AL-MUSTAQBAL UNIVERSITY COLLEGE

CIVIL ENGINEERING DEPARTMENT

FOUNDATION ENGINEERING

2018-2019

INSTRUCTOR

Lect. Dr. Mahmoud Shakir Abdulkareem

FOUNDATION ENGINEERING

Syllabus:

Chapter 1: Site Investigation

1. Site Investigation
2. Ground Water Investigation
3. Geophysical Investigation
4. Field Tests

Chapter 2: Lateral Earth Pressure

1. Introduction
2. Rankine Active Earth Pressure Theory
3. Coulomb Active Earth Pressure Theory
4. Coulomb and Rankine Passive Earth Pressure.

Chapter 3: Retaining walls

1. Types of retaining walls.
2. Proportioning Retaining Walls.
3. Stability Requirements.
    1) Safety against overturning (Rotation).
    2) Safety against sliding.
    3) Safety against bearing capacity failure.

Chapter 4: SHEET PILE WALLS

1. Introduction
2. Construction Methods.
3. Cantilever Sheet Pile Walls.
4. Anchored Sheet-Pile Walls.

1) Free Earth Support Method

2) Free Earth Support Method

5. Braced Excavation (Cut)

1) Earth pressure distribution on temporary braced excavation.

2) Design of Braced excavation (Cuts) walls.

6. Single-wall Cofferdams in Water

Chapter 5: Slope Stability

1. Introduction
2. Infinite Slope
3. Finite Slope

Chapter 6:

1. Soil Bearing Capacity
2. Safety Factor
3. Determine Soil Bearing Capacity by Field Tests

Chapter 7:

1. Settlement
2. Initial Settlement
3. Consolidation Settlement
4. Secondary Settlement

Chapter 8:

1. Structural Design of Foundation
2. Spread Foundation
3. Combined Foundation
4. Mat Foundation

5. Pile Cap Design

Chapter 9:

1. Piles Foundation
2. Types of Piles
3. Ultimate Caring Load of Single Pile
4. Ultimate Caring Load of Piles Group

REFERENCES:

1. "Foundation Engineering Handbook" Hans F. Winterkorn

2. "Foundation engineering handbook" Fang, H.Y., 2013. Springer Science & Business Media.

3. "Foundation Analysis and Design" Joseph E. Bowles, 5th edition.

4. "Principle /foundation Engineering" Baraja M. Das, 7th edition, 2015.

CHAPTER ONE

(1) SITE INVESTIGATION

The proper design of civil engineering structures requires adequate knowledge of subsurface conditions at the sites of the structures and, when structures are to consist of earth or rock fill materials, of subsurface conditions at possible sources of construction materials.

1. Purpose of site investigation:

1) Guess the stability of the site for the proposed project.
2) Find out the real extent, depth and thickness of each identifiable soil stratum within a limited depth dependent on the size and nature of the structure in addition the nature of soil its self.
3) locating the depth to top of rock (bedrock) as well as the characterization of the rock including the lithology; area extent; depth and thickness, strike and spacing of joints.
4) Obtaining disturbed and undisturbed soil samples for classification and used in laboratory tests to find the engineering properties of soil and rock such as shear strength, compressibility, permeability and so on. In addition, to determine the chemical and physical properties of soil.
5) Locating ground water table, presence, and magnitude of artesian pressure. The properties of ground water must be studied as well as to explore the effects on the structures.

2. The required information by site investigation:

1) Information necessary for adequate selection and design of foundation such as shear strength and compressibility.
2) Information necessary for construction process such as amount excavation material and its properties and whether it can be used for backfilling particularly in earth structure such as embankments and earth dams.
3) Information about ground water and how it can be controlled during construction and using the structure. This Information involved ground water table, seasonal fluctuation and chemical properties of aquifer.

3. Phases of Site Investigations:

1) Reconnaissance Investigation.

The reconnaissance investigations provide information for prefeasibility studies and for planning the explorations for the succeeding phase, explorations for preliminary design. This program, for a localized project such as a building that is to be constructed on a preselected site, will be somewhat limited in scope. However, when a dam or highway project is under consideration, several alternative sites or alignments must be considered. The information obtained in this phase aids in the selection of the alternative sites or alignments for investigation.

A large portion of the work during this phase falls into the category of research. Also included would be field reconnaissance by a geologist and a soils engineer plus such geophysical explorations and borings as are deemed essential.

2) Preliminary investigation.

Preliminary investigation can be accomplished by making number of pits and/or borings in order to obtain the following:

1. Depth, thickness, areal extent, and composition of all soil strata.

2. Ground water level.
3. Depth of the top of bed rock.
4. Obtained disturbed and undisturbed soil samples to determine the engineering properties of the soil.
5. Preliminary selection for foundation type and initial cost information.

3) Detailed Investigation.

This stage involved the following:

1. Designation the geological structure for the site.
2. Designation the situation of ground water.
3. Obtaining the disturbed and undisturbed soil samples for the laboratory tests.
4. Carried out the field tests to investigate the mechanical properties of the soil in the field.

4. Spacing and Depth of Boring:

A) Spacing between tests boring:

i) Preliminary Investigation

In this stage of investigation, the spacing between borings ranged from (30-150) m depending on type of project and stratification of soil.

ii) Detailed Investigation

In this stage, the spacing between the borings was reduced to be made between the borings made in a previous stage. The spacing may be reached of 10 m between boring hole and another depending on the type of project (structure) and soil stratification. Generally the spacing between borings must be enough to draw the geological profile for the site.

In addition, in the site were cavities are expected to exist such as that in lime stone layers, steel bars are driven with close distances to determine the dimensions of such cavities.

A) Depth of Boring Holes

The depth of test boring depends on size and type of structure and also on properties and stratification of loaded soil beneath the structure. **Generally the following points must be taken in to account when boring depth is set:**

1. The drilling must penetrate all weak layers until reach a suitable layer has adequate bearing.

2. In the case where there is a compressible stratum near soil surface, the drilling must continue until the stress and consolidation settlement resulting by structure be very small.

3. When the stiff layers are at shallow depth, the drilling must continue through all these layers to a depth where any weak layer under these stiff layers has no effect on soil bearing and settlement.

4. When a bed rock is encountered the drilling, the drilling must penetrate 3m inside the bed rock layer if it's properties and areal extent are unknown or 1.5 m is enough.

5. In detailed investigation stage, it is preferred to extent the depth of one or more of test borings more than the required depth to ensure that there is no un expected soil layer or ground water.

It should be noted that the depth of test borings must be continue to a depth 150% more than the width of structure (1.5B), if the applied pressure of structure is less than 20 ton/m^2. Furthermore, the depth of boring hole must be reached to 200% more than the width of structure (2B), if the applied pressure of structure is more than 20 ton/m^2. In these cases, the amount of increment in the vertical stress at the end of drilling ranged about (10-20%) of that at the base of foundation. The total and differential settlements are usually small at this depth.

5. Boring Methods:

1. Trial pits
2. Hand and power driven auger
3. Wash boring
4. Percussion drilling
5. Rotary drilling

1. Trail Pits:

Simple and limited method for a depth not more than 4-5 m. The pit must be made with safety slop or stepped edges/sides. The excavated soil must be put at a distance not less than 1m from the edge of pit. In the case of excavation under water table, dewatering is necessary particularly for high permeability soil. The feature of this boring method:

1) Can be viewed the soil at its original location.
2) Easy to obtain disturbed and undisturbed soil samples.
3) For cohesion soil, the samples can be cut by hand from sides and bottom of pit and easy to obtain Shelby tube from the bottom of pit.
4) This method is suitable for all soil types.

2. Hand and power driven auger

Using hand auger is considered as a cheap method to make boring of a hole at depth about 6 m. It can be obtained disturbed soil sample and also undisturbed samples with small diameter.

The hand auger method is not suitable for the following soil:

1) Large size gravel soil.
2) Relatively stiff soil.
3) Soil that collapsed without bracing the sides of boring such as loose sand under water table.

There are many types of hand auger:

a) Iwan auger
b) Helical auger
c) Spiral auger
d) Gravel auger

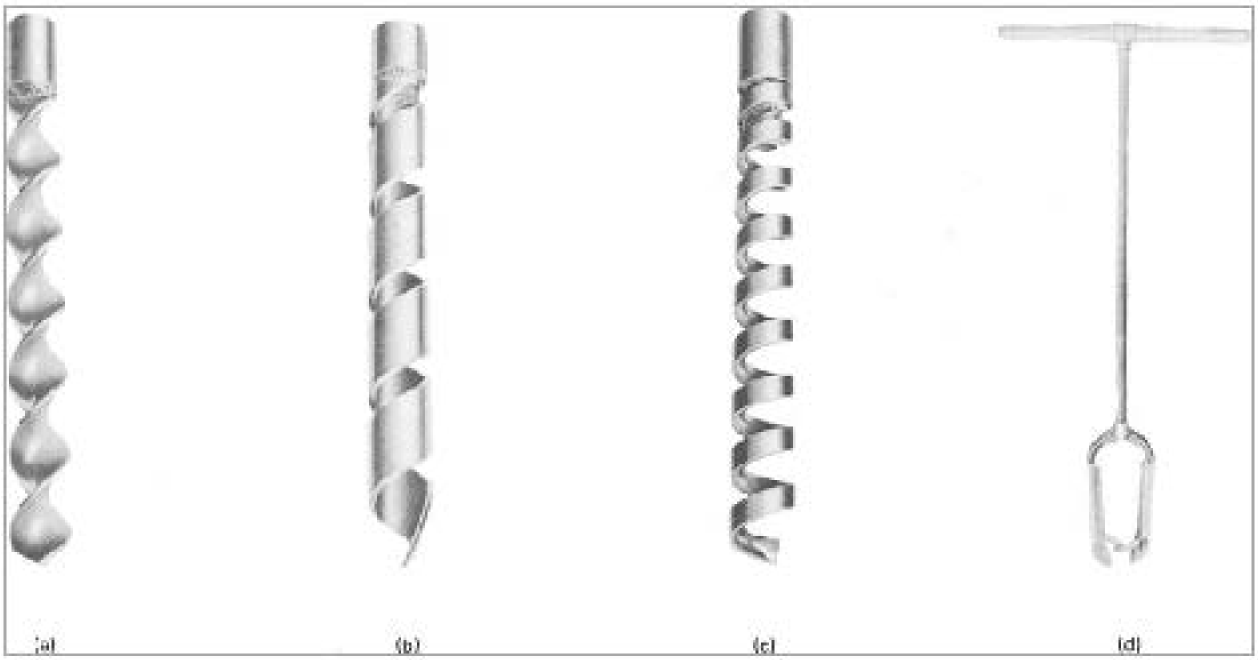

Figure 1.1: Hand augers: (a) helical auger; (b) closed spiral auger; (c) open spiral auger; (d) Iwan auger.

The power driven auger is used for deep investigation. A huge machine is used to rotate the auger. The depth of drilling can be reached about 30m. In different diameter of bore holes can be ranged from (0.1 – 1.5) m. This method is developed to use a hallow stem auger which is used for sampling without remove the auger.

This method is suitable use for sand soil above ground water table and for soft to stiff clayey soil.

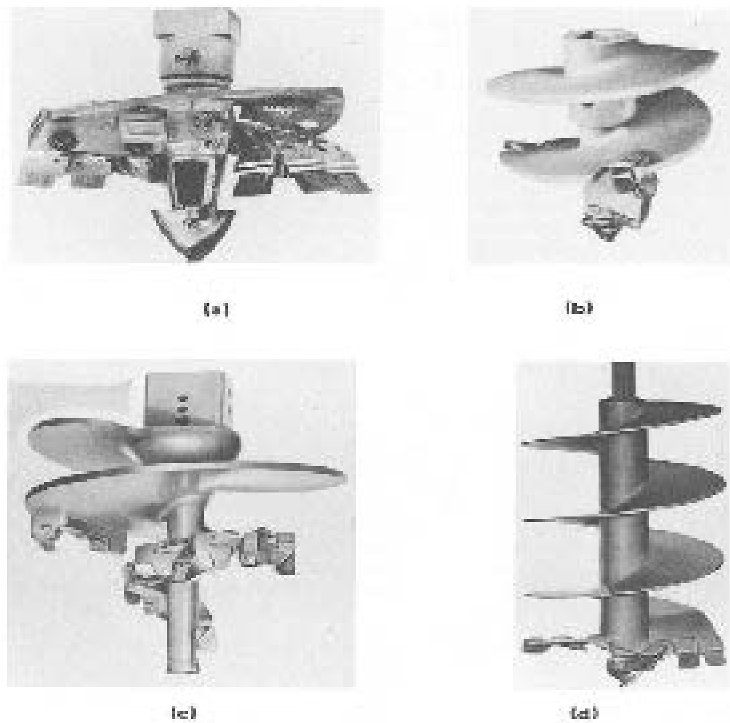

Figure 1.2: Power augers: (a) single-flight earth auger; (b) double flight earth-rock auger; (c) double-flight rock auger; (d) high spiral auger.

3. Wash boring

The term "wash boring" refers to the process in which a hole is advanced by combination of chopping and jetting to break the soil or rock into small fragments called cuttings, and washing to remove the cuttings from the hole. In the past this method also has been used to obtain samples commonly referred to as "wash samples." These consisted of the cuttings that are carried to the surface by the drilling fluid. The samples are obtained by allowing the cuttings to settle out of suspension in a sump tank or a sump hole in the ground adjacent to the drill rig.

Samples thus obtained generally are not representative of the material in situ owing to the breakdown of particles by chopping, the loss of fines in transporting the particles to the surface, and the segregation of the particles during the sedimentation process in the sump tank. Thus, this method is no longer acceptable as a means of obtaining samples. Some indication of the changes in strata may be inferred from the reaction of the chopping tools as the hole is advanced or on the basis of the color of the drill water or type of sediment carried by it. The wash boring method may be used in both cased and uncased holes. Even in the latter it is common practice to install a short section of casing with a wash tee at the top of the hole to stabilize the top of the borehole. Figures 1.3 a and b show, respectively, a rig as it appears when casing is being driven and when the hole is being advanced.

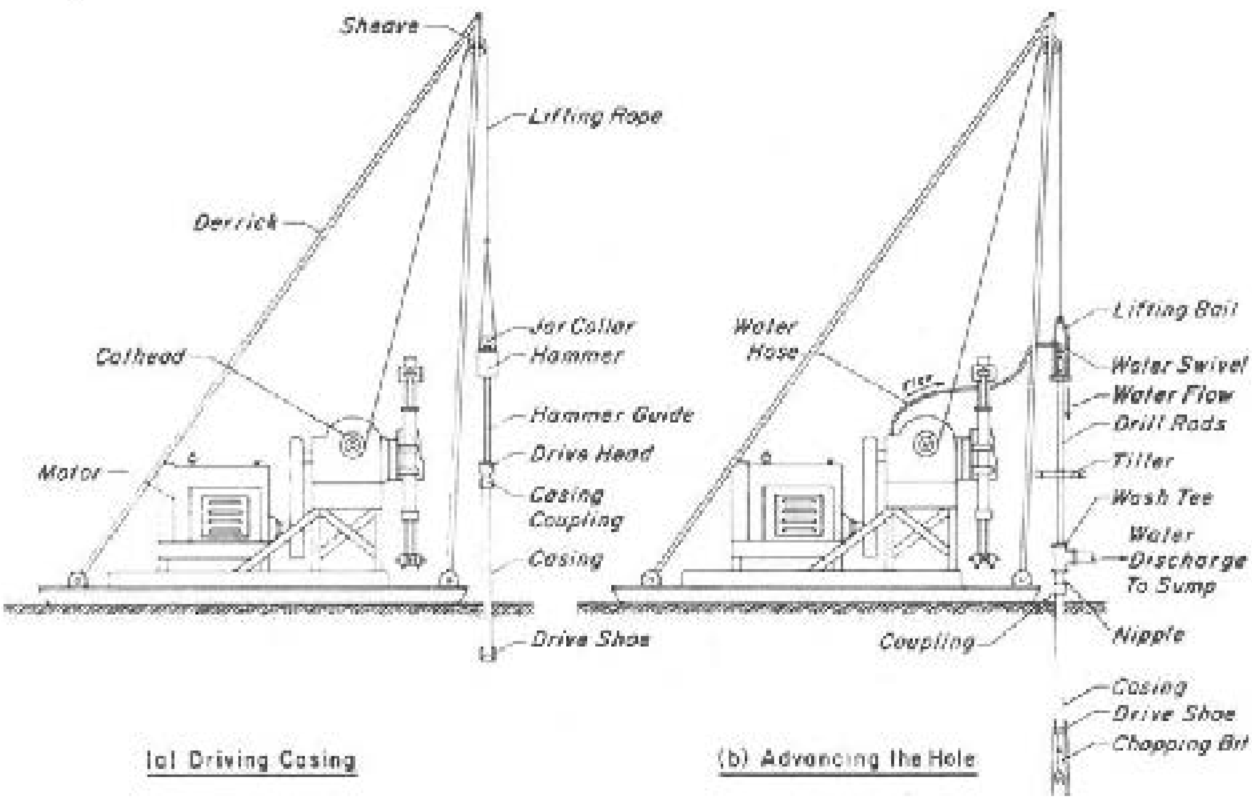

Figure 1.3: Wash boring.

The wash boring method can be used to advance both small- and large-diameter holes. The equipment used for this method is light and relatively inexpensive. The primary disadvantages are that the method is slow in the stiffer and coarser-grained soils and it is not efficient in materials such as hard or cemented soils, rock, and materials that contain boulders.

Figure 1.4: Chopping and jetting bits: (a) straight; (b) chisel; (c) cross. (Wash boring).

4. Percussion Drilling

This method is used to penetrate the strong rock and gravel layer. The drilling tool consist of drill bit with series of drill steams (made of high carbon steel) connected immediately above the drill bit. The percussion drilling method of advancing a boring is of common use in drilling water wells and is referred to, also, as cable tool drilling or churn drilling. Advance of the hole by this method is accomplished by

1) alternately raising and dropping a combination of heavy drilling tools to break the material to be removed and form a slurry of this material and the groundwater or water introduced into the hole; and
2) Periodically removing the slurry thus formed by means of the bailers described below. The amount of water introduced into the hole in this

method is kept to the minimum required to form the slurry. In certain materials such as soft soils and cohesionless materials below groundwater table, it is not uncommon for the hole to be made without having to add water.

This method can be used for any type of soil. However, the disadvantage of this method is the disturbance took place during the drilling process.

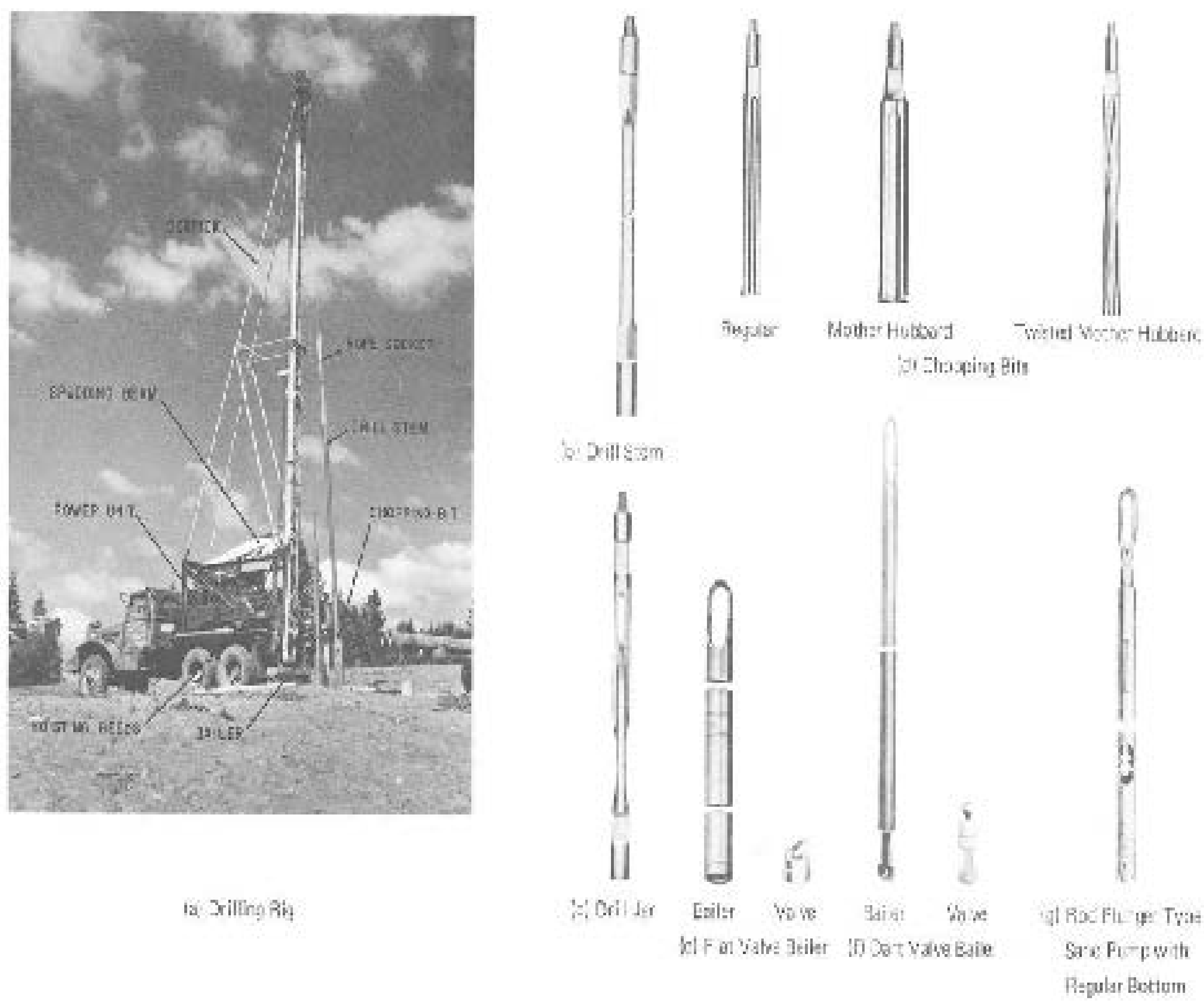

Figure 1.5: Percussion drilling equipment.

5. Rotary Drilling:

In the rotary drilling method, the hole is advanced by rotating a drill string consisting of a series of hollow drill rods to the bottom of which is attached either a cutting bit or a core barrel with a coring bit. Cutting bits shear off chips of the material penetrated and thus are used primarily for penetrating overburden between the levels at which samples are required. Coring bits, on the other hand, cut an annular hole around an intact core that enters the barrel and retrieve. Thus, the core barrel is used primarily in bedrock, which, under most circumstances, is cored continuously. As the rods with the bit or barrel are rotated, a downward pressure is applied to the drill string to obtain penetration, and drilling fluid under pressure is introduced into the bottom of the hole through the hollow drill rods and passages in the bit or barrel. The drilling fluid serves the dual function of cooling the bit as it enters the hole and removing the cuttings from the bottom of the hole as it returns to the surface in the annular space between the drill rods and the walls of the hole. In an uncased hole, it also serves to support the walls of the hole.

The procedure described above is referred to as straight rotary drilling. A second method of rotary drilling commonly used is referred to as reverse rotary or reverse circulation drilling. The difference in the two methods is primarily in the circulation of the drilling fluid to remove the cuttings and in the equipment used; also, the reverse rotary is limited to use with noncoring bits. In the reverse rotary method, as the rods are rotated, the drilling fluid is introduced under gravity into the annular space between the drill rods and the walls of the hole. The fluid, laden with cuttings from the bottom of the hole, returns to the surface via the hollow drill rods.

When compared to straight rotary drilling, this method has the dual advantage of (1) Minimization of disturbance to the walls of the hole owing to the higher head in the hole and more outward seepage pressure on the hole walls; and (2) more rapid and efficient removal of cuttings from the hole because the area of the drill rods is less than the annulus, thereby giving higher upward velocity. However, it is best suited to holes 12 inches and larger in diameter.

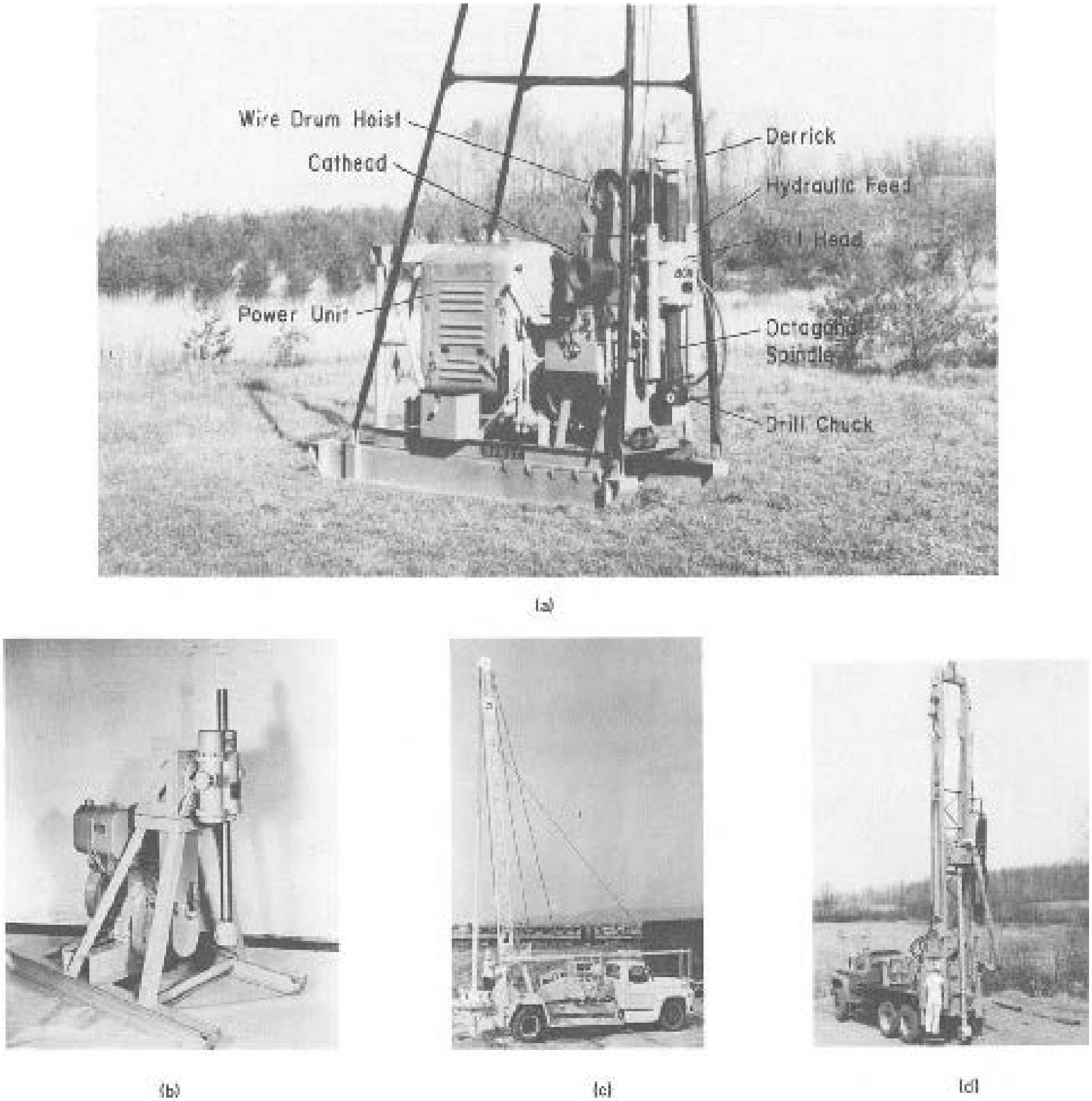

Figure 1.6: Rotary drill rigs: (a) hydraulic feed; (b) screw feed; (c) rotary table; (d) reverse circulation.

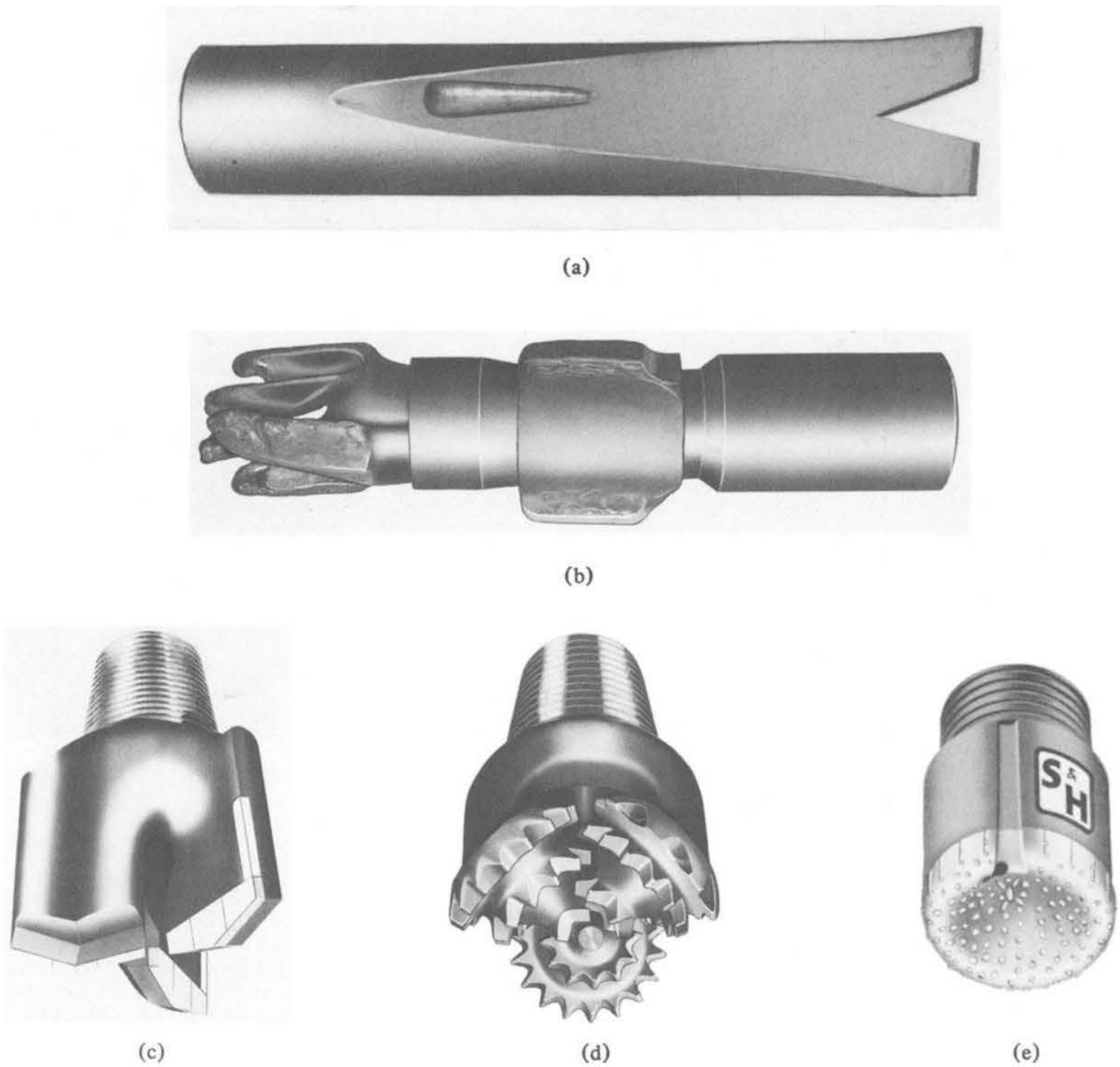

Figure 1.7: Rotary bits: (a) fishtail bit; (b) Hawthorne replaceable-blade drag bit; (c) carbide insert drag bit; (d) tricone bit; (e) diamond plug.

6. Ground Water Investigation:

The purpose of ground water investigation:

1) Determine ground water level and seasonal variation.
2) Determine the pressure of ground water.
3) Determine the permeability of the subsurface materials (soil).
4) Determine the chemical properties of ground water.

Boreholes are common used to establish the water table elevation at a site by measuring the depth to water in the boreholes. The length of time required for water levels in boreholes to stabilize at the groundwater level is a function of the permeability of the soil. There is no doubt that the water should be allowed to stand for a minimum period, preferably 24 hours, following completion of the hole. However, even under these circumstances, the reading may be accurate only if the soil is pervious. Accurate readings can be obtained if readings are taken over a long period of time. In one-shift-a-day drilling the groundwater level is usually observed as the first order of business in the morning. This gives 14-16 hours time for stabilization and this is frequently adequate. Drilling mud obscures observations of the groundwater level owing to filter cake action and its specific gravity being greater than water.

To determine in situ soil permeability (particularly for sand and gravel soils which are difficult to obtain the undisturbed soil samples), three types of test are commonly used; falling head, rising head, and constant head. In addition, pumping test can be used to determine the field permeability. This test consist of pumping water from a well and observation the effect on the water table in adjacent wells.

Obtaining ground water samples is required to determine the chemical properties, it is necessary to empty the hole by pumping all ground water and leave it to full by ground water again. Thereafter, samples can be taken for laboratory tests. The required tests involved:

1. Sulphates percentage So_4 and So_3;
2. Total dissolved salts (TDS);
3. Clorides content Cl^{-1};
4. pH –value.

7. Sampler and Sampling Techniques:

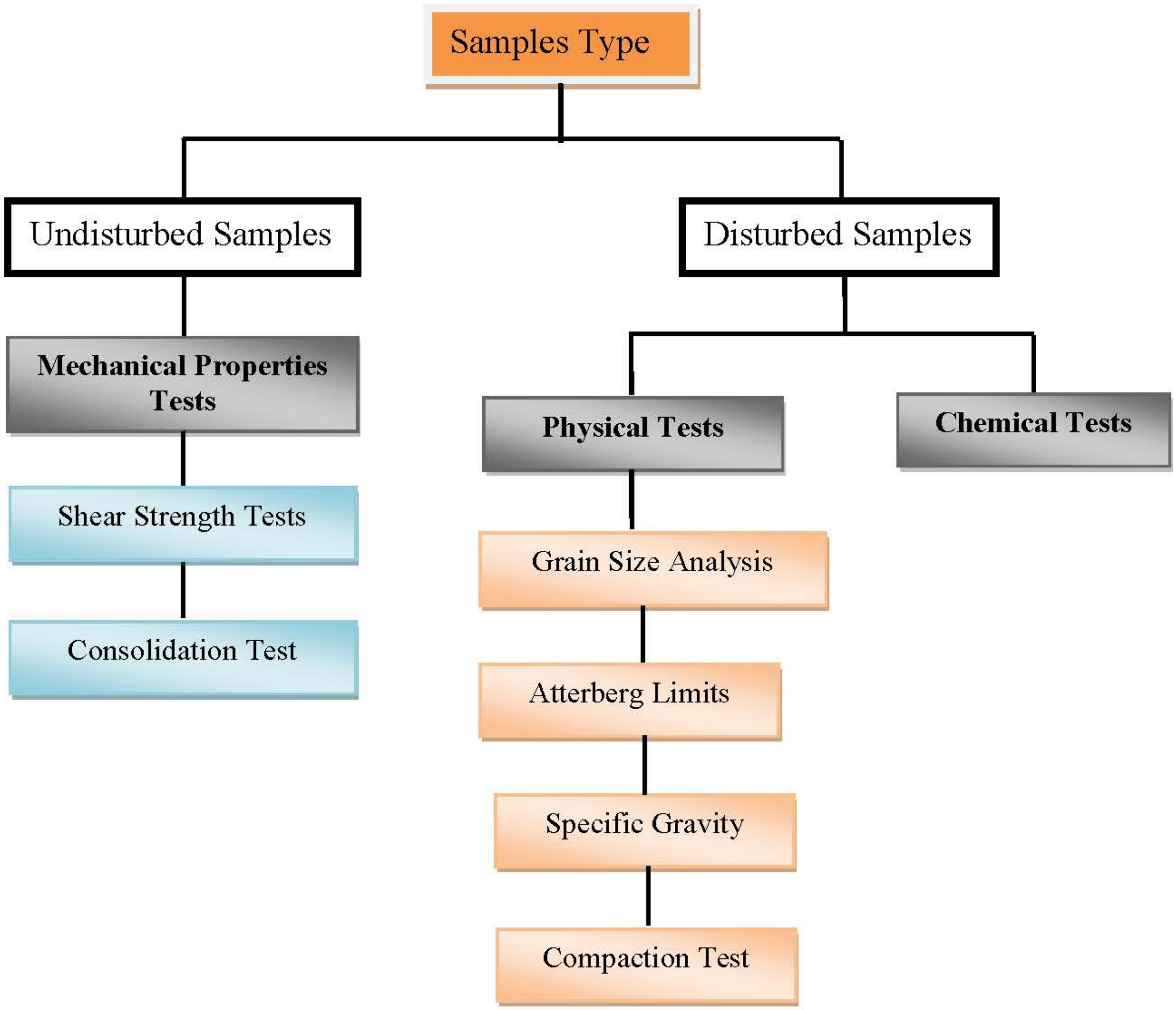

Figure 1.8: Types of Soil samples.

1) Disturbed Soil Samples:

A disturbed sample may be defined as one that contains all of the constituents of the in situ material in proper proportions but that has suffered sufficient disturbance to its structure so that the results of laboratory tests to determine engineering properties such as compressibility, shear strength, and permeability would not be properly representative of the material in situ. Disturbed samples generally are used for identification tests such as visual classification, water content, grain size analyses and Atterberg limit tests, and for specific gravity and compaction tests. Disturbed samples are also used for the preparation of compacted specimens for permeability, shear, and compressibility tests on materials proposed for use in earth structures. Included in this category are samples obtained by driving a sampler into the ground, by auger boring, or by normal test pit excavation.

1) Undisturbed Soil Samples:

An undisturbed sample is one obtained with samplers and sampling techniques designed to preserve as closely as possible the natural structure of the material. These samples are suitable for shear, consolidation, and permeability tests of foundation materials. They may be used, also, for all tests for which disturbed samples are used. Undisturbed samples include those obtained by thin-wall tube samplers with and without stationary pistons, Denison-type double-tube core barrel samplers, and careful excavation of soil from test pits.

Types of Mechanical Disturbance:

1) Stress Relief:

Shearing off the sample from the surrounding soil led to change in the total vertical and horizontal stresses. These stresses will be caused change in soil structure and then sample disturbance.

2) Area Ratio:

When the sampler was driven into the soil, a part of soil was displaced to open a space of sampler wall leading to compress the soil and some sample disturbance.

To minimize the disturbance of sample, the ratio of area of displaced soil to the area of sample must be minimized.

$$A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100\%$$

Where

D_o is the outer diameter of sampler.
D_i the inner diameter of sampler.

To obtain a sample with low disturbance, A_r must be less than 20% for stiff clay and less than 10% for soft clay soil.

3) Effect of Adhesion and Friction:

When the sampler is long relative to it's diameter, the friction and adhesion forces between the soil and inside wall of the sampler may lead to bearing failure. To minimize this effect, the inside diameter of the sampler is made little greater than the inside diameter of the bit. This clearance is called inside clearance (Ci):

$$C_i = \frac{D_s - D_2}{D_2} \times 100\%$$

Where

C_i Inside clearance ratio.
D_s Inside diameter of the sampler.
D_2 Inside diameter of the bit.

Noting that, increase of Ci ratio may be led to inverse undesirable effect where it allows the sample to expand. In practice, clearance ratio Ci is ranged about (0.3-4)%.

Sampler Driven Techniques

Sampler Driven Techniques	
Hydraulic Pressing	**Hammering**
Continues pressing with constant rate. Less disturbance.	More disturbances. may be caused shattering the soil.

Type of Sampler:

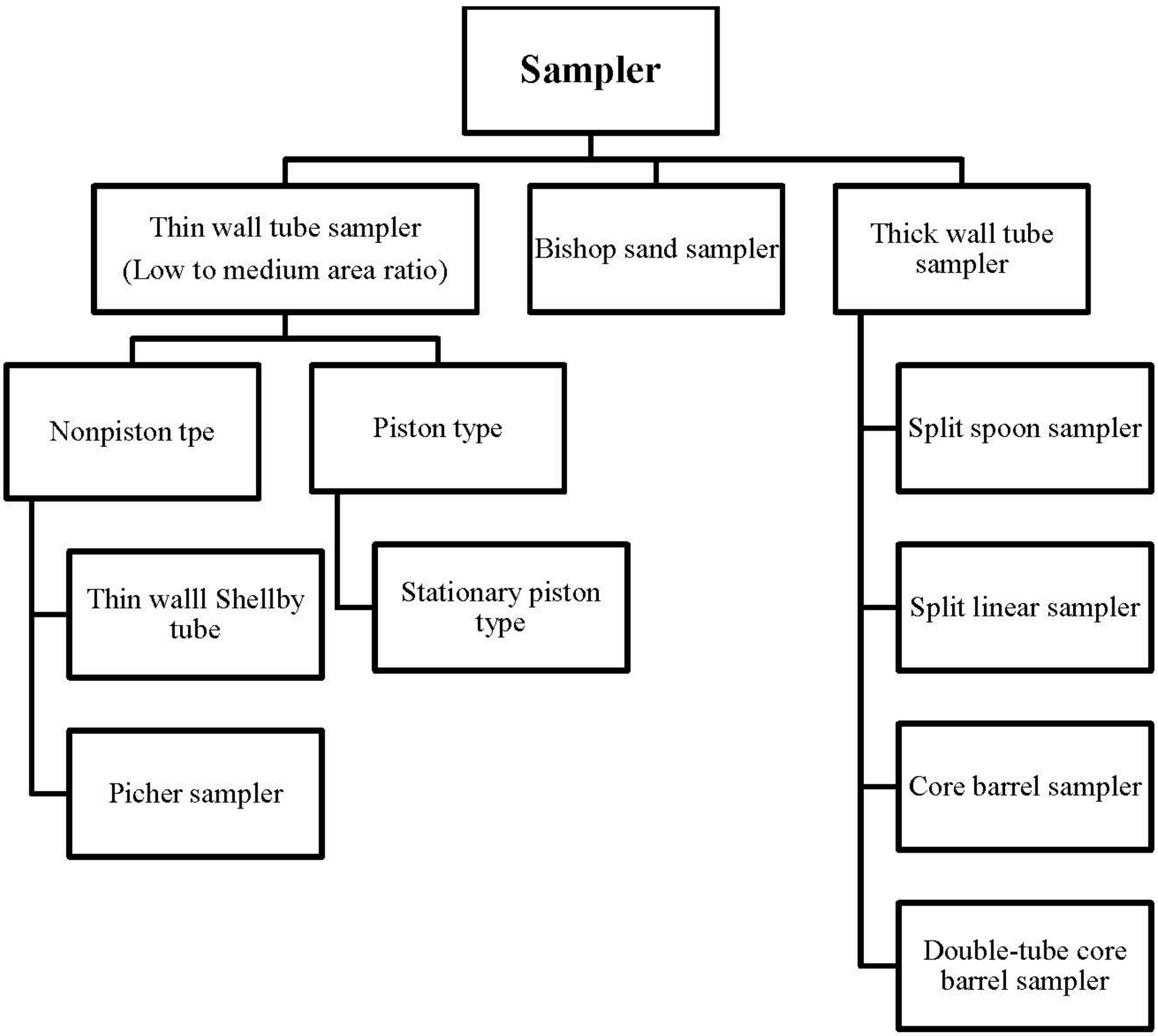

Figure 1.9: Type of Samplers.

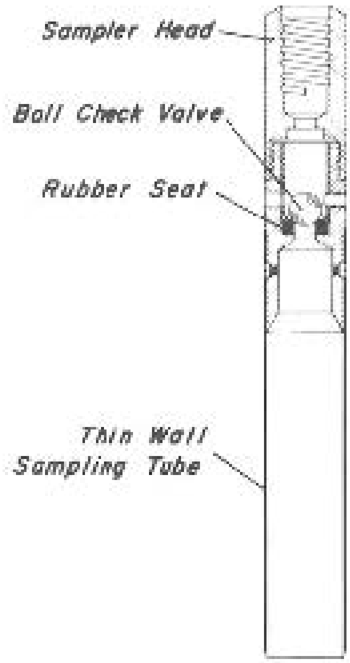

Figure 1.10: Thin-wall "Shelby tube" sampler.

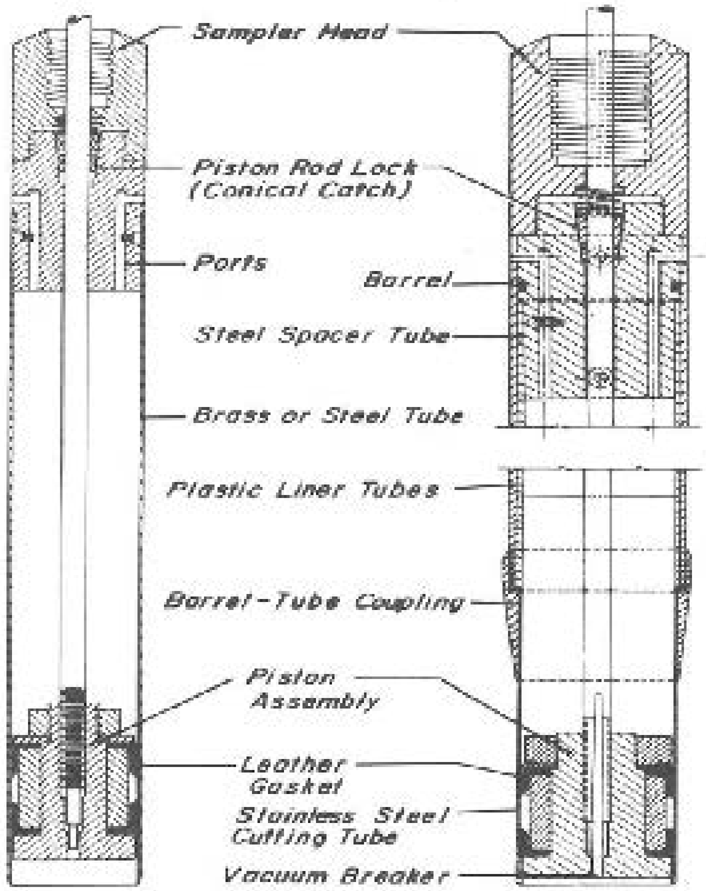

Figure 1.11: (left) Thin-wall stationary piston sampler. (right) Lowe-Acker stationary piston sampler with liners.

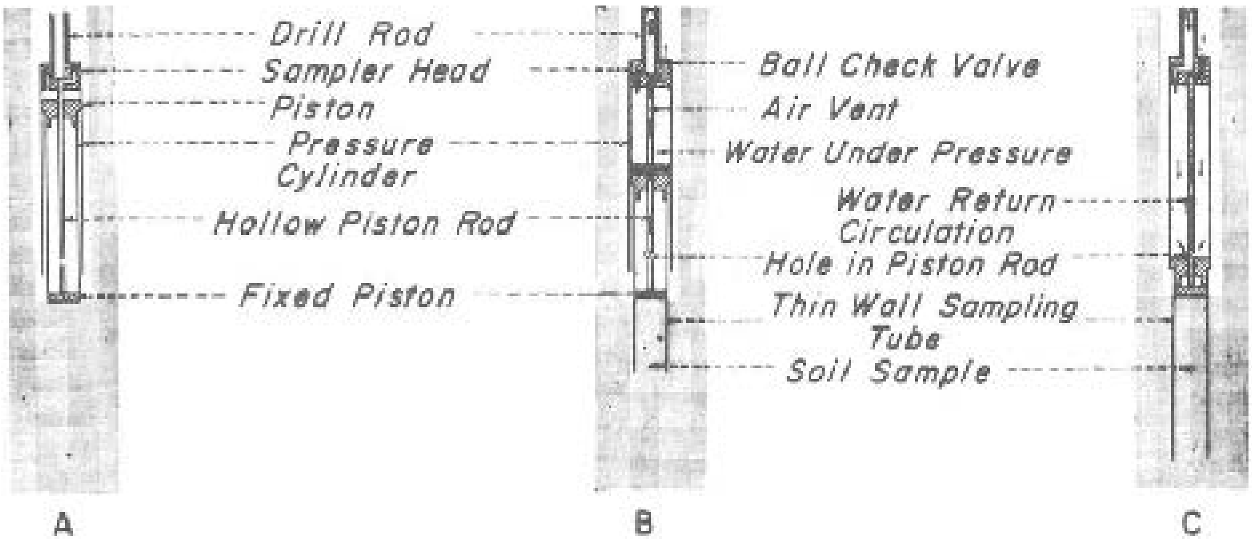

Figure 1.12 : Osterberg piston sampler.

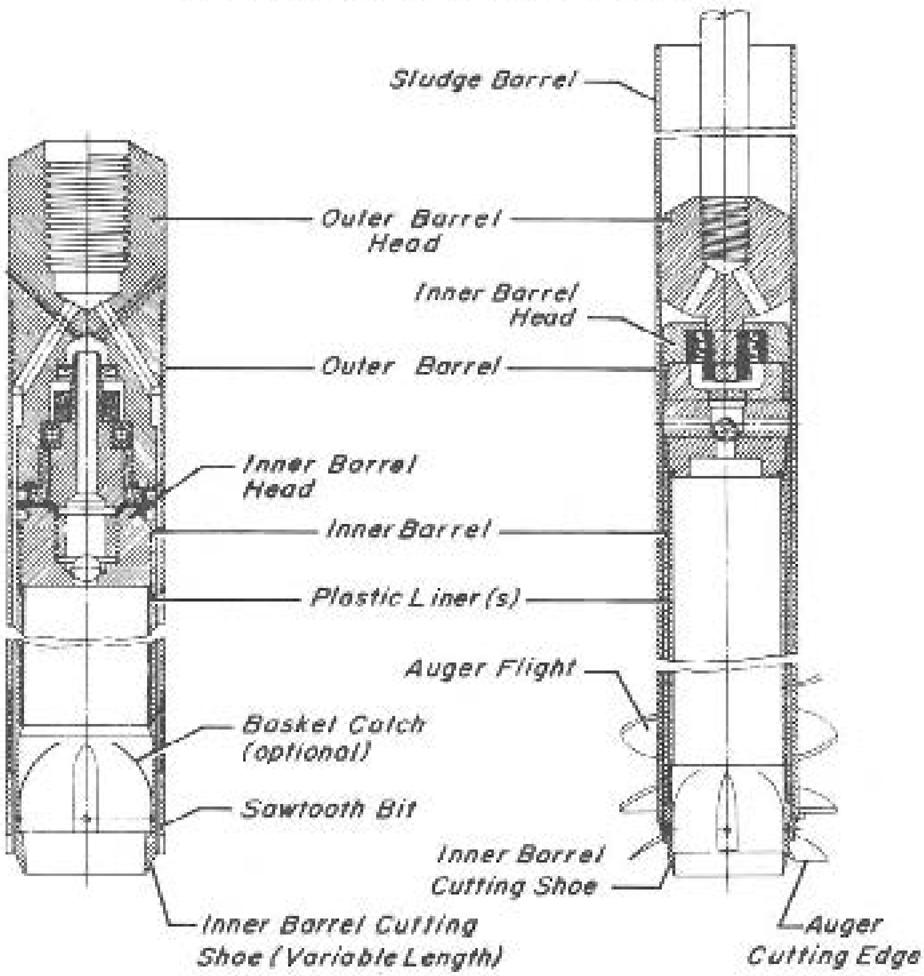

Figure 1.13: left) TAMS double-tube core barrel soil sampler. (right) TAMS double-tube auger sampler with liners.

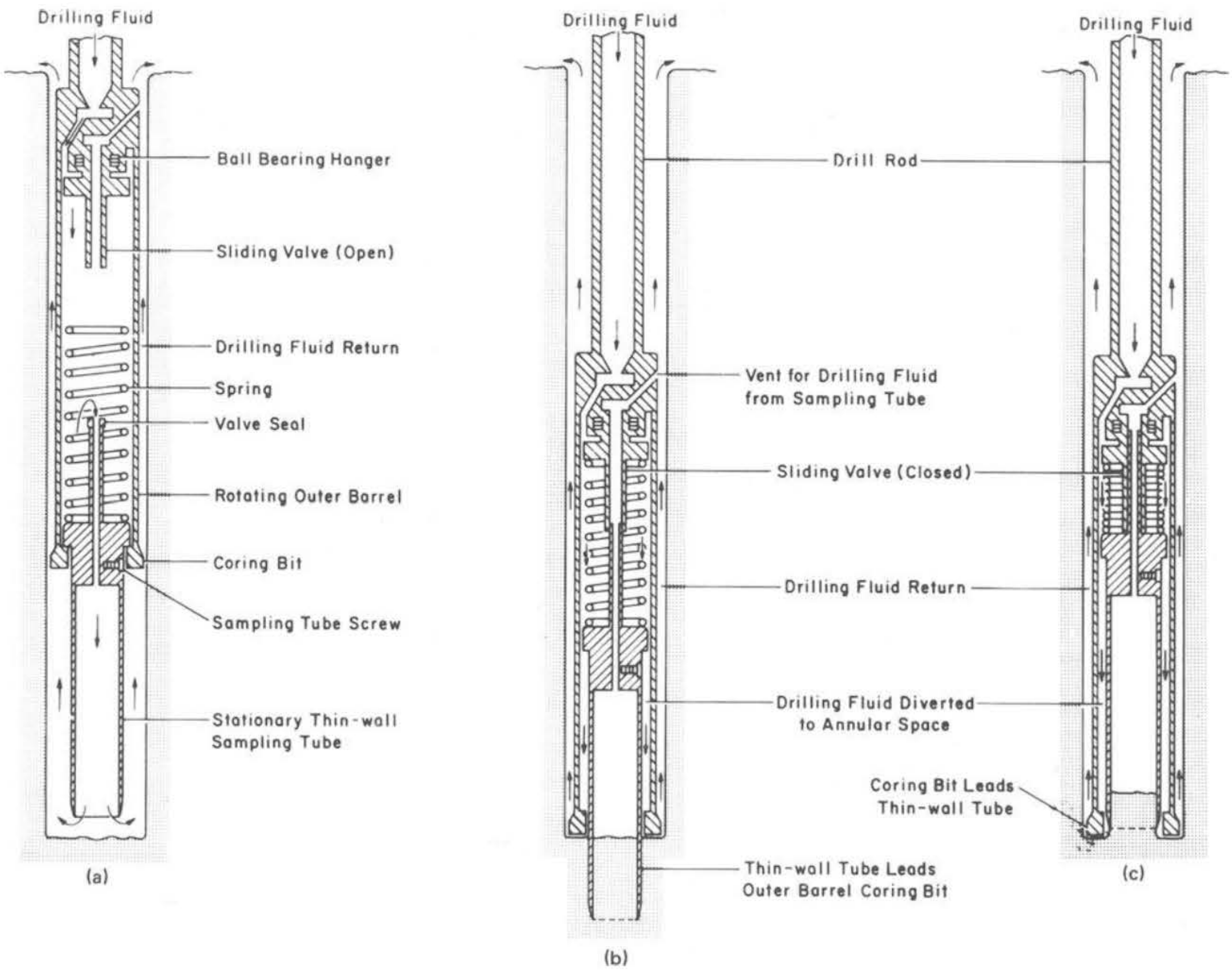

Figure 1.14: Pitcher sampler. Schematic drawing showing: (a) sampler being lowered into drill hole; (b) sampler during sampling of soft soils; (c) sampler during sampling of stiff or dense soils.

Preservation, Shipment, and Storage of Samples:

1) Undisturbed Samples.

After extract the sampler, the two ends of the sampler are opened. Soil at the first 50 mm is removed from each end. Therefore, the two ends are capped by metal discs or aluminum foil and sealed by multiple layers paraffin wax to preserve the natural moisture content of soil sample.

Each sample must be labeled and clearly marked at the following information:

1. Project name and location.

2. Date of boring.
3. Borehole number.
4. Sample number.
5. Depth of sample below ground surface.
6. Brief description of soil type.

It is necessary to peak the samples in wooden boxes with partition. It is preferred to send the sample to the laboratory at the end of each day with boring logs.

2) Disturbed Samples.

The disturbed soil samples must be placed in screw top air-tight plastic, glass, or metal jar. The size used should be such that the sample will fill the jar as nearly as possible. This will prevent loss of moisture from the sample through evaporation and subsequent condensation on the walls of the jar. Samples should be placed in the jars as soon as they are retrieved and the jars should immediately be capped and sealed to preserve the original moisture content as closely as possible. The jars used for preserving the samples are commonly supplied in cardboard boxes with corrugated cardboard inserts to separate one jar from another.

3) Rock Core (Rock Samples).

Because of high cost rock boring, all rock fragments should be collected and stored in partitioned boxes. The project name and boxes number should be put at the ends and cover of the box. All identification information must be marked for each core.

Storage of Samples:

All samples must be stored in such manner to prevent sample freezing or expose to high temperature or mechanical disturbance. The soil samples must be stored at roofs so that the temperature is $4\ c^o \leq T \leq 45\ c^o$ and daily temperature variation is not more than 20 c^o.

8. Visual Classification of Soil Samples:

The following system can be followed for visual description of samples:

a. Color.
b. Main components.
c. Secondary components.
d. Consistency or relative density.
e. Addition description such as an existing the organic matters.

The following expressions may be used to describe the secondary components based on the percentage of these components:

Percentage %	Description
$\leq$ 10%	with trace
10-25%	with little
25-40%	with some
50%	and

Based on the soil state, the consistency description of cohesive soil may be categorized as follows:

Soil State	Consistency
➢ The clay is near to the liquid state	Very soft Clay
➢ Easy to knead by fingers	Soft Clay
➢ Cannot be Knead, but can be notched by thumbs	Medium to stiff clay
➢ Can be scratched by fingernail	Very stiff clay
➢ Can be scratched by fingernail	Hard clay

For cohesionless soil, depending on relative density granular soil can be described as the following descriptions:

Relative Density %	Description
0-20	Very loose
20-40	Loose
40-60	Medium
60-80	Dense
80-100	Very dense

Furthermore, the description of cohesionless soil should be involved the following:

a. Particles size (for sand and gravel).
b. Mineral composition such as (Silica, Quartz, Mica).
c. Shape of particles (Spherical, Plated, elongated, or angular).
d. Particles grading (well graded, poorly graded, gap graded).

For rock description, the same system used for soil can be adopted to describe the rock samples. In addition, alteration and weathering state, joints and fissures, estimation of rock materials, and any other features should be mentioned as well.

9. Investigation by Geophysical Methods (Geophysical Exploration).

Two geophysical methods, seismic and electrical resistivity, have proven useful as rapid means of obtaining subsurface information and as economical supplements to borings in exploratory programs for civil engineering purposes. **Geophysical exploration provides information about:**

(1) Depth of bedrock

(2) Limits between soil strata

(3) Depth of ground water level.

However, the obtained information by this method are limited reliability; therefore, all obtained information must be supported by boring holes.

1) Seismic Methods

Seismic methods of exploration are based on the fact that shock waves travel at different velocities through different types of materials. Since the velocity of wave propagation depends on numerous factors such as density, moisture, texture, void space, and elastic constants, the nature and stratification of subsurface materials can be determined. However, most subsurface materials are non-homogeneous and anisotropic and this makes the analysis of seismic exploration data somewhat complex.

In seismic explorations, artificial impulses are produced either by the detonation of explosives or a mechanical blow (usually with a heavy hammer) at ground surface or at shallow depth within a hole. These artificial shocks generate three types of waves, namely:

1) **Compression wave.**
2) **Shear wave.**
3) **Surface wave.**

In general, only compression (longitudinal) waves are observed. These are classified as direct, reflected, or refracted waves. Direct waves travel in approximately straight lines from the source of impulse to the surface. Reflected or refracted waves undergo a change in direction of propagation when they encounter a boundary separating media of different seismic velocities.

I) Seismic Refraction Method.

Seismic refraction methods have been used to investigate subsurface conditions from ground surface to depths of approximately 300 m. The device consists of group of geophone to detect the refracted waves. All geophone are connected with seismograph which record the time from the beginning of shock wave generated to the time of arrival of the wave at each geophone. The distance between the geophones must be equal and the total distance between the first and last geophones must be 3-4 times the depth of investigated. The recorded data are plotted in form of (Time-Distance curve), the slope of this plot represent the velocity of the wave. By this velocity, it can be determine the depth of each layer and obtain a general idea of the nature of materials (Soil). This method is efficient to determine the depth of bed rock by the following formula:

$$H = \frac{D}{2}\sqrt{\frac{v_2 - v_1}{v_2 + v_1}}$$

Where
H is the depth of bedrock (m).
D is distance between wave sources to the meet point (m).
v_2 is wave velocity at the bedrock layer (m/sec.).
v_1 is wave velocity at the upper layer (m/sec.).

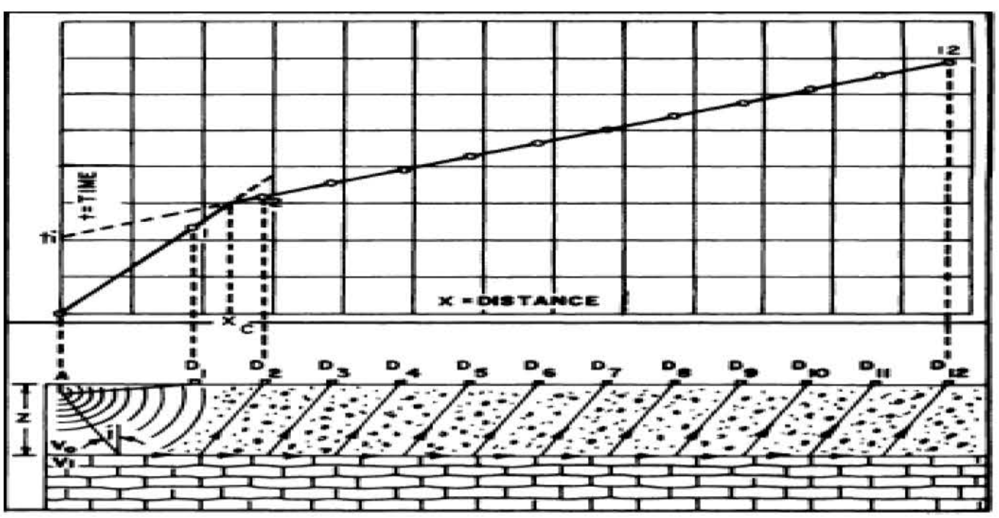

Figure 1.15: Schematic representation of refraction of seismic energy at a horizontal interface and the resultant time-distance graph.

I) Seismic Reflection Method.

Continuous seismic profiling, a sonar seismic method based on the principles of reflection, is used extensively in studies for deep water projects. The method utilizes sonic waves produced at or near the water surface to provide a continuous profile of the sea bottom and to map the underlying materials. This method is used in petroleum industry to investigate the subsurface conditions at depth greater than 300m. Continuous seismic profiling has been used for subsurface investigations for pipeline crossings, dam sites, bridges, marine structures, and dredging projects.

The refracted wave fades and no disturbance occur at less than 600m depth, the refraction and reflection waves arrived at the same time to geophones and then cannot recognize. This method is limited to use in civil engineering projects.

2) Electrical Resistivity Method.

The electrical resistivity method of subsurface exploration is based on the fact that different materials offer different resistance to the passage of an electric current. Thus, by the determination of vertical and lateral variations in this resistance it is possible, within certain limitations, to infer the stratification and lateral extent of subsurface deposits. The electrical resistivity for soil and rock depends on:

1. Concentration and type of dissolved salts.
2. Moisture content.
3. Void ratio.
4. Particle size.
5. Stratification.
6. Temperature.

This method consist 4 equally spaced electrodes driven approximately 8 inch into the ground. Electric current is passed between the two outer electrodes. An electrical field is produced within the soil. The potential drop is measured by the inner electrodes. The electrical resistivity can be calculated by the following formula:

$$\rho = \frac{2\pi a V}{I}$$

Where
ρ is the electrical resistivity (ohms).
a is the distance between electrodes.
V is the potential drop.
I is electric current.

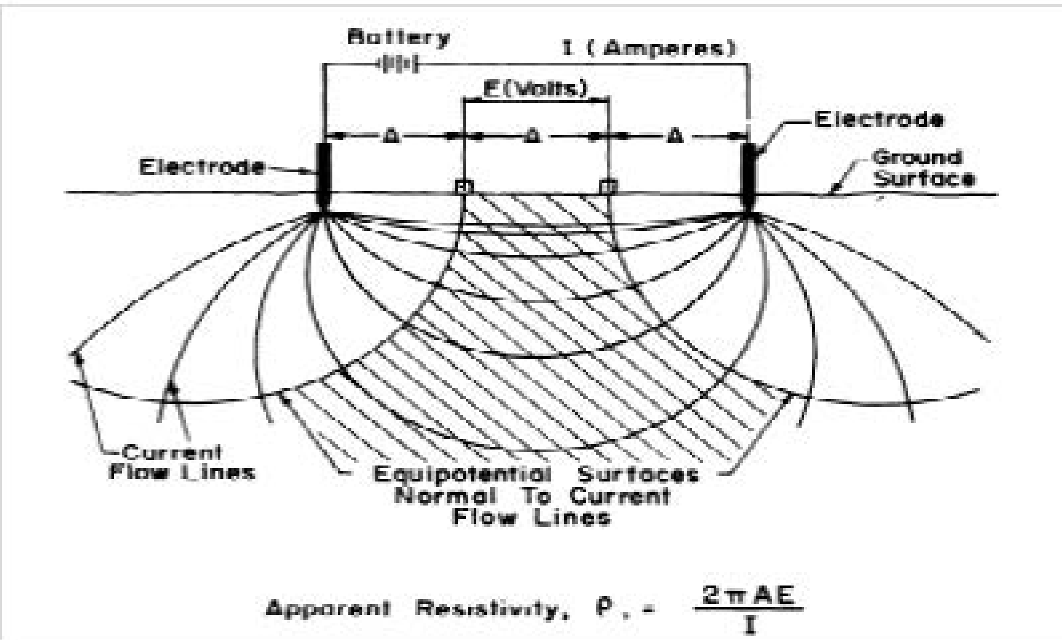

Figure 1.16: Diagram showing theory of earth resistivity methods.

By changing the electrical resistivity ρ, the nature of soil can be detected. To detect the horizontal change in soil layer, the spacing between electrodes is fixed and moved horizontally along test line. To detect the vertical change in soil layers, increase the spacing between electrodes at the same central point starting with 0.3m spacing. It must be noted that, this method cannot be used for investigated depth.

10. Field Tests (In-situ Tests)

The in-situ tests can be depended on in the case when obtaining undisturbed soil samples is difficult such as in the state of granular soils and soft clay and sility soils. The field in-situ tests involved the following:

1) Vane Shear Test (VST):

This test is a simple to determine the peak and remolded undrained shear strength (c_u), for the soft to medium stiff clay soil that their shear strength is ranged (5-75) kN/m^2. The equipments consist of 4 blades vanes of diameter (D) and height (H=2D). The vanes are driven into the soil at depth of at least o.5m below the bottom of the borehole where no or little disturbance. The vanes are rotated by a rate of (6-12 degree/min.). The maximum torque (T) which causes shear failure is recorded. The peak undrained shear strength (cu) can be calculated by the following equation:

$$c_u = \frac{T}{\pi D(\frac{H}{2} + \frac{D}{6})}$$

For H=2D

$$c_u = \frac{T}{\pi D(D + \frac{D}{6})}$$

$$c_u = \frac{T}{\pi D(\frac{7D}{6})}$$

$$\boldsymbol{c_u = \frac{6T}{7\pi D^2}}$$

Where

T Max. Torque kN

D Vane diameter (m)

H Height of vane.

This equation is driven based on the following assumption:

1) The shear strength is uniformly distributed at the two ends and along the surface area of the four vanes.
2) The test is undrained.
3) The soil is isotropic.

After the peak Torque is determined, the vanes are rotated rapidly about 12c times to remold the soil. Then, after 5 minutes the test is repeated to determine the remolded shear strength and fined soil sensitivity from the following equation:

$$\textit{Soil Sensitivity} = \frac{\textit{Peak } c_u}{\textit{Remolded } c_u}$$

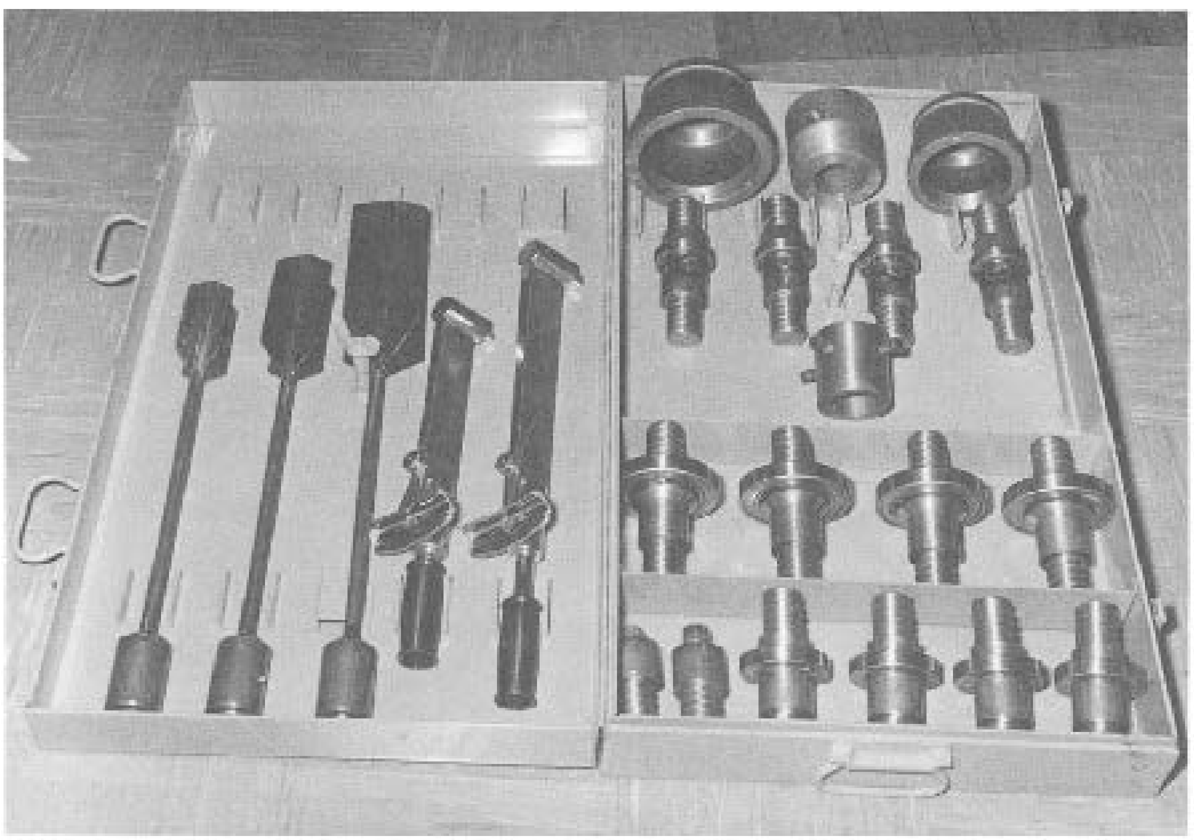

Figure 1.17 : Vane shear equipment: vanes, torque wrenches, bushings for drill rods, and casing cap.

2) Standard Penetration Test (SPT):

This test is widely used for the granular soil where difficult to obtain undisturbed soil samples. The test involved driving split spoon sampler (thick walled sampler) into the soil at the bottom of the borehole. The hammer used for driving of standard weight (140 Ib) falling by its weight from a standard height (30 inch).

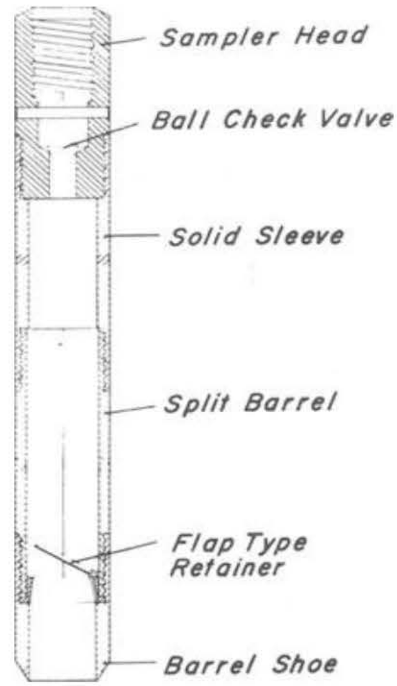

Figure 1.18: Split-barrel sampler in SPT.

At the beginning, three distances (150 mm each) are pointed at the drill rod at the ground surface. The number of blows required to drive all the three distance are recorded. The blows for the first 150 mm are ignored. The blows for the latest 300mm are called N-value. It should be noted that, the test is stopped when blows exceed 50. In this case, the driven distance corresponding to 50 blows must be recorded.

The obtained sample by split spoon sampler is disturbed sample which can be used for soil classification. In the case of gravel layer, the split spoon sampler is replaced by high carbon steel cone with angle of 60^{o} and the same procedure is followed.

Tow corrections must be made for N-value, these corrections are:

a) Under ground water table correction, this correction is made under the following condition:

1. The soil is fine sand or fine silty sand.
2. $N \geq 15$
3. The test is conducted under ground water table.

$$N_c = 15 + 0.5(N_m - 15)$$

Where:

N_c = Corrected N-value.
N_m = Recorded N-value.

b) Overburden pressure (Stress) correction.

Since N-value is highly affected by overburden stress and relative density, N-value must be corrected by multiple by the correction factor (N_c).

$$C_N = 0.77 \log_{10} \frac{20}{\sigma`_o}$$

$$N_1 = C_N \times N_m$$

Where

C_N is correction factor
$\sigma`_o$ is effective overburden pressure obtaining at depth of (SPT)
N_1 is number of blows at effective overburden pressure of 1ton/ft^2.
N_m is Recorded N-value.

3) Cone Penetration Test (CPT):

The equipments consist of cone with angle 60^{o} and area of $10cm^2$ connected with steel rods and cased by sleeve. The test involved pushing the cone into the soil at rate (1.5-2) cm/sec. For a distance of 80 mm, the pressure required is recorded. Then, the sleeve is pushed for a distance 80mm, in this stage the cone is fixed. Therefore, both cone and sleeve are pushed 120mm and record the required pressure to achieve this distance. By this process, it can be found the cone end resistance and sleeve skin friction. The above steps are repeated every 200mm to draw the relationship of cone resistance and sleeve friction resistance with depth.

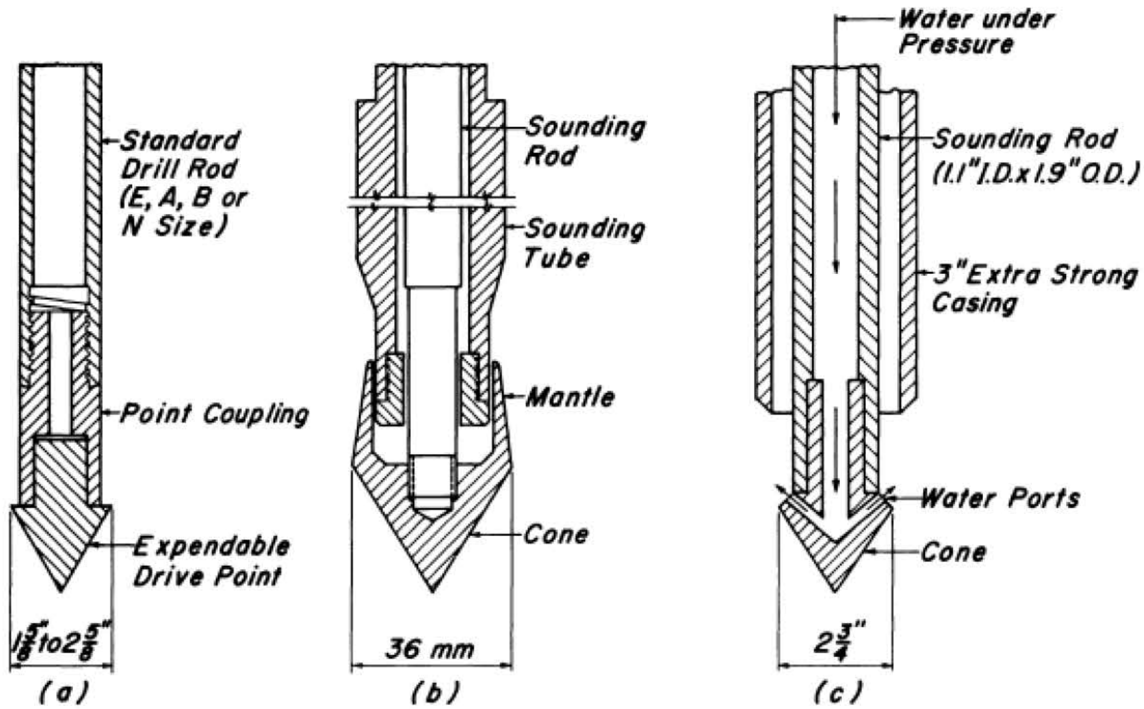

Figure 1.19: Cone pentrometers: (a) drive point penetrometer; (b) Dutch con penetrometer; (c) Terzaghi wash-point penetrometer.

The relationship between CPT and SPT as shown in below Table, this relation is highly depended on size and grain distribution.

Soil Type	Cone resistance (kN/m^2) / N-value
Silt	200-300
Fine to medium sand	300-500
Coarse sand	500-1000
Fine to medium gravel	800-1800

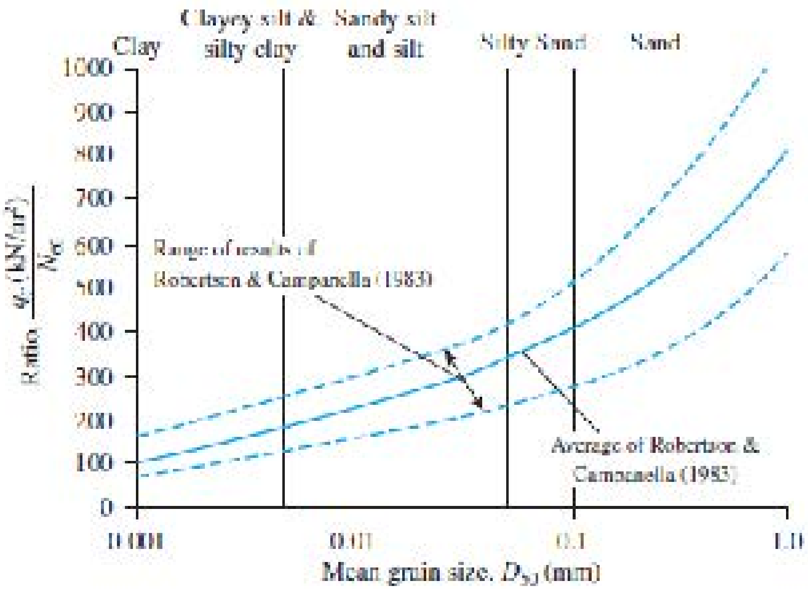

Figure 1.20: General range of variation of q_c/N_{60} for various types of soil

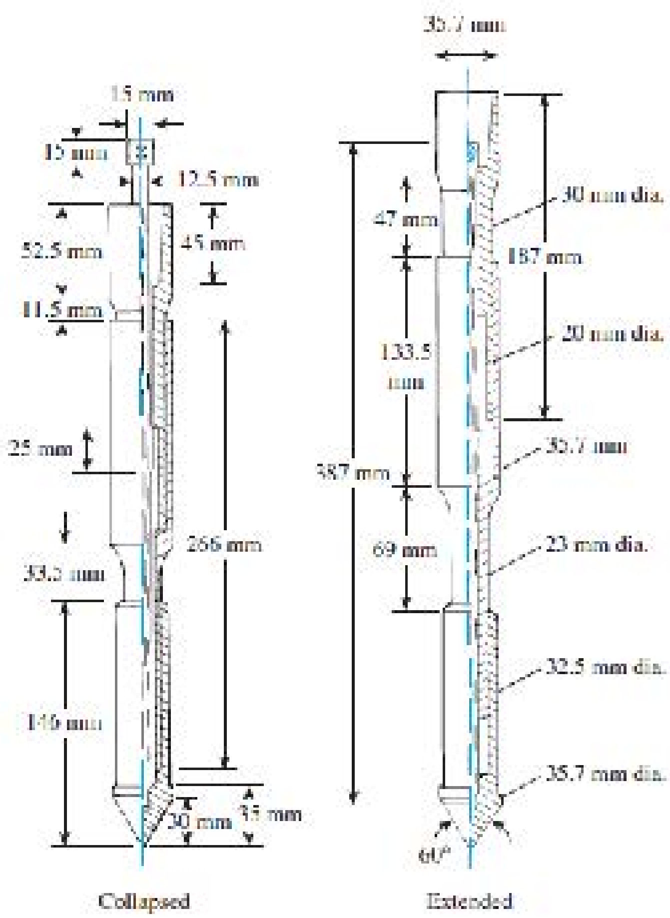

Figure 1.20: Mechanical friction-cone penetrometer.

4) Plate Loading Test (PLT)

This test can be used to estimate the soil bearing capacity and settlement. It may be used for the following cases:

a. For the granular soil that contains big gravel or boulder where SPT and CPT cannot be performed.
b. When the structure is sensitive to the settlement.
c. For fractured or jointed weak rock.

The test involves of loading a horizontal plate and record the settlement with time. The loading must be increased gradually with increment of 1/5 of the total load applied by the structure on the soil. The loading must be continued until the total load becomes two times of the applied load of superstructure or soil failure is reached. The new load increment is added when the rate of settlement becomes 0.25 mm/hr. for the previous load increment. This test can be performed for loading and unloading states.

To determine the bearing capacity of the soil and undrained deformation modulus (modulus of subgrade reaction, K), the plate load test must be carried out with constant rate of settlement. The following factors must be taken into the consideration:

I. Plate Size:

The plate diameter (width) must be at least 6 times the maximum grain size. For the bedrock, plate diameter must be 6 times the distance between the fissures. For all cases the plate diameter must be at least 300mm.

II. Number of Test:

Due to the non-homogeneity and anisotropic of the soil and rock, the test must be repeated at different position and location.

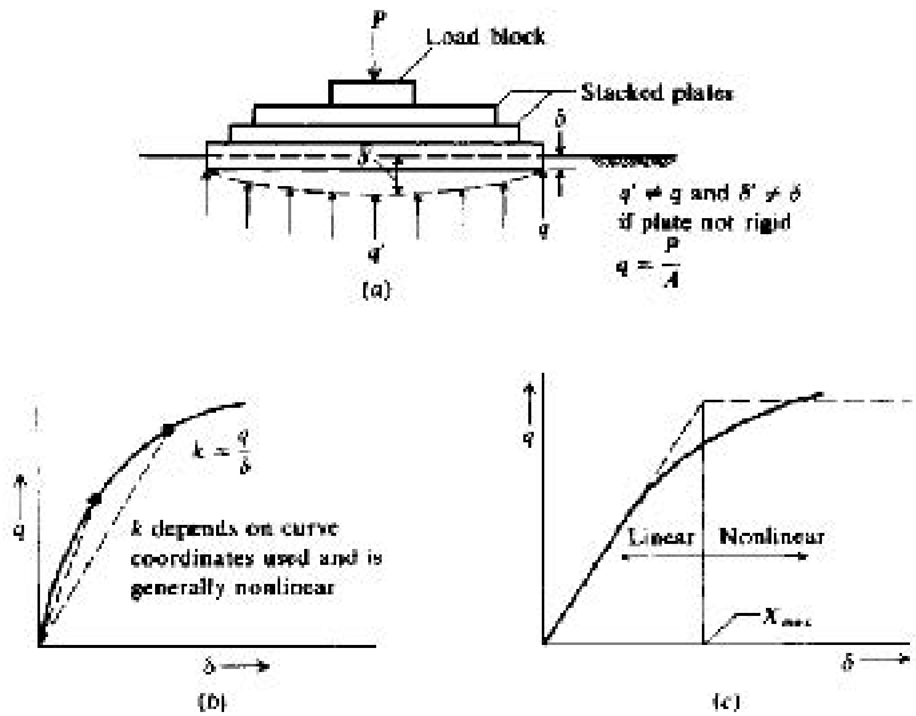

Figure 1.21: Determination of modulus of subgrade reaction *ks.*

A major problem is to estimate the numerical value of *ks*. One of the early contributions was that of Terzaghi (1955), who proposed that *ks* for full-sized footings could be obtained from plate-load tests using the following equations:

For footings on clay[3]

$$k_s = k_1 \frac{B_1}{B}$$

For footings on sand (and including size effects)

$$k_s = k_1 \left(\frac{B + B_1}{2B}\right)^2$$

Where in these two equations use B_1 = side dimension of the square base used in the load test to produce (k_s). In most cases B_1 = 0.3 m (or 1 ft), but whatever B_1 dimension was used should be input. Also this equation deteriorates when $B/B_1 \geq 3$.