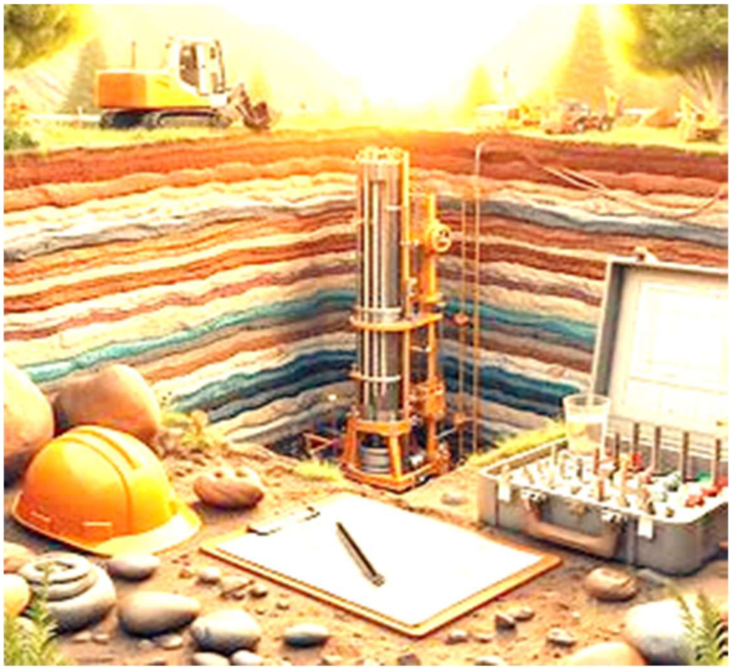

KURDISTAN ENGINEERING UNION (KEU)

Conditional Engineering Promotion Report to the rank of consultant engineer

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October,2024

# SOIL INVESTIGATION

Engineering Investigation Program

Soil investigation involves drilling, sampling, and testing soil properties to determine its suitability for construction, ensuring stability and safety for structures.

# CONTENTS

## *KNOWLAGEMENT*

Over the past few years, there has been rapid growth in the economy of the country and the region, due to the rapid changes in the world and the region. The level of public demand has risen significantly compared to previous demands, which has led to an increase in the needs of ordinary citizens in residential projects, large energy generation projects, and multi-story towers aimed at taking advantage of a small area of land for vertical urban development. Projects the natural environment, human lifestyles, and the challenges of needs. One of the most important steps in any project is to determine the project's location from an engineering point of view. It has a direct impact on how projects are designed and implemented.

During my years of work experience in the past, I have been concerned about the lack of public education among the project owners and even the Entrepreneurs on the importance of this step, which resulted in an inappropriate design with a wrong position and implementation that resulted in a lot of damage to the cost of the project and its use for its original purpose.

Considering my expertise in this field, as apart from the Kurdistan Union of Engineers' criteria for promoting my professional title, I have prepared this research project which is a way for my colleagues to further develop this aspect and solve mistakes or shortcomings. Hopefully, it will end up being useful to our engineering side.

# *Chapter one: GEOTECHNICAL PROPERTIES and LABORATORY TESTS OF SOIL*

## 1-1 Introduction:

In this chapter, we will discuss laboratory testing of soil samples taken from the project site ، and we will discuss the classifications and tests that need to be performed to obtain the information needed for project engineers and structural designers about the soil. Due to the special laboratory conditions and the need for special equipment and techniques that are only available in the laboratory and the tests that must be performed in the laboratory ،on the other hand, these tests are costly and exceed the expected amount. In general, the total cost of a project site inspection should not exceed 1% of the total cost of the project, except for some special scientific or military projects.

## 1-2 Size Limits for Soil:

### 1-1-1 Sieve Analysis:

Well-pulverized soil and passing it through a stack of progressively finer with a pan at the bottom as defined in the table below. The amount of soil retained on each sieve is measured, and the cumulative percentage of soil passing through each is determined.

TABLE 1-3: USA. Standard of sieve sizes.

| Sieve No. | Opening (mm) |
|---|---|
| 4 | 4.75 |
| 6 | 3.35 |
| 8 | 2.36 |
| 10 | 2 |
| 16 | 1.18 |
| 20 | 0.85 |
| 30 | 0.6 |
| 40 | 0.425 |
| 50 | 0.3 |
| 60 | 0.25 |
| 80 | 0.18 |
| 100 | 0.15 |
| 140 | 0.106 |
| 170 | 0.088 |
| 200 | 0.075 |
| 270 | 0.053 |

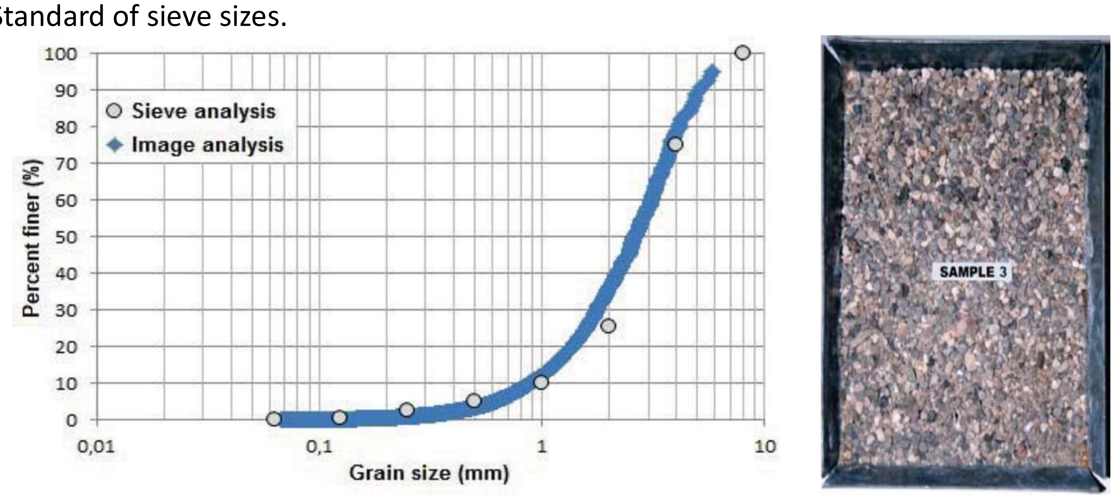



*Figure 1-1. Comparison of sieve-analysis and image-analysis results for sample.*

Tow parameters can be determined from the grain size distribution curve of coarse-grained soils:

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{D_{30}}{D_{60} * D_{10}}$$

*$C_u$: uniformity coefficient.*
*$C_c$: coefficient of ground or coefficient curvature.*

### 1-1-2 Hydrometer Analysis:

Hydrometer analysis based on the principle of sedimentation of soil particles in water.

$$D = \sqrt{\frac{18\eta}{(G_S-1)\gamma_\omega}} * \sqrt{\frac{L}{t}}$$

*$D$: diameter of soil particle*
*$Gs$: specific gravity of soil solids.*
*$\eta$: viscosity of water*
*$\gamma_\omega$: unit weight of water*

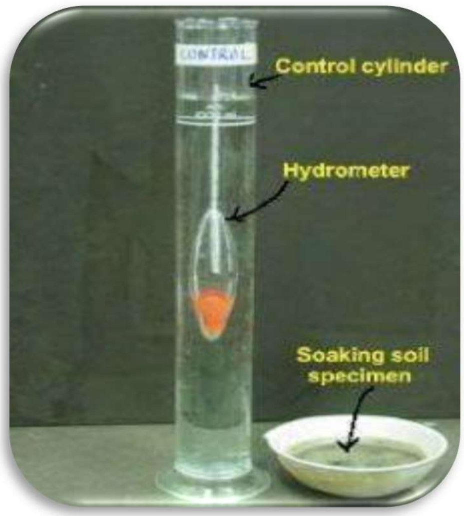



*Figure. hydrometer analysis*

TABLE 1-2: soil separate size Limits

| Classification system | Grain size (mm) | |
|---|---|---|
| Unified soil classification | Gravel | 75-4.75 |
| | Sand | 4.75-0.075 |
| | Silt and Clay | Finest<0.075 |
| AASHTO | Gravel | 75-2 |
| *(American Association of State Highway Transportation Officials)* | Sand | 2-0.05 |
| | Silt | 0.05-0.002 |
| | Clay | <0.002 |

## 1-3 Relative density:

In granular soils, the degree of compaction in the field can be measured according to the relative density, defined as:

$$D_r\% = \frac{e_{max.} - e}{e_{max.} - e_{min.}} * 100$$

OR

$$D_r\% = \left[\frac{\gamma d - \gamma d_{min.}}{\gamma d_{min.} - \gamma d_{min.}}\right] * \frac{\gamma d_{min}}{\gamma d} * 100$$

*$e_{max.}$: void ratio of the soil in the loosest state*
*$e_{min.}$: void ratio in densest state*
*$e$: In Stu void ratio*
*$\gamma d$: In dray unit weight*
*$\gamma d_{max.}$: Dry unit weight in dens state ($e_{min.}$)*
*$\gamma d_{min.}$: Dry unit weight of the loosest state ($e_{max.}$)*

TABLE 1-3: Denseness of a granular soil

| Relative density ($D_r\%$) | Description |
|---|---|
| 0-20 | Very loose |
| 20-40 | Loose |
| 40-60 | Medium |
| 60-80 | Dense |
| 80-100 | Very dense |

## 1-4 Atter berg limits:

***Shrinkage Limit (S.L):*** solid or semisolid state of soil that has little ratio of moisture content soil does not undergo any further change in volume with loss of moisture (ASTM Test Designation D-427).

***Plastic Limit (PL):*** The soil state change from (L.L) to (S.L) called (PL), the moisture content at which soil crumbles when rolled into a thread of 3.18mm in diameter (ASTM Test Designation D-4318).

***Liquid Limit (LL):*** This limit is determined by Casagrande's liquid device (ASTM Designation D-4318).

***Plasticity Index (PI):*** the difference between the liquid limit and the plastic limit of soil.

$$PI = LL - PL$$

## 1-5 Hydraulic conductivity of soil: (*k*)

In soil mechanics and foundation engineering, you must know how much water is flowing through the soil per unit time required, to design some engineering structure such as a dam. The value of (k) is determined in laboratory experimentation generally two types of tests *(constant head)* and *(falling permeability)* the first is more suitable.

$$\upsilon = ki$$

*$\upsilon$: Darcy velocity(cm/sec.)*
*k: hydraulic conductivity of soil(cm/sec.)*
*i: hydraulic gradient $\{i = \frac{\Delta H}{L}\}$.*
*$\Delta H$: piezometric difference head.*
*$L$: distance between two piezometers.*

**Steady-state seepage**:

Passing water from one side to another through soil particles, the flow path changes diversion is not uniform over the entire area. One of the ways to determine the rate of seepage refers to the flow net concept based on Laplace's theory:

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} = zero$$

*$k$: hydraulic conductivity of the soil.*

*$h$: hydraulic head point.*

## 1-6 Effective stress:

The stress is the unit weight of load per unit area. Or it is the unit volume of surcharged soil multiplied by the thickness of the layer. This effective stress causes the change in soil thickness by increasing the soil layer's density this property is called *soil consolidation settlement ($S_c$)*:

$$S_c = \frac{\Delta_e}{1 + e_\circ} H_c$$

*$H_c$: thickness layer of clay.*

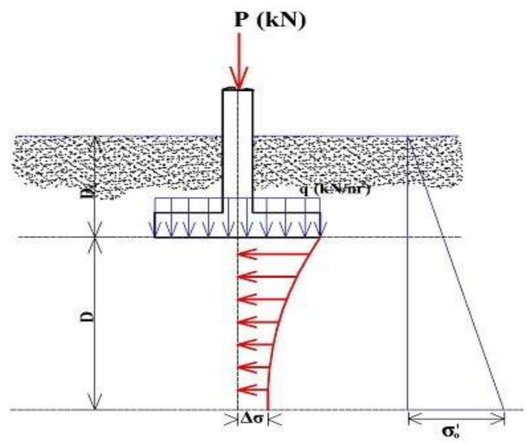



*Figure 1-2: effective stress on soil*

## 1-7 Soil Consolidation:

(STM Test Designation D-2435) to determine the consolidation settlement used by various incremental loading. From the consolidation test we can calculate the following:

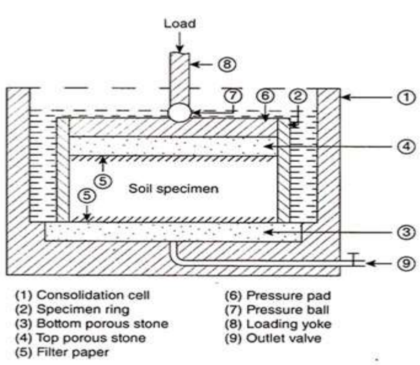



*Figure 1-3: consolidation test*

**Compression index (*Cc*):** $C_C = \frac{e_1 - e_2}{\log \sigma_2^- - \log \sigma_1^-}$ Or $C_C = \frac{e_1 - e_2}{\log\left(\frac{\sigma_2^-}{\sigma_1^-}\right)}$

**Swelling index (*Cs*):** $C_S = \frac{e_3 - e_4}{\log\left(\frac{\sigma_4^-}{\sigma_3^-}\right)}$

**Coefficient of consolidation: (*Cv*)** $C_V = \frac{k}{m_v \gamma_\omega}$

$$m_v = \frac{\Delta e}{\Delta \sigma^- (1 + e_{av.})}$$

**Degree of consolidation: (*U*)**

$$U = \frac{S_C(t)}{S_C(max.)}$$

## 1-8 Shear strength:

$$S = C^- + \sigma^- \tan \emptyset^-$$

$\sigma^-$: *effective normal stress on the plane of shearing.*
$C^-$: *cohesion, or apparent cohesion.*
$\emptyset^-$: *effective stress angle of friction.*

Direct Shear test:

$$\sigma^- = N/A$$
$$S = R/A$$

In sand we can find the fractional angle:

$$\emptyset^- = \tan^{-1} \frac{S}{\sigma^-}$$

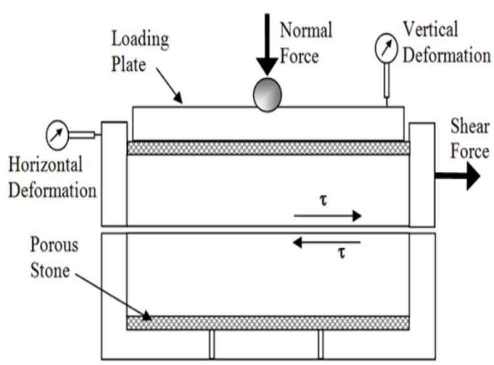



*Figure 1-4: Shear strength*

- Triaxial test for shear:

The equipment and type of testing are shown below:

- Consolidated-Drained test
- Consolidated-Undrained test
- Unconsolidated-Undrained test

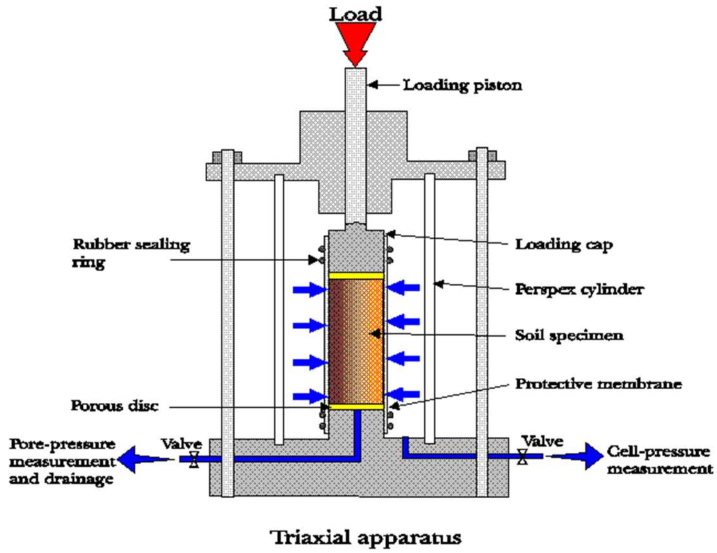



*Figure 1-5: Triaxial test for shear*

## 1-9 Unconfined compression test:

In this test, an axial stress $(\Delta\sigma)$ is applied to the specimen to cause this failure. The axial stress at failure, $\Delta\sigma_f = q_u$. The shear strength of saturated clays under this condition$(\emptyset = zero)$

$$S = C_u = \frac{q_u}{2}$$

It can be used as an indicator of the consistency of clays sometimes conducted on unsaturated soils, with the void ratio of a soil specimen remaining constant, it rapidly decreases with the degree of saturation.

After remolding the specimen soil and retesting some, if the value of shear strength is much less than the 1st test without changes in moisture content this property is called soil sensitivity, the degree of sensitivity ratio between 1st and remolded test is:

$$S_t = {q_u(undesterbed)}/{q_u}\,(remolded)$$

## *CHAPTER TWO: SEISMICITY INVESTIGATION*

## 2-1 Introduction:

Earthquakes are one of those natural events in which humans are always helpless in the face of the time and place of occurrence the force of the earthquake and the duration of the earthquake for this purpose in this chapter I will focus on the information that needs to be prepared during site discovery and give the data to the geotechnical engineer to design a suitable foundation for the structure of the foundation.

## 2-2 Site classification procedure for Seismic design:

### 2-2-1 Site classification:

The site soil shall be classified under Table (2-1) based on the upper (30m) of the site profile. This depth is appropriate soil properties are permitted to be estimated by the registered design professional preparing the soil investigation report based on unknown geological conditions where the site specification data are not available.

### 2-2-2 Site class definition:

a) *Site class (F)*: if the following conditions are available:
   1) Soils vulnerable to potential failure or collapse under seismic loading, such as liquefiable soils, quick and highly sensitive clays, and collapsible weakly cemented soils.
   2) Peats or highly organic clays *[H (thickness of layered soil) >3m].*
   3) Very high plasticity clay *[H>7m, with PI>75].*
   4) Very thick soft/medium stiff clays *[H>37m]* with [$s_u$ <50 $kP_a$.].
b) *Site class (E)*: where the site does not qualify under the criteria for site Class F and *[H>3m]* where soft clay layer is defined by [$s_u$<25 $kP_a$], *W>40%, PI>20.*
c) *Ste class (C, D, and E)*: shall be classified by using one of the following methods for the top (30 m):
   1) Average Shear Wave Velocity ($Vs^-$).
   2) Average Field Standard Penetration Resistance ($N_e$).
   3) Average Standard Penetration Resistance for Cohesionless Soil Layers ($N_{e\,(Ch)}$). Where the ($N_{e\,(Ch)}$) and ($s_u^-$) criteria differ, the site shall be assigned to the category with the softer soil.
d) *Site class (B)*: The shear wave velocity for rock, shall be either measured on-site or estimated by the geotechnical engineer. Softer and more highly fractured and weathered rock shall either be measured on site for ($Vs^-$).
e) *Site class (A)*: the hard rock, category shall be supported by shear wave velocity measurement either on site or on profiles of the same rock type in the same formation with an equal or greater degree of weathering and fracturing. The ($Vs^-$) for (30m) are known with rock conditions.

TABLE 2-1: site classification

| Site class | Site description | *($Vs^-$) ft/s* | *($N_e$) blows/ft* | *($s_u^-$) Ib/ft$^2$* |
|---|---|---|---|---|
| A | Hard rock | >5000 | NA | NA |
| B | Rock | 2500-5000 | NA | NA |
| C | Very dense soil and soft rock | 1200-2500 | >50 | >2000 |
| D | Stiff soil | 600-1200 | 15-50 | 1000-2000 |
| E | Soft clay soil | <600 | <15 | <1000 |
| F | Organic or loose soil | PI>20<br>W≥40%<br>$S_u^-$<25 $kP_a$ | | |

*Note: 1ft= 0.3048m, and 1 Ib/ft$^2$=0.0479 KN-m$^2$*

## 2-3 Seismic ground motion values

**2-3-1 Spectral acceleration value:** according to the geographical location and geological formations in Iraq divided into some geographical locations and has two factors defined as:

a) *Short period ($S_S$):* spectral acceleration factor for (0.2 sec.), according to the Iraqi geographical map shown in figure (2-1)

TABLE (2-2): Site Classification $F_a$

| Sita Class | $S_S$≤0.25 | $S_S$≤0.5 | $S_S$≤0.75 | $S_S$≤1 | $S_S$≤1.25 |
|---|---|---|---|---|---|
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 1 | 1 | 1 | 1 | 1 |
| C | 1.2 | 1.2 | 1.1 | 1 | 1 |
| D | 1.6 | 1.4 | 1.2 | 1.1 | 1 |
| E | 2.5 | 1.7 | 1.2 | 0.9 | 0.9 |
| F | | | See the note | | |

TABLE (2-3): Site Classification $F_V$

| Sita Class | $S_1$≤0.1 | $S_1$≤0.2 | $S_1$≤0.3 | $S_1$≤0.4 | $S_1$≤0.5 |
|---|---|---|---|---|---|
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 1 | 1 | 1 | 1 | 1 |
| C | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 |
| D | 2.4 | 2 | 1.8 | 1.6 | 1.5 |
| E | 3.5 | 3.2 | 2.8 | 2.4 | 2.4 |
| F | | | See the note | | |

b) *Long period ($S_1$):* spectral acceleration factor for (1 sec.) shown in figure Iraqi geographical map figure (2-2)

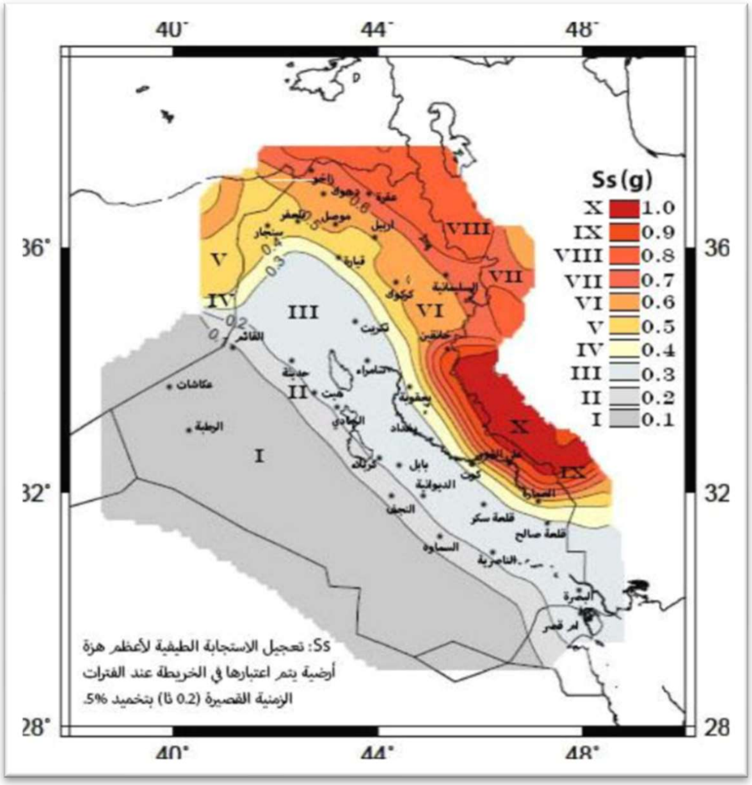



*Figure (2-1) Map showing the values of the spectral acceleration of ground motion ($S_S$) seismic at a time interval (0.2) second.*

**2-3-2 Site soil class**:

The site soil classification is discussed in the previous section of this chapter, the site shall be classified as site class (A, B, C, D, E, or F).

**2-3-3 Modification of spectral acceleration factor ($S_M$):**

Based on the soil classification, the value of ($F_a$, $F_v$) from the following TABLES (2-2), TABLE (2-3) respectively note that use straight-line interpolation for intermediate value the value of ($S_M$) equations:

$$S_{MS} = F_a S_S \quad \textit{short period modification}$$

$$S_{M1} = F_v S_1 \quad \textit{long period modification}$$

Special tests and dynamic analysis of the soil of sites classified in the classification category, according to the approved standard specifications (F), are conducted. Site-specific soil investigations must also be carried out to analyze the site's kinetic response, except in the case of structures where vibration periods are equal to or less than (0.5) seconds, the values (F) of the soils that can be disabled, are taken equal to the value of the calculated site item without taking into account.

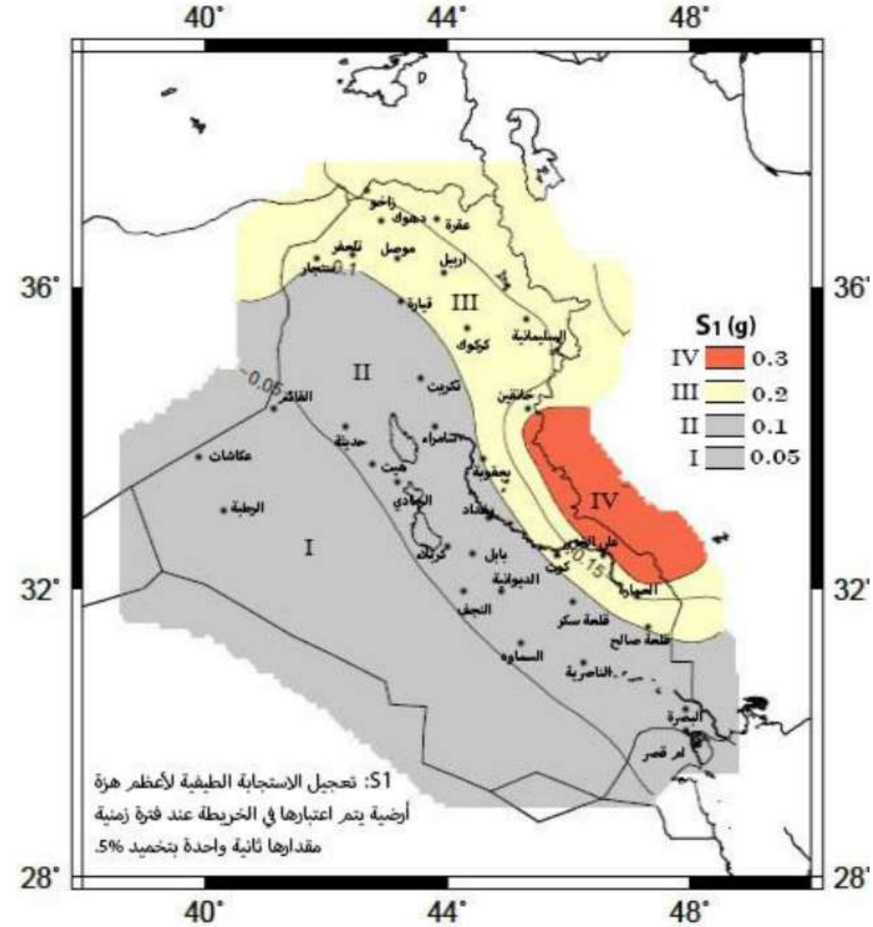



*Figure 2-2: Map showing the values of the spectral acceleration of ground motion ($S_1$) seismic at a time interval (1) second.*

### 2-3-4 Design Spectral Acceleration Parameters ($S_D$):

in short period symbolled as ($S_{DS}$), and in long period is symbolled as ($S_{D1}$) calculated as follows:

$$S_{DS} = 0.75 S_{MS}$$

$$S_{D1} = 0.75 S_{M1}$$

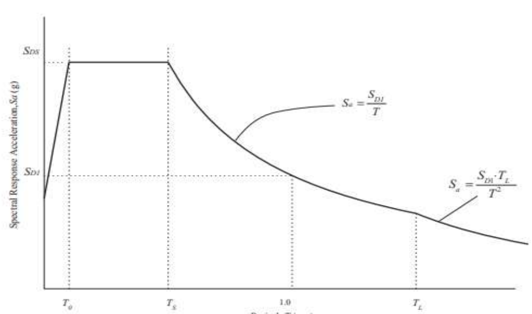



*Figure 2-3: Design Response Spectrum*

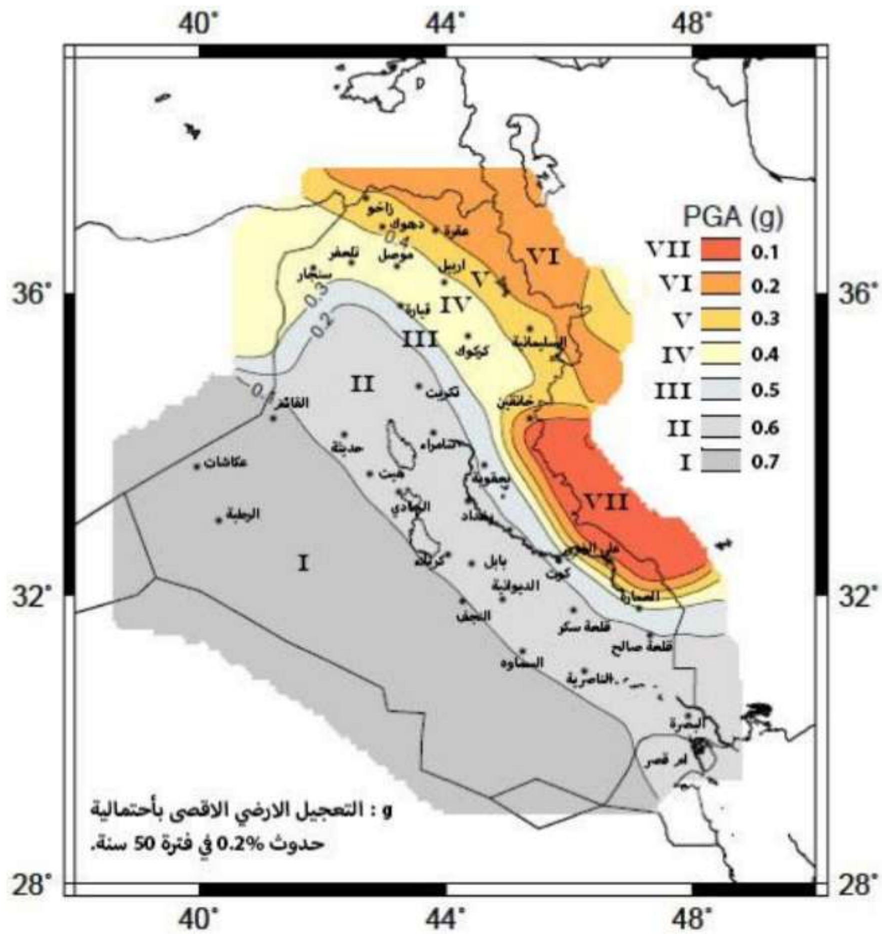



*Figure 2-4: A map showing spectral acceleration values the probability of an earthquake exceeding the value of this acceleration is 2% for 50 years period.*

*PGA (Pick Ground Acceleration) coefficient also from site class ben map will be detected.*

### 2-3-5 Design Response Spectrum:

Design Response Spectrum is required by standards and site-specific ground motion procedures are not used the design response spectrum curve shall be developed:

$$S_a = {D_{D1}}/{T}$$

$$S_a = S_{D1} * {T_1}/{T^2}$$

# *CHAPTER THREE: SUB-SURFACE EXPLORATION*

## 3-1 Introduction

In this chapter, the topics of research on soil analysis sites methods of soil analysis, and the acquisition of selected soil data are discussed in detail.
As we have already mentioned ‹some of the tests that require laboratory tests need to be translated from the site in a scientific and engineering manner and for this purpose, the samples are discussed. This is one of the most important parts of the book where the reader can get a lot of information about each of them.

## 3-2 Sub-surface exploration programs:

sub-surface exploration comprises several steps:

1. **Collection of preliminary information**:

This step involves obtaining information regarding the type of structure to be built and it is general use. For the construction of a building, the approximate column loads and their spacing and the local building code and basement requirements should be known.

2. **Reconnaissance:**

An Engineer should always make a visual inspection of the site to obtain information about

1) the general topography of the site, the possible existence of drainage ditches abounded dumps of debris, and other materials present at the site. Also, evidence of creep of slops and deep wide shrinkage cracks at regularly spaced intervals may be indicative of expensive soils.
2) Soil stratification from deep cuts, such as those made for the construction of nearby highways and railroads.
3) The type of vegetation at the site which may indicate the nature of the soil.
4) Heigh watermarks on nearby buildings and bridge abutments.
5) Groundwater levels, which can be determined by checking nearby wells.
6) The type of construction nearby the existence of any crack in walls or other problems, also can be obtained from any available soil reports and exploration for existing structures.

3. **Site investigation:**

The site investigation phase of the exploration program consists of planning, making test boreholes, and collecting soil samples at desired intervals for subsequent observation and laboratory tests.

## 3-3 Methods of Soil Exploration:

a) **Open excavation**:

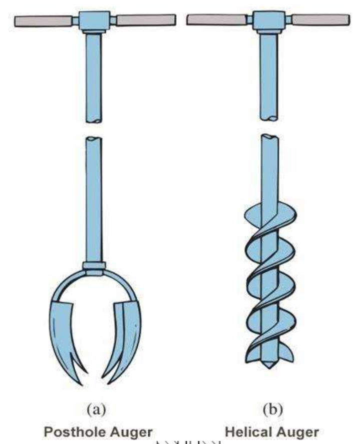
A pit eventually, can be excavated for exploring shallower depth, say of the order of 2-5m, or so. Such a pit can be easily excavated at the proposed construction site if the soil has a bit of cohesion and the soil sample can be lifted from such different depths, besides making the easy visualization and examination of the different strata. Even undisturbed soil samples can be lifted from such a pit by a process called chunk sampling.

**b) Boring's method**:

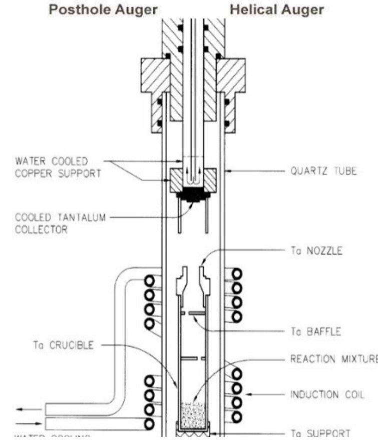
Soil samples can be lifted from deeper depths by drilling boreholes using mechanical devices called samplers. The process consists of the:

1) Drilling the hole and visually examining the cutting coming out from different depths.
2) Lifting the soil samples from different depths by using mechanical devices(sampler).

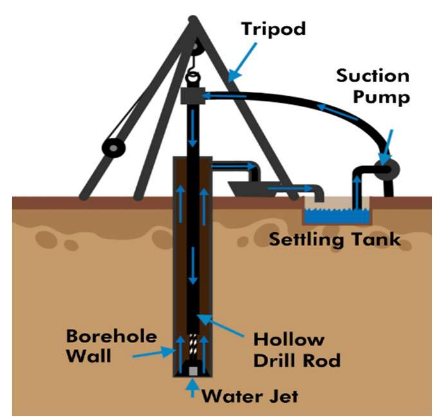
1. Auger boring: this is the simplest method of boring a hole by hand drilling. This can be used for shallower depths generally confined to depths of about 5m or so. In cohesive and other soft soil above the water table, augers are suitable for soft soil or stiff clay, and very stiff and hard clays and sand pumps for sandy soil may be used. Figure 3-1:




2. Auger and Shell boring: cylindrical augers and shells are used for making deep boring. Hand operated for 25 m; mechanical rings are used for 50m.Figure 3-2:




3. Wash boring: this is a simple and fastest method, used for making holes in all types of soils except boulders and rocks. Figure 3-3
4. Percussion boring: this method is used in all types of soil including boulders and rock, to drill a hole.



Rotary boring (Mud rotary drilling): this method is used to advance holes in rock and soil. Rotating core barrels which are provided with commercial diamond bits or a steel bit with slots are used for rotary drilling. This method is used to obtain the rock cores, so this method is called core boring or core drilling. Figure 3-4

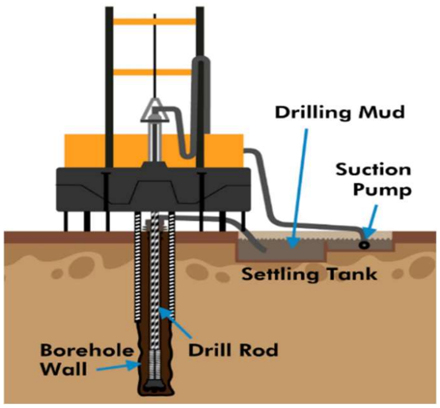



*Figure: 3-4*
*Mud rotary drilling*

The approximate required minimum depth of the boring should be predetermined. The depth can be changed during the drilling operation, depending on the subsoil encountered. To determine the approximate minimum depth of boring, one can use any empirical equation for this equation according to country or engineers may use the rules established by the (A.S.C.E.) (*American Society of Civil Engineers 1972*) see figure 1-2.

1. Determining the net increase in the effective stress $\Delta\sigma^{-}$ under a foundation with depth.
2. Estimate the variation of the vertical effective stress $\sigma^{-}$ with depth.
3. Determine the depth $D=D_1$, at which the effective stress increase $\Delta\sigma^{-}$ is equal to $0.1q$.(*q: estimated net stress on the foundation.)*
4. Determine the depth $D=D_2$ at which $(\Delta\sigma^{-}/\sigma_0^{-}) = 0.05$.
5. Choose the smaller of the two depths $D_1$ and $D_2$, just determined as the approximate minimum depth of boring required, unless bedrock is countered.

When deep excavation is anticipated, the depth of boring should be at 1.5 times the excavation. Sometimes sub soil conditions require that the foundation load be transmitted to the bedrock. the minimum depth of the core boring or weathered, the core boring may have to be deeper. There are no hard-and-fast roles for borehole depth and spacing, from *table (3-1)*, and *table (3-2)* respectively give some general guidelines. Spacing be increased or decreased, depending on the condition of the subsoil. Also, can use the following equations to determine the boring depth:

$Db = 3S^{0.7}$ *(For light steel or narrow concrete building)*

$Db = 6S^{0.7}$ *(For heavy steel or wide concrete building)*

*Db: depth of boring in meter*
*S: number of stories.*

TABLE 3-1: Approximating coring depth with stories number of buildings

| No. of stories | Boring depth (m) |
|---|---|
| 1 | 3.5 |
| 2 | 6 |
| 3 | 10 |
| 4 | 16 |
| 5 | 24 |

TABLE 3-2: Approximate spacing of boring according to different type of project

| Type of project | Boring spacing (m) |
|---|---|
| Multi-story building | 10-30 |
| One-story industrial plant | 20-60 |
| High ways | 250-500 |
| Residential subdivision | 250-500 |
| Dams and dikes | 40-80 |

The number and spacing of boreholes and it are depth are increasing or decreasing according to subsoil conditions of and predicable soil strata or from existing investigations and soil reports.

**c) Geophysical method**:

**1) Electrical resistivity method ($\rho$)**

This method is based on the measurement and recording of changes in the mean resistivity or apparent specific resistance of various soils. The test is done by driving four metal spikes to act as electrodes into the ground along a straight line at an equal distance. This is shown in the figure 3-6.

Direct voltage is applied between the two outer potentiometer electrodes and then the mean for the potential drop between the inner electrodes is calculated as mean resistivity *(ohm-cm).*

$$\rho = 2\pi D \frac{E}{I}, \qquad \rho = 2\pi D R$$

*D*: distance between the electrodes(mc)

*E*: potential drop between outer electrodes(volts)

*I*: current flowing between outer electrodes(amperes)

*R*: resistance (ohms)

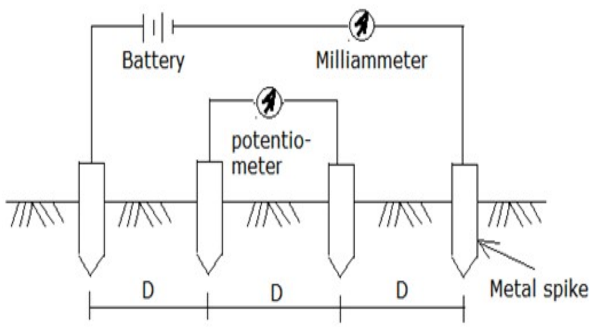



*Figure 3-6:*
*Electrical resistivity method*

**Resistivity mapping**: this method is used to find out the horizontal changes in the subsoil, the electrodes kept at a contact spacing, are moved as a group along the line of tests.

**Resistivity sounding**: this method is used to study the vertical changes; the electrode system is expanded, about a fixed central point by increasing the spacing gradually from an initial small value to a distance roughly equal to the depth of exploration desired.

**2) Seismic refraction method**

This method is very fast and reliable in establishing profiles of different strata, provided the deeper layers have increasingly greater density, higher velocities, and greater thickness. Governed by *Shell's Law* of refraction. The seismic refraction method utilizes the refraction of seismic waves by rock or soil layers to characterize the sub-surface geologic conditions and geologic structure.

The waves are refracted when they cross the boundary between different types (or conditions) of soil or rock.

**P-wave refraction**:

It evaluates the compression wave generated by a seismic source located at a known distance from the array. The wave is generated by vertically striking a plate with a sledgehammer, shooting a seismic shotgun into the ground, or detonating an explosive charge in the ground. Since the compression wave is the fastest of the seismic recording as compared to the other seismic waves.

**S-wave refraction**:

Evaluated the shear wave generated by a seismic source located at a known distance from the array. The wave is generated by horizontally striking an object on the ground surface to induce the shear wave. Since the shear wave is the second fastest wave, it is sometimes referred to as the secondary wave. When compared to the compression wave, the shear wave is approximately one-half (but may vary significantly from this estimate) the velocity depending on the medium.

## 3-4 Sub-surface exploration tests:

These tests are carried out to measure the resistance to penetration of a sampling spoon, a cone, or any other shape tools under dynamic or static loading. These tests are used for the exploration of erratic solid profiles for finding depth to bedrock or stratum and to get an approximate indication of the strength and other properties of soil. The methods of subsurface sounding are:

### 3-4-1 Cone Penetration test: (Dutch cone test)

This type of test is carried out to get a continuous record of the resistance of the soil by penetrating steadily under static pressure, a cone with a base of 10 $cm^2$. and an angle of $60^o$ at the vortex pushed in to the ground a steady range about 20mm/sec. To find out the cone resistance, the cone alone is first forced down for a distance of 8cm, and the maximum value of resistance penetration called (*point resistance*) is measured. This test is very useful in finding:

a. The bearing capacity of pits in cohesionless soil. Cone resistance *qc(kg/sq.cm)* is approximately equal to 10 times the penetration resistance *N*. It is equal to the vertical force applied to the cone.
b. The frictional resistance *(Fc)* is the resistance measured by the sleeve located above the cone with local soil surrounding it.
c. Calculating the friction ratio *(Fr)* obtained from the test and using the following equation:

$$Fr = \frac{F_c}{q_c}$$

### 3-4-2 Standard Penetration Test: (SPT)

It is carried out in a clean hole of diameter about 55-155mm. the side of the hole is supported by casing or drilling mud. A split tube sampler with an outer diameter of 50.8mm and inner of 38mm is driven into undisturbed soil and placed at the bottom of the hole under blows of 65kg driven weight with 75cm free fall. The minimum open length of the sampler is 60cm, the sampler is first driven through 15cm as a seating drive is known as penetration resistance and it is denoted by *N*. When *N* is greater than 15, Terzaghi and Peck have recommended the use,

$$N_e = 15 + \frac{1}{2}(N - 15)$$

of an equivalent penetration resistance, *Ne* in place of the observed value of *N*.

The value of *N* has a modification for air-dry or moist sand can be represented by the relation from the equation below (*the equation from Gibbs and Holtz's experimental study of the effect of overburden pressure*) it is applied first and then dilatancy correction is applied,

$$N_e = N\left[\frac{350}{\sigma' + 70}\right]$$

$N_e$*: corrected value.*
*N: actual value of bows.*

*σ': effective overburden pressure (KN/Sq. m.) is applied first and then dilatancy correction is applied*

standard penetration test provides several useful correlations such as:

1. The consistency of clayey soils can often be estimated from the standard penetration number $N_e$ as shown in the table 3-3.
2. Correlation between *N* and the undrained shear strength of clay *Cu.*

$$Cu = K\,N_e$$

*K: constant = (3.5-6.5 KN/m²)*

TABLE 3-3 The standard penetration number $N_e$ and clayey soil consistency

| $N_e$ From S.P.T. corrected | Consistency | Unconfined Compressive strength $q_n$ *(KN/m²)* |
|---|---|---|
| 0-2 | Very soft | 0-25 |
| 2-5 | Soft | 25-50 |
| 5-10 | Medium stiff | 50-100 |
| 10-20 | Stiff | 100-200 |
| 20-30 | Very stiff | 200-400 |
| >30 | Hard | >400 |

3. The over-consolidation ratio *(OCR)* of a natural clay deposit can also be correlated with *S.P.T.*

$$OCR = 0.193\left(\frac{N_e}{\sigma_\circ^-}\right)^{0.689}$$

*$\sigma_\circ^-$: effective vertical stress in (MN/m²)*

4. Can obtain the fraction angle (Ø) of the soil sample after correcting the value of $N_e$ as shown in the equation below then the fraction equation is:

$$(\emptyset deg.) = 27.1 + 0.3(N_1)_e - 0.0054\left[N_{1(e)}\right]^2$$

*Peck, Hanson, and Thornborn (1974) in graphical which can be approximate (walff1989)*

$$(\emptyset deg.) = \tan^{-1}\left[\frac{N_{60}}{12.2 + 20.3\left(\frac{\sigma_\circ^-}{P_a}\right)}\right]^{0.34}$$

*Schertmann (1975) provides this equation mathematically the correlation can be approximated as (Kalhway and Mayne 1990)*

- **Factors effective on the value of $N_e$:**

**In granular soils:**

The value of *N* is affected by the effective overburden pressure $\sigma_\circ^-$ for that reason, the value of $N_e$ obtained from exploration under different effective overburden pressures should be changed to correspond to a standard value of $\sigma_\circ^-$.

$$(N_1)_e = CN\ N_e$$

$(N_1)_e$: *corrected value of $N_e$ to standard value of $\sigma_\circ^-$ (100 KN/m²)*

*CN: correlation factor*

$N_e$: *value of N obtained from filed after correction.*

*CN* has a relationship with $\sigma_\circ^-$ and $P_\circ$ while $P_\circ$ is the effective overburden pressure *(100KN/m²)*

$$CN = \sqrt{\frac{1}{\left(\frac{\bar{\sigma_\circ}}{P_\circ}\right)}}$$

*Liao and Whitman's relationship 1986*

$$CN = \frac{2}{1+\left(\frac{\bar{\sigma_\circ}}{P_\circ}\right)}$$

*Skempton's relationship 1986*

**IN SAND**

An approximate relationship between the corrected standard penetration number and the relative density of sand is approximate primarily because the effective overburden pressure and stress history of the soil significantly influence and $N_e$ value of sand the empirical relationship is a correlation between $N_e$ and the relative density of sand (%*Dr*):

$$D_{r\%} = 11.7 + 0.76\sqrt{222N_e + 1600 - 7.68\bar{\sigma_\circ} - 50Cu^2}$$

*Marcuoson and Biegrousekg (1977)*

$$D_{r\%} = \left[\frac{N_e\left(0.23 + \frac{0.06}{D_e}\right)^{1.7}}{q} * \left(\frac{1}{\frac{\bar{\sigma_\circ}}{P_\circ}}\right)\right]^{0.5} * 100$$

*Cubrinouski and Ishihara (1999) also proposed a correlation between $N_{60}$ and the relative density of sand ($D_r$)*

*$D_r$: relative density*
*$N_e$: Standard penetration number*
*$\bar{\sigma_\circ}$ : effective overburden pressure ($KN/m^2$)*
*$Cu$: uniformity coefficient of sand*
*$P_a$: atmospheric pressure ($\approx 100\ KN/m^2$*
*$D_{50}$: sieve size through which 50% of the soil will be passed (mm)*

The following qualification should be noted when the standard penetration resistance value is used in the preceding correlations to estimate soil parameters:

1. The equations are approximate.
2. The value of $N_e$ obtained from a given borehole very widely, because the soil is homogenous.
3. In soil deposits that contain large boulders and gravel. Standard penetration numbers may be erratic and unreliable.

### 3-4-3 Vane Shear test: (ASTM D-2573)

The Vane Shear test may be used during the drilling operation to determine the in situ undrained shear strength *(Cu)* of clayey soils- particularly soft clay. That apparatus consists of four blades in the end of the road, the height of the Vane is twice the diameter it can be either rectangular or tapered. The dimensions of the Vane used in the field are various cases and each case has a diameter relatively high and a blade thickness with a road diameter. The Vane of the apparatus is pushed into the soil at the bottom of a borehole without disturbing the soil appreciably Torque is applied at the top of the road to rotate the Vane at a standard rate of $0.1^\circ/sec.$, the rotation will induce failure in the soil of cylindrical shape surrounding the Vane. The maximum torque T applied to cause failure is measured.

$$[T = f(cu, H \text{ and } D)]$$

$$\left[Cu = \frac{T}{K}\right]$$

$$\left[K_{cm} = \left(\frac{\pi}{10^6}\right) * \left(\frac{D^2 * H}{2}\right) * \left(1 + \frac{D}{3H}\right)\right]$$

$$\left[K_{(cm)} = 366 * 10^{-8} * D^3\right] \quad \left(if \frac{H}{D} = 2\right)$$

*T: Torque in (N.m)*
*Cu: shear strength in (KN/m$^2$)*
*K: a constant with magnitude depending on the dimension and shape of the Vane.*
*D: Vane diameter*
*H: measured height of Vane.*

The value of *(Cu)* obtained in the field is too high, described as [*Cu $_{(VST)}$*], in this case, recommended that correlation be required for actual design purposes.

$$\left[Cu_{(corrected)} = \lambda Cu_{(VST)}\right]$$

$\lambda$: *correction factor from the flowing equations.*

a) $\lambda = 1.7 - 0.54 \log[PI^{\%}]$ *(Bjerrum 1972)*
b) $\lambda = 1.18e^{-0.08(PI)} + 0.57$ OR $\lambda = 7.01e^{-0.08(LL)} + 0.57$ *(Morris and Williams (1994))*
*Where:*
*PI>5 and LL is in %*

c) $\lambda = f\left[\frac{Cu_{(VST)}}{\sigma_o^-}\right]$

From the Vane shear test can be calculated, $\sigma_c^-$ (*pre-consolidation pressure*) and, *OCR (over consolidation ratio)* from the driven empirical relationships by *(Mayne and Mitchell (1988))*

$$\sigma_c^- = 7.07\left[Cu_{(VST)}\right]^{0.83}$$

$$OCR = \beta \frac{Cu_{(VST)}}{\sigma_o^-}$$

$$\beta = 22(PI)^{-0.48}$$

*While:*
$\sigma_c^-$*: pre-consolidation pressure (KN/m$^2$).*
$Cu_{(VST)}$*: Vane shear test from the field.*
$\sigma_o^-$*: effective overburden pressure.*
$PI$*: Plasticity index.*

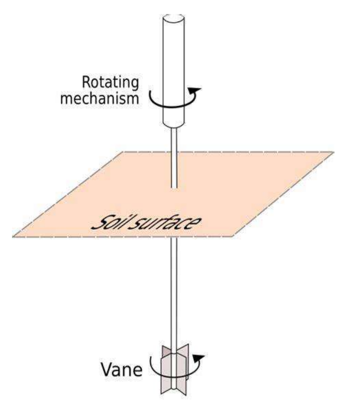



Figure 3-5:
Vane Shear test instrument

## 3-5 Soil Sampling procedure:

Two types of soil sampling can be obtained in the field:

1. Disturbed soil sampling:

Generally, this type of soil sample can be used for the following laboratory tests;

a. Graine-size analysis.
b. Determination of liquid and plastic limits.
c. Specific gravity of soil solids
d. Determination of organic content.
e. Classification of soil.

2. Undisturbed soil sample:

Can be used for the following laboratory tests:

a. Soil consolidation.
b. Hydraulic conductivity.
c. Shear strength test.

### 3-5-1 Split-spoon sampling (cutting edge):

Used to obtain soil samples that are generally disturbed, but still representative. Sometimes the sample will be difficult to recover in this case the spring core may be placed inside the spit spoon. The tool consists of a steel-driving shoe, a steel tube that is split longitudinally in half, and a coupling at the top and the coupling connects the sampler to the drill road.

The degree of disturbance for a soil sample is usually expressed as:

$$[Ar\% = \frac{D_{\circ}^2 - D_i^2}{D_i^2} * 100]$$

*$A_r$: area ratio (of the disturbed area to the total area of soil)*

$D_{\circ}$: *outside diameter of the sampling tube.*

$D_i$: *inside the diameter of the sampling tube*.

### 3-5-2 Thin-walled tube: (Shelby tube)

They are made of seamless steel and are frequently used to obtain undisturbed clayey soil. The most common thine-weld tube samplers have outside diameters of 50.8mm and 76.2mm, and the first one has an inside diameter of 47.63mm. the bottom end of the tube is sharpened. The tubes can be attached to drill road boreholes, and the sampler is pushed into the soil. The soil sample inside the tube is then pulled out. The two ends are released, and the sampler is sent to the laboratory for testing, any increase in the diameter of the samples will increase the cost. This sampler can be used for consolidation and shear strength of soil.

$$A_{R\,\%} = \frac{D_\circ^2 - D_i^2}{D_i^2} * 100$$

From the equation above for the sampler has (50.8mm, 47.63mm) for outer and inner diameter respectively the value of $A_R\%$ is:

$$A_R\% = \frac{50.8^2 - 47.3^2}{50.8^2} = 13.75\%$$

### 3-5-3 Piston Sampler:

When the soil sample is very soft or larger than 76.2mm the previous method is not practical in this case the mechanical piston sampler *(proposed by Osterberg (1952))* is useful under such conditions consisting of a walled tube with a piston. The piston closed the end of the tube. The tube is pushed into the soil hydraulically past the piston. Then the pressure is released through a hole in the piston road. To a large extent, the presence of the piston prevents distortion in the sample by not letting the soil squeeze into the sampling tube very fast and by not admitting excess soil at the lower part of the sampler. This sample is less disturbed than the previous sampler.

### 3-5-4 Coring of Rock:

When a rock layer is encountered during a drilling operation, rock coring may be necessary. A *core barrel* is attached to a drilling road. A *coring bit* is attached to the bottom of the barrel. The cutting element may be a diamond, tungsten, carbide, …etc.  The coring is advanced by rotary drilling. Water is circulated through the drilling road during coring, and cutting washout.

When the core samples are recovered for further evaluation in the laboratory. Based on the length of the rock core recovered from each run, the following equations and table can determine the in-situ rock quality:

$$recovery\ ratio = \frac{lenght\ of\ core\ recoverd}{theorical\ length\ of\ rock\ cored}$$

$$RQD = \frac{\sum length\ of\ recoverd\ pieces\ equal\ to\ or\ larger\ than\ 101.6m}{theorical\ length\ of\ rock\ core}$$

TABLE 3-4: Relation between in-situ Rock Quality and (RQD) Rock Quality Design

| RQD | Rock quality |
|---|---|
| 0-0.25 | Very poor |
| 0.25-0.5 | Poor |
| 0.5-0.75 | Fair |
| 0.75-0.9 | Good |
| 0.9-1 | Excellent |

## 3-6 Water Table:

The Presence of a water table near a foundation significantly affects the foundation's load-bearing capacity and settlement. The water level will change seasonally. In many cases, the water table of level the highest and lowest possible levels of water during the life of the project may be necessary. During boring and site exploration if water is observed, it must be recorded, and the borehole must be monitored for 24 hours if there is a collection of water in boreholes it means that the soil has a high hydraulic conductivity. For determining the water level in boreholes using chain or tape. It required several weeks to stabilize the water table level in this case another instrument required which called a piezometer (*basically consists of a porous stone or perforated pipe with a plastic sand pipe, used for water level measurement*)

## 3-7 Preparation of Boring Logs:

The detailed information gathered from each borehole is presented in a graphical form called the boring log.

The following information in a standard log should recorded by the driller and should never be left to memory:

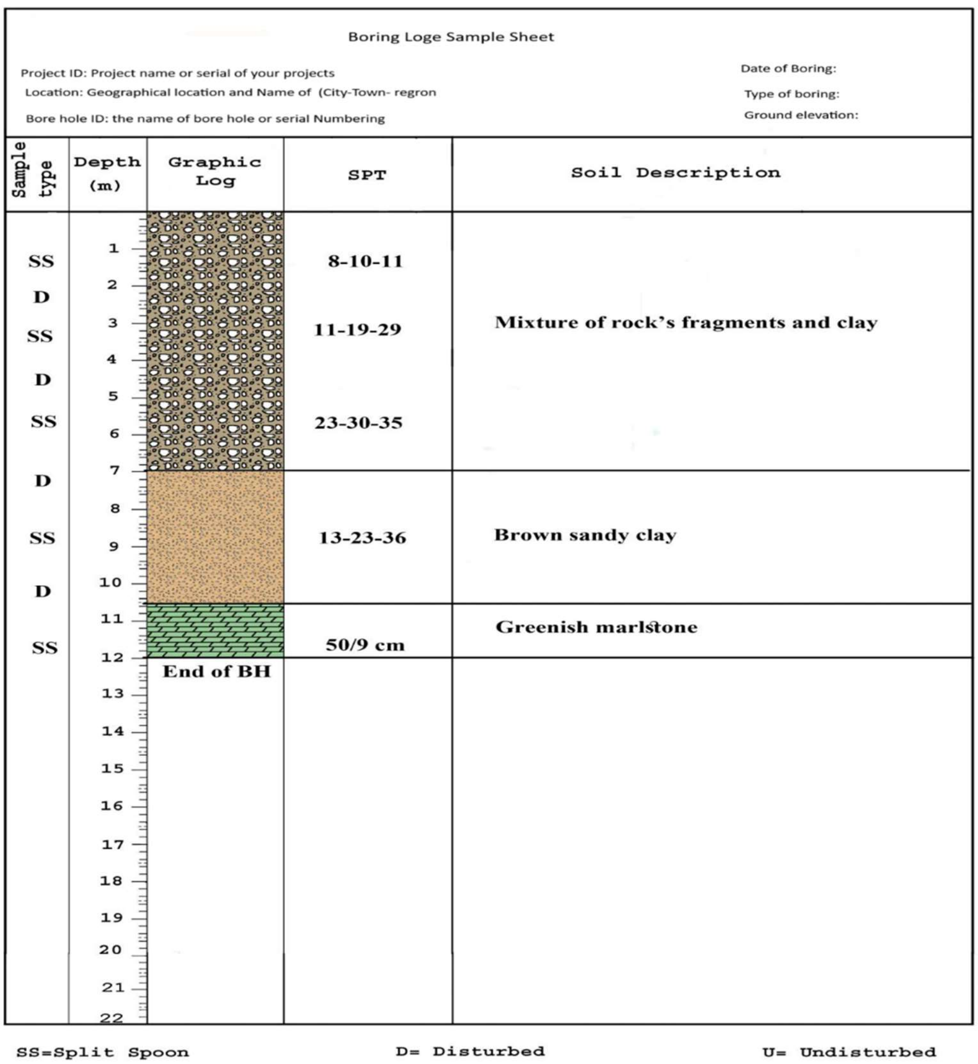
1. Name and address of drilling company
2. Driller's name
3. Job description and number
4. Number, type, and location of boring.
5. Date of boring
6. Subsurface stratification can be obtained by visual observation of the soil bought out by auger, split-spoon sampler, and thin-walled Shelby tube sampler.
7. Water table elevation and observed date, using mud or casting …etc.
8. Standard penetration resistance SPT and it is depth.
9. Soil sample collected number, depth.
10. In the case of rock coring, the type of core barrel used and for each run the actual length of coring, and length of core recovery an RQD.

## 3-8 Subsoil Exploration Report:

At the end of the soil exploration programs, the soil and rock specimens collected in the field are subjected to visual observation and appropriate laboratory testing. To determine the geotechnical properties of soil as described in chapter (1). After all required information has been compiled, a soil exploration report is prepared for use by a design office and for reference during future construction work. The exploration report should be well-planned and documented, as they will help in answering the question and solving foundation problems that may arise later during design and construction. The report should include the following items:

1. A description of the scope of the investigation.
2. A description of the proposed structure for which the subsoil exploration has been conducted.

3. A description of the location of the site, including any structure nearby, drainage conditions, the nature of vegetation on the site and surrounding it, and any other feature unique to the site.
4. A description of the geotechnical setting of the site.
5. Details of the field exploration include the number of borings, depths of borings type of borings involved, and so on.
6. A general description of subsoil conditions, as determined from soil specimens and related laboratory tests, standard penetration resistance, and cone penetration resistance…etc.
7. A description of water-table conditions.
8. Recommendations regarding the foundation, including the type of foundation recommended, the allowable bearing pressure (*bearing capacity*), and any special construction procedure that may be needed; alternative foundation design procedures should also be discussed in this portion of the report.
9. Conclusions and limitations of the investigations.



## CONCLUSION:

To design a foundation that supports adequate structural load, one must understand the nature of the soils that will support the foundation. Detailing the layers of natural soil deposits that will underlie a purposed structure and their physical properties is generally referred to as sub-surface exploration. The purpose of a soil exploration program is to obtain information that will aid the geotechnical engineer in the following:

1. Select the type of and the depth of foundation suitable for a given structure.
2. Evaluation of the load-bearing capacity of the foundation.
3. Estimation of the probable settlement of the structure.
4. Determination of potential foundation problems (expansive soil, collapsible soil, sanitary and fill…. etc.)
5. Establishment of groundwater table.
6. Principle of lateral earth pressure for structures like retaining walls, sheet piles, bulkheads, and braced cuts.
7. Establishment of construction methods of charging subsoil conditions.

Sub-surface exploration may also be necessary when addition and alteration to existing structures are contemplated. Foundation engineers should always remember that the soil data given site is frequently nonhomogeneous that is the formation of soil profile may be variable. Soil mechanics theories concern idealized conditions. The application of this theory to foundation engineering problems involves judicious evaluation of the information on the site conditions and soil parameters involves judicious evaluation of the information on the site condition and soil parameters obtained from field exploration programs. Good professional judgment constitutes a major part of geotechnical engineering, and it comes with practice.

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Principle of FOUNDATION ENGINEERING Sixth Edition, Braja M. Das

ASCE STANDARD
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Minimum Design Loads and Associated Criteria for Building and Other Structures