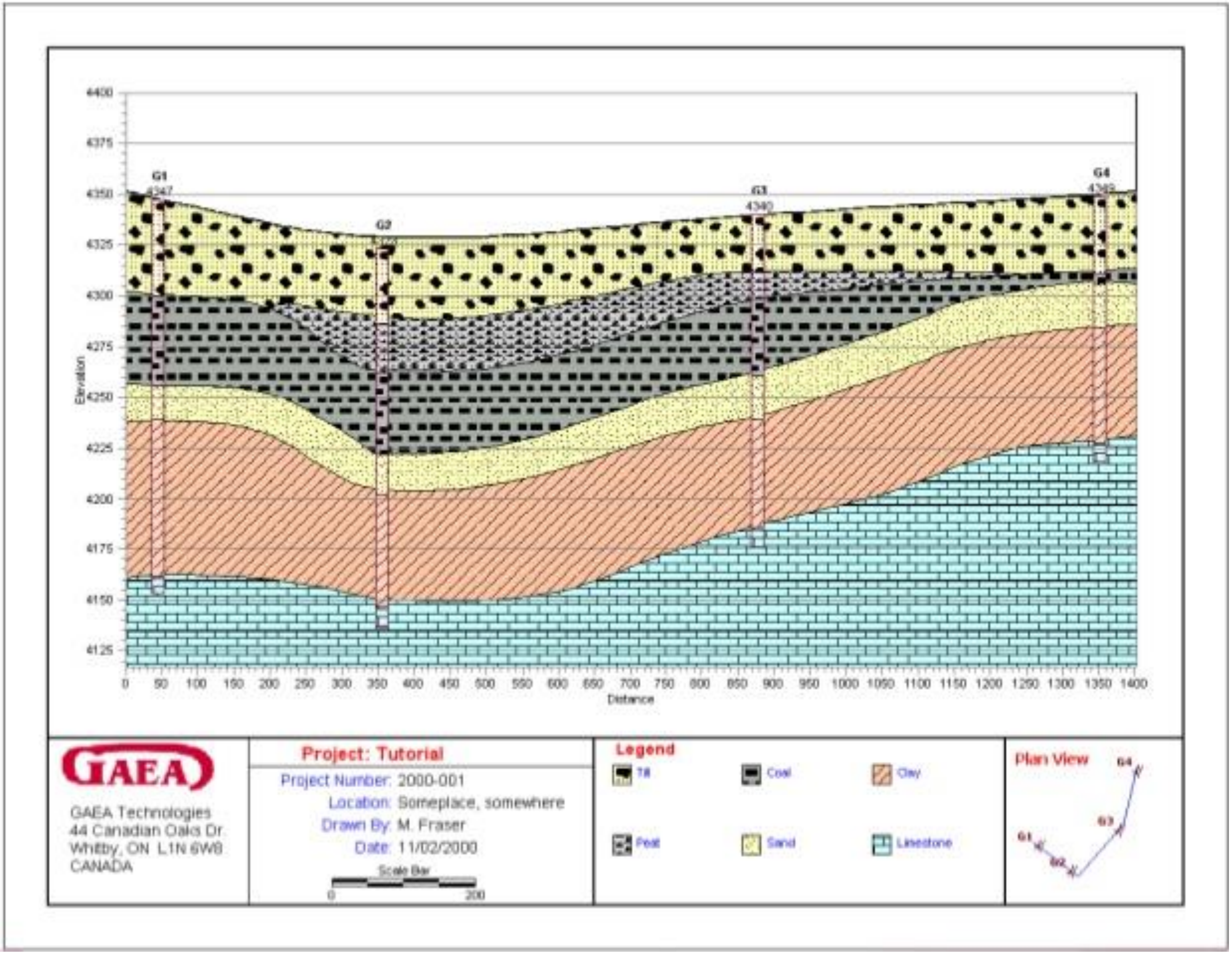


Fig: Borehole log

Example Table of Contents for a Geotechnical Investigation (Data) Report

Examples

1. A silty sand was subjected to an SPT at a depth of 3m. A standard sample was used in a borehole 150mm diameter. Groundwater level occurred at a depth of 1.5m below the surface of the soil which was saturated throughout and had a unit weight of 19.3kN/m^3. the average N count was 15. During calibration of the test equipment, the energy applied to the top the driving rods was measured as 350 Joules. Determine the corrected N_{70} value for the soil.

Solution

$$theoretical\ hammer\ energy = mgh$$

$$= 63.5kg\ x\frac{9.81m}{s^2}x\ 0.76m = 473J$$

$$Er(\%) = \frac{350}{473} = 74\%$$

$$Po = (3x19.3) - (1.5x9.81) = 43.2kN/m^3$$

$$C_N = \sqrt{\frac{95.76}{Po}} = \sqrt{\frac{95.76}{43.2}} = 1.5$$

$$\eta_1 = \frac{E_{r(i)}}{E_{r(70)}} = \frac{E_{r(i)}}{70} = \frac{74}{70} = 1.05$$

$$\eta_2 = \begin{cases} 1.0; & for\ L > 10\ m \\ 0.95; & for\ 6 < L \le 10\ m \\ 0.85; & for\ 4 < L \le 6\ m \quad \leftarrow \\ 0.95; & for\ L \le 4\ m \end{cases}$$

$$\eta_3 = \begin{cases} 1.0; & without\ liner \quad \leftarrow \\ 0.8; & with\ liner\ in\ dense\ sand\ and\ clay \\ 0.9; & with\ liner\ in\ loose\ sand \end{cases}$$

$$\eta_4 = \begin{cases} 1.0; & for\ 60 \le \phi \le 120\ mm \\ 1.05; & for\ \phi = 150\ mm \quad \leftarrow \\ 1.15; & for\ \phi = 200\ mm \end{cases}$$

$$N_{70} = C_N\mu_1\mu_2\mu_3\mu_4N = 21$$

2. A standard penetration test has been conducted in loose coarse sand stratum to a depth of 4.8m below the ground surface. The blow count obtained in the field were as follows: 0-0.15m=4 blows; 0.15-0.31m=6 blows; 0.31-0.46m=8 blows. The test were conducted using a donut hammer in a 152cm diameter boring with a standard sampler and liner. The effective unit weight of the loose sand stratum is about 15kN/m^3. Determine the corrected SPT if the testing procedure is assumed to only be 70% efficient.

Solution

$$N = 6 + 8 = 14$$

$$Po = 4.8m\,x\,\frac{15kN}{m^2} = 72kPa$$

$$C_N = \sqrt{\frac{95.76}{Po}} \qquad C_N = \sqrt{\frac{95.76}{72}} = 1.15$$

$$\eta_1 = \frac{E_{r\,(i)}}{E_{r\,(70)}} = \frac{E_{r\,(i)}}{70} = \frac{45}{70} = 0.64$$

$$\eta_2 = \begin{cases} 1.0; & for \quad L > 10 \quad m \\ 0.95; & for \quad 6 < L \le 10 \quad m \\ 0.85; & for \quad 4 < L \le 6 \quad m \quad \leftarrow \\ 0.95; & for \quad L \le 4 \quad m \end{cases}$$

$$\eta_3 = \begin{cases} 1.0; & without \ \ liner \\ 0.8; & with \ \ liner \ in \ dense \ sand \ and \ clay \\ 0.9; & with \ \ liner \ in \ loose \ sand \quad \leftarrow \end{cases}$$

$$\eta_4 = \begin{cases} 1.0; & for \ 60 \le \phi \le 120 \ mm \\ 1.05; & for \ \phi = 150 \ mm \quad \leftarrow \\ 1.15; & for \ \phi = 200 \ mm \end{cases}$$

$$N_{70} = C_N \mu_1 \mu_2 \mu_3 \mu_4 N = 8$$

3. A vane shear test as conducted in a saturated clay. The height and diameter of the vane were 101.6mm and 50.8mm respectively. During the test, the maximum torque applied was 0.0168Nm. Determine:
   a. The undrained shear strength of the clay
   b. The corrected undrained shear strength of the clay for design purpose if it has a liquid limit and plastic limit of 64 and 29 respectively.

Solution

$$T = Cu\, x\, \pi \left(\frac{d^2 h}{2} + \frac{d^3}{6}\right)$$

$$d = 50.8mm, h = 101.6mm$$

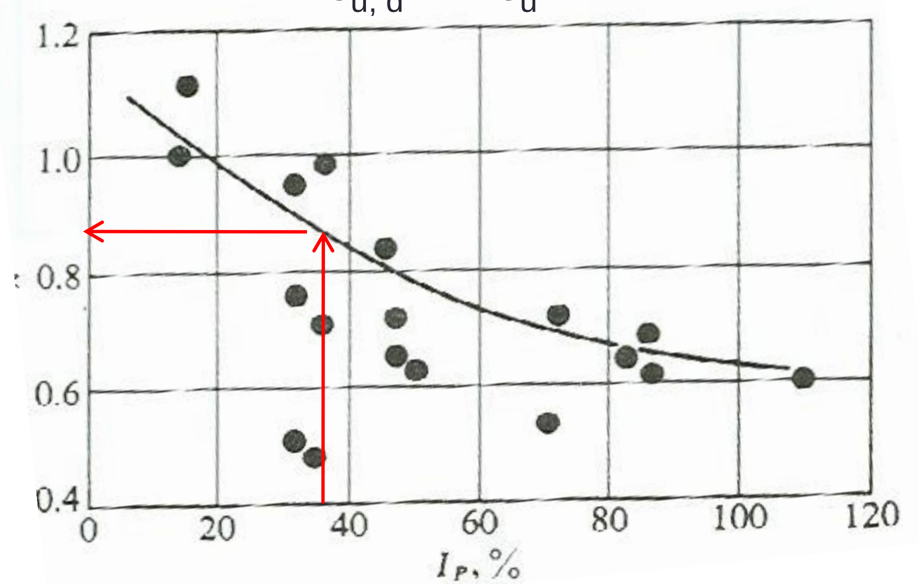
$$T = 0.0168N.m.$$

$$Cu = \frac{0.0168N.m}{\pi\left(\frac{50.8^2 x 101.6}{2} + \frac{50.8^3}{6}\right)} = 35kN/m^2$$

$$LL = 64, PL = 29$$

$$PI = LL - PL = 35$$

$$c_{u,\,d} = \lambda\, c_u$$



$$Cu,d = 0.85x35kN/m^2 = 29.8kN/m^2$$

4. A vane used to test a deposit of soft alluvial clay required a torque of 67.5Nm. The dimensions of the vane were D=75mm; h=150mm. Determine a value for the undrained shear strength of the clay.

Solution:

$$T = c_u \frac{\pi D^2 H}{2}\left(1 + \frac{D}{3H}\right)$$

i.e.

$$67.5 = c_u \pi \times \frac{0.075^2 \times 0.15}{2}\left(1 + \frac{0.075}{0.45}\right) \times 1000 \text{ kPa}$$

$$\Rightarrow \quad c_u = 44 \text{ kPa}$$