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UGWU, MICHAEL OKENNA

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Soil Mechanics

ATLANTIC INTERNATIONAL UNIVERSITY

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1.0: Introduction

The word soil can be trace to the Latin word *Solium* which refers to the uppermost (loose) part of the earth which can be tilled and ploughed for agricultural purposes. It can be said that the word soil means different things to different fields (Helwany, 2007). The definition above applies specifically to the field of agronomy where soil is viewed specifically from the line of planting agricultural crops. In the field of geology, soil is defined as the disintegrated rock materials which remains in it position (K.R, 2004). In other words, the materials remain in-situ without disturbances. In the field of civil engineering, the term soil is viewed as the loose unconsolidated inorganic materials derived primarily from rock disintegrations. The term soil is of particular importance to the field of civil engineering because the foundations of all engineering structures must be places on soil. As such the civil engineering pays particular attention to the engineering behavior of soil. The word “Soil Mechanics” was first used by Dr Karl Terzaghi in the year 1925 in his book titled *Erdbaumechanic*. In the book Terzaghi defines soil mechanics as the application of the laws of mechanics and hydraulics to the solution of engineering problems dealing with unconsolidated soil particles especially generated from the effect of rock disintegrations (K.R, 2004). In more simple terms, Terzaghi views soils mechanics as the study of action of forces on soil and the flow of water through it. Soil Mechanics is the branch of physical science which deals with the structure, properties and response of soils when subjected to the effect of loads (W.Taylor, 1948). It can be viewed simply as the application of the knowledge of physics, mechanics and hydraulics to the behavior of soils. In this discussion the following topics have been briefly dealt with: objectives of soil mechanics, origin and formation of soil, modeling of soil, application of soil mechanics, phases and profile of soil, soil compaction, compressibility of soil, consolidation and compaction of soil, shear strength, Mohr-Coulomb theory, particle size analysis, soil stabilization, investigation, earth pressure, bearing capacity of foundations and slope stability.

The knowledge of soil mechanics is very important to the field of civil engineering. This is because the principles of soil mechanics are applied to the design and construction of the foundations of various civil engineering structures.

2.0: <u>Objectives of Soil Mechanics</u>

The key objectives of the mechanics of soil include but not limited to the following:

- To accomplish the requirements for various engineering surveys
- Develop acceptable and standard methods for soil samples and devices for them
- Develop acceptable methodologies and devices for testing of soils
- Deploy the knowledge of soil mechanics to the collection, classification of various soils samples and their properties
- To characterize various types of soils based on their determined coefficient for physical and chemical properties
- To determine and interpret soil test results and their applications as for construction purposes
- To determine the impact of various factors such as dynamic and static loads as well water and temperature

3.0: Origin of Soil

Origin of Soils can be traced to the weathering of rock due to mechanical or chemical activities. These continuous mechanical and chemical activities result in large rock being broken into smaller particles which when deposited in a particular location form soils. Equally, soils can be viewed as the products of geological activities which take place on the surface of the earth. Examples of such geological activities include erosion, transportation and upheavals. When the particles resulting from these activities are transported to new locations, they form soils in a phenomenon referred to as geological cycle (SMITH, 2014).

3.1: Soil Formation

In general soil is considered to be three-phase materials made of solid particles, water and air (void). Generally speaking the dominate characteristics of soil is largely determined by the sizes of the solid particles and void. In discussing soil in terms of their formation, we can classify soil into two various types:

- Soils that are formed as a result of physical and chemical disintegration (weathering) of the parent rocks. This is basically due to the grinding (physical) actions of flowing water, ice, wind, animal and plant on the parent rocks. Examples of soils in this category include gravels and sand. On the other hand the causes of chemical weathering include oxidation, carbonation, hydration, leaching due to organic acid and clay. Examples of soils formed by chemical actions include clay and silts.

- Soils which are of organics origin: these are formed by the deposit of organic matters such plant and animal residues at the various stages of the decomposition. Examples include lichens, mosses, grasses, leaves, trees and other vegetative matter. These ingredients add to the nutrients making it to be loose and more adaptable for agricultural purposes.

3.2: Soil Modeling

The term modeling refers to the relationship between stress and strain for soils. The type of models to be adopted depends on a particular civil engineering problem being solved. When the problems involve conventional design calculations for geotechnical engineering, the concept of plasticity and elasticity models are adopted. When the problem involves ground movements, the concept of linear elastic soil model is assumed. When the problem involves slope stability, the model that assumes rigid, perfectly plastic behavior of the soil. It is important to note that no particular soil model can describe the behavior of real soil under all conditions (Kok Sien Ti, 2011).

3.3: Application of the principles of Soil Mechanics

The principles of Soil mechanics are applied in many areas of civil engineering. This has informed the reason why sound knowledge of the principles of soil mechanics is key to successful engineering project design and execution. Among the important areas of application are:

i. **Foundation**: All civil engineering structures like building, bridge, dams, etc must rest on properly designed foundations. The job of the foundations is to transfer the loads from the structures to the soil in a safe and efficient manner

ii. **Retaining Walls**: This is another area where the principles of soil mechanics are applied. In this case soils of different levels are to be kept on either side of the wall to keep them in place and at different slopes

iii. **Slope Stability**: The principles of soil mechanics are applied where we have non-horizontal soil surface to keep the soil in the shape

iv. **Underground structures:** This is another area where the soils mechanics principles are applied. In this case, structures like tunnel, conduits and shafts are designed using the principles to determine the forces exerted on them due to the soil mass

v. **Pavement Design:** For pavement to be designed, the engineer needs to know the behavior of the subgrade on which the pavement is to be paid. Improper determination/selection of the subgrade may lead to failure of the pavement

vi. **Earth Dam:** Proper design of earth dams requires thorough knowledge of soil mechanics to avoid catastrophic failure after design.

vii. **Others Areas**: Other areas of soil mechanics application include design of soil heaves, shrinkages and swelling of soils.

3.4: Cohesive and Cohesionless Soils

Soils particles behave differently under the effect of adsorbed water. The level of water contents and their mode of deformation will determine the class of soil. Soils are said to be cohesive if the adsorbed water and the soil particles attraction is such that they deform plastically at different water content. This cohesive property has been described largely due to the presence of clay and other minerals in the soils. This is the reason why cohesive soils are referred to as clay soils (Das, 2011). On the other hand, soils that contain bulky grains are referred to as Cohesionless soils. It is important to note that the fineness of the smallness of the soil particles do not change the property of the soils. This is because rock may have very small sizes yet will be referred to as Cohesionless soils. The same applies to non-plastic silts and coarse grained soils.

In terms of structures, the Cohesionless soils can be divided into two categories: single grained and honeycombed. In single grained, the individual soil particles are at rest with the immediate surroundings. In the honey combed class, the soil particles form arches and chains and as such display large void ratios between themselves. Two distinct types of forces are at play in the cohesive soils: negative and attractive forces. The forces are experienced only when the particles come close to each other. The negative force is a repulsive while the attractive one is largely referred to as Van der Waal force (W.Taylor, 1948).

3.5: <u>Soil Profile</u>

When soil is fully formed and especially after many years, it creates what is commonly referred to as soil profile. The soil profile is a vertical section through the soil that shows different sizes of soil. The layers appear in what is generally referred to as horizon and typically profiles follow a particular order i.e.: humus, top soil, subsoil, rock fragments and bed rock.

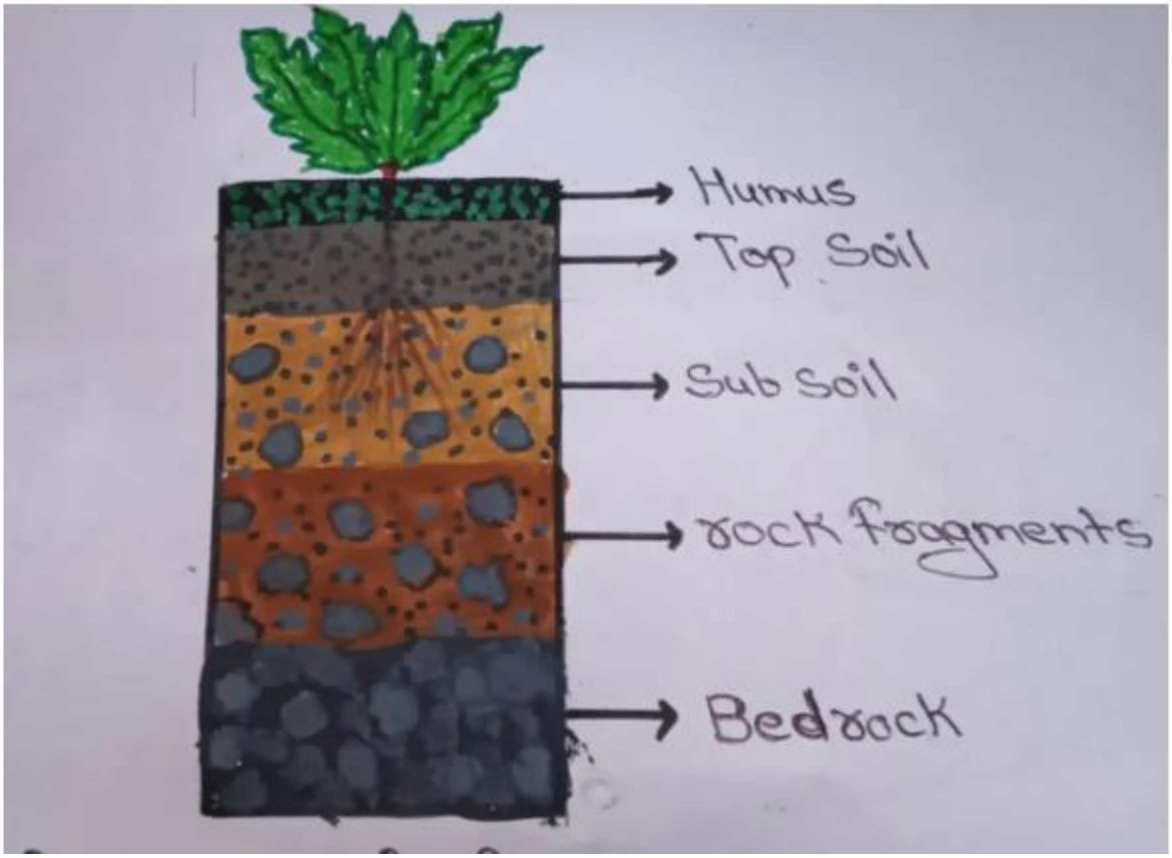


Fig-1: Soil Profile

3.6: Soil Phases

Naturally soil is a heterogeneous, porous, multiphase system made of solid particles, air water. In summary, soil can be said to exist in three phases of solid, liquid and gases. In other words, soil can be dry, partially saturated and fully saturated. Therefore the weight of a typical soil sample will be derived from the weight of solid, water and air. Also the volume of a typical soil sample will be the total volume of solid, water and air that make up the sample.

$V = V_S + V_W + V_A$

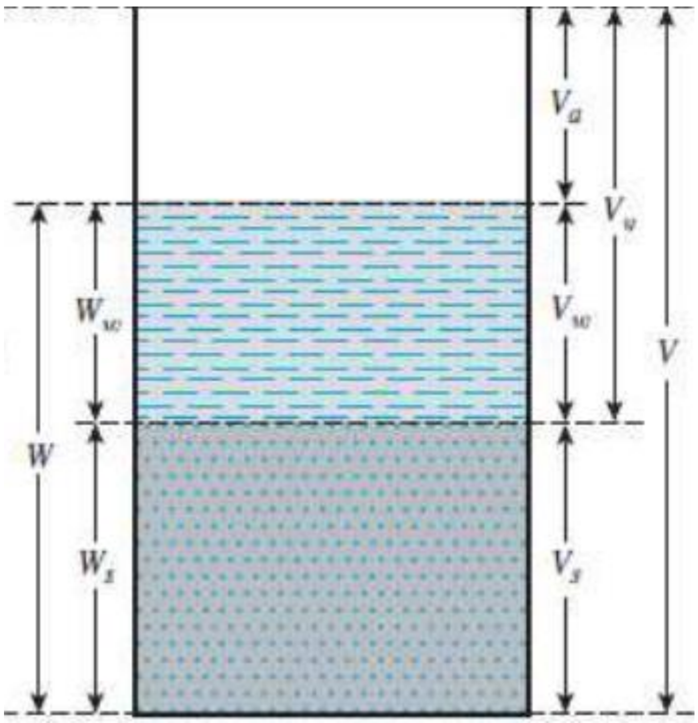


Fig-2: Three Phase Diagram of soil

4.0: <u>Soil Compaction</u>

As stated, soil is made of water, solid and air in different proportions. The amount of each of the three components above will determine the behavior of the soil sample. During construction of various civil engineering projects like roads embankment, dams etc, there is a need improve the density of the soil by removing water and air to make the loose soil particles to be more compact (MOHAMMED, 2015). This process of removing the air voids from a soil sample using mechanical means is called compaction. This process is equally referred to as densification as it helps to improve the strength of the soil by increasing the dry unit weight. As such the degree of compaction is measured in terms of the unit weigh of the sample. There are many reasons for carrying out compaction of the soil sample and these include but not limited to:

- Improve on the bearing capacity of the soil
- Improve the structural settlement
- Improve the stability of slopes
- Reduction of water content and hydraulic capability of soil

4.1: <u>Factors Affecting Compaction</u>

Success in compaction is affected by certain factors and most prominent of them include:

i. *Compaction effort-* An increase in the compaction effort increases the unit density and reduces the optimum moisture contents of soil
ii. *Moisture contents*-addition of water improved compaction
iii. *Type of soil and level of gradation*-The type of soils has great impact on the dry density and optimum moisture content of soil
iv. *Method of compaction-* The method of compaction influences the shape of compaction curves

4.2: <u>Compressibility of Soil</u>

One of the characteristics of soil is tendency to decrease in volume under the effect of applied load. This ease with which a soil decreases in volume under the mechanical load is called the compressibility of soil. The process under which a soil sample decreases in volume under the applied load is compression. The decrease in volume of the soil due to mechanical load is used to describe the amount of settlement of the soil. The compression of soil sample can occur due to many factors which include:

i. Displacement of water and air from the void spaces of the soil sample
ii. Movement/Shifting of the soil particles
iii. Deformation of the soil particles

4.3: <u>Consolidation of soil</u>

It has been established above that a soil experiences a decrease in volume under the effect of applied load. This decrease is due largely to the change in particle arrangement in the soil. Since both water within the voids and soil particles are assumed to be incompressible and the soil is fully saturated with water, it means that the only way for the soil to experience a change in volume is by the loss of water through the voids due to applied load. The phenomenon by which a fully saturated soil under the effect of load loses water through the voids is called consolidation. Consolidation of soil occurs in three different forms:

i. *Initial consolidation*: This occurs immediately a saturated soil comes under the effect of load. This is due to the removal of air from the soil void which will result in the compression of the soil particles
ii. *Primary consolidation*: After the initial consolidation which is due to removal of air particles, further reduction in volume will occur due to expulsion of water from the voids. This further reduction in volume is called primary consolidation.
iii. *Secondary Consolidation:* After the primary consolidation, soil will continue to experience decrease in volume though at a very slow rate depending on some

soil samples like peats and organic clays. This decrease in volume which is recorded after the primary consolidation is termed secondary consolidation

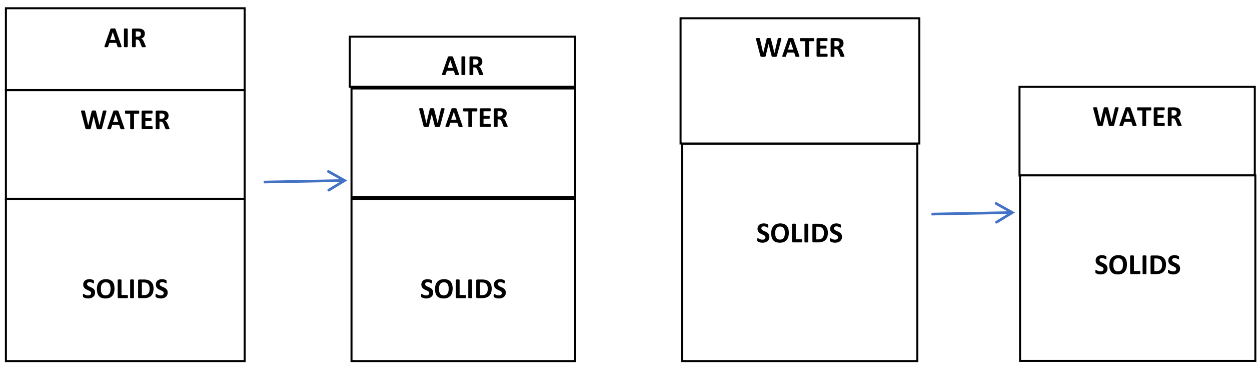
4.4: Factor Affecting Consolidation

The rate of consolidation is affected by three factors:

i. Nature/Type of Soil
ii. The stress history of the soil
iii. The effective stress of the soil

4.5: Difference between Consolidation and Compaction

The term consolidation is often confused with compaction. Compaction is a process of improving the density of unsaturated soil sample by reducing the volume of air in the voids. Consolidation on the other hand is a time-dependent phenomenon of improving the density of saturated soil sample by removing the water content through the voids.



Compaction (Reduction in air Volume) **Consolidation (Reduction of water volume)**

Fig-3: Compaction verses Consolidation of Soil

4.6: Normally Consolidated and Overconsolidated Soils

In discussing consolidation especially for clay soils, it is important to identify two scenarios for clay consolidations. A clay soil is normally consolidated if the current effective overburden pressure it is subjected to is the maximum it has ever experienced in the history. On the other hand, it is said to be overconsolidated if the present overburden pressure being experience is less the effective overburden pressure that it has been subjected to in history. The ratio between the maximum overburden pressure it has experienced in the past and the present overburden pressure is referred to as overconsolidation ratio. For normally consolidated clay, the overconsolidation ratio is less than 1, while the overconsolidation ratio of an overconsolidation clay soil is greater than 1.

4.7: Shear Strength of Soil

One of the fundamental characteristics of soil is that it is made up of individual particles that always roll and slide relative to one another. Therefore, the term shear strength of soil refers to the cohesion between the individual particles and the attendant resistance to the sliding over each due to friction. In other words, it is the internal resistance of over a defined area which a soil mass can offer to resist failure and sliding along a defined plane. Soil shear strength depends primarily on how the individual particles interact with one another. As such shear failure of soils is experienced when the soil particles are exposed to the stress that makes them role or slide over one another. The concept of soil shear strength of the soil is useful for the determination of bearing capacity of foundations, slope stability and lateral pressure on retaining wall structures. The shear strength parameters of the soil are:

i. Cohesion(C): this is a measure of binding force between the soil particles

ii. Internal Friction(φ): This defines the shear strength of the soil due to friction

4.8: <u>Mohr-Coulomb Failure Theory</u>

In the year 1900, Mohr presented the popular failure theory which is termed the Mohr-Coulomb failure theory for rapture materials. The theory states that materials fail because of critical combination of normal and shear stresses. The theory presented a relationship between the shear and normal stresses on a failure plane thus:

$\boldsymbol{\tau f} = \boldsymbol{c} + \boldsymbol{\sigma}\ \boldsymbol{tan}\emptyset$ (Mohr–Coulomb failure criterion)

where c = cohesion; ∅ = angle of internal friction, σ = normal stress on the failure plane;

τf = shear strength.

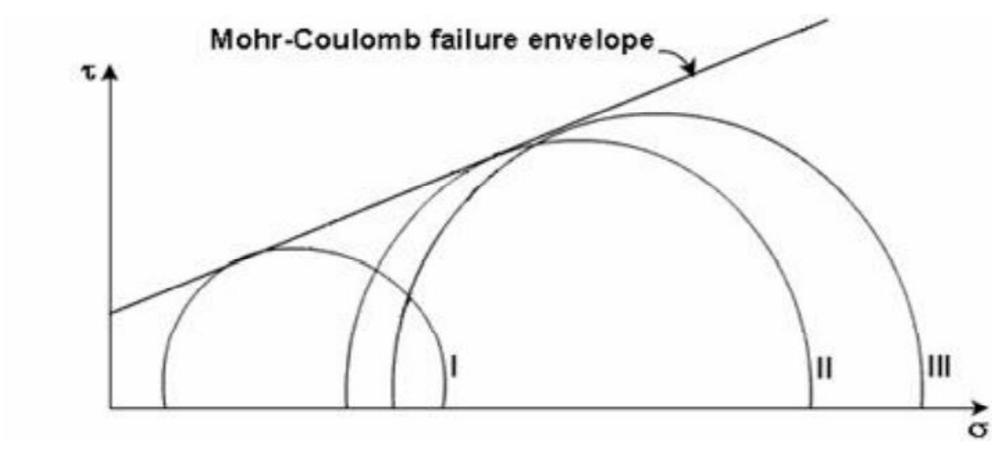


Fig-4: Mohr-Coulomb Failure envelop

4.9: Determination of Shear Strength parameters

The popular laboratory tests for determination of the shear strength parameters(c, φ,) of soil are:

i. Direct shear test
ii. Triaxial test
iii. Direct simple shear test
iv. Plane strain Triaxial test
v. Torsional ring shear test

The direct shear and Triaxial tests are the most commonly used laboratory test for determination of the shear strength parameters of soil.

5.0: Particle Size Analysis

The concept of particle size analysis refers to the measurement of the proportion of primary solid particles from soil. The determination of the various sizes is based on the ability of the various sizes of the particles to pass through different mesh sieves. This is popularly referred to as mechanical analysis and presents the quantity by mass of the various sizes of particles present in the soil sample. The result of such analysis is presented graphically and called the particle size distribution curve. The process of mechanical analysis is accomplished in two stages:

i. Sieve Analysis
ii. Sedimentation analysis

The sieve analysis is used for coarse-grained soil whose size is greater than 75 microns and can easily pass through a set of sieves. The sedimentation analysis is used for fine-grained soil whose size is less than 75 microns. Soil sample may contain both coarse and fine sizes of particles. It is therefore necessary that a combined analysis be completed for the soil samples.

5.2: Soil Stabilization

One of the design criteria to be considered prior to the design of geotechnical project is the bearing capacity of the subsoil. Once the bearing capacity of the subsoil is not suitable to support the project, two choices open to the engineer are either abandon the site and look for a suitable one or carry out an improvement work on the site (Makusa Paul, 2012)**.** It is usually very difficult to find a construction site that meets the design requirements without ground improvement/modifications. The common practice is to improve the engineering properties of the site soil to meet the desired design requirements/specifications of the projects. The geotechnical properties of soils like soft clay and organic materials can be modified to suit the design requirements. Some of the engineering properties that are of great interest to geotechnical engineer include volume, stability, strength, compressibility and permeability. One of the methods for improving the properties of soil is soil stabilization. The process of soil improvement is aimed at enhancing the soil strength in order to improve on the resistance to softening by the effect of water through particle bonding or by water proofing the particles. The processes of stabilization commonly employed are compaction and drainage; the aim being to ensure the water is drained out from the wet soil. In considering the process of stabilization, it is important to evaluate the effects on the immediate environment (nearby building structures). This will influence the materials selections and their proportion for use. The knowledge of the environmental impact will determine the selection of equipment for the mixing, spreading, rolling, thickness etc (Anjan, 2019). This can be accomplished through two basic methods:

i. Mechanical: this involves physical processes the tend to alter the physical nature of the parent soil through mechanical vibrations and compaction
ii. Chemical: This process relies on the chemical reactions between stabilizers (cementitious materials) and the parent soil minerals to achieve the desired improvement on soil properties. Some of the examples of cementitious materials include cement, lime, fly ash, bitumen etc

The components of stabilization include:

i. Soil like soft clay, clayey peat, organic soils
ii. Stabilizing agents like cement, lime, fly ash and blast furnace slag

6.0: <u>Site Investigation</u>

Prior to the design of engineering projects, it a general practice to gather the subsurface information of the site of the project. This process of gathering the information about the proposed site of civil engineering projects is referred to as site investigation. The scope of soil investigation varies especially with the size of the projects. The purpose of site investigation includes:

i. The site investigation is aimed at determining sufficient subsurface information to support the economy and safe design of the foundation of any proposed structure

ii. The site investigation should provide sufficient information to support the design and construction of the proposed project in a safe and economical manner

The scope of site investigation should cover the following:

i. Topography
ii. Site Profile
iii. Ground-water condition

There are generally four stages of site investigations which include:

i. *Desktop study and site reconnaissance*-this covers researching to gain as much information as possible from the site using survey maps(geological map, Aerial photography, previous records) and site walk through
ii. *Preliminary ground investigation*: Involves predicting the geological structures, soil profile, and ground water table
iii. *Detailed ground investigation*: this stage involves defining the scope of test, number/depth of boreholes, list of equipment and location for laboratory
iv. *Monitoring:* this stage ensures that the design expectations are met. This may involve taking measurements for settlement, displacement, deformation, inclination and pore water pressure

6.1: <u>Steps for Soil Exploration</u>

Soil exploration for civil engineering project execution follows some defined stages which include the following:

A. *Boring*: This is the most common method of surface exploration where a bore is used to determine the nature of the ground to take some disturbed and undisturbed samples for laboratory analysis. The choice of the boring will determine the type of equipment to be used. For shallow depths like 6m, hand Auger is used. Depths between 10m to 30m required power Augers.
B. *Sampling*: This involves the taking of representative soil samples from the bore holes. Two types of samples (disturbed and undisturbed) are usually taken depending on the need. While disturbed samples are needed for index properties, undisturbed samples are required for engineering properties.
C. *Testing*: This involves the testing of the soil samples. This usually happens in the soil mechanics laboratory.
D. *Soil Exploration Report*: Upon the completion of the soil exploration program, the report should is presented. The report should cover all details like scope of investigations, information on proposed site and general site conditions

7.0: <u>Theory of Earth Pressure</u>

The stability of the soil mass is guaranteed when the surface of the soil mass is flat. This is not always the case as the soil surface may be in a slope which will require the soil to be retained at a slope steeper than allowed for safely. In such situation, it becomes necessary to employ the support or retaining structure to provide lateral support to the soil mass. In such situation the soil mass will be retained behind the structures. Hence the work of the retaining structure will be to hold the soil mass at different elevations on both sides (Richard, 2022). A key consideration in the design of the retaining structure is determination of magnitude and line of action of the lateral earth pressure. The determination of the lateral earth pressure is based on the theories of Coulomb, Rankine and Terzaghi and based on the assumption of the rigidity of the retaining structures with the soil-structural interactions being neglected (K.R, 2004).

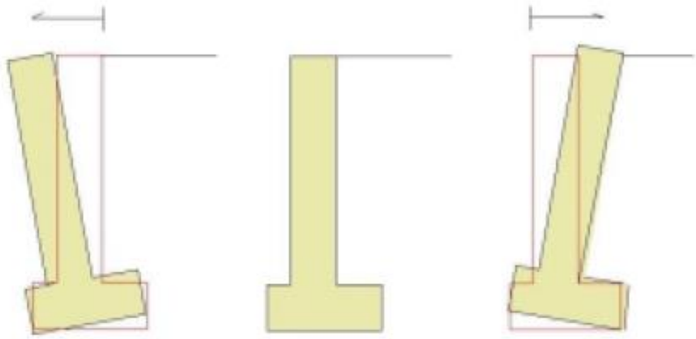
7.1: Types of Lateral Earth Pressure

There are basically three types of lateral earth pressure and the categorization is dependent on the movement experienced by the retaining structure which the pressure is acting on. The different types of lateral earth pressure are:

i. *At rest earth pressure*: This type of pressure is usually developed when the retaining structure experiences no lateral movement. This is experienced when the retaining structure is restrained from both lateral and rotational movement

ii. *Active Pressure*: This pressure develops when the retaining structure is free to move outward as experienced in retaining wall and soil mass is sufficient to mobilize enough shear strength

iii. *Passive Pressure*: This pressure develops when the wall moves into the soil thereby compressing the soil. This is usually experienced within the section of the wall that is below the soil grade and on opposite side of the retained fill



Active Case (Wall moves away from soil)

At Rest Case (No movement)

Passive Case (Wall moves into soil)

Fig-5: Retaining structures movement

7.3: <u>Determination of the Lateral Pressure Coefficients</u>

The determination of the lateral pressures is based on the relationship between the vertical pressure and the coefficient. The lateral pressure is therefore the product of the vertical pressure and the appropriate earth pressure coefficient. The definition of the coefficients are:

i. K_o: Coefficient of At-Rest pressure
ii. Ka: Coefficient of Active Pressure
iii. Kp: Coefficient of passive Pressure

The coefficient of the At-Rest pressure is determined from the formula:

$K_O=1-Sin(\emptyset)$

K_o is the At-Rest earth pressure coefficient, while ∅ is the soil friction value

Active and passive coefficients are derived from two popular theories:

i. Rankine Earth pressure theory
ii. Coulomb Earth Pressure theory

Rankine theory is based on certain fundamental assumptions:

i. Zero adhesion and friction between the wall and the retained soil
ii. The lateral pressure only applies to vertical walls
iii. Any failure in the backfill will occur as a sliding wedge along assumed failure plane
iv. Lateral pressure is linearly related to the depth with the resultant appearing at one-third of the wall height
v. The resultant force is parallel to the backfill surface

The Coulomb theory is similar to Rankine except that

i. There is friction between the wall and soil
ii. Lateral pressure does not apply to vertical wall only
iii. Due to the soil friction, the resultant force is not parallel to the backfill

The Rankine active and passive pressure coefficients are calculated from the relations below:

i. Active--------------Ka=(1- (Sin(∅)/(1+sin(Sin(∅))
ii. Passive------------Kp=(1+Sin(Sin(∅))/(1-(Sin(∅))

The Coulomb active and passive earth pressure depend on angle of at the back of the wall, soil-wall friction and angle of backfill. Tabulated values of both Rankine and Coulomb earth pressure are always available in soil mechanics books.

8.0: Bearing Capacity of Foundation

The Foundation is the most important section of a civil engineering structure. The most outstanding property of the foundation is its role in transferring the entire load from the structure to the ground. The foundation is therefore the bridge between the entire superstructure and the supporting soil (Abhishek Aryai, 2017). In the design of the foundation, two parameters are of interest to the structural engineer: bearing capacity and settlement. It is important to ensure that the soil below the structure will not fail and that the settlement of the structure is within the allowable limit. The pressure with which the soil can safely support the structure is referred to as the allowable bearing pressure (K.R, 2004). It is therefore to be said that the work in foundation design consists of determining the ultimate bearing capacity of the soil under the foundation and the maximum allowable settlement that the foundation can undergo without adversely affecting the superstructure (Abhishek Aryai, 2017).

8.1: Types of Foundations:

There are basically two types of foundations:

1. Shallow Foundations: Shallow foundations are the types that transmit the load of the structure within the shallow depth of the soils. Common examples of shallow foundations include square, circular, strip and mat foundations

2. Deep Foundations: Deep foundations transmit the load of the structure to a considerable depth. If the depth of the footing is greater or equal to the width of the footing, it is referred to as deep foundation. Deep foundations are used where the bearing capacity of the soil is too low to support the loads from the superstructures. Examples of deep foundations include piles, pier and well foundations.

   In discussing bearing capacity of foundations, there are many theories of analysis; some of which are briefly considered below:

   i. **Rankine**(1885): Rankine analysis is based on the bearing capacity of shallow foundations on loose, dry granular sandy soils
   ii. **Prandtl** (1921): Prandtl bearing capacity analysis is based on the assumption that for ultimate bearing capacity of Cohesive soil is independent of the width of the footing (B). This is however not the cases with Cohesionless soils, as this theory shows that the ultimate bearing capacity is directly related to the width of the footing (B).
   iii. **Terzaghi and Hogentogler Analysis** (1929): This is based on shear failure beneath the footing being in straight form. This theory assumes that the failure pressure is equal to the ultimate bearing capacity of the soil
   iv. **Terzaghi Bearing Capacity Analysis (1943)**: This theory gives the general bearing capacity of soils under strip footing. The bearing capacity factors in Terzaghi equation are dimensionless and depend only on the angle of shearing resistance of the soil
   v. **Westergaurd(1938):** This theory is based on soil being an elastic medium of semi-infinite half space and shows pressure distribution in soils under point loads

vi. **Meyerhof**(**1951**): The bearing capacity derivation here is based on consideration of shear resistance of soil mass above the foundation level

9.0: <u>Stability of Slopes</u>

A Slope either man-made or natural refers to the unsupported and inclined portion of the earth surface. Over the years, the failure of slopes had resulted to huge loss in terms of properties and lives. It is therefore imperative to review the stability of any slopes prior construction activities (K.R, 2004). Attempts to carry out stability analysis of existing natural slopes and safe design of man-made slopes had exposed the field of engineering into advancement. This is because this had led to better understanding of both short-term and long-term stability in terms of both total and effective stress. The civil engineer is therefore expected to have sound knowledge of the established methods for carrying out the stability of slope and their specific applications to ensure safe designs. In general slope failures are usually witnessed when the force leading to the failure exceeds the shearing resistance which is developed along the plan of failure (Das, 2011). There are two factors that are generally responsible for slope failures:

i. Increase in shear stressed-This may be as a result of water saturation of soils, surcharge loads, seepage or erosion etc
ii. Decrease in shear strength of soil-this may be due to increase in water content, pore pressure, weathering etc

9.1: Assumptions for Slope stability Analysis

In completing analysis of soil to ensure that is safe against slope failure, the following assumptions are made:

- The stress is taken to be two-dimensional
- The applicability of Coulomb equation with soil strength parameters known
- The seepage condition as well as water level is known and can be used for estimating pore water pressure
- Conditions of plastic failure are met along the critical failure surface

9.2: Factors of Safety for Slope Stability Analysis

In discussing slope stability analysis, it is important to clearly specify the factor of safety. The following are the common factors of safety for slope stability analysis:

i. *Factor of safety relating to shear strength*- This refers to the ratio of the shear strength to the shear stress with respect to the failure surface
ii. *Factor of safety relating to Cohesion*-This is determined by the relationship between the available cohesion and the mobilized cohesion
iii. *Factor of safety relating to friction*-This is determined from the relationship between the available frictional strength to the mobilized frictional strength

9.3: Types of Slope Failures

Analysis of slope stability focuses on the determination of shear stress that is required for the static equilibrium of the sliding mass and the shear strength required for factor of safety. Slope failure comes in many forms which include the following:

1) *Rotational Failure*: This occurs when the slip surface experiences rotation when the soil mass rotates downward or upward. This type of failure can occur on the toe, slope or base of the soil mass
2) *Translational Failure:* This is experienced for slopes that are continuous and still have uniform soil properties. In this case the failure occurs along the very long surface parallel to the surface of the slope
3) *Compound failure*: In some cases, the failure might be a combination of both rotation and translational slips.
4) *Wedge Failure*: When the slip failure is along an inclined plane, it is referred to as wedge failure

9.4: Improving the Stability of Slope

It is possible to make slopes that exposed to failure by sliding safe and usable again. Many methods have been adopted to improve the safety which is aimed at the stabilization of slopes. The overall focus is on either the reduction of mass of the soil or improvement on shear strength of the soil. Some of the adopted processes are:

i. Slope flattening aimed at reducing the soils that will potentially cause slip
ii. Improving resistance to movement by introducing a berm below the toe of the sliding slope
iii. Introduction of drainage to reduce the seepage and thereby improving the stability of the soil
iv. Improving the density of the soil mass to increase the shear strength of the Cohesionless soil

v. Consolidation by surcharging to improve the stability of the soil

vi. Grouting and introduction of other compounds like cement in identified zones to improve stability

vii. Installation of sheet piles and other forms of retaining walls also help to improve soils stability

viii. Stabilization of the soil also help to improve stability of soil

The method to be adopted for slope improvement largely depends on the economic considerations as some of the methods above are very expensive.

10.0: Conclusion

Every structure, be it building, bridge and dams and others must have its foundation resting on soil. One of the fundamental challenges facing the geotechnical engineer is the determination of a suitable foundation for such engineering structures. Since all structures must rest on the soils, it becomes imperative that the role of soil as a foundation material cannot be over emphasized. One of the prominent challenges with providing suitable foundations for the structures is due to the nature of soil. Soil exhibits variable characteristics and using the soils for engineering constructions presents a huge/complex challenge to the geotechnical engineer. This complexity of the physical properties of soils makes it imperative that sound knowledge of soil must be developed. The application of the fundamental principles of mechanics to the construction materials like soil is central to the success of geotechnical engineering. Such studies involving the relationship between stresses, strain and modulus of elasticity form important part of applied mechanics. The introduction of these basic principles of applied mechanics to soil became important in the understanding of behavior of soil under load. This approach to the rational application of principles of applied mechanics to understand soil actions under the effect of loads is referred to as soil mechanics. This write up has highlighted some basic concepts of soil mechanics and their applications to engineering.

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