AIU Exams: Foundations

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Introduction

Foundation is that portion of a structural system that transmits the load from the structure to the soil. Foundation is that portion of a structure that is located below the ground level with the primary function of transmitting the loads from the various portions of the structures to the soil. In other words, foundation is the link between the superstructures and the underlying soil (Das, 2011). The foundation provides the required stability of the structure from the ground. This is achieved by distributing the entire weight of the structures over a large area of the soil thereby preventing overloading of the immediate underlying soil (Donald P. Coduto, 2016). Foundation is described as the most essential portion of any structures. It is the lowest portion of the structure that transmits the dead weight of the structures in addition to the live loads, seismic and winds to the ground surface above which the structure is standing, thereby ensure that the safe bearing capacity of the soil is not exceeded (Abhishek Aryai, 2017).

A structure is usually divided into two sections: the superstructure and the substructure. The portion between the plinth level and the roof is called the superstructure while the portion between the plinth and the underlying soil is referred to as substructure. This substructure is generally referred to as the foundation. The effectiveness of the foundation is key to the success and stability of the structure. As such, emphasis should be placed on the engineering, design, construction and supervision for the foundation of any structure. Experience has shown that about 30% of the cost of a structure is spent on the foundation (Shanmuga G, 2018).

Apart from transmitting the loads from the superstructure to the adjoining soil, the foundation plays key role in the prevention of differential settlement as well as providing stability of the structures. Other functions of the foundation include prevention of lateral movement of the supporting soil and securing level and firm bed for the structures to rest on (Shanmuga G, 2018) (Das, 2011).

There are two main types of foundations: shallow and deep foundations. Structures are built to serves different purposes. It is essential to note that the choice of foundation for a structure will depend largely on the types of structures and the soil condition on which the structures will be placed. Shallow foundation is divided into five basic types: Spread footing or open trench foundations, Grillage foundations, Raft foundations, Stepped foundations and Inverted arch foundations. Deep foundation on the other hand is divided into the following: Pile foundations, Well foundations and Caisson foundations (Smith, 2008).

Structures are designed for specified lifespan. Since the foundation is the most essential portion of the structure, it becomes important that the foundation of any structure must exhibit certain essential principles. The foundation must be designed for permanence and placed in an area that will not be impacted by future construction. The stability of the foundation must be guaranteed and able to transmit the load to the adjoining soils without breaking or warping. The depth of the foundation must be such as to withstand shock and stress throughout the life of the structure. Lastly, the foundation should have rigid base in order to support the superstructure. A combination of the above factors will guarantee that the foundation is fit-for purpose and can support the structure and other loads for the design life of the structures (Shanmuga G, 2018) (R.F, 2004).

1. Objectives of Foundation

The purposes of foundation for all engineering structures are:

i. To distribute the loads from the structure over a large bearing surface to ensure that the intensity of the load is within the safe bearing capacity of the adjoining soil
ii. To provide the required support to the structure in such a way that the shape of the structure is not compromised throughout the design life
iii. To prevent differential settlement by ensuring that the adjoining soil id evenly loaded
iv. To prevent lateral movement of the supporting soil
v. To secure firm and level base for the structure
vi. To increase the stability of the structures

2. Conditions for adoption of Isolated Footing

Isolated footing is used to support individual columns in framed buildings. They can be either the steeped type or have projection in the concrete-base. The conditions for adopting isolated footing are:

i. When the soil bearing capacity is high
ii. When the loads on footings are less

iii. The spacing of the columns is too close

iv. In frame structures where the number of columns is large

3. Deep Foundations

A Deep foundation is a type of foundation which is placed at a greater depth below the ground. The fundamental philosophy of deep foundation is load transfer to greater depth. Here the depth to width ratio of deep foundations is usually greater than 4 to 5. Deep foundation is usually adopted where the bearing capacity of the soil is very low. In such cases deep foundations are used to transfer the structural loads to a stronger layer, which may be located at a significant depth below the ground surface. The load transfer is through skin friction and end bearing (fig1). There are basically three types of deep foundations:

- Pile Foundation
- Pier Foundation
- Well foundation

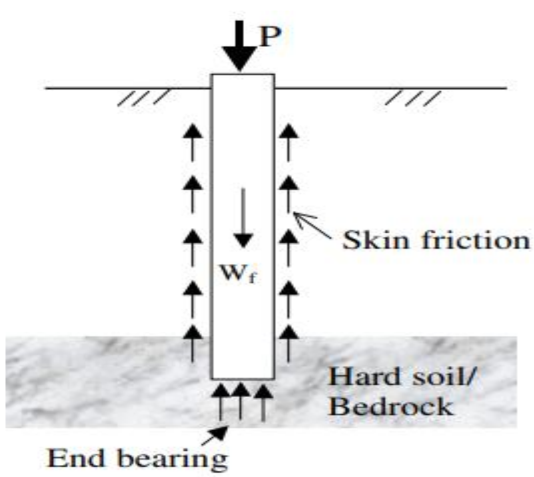

Fig 1: *Axial Compressive Load transfer in deep foundations*

4. Circumstances for adoption of a pile foundation

Pile foundation is one of the three types of deep foundations. As typical of deep foundations, pile foundation is used to transfer the load of the structure to a higher depth below the soil surface. Pile foundation is usually adopted under the following circumstances:

I. Under high sub-soil water table such that the shallow foundations cannot support the loads from the structure, pile foundation is adopted
II. When the load coming from the superstructure to the soil is heavy and uniform
III. At times construction of raft or other types of shallow foundations may be very costly. The choice of pile foundation becomes therefore unavoidable to save cost of construction
IV. Where the effect of settlement is established to be huge, the choice of pile foundation is usually pursued

5. The basic needs of a foundation for a machine

In addition to the conventional design for static loads, machine foundations are designed to cater for the dynamic loads due the vibration effect of the vibrating machinery. In other words, machine foundations require special requirements because they are required to transmit dynamic loads to the soil in addition to the static loads due to the weight of the foundation and superstructure. In principle, the dynamic load resulting from the vibrating machinery is generally small compared to the static loads from the weight of the machine and supporting foundation. The three most common types of machines are: Reciprocating, Impact and Rotary machines. The classification is typically based on the speed of operation. Some of the basic requirements of foundations for machinery are:

I. The foundation for machinery should be safe from bearing capacity failure when subjected to a combination of dynamic and static loads
II. The settlement of the foundation under the loading conditions must be less than the limiting value
III. Under service loading conditions, the dynamic amplitudes of the machine-foundation-soil interface must be within allowable limit
IV. Under the worst loading condition, the natural frequency of the machine-foundation-soil system should be away from the forcing frequency of the machine
V. As much as possible, the centre of gravity of the machine should coincide with the vertical line as that of the foundation system
VI. The amplitude of the vibration of the machine-foundation-soil system should be within the allowable
VII. Other requirements that should be considered include, low ground water table, clear separation from adjacent property and hot surfaces, oil, acid and lastly should be located at a lower level than adjacent properties

6. Block Foundation and use in impact-type machines

A block foundation is simply made of a pedestal which is resting on a footing. One outstanding advantage of a block foundation is that it has mass which helps to reduce the natural frequency.

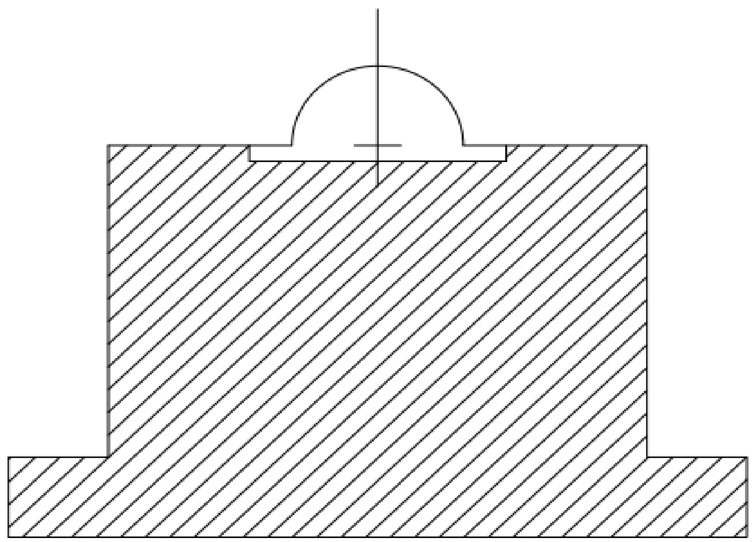

Fig 2: Block Type Machine Foundation

7. Classification of Soils

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. Soil is mainly classified by its texture, proportion and composition of organic materials into the following:

I. **Sandy Soil**-Sandy soil consists of small particles of weathered rocks. In terms of growing crops, sandy soils is poor due the low nutrients and low water holding capacity which makes it difficult for plants to have the required amount of water for growth. One useful area of sandy soil is in the formation of drainage systems

II. **Silt Soil**-In terms of particle size, silt is known to be smaller than sandy soils. Silt is made up of rock and other minerals which are smaller than sand and larger than clay soils. The smoothness and compact nature of silt makes it easier for it to hold water better than sandy soil. Due to the high fertility of silt, it is very useful for agricultural purposes

III. **Clay Soil**- In terms of particle size, clay is the smallest among the other two types. The particles are highly close to one another thereby presenting very little airspaces. Clay soil has very good water retention capacity thereby making it hard for moisture and air to penetrate into it. Due to the dense nature of clay soils which makes it difficult for water to drain, plant roots do not flourish well in clay soil

IV. **Loamy Soil**- Loamy soil is a combination of silt, sand and clay thereby benefiting from the properties of the various soils. It has good properties for retaining water and nutrients, thereby making it very suitable for agricultural purposes. For this reason, loamy soils are generally referred to as agricultural soil. It has the very contents of calcium and PH level due the presence of inorganic components

8. Methods for improving the Bearing Capacity of the soils

The term bearing capacity of the soil can be defined as the allowable load that the soil can withstand such that it nether experiences shear failure not exceed the allowable settlement. In other words, it is the maximum stress which a footing can support without failure. The safe bearing capacity of the soil is determined by dividing the ultimate load on the soil by the standard safety factor. The unit of bearing capacity is KN/M^2. When it is established that the bearing capacity of the soils is not adequate, there are many methods for improving the bearing capacity of such soils which include the following:

I. *Increasing the depth of the foundation*-Soils become more compact as we go much lower on the ground level and therefore improves the bearing strength
II. *Removal of water on the subsoil*-Water has negative impact on the cohesive properties of soil. Reducing the water therefore improves the bearing capacity
III. *Compaction of soil*-Compacting the soils helps to remove the void on the soil particles and therefore improves the bearing strength

IV. *Increasing the width of foundation*-Increasing the width of foundation helps to reduce the intensity of the loads. Reduced intensity helps the bearing capacity of the soil

V. *Grouting*-This is achieved by pumping cement into the soil. This improves the cohesive strength of the soil and by extension the bearing capacity

VI. *Chemical additives*-Addition of certain chemicals like calcium chlorides helps to improve the bearing properties of soil

9. Describe briefly strip footing with a sketch

Strip foundation is one of the types of shallow foundations. It is at times referred to as strip footing. It is commonly deployed for the construction of low to medium rise buildings. This type of foundation is usually preferred where the ground conditions are very stable with established good bearing capacity. One of the advantages of the strip foundation is that it is cost-effective and easy to construct.

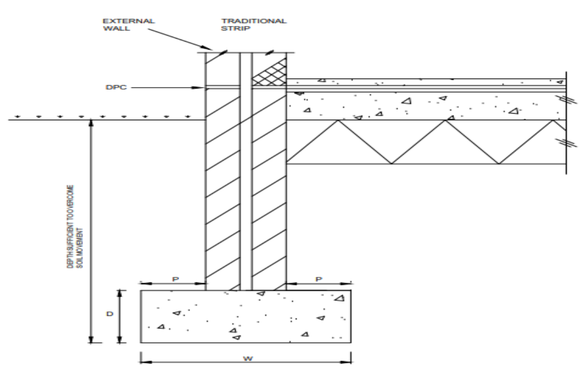

Fig 3: Strip Foundation

10. Explain briefly with neat sketch, the raft foundation for water Tanks

Raft foundation is formed by constructing reinforced concrete slabs of uniform thickness and covering the entire area of the structure. This type of foundation is usually employed for structures where the bearing capacity of the soils is poor. Structures like storage tanks, silos, heavy industrial machineries are usually constructed on raft foundations. Typically, these types of structures are heavy and using isolated footings will require the columns to be as close to each as possible. Therefore, it becomes more economical to deploy raft that covers large area of the base of the structures and therefore helps to evenly distribute the loads.

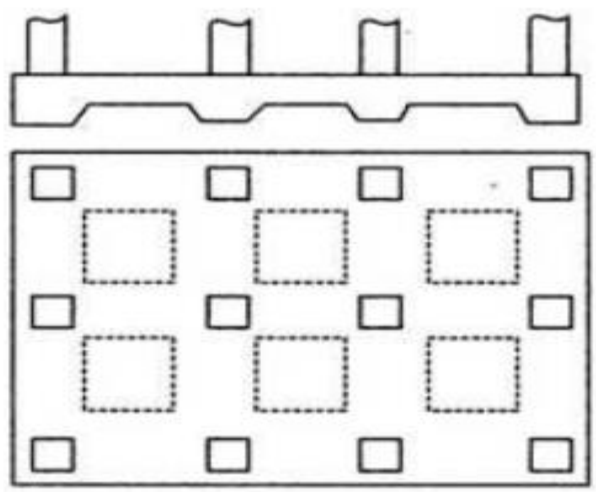

Fig 4: Plan and elevation of Raft Foundation for water Tanks

11. Briefly explain foundations for:

I. *Chimneys and Cooling Towers*: Chimneys are very important structures in industries. This is because of their use in the discharge of industrial pollution to very high level in the atmosphere; with the heights ranging from 100m to 400m. Chimneys are unique due to their special geometrical features of slender and tapering geometry. As such they are very sensitive to wind loads. The choice of foundation for chimneys is circular raft but in terms of economy, the annular raft foundations are more reasonable. In a location where the geotechnical conditions are not favourable, piled foundations can also be used. Studies have shown that skin friction piles are more suitable for chimneys than end bearing piles due to availability of greater uplift capacity. Cooling towers are typically constructed as hyperboloid, doubly-curved concrete structures and mostly supported on series of concrete struts. The foundations for cooling towers are usually inclined wall forming circular beam with concrete strip. In this case the beam act as bracing to resist the lateral loads of the structures.

II. *Telecommunication Towers*: These include all types of structures that transmit any communication signals like radio, TV or any other emergency services. They are usually tall structures that are designed to support antennas for telecommunications. There are basically two main types of towers: guyed and self-supporting structures. The soil conditions and the forces at play on the tower will determine the foundation to be used. Annular raft foundation which runs through conical substructures is usually preferred but due to hoop tension on the conical section, prestressing is applied to take care of the hoop tension.

12. Explain in details some typical foundations for transmission line towers with neat sketches

A. *Block Foundation:* This is one of the foundations used for transmission line towers. It is constructed on a trapezoidal reinforced concrete with anchor bolt installed into the concrete with base plate on top of the concrete where the transmission tower leg is bolted.

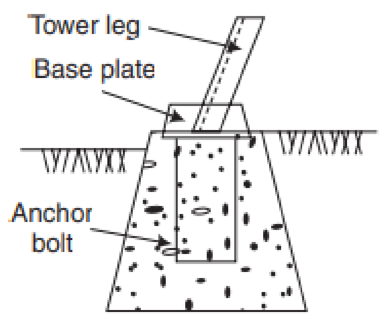

Fig 5: Block foundation

B. *Piled foundation*: Transmission line tower is equally installed using a pile especially where the bearing capacity of the soil is very low. The piles can be vertical or batter or vertical piles with piles cap which serves as the footing. Inside the pile cap is installed anchor which projects above the pile cap and holds the tower legs.

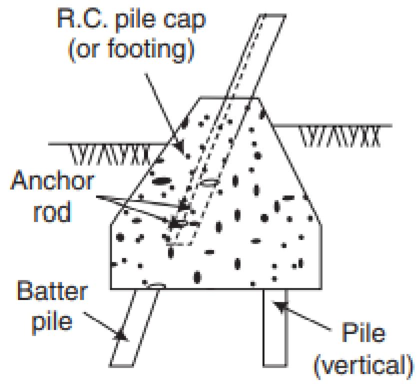

Fig 6: Piled foundation with capping legs

C. *Spread footing*: Where the bearing capacity of the soil is strong, spread footing can be used for the construction of foundation for transmission line towers. This is constructed like a conventional spread footing with stem that terminates at the surface of the soil. The sides of the footing are backfilled with consolidated soil materials. Inside the stem is embedded an anchor rod that holds the tower legs.

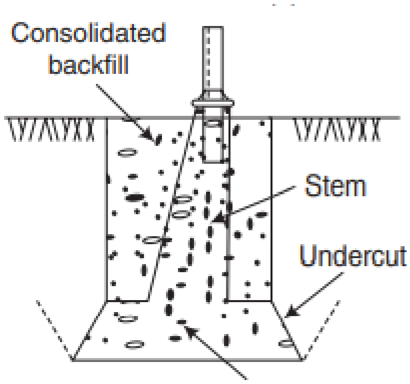

Fig 7: Spread footing

D. Pillar Foundation: This foundation is constructed with reinforced concrete block which is referred to as pillar block. Inside the pillar block is installed the starter rod for the tower legs.

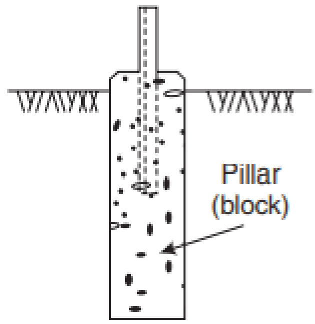

Fig 8: Pillar foundation

E. *Anchor Leg:* This is another type of foundation used for the construction of transmission line tower legs. This is achieved by constructing massive concrete grout in a bore. Inside the grout is installed the keying rods to a reasonable depth that projects above the level of the grout and serves to hold the tower leg stub.

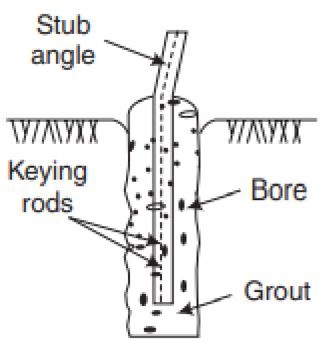

Fig 9: *Anchored Leg*

13. Give a detailed account on foundation for

I. *Guyed Structures*: Guyed structures are typically tall and relatively slender truss-framed structures that are supported on piles foundations. Guyed structures are usually employed for the radio antennas and telecommunication masts. The tower is held in the right position by a number of guy lines that are attached on the swiveled leads at tower and attached on clump weight which are usually resting on the ground level but a secured on the embed anchors piles. The guy lines are employed to resist lateral forces and for effective functionality, three of the lines must be installed and at an angle of 120^0 from each other.

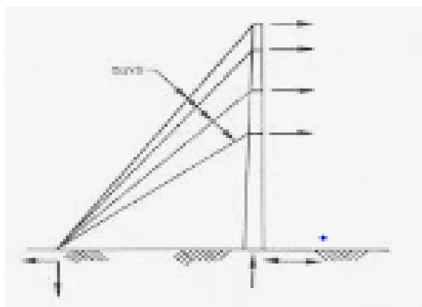

Fig 11: Guyed tower structure

II. Industrial structures: Most often, engineers are confronted with the need to design a foundation for industrial structures. The main challenges in the design of foundation for industrial structures are defining the loads, establishing the performance criteria and incorporating them in the design. The loads on industrial structures are static and dynamic. While the static loads come from the weight of the structures and the accompanying equipment, the dynamic loads occur during the operation of the machineries in the structures and are principally from the in equilibrium of inertia of moving parts or the flow of gases and fluids within the machineries. The magnitudes of the dynamic loads depend on the speed of the moving portion of the machinery. Here the essence of the design is to ensure that the amplitude of the moving part does not exceed the limit of resonance of the supporting structures.

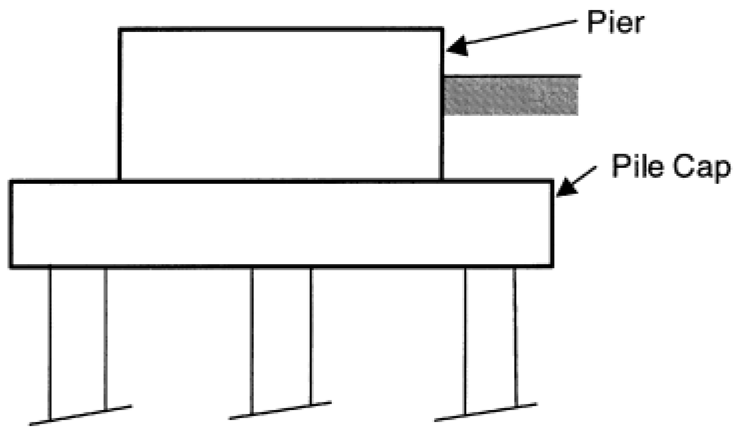

Fig 12: Piled foundation for industrial structures

14. With neat sketches, explain the various types of foundations for ground storage tanks

A Storage tank is a high capacity vessel used for storing oil, gas, and other petrochemical products prior to the when such product is needed. Storage tanks are available in many shapes: vertical or cylindrical, open top, close top, flat bottom, cone bottom, slope or dish bottom. Tank foundation is the base that is designed to support the weight of the tank and its contents. The requirement for tank foundation is to provide total support for the tank bottom. The key consideration is ensuring that the foundation bases need to be thick to enable the even dispersion of the loads and reducing the bearing pressure on the soil. Some of the common foundations for ground tanks are:

i. *Oiled sand pad:* This is constructed massive compacted gravel which rest on the ground. The thickness of this is determined by the weight of the tanks and its contents. The edge of the embankment is lined with graded crushed stone inclined to prevent slipping of the gravel. The surface of the foundation is overlain with oiled sand cushion.

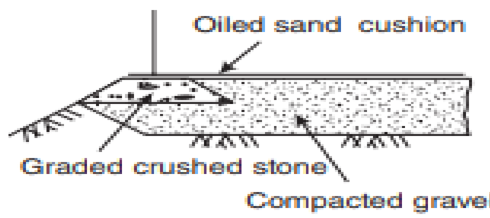

Fig 13: Oiled Sand Pad

ii. *Sand Cushion:* This type of foundation is constructed on massive compacted sand pad that tapers into the drainage ditch that ensure that that rain water does not rest on the mass sand pad.

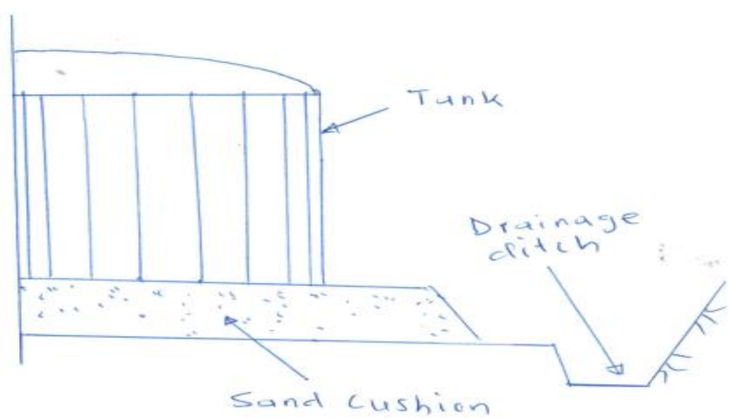

Fig 14: Cushion Type tank foundation

III. *Compacted Rock fill:* This is constructed by excavating to remove weak soil up to the depth of firm base. The excavated base is filled with compacted rock fill up the desired level to receive the tank.

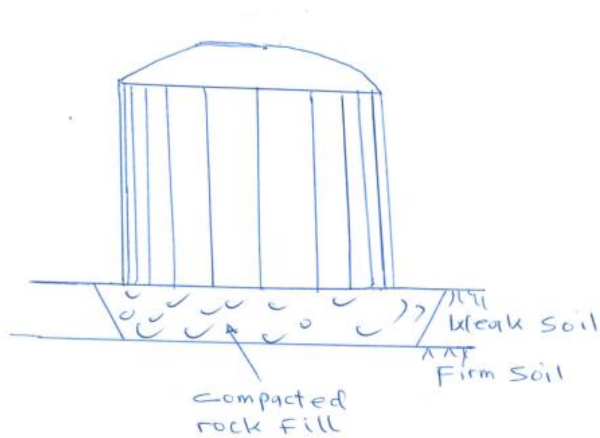

Fig 15: *Compacted Rock fill*

IV. *Concrete Ring*: This is constructed by on a trapezoidal retaining wall and filling with crushed rock. The side of the ring is filled by sand cushion that supports the rock wall. The surface lined with foundation plate upon which the ground tank is positioned.

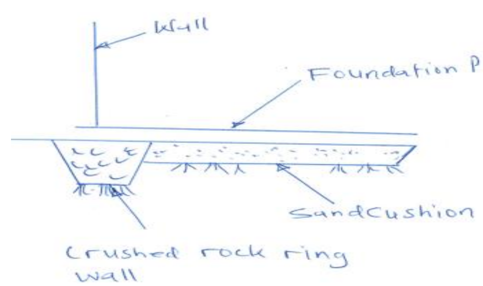

Fig 16: Concrete Ring

V. *Sheet Pile*: This type of tank foundation is constructed by driving two sheet pile structures with the depth being determined by the size of ground tank to be placed on it. The sheet pile is driven to the level of firm clay and space filled with compacted sand bed that holds the tank base.

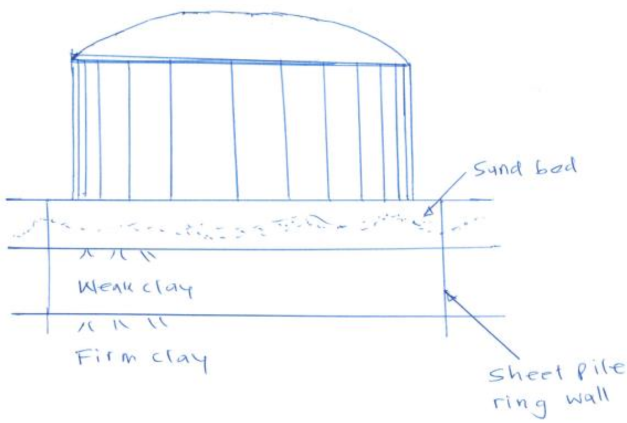

Fig 17: Sheet Pile tank foundation

VI. Pile foundation: This is selected for large volume tank on a very weak soil. The pile is driven to the designed depth with crushed rock serving as the pile caps. The space between the pile caps and the ground level is filled with compacted fill on which sits the ground tank

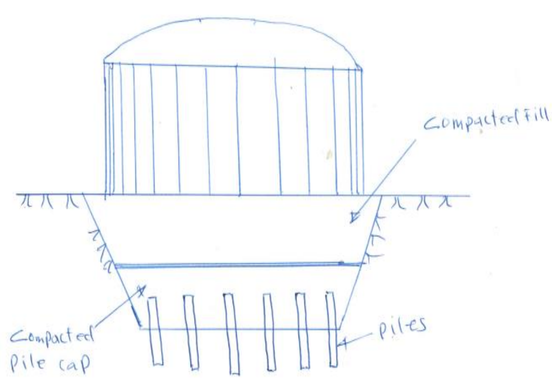

Fig 18: Pile foundation

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.

In this course, the concepts of foundation had been covered with focus on the clear definition of foundation as that part of the structure which is in direct contact with the ground to which loads are transmitted to the underlying soil strata. The basic function of foundation as load transfer from the superstructure to the soil has been covered and the requirements of the foundations to perform this function have been covered in this course.

The various types of foundations and the conditions that will determine the choice for each type of foundation has been covered in this course. Foundation is critical to the success of structure and as such must be design to meet certain criteria. The basic requirements for good foundation have been covered in this course.

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 becomes important in the understanding of behavior of soil under load.

This course has equally covered foundation for specialized structures such as chimney and cooling towers, telecommunication towers, transmission lines, guyed and industrial structures, block foundation for machinery as well ground water tank foundations.

In completing this course, I consulted with many journals papers and text books. Therefore the course has helped me to have a deeper understanding of engineering foundation and the concept of foundations. I am therefore better equipment to review foundation design works for any projects that may be assigned to me in the future.

Structural failure is a common phenomenon in my country. Most often the causes of these failures are related to soil engineering and foundation problems. Sound knowledge of foundation engineering is central to addressing the prevalent cases of building and structural failure. Each failure comes with huge losses in terms of life and asset. Therefore, having gone through this course, the knowledge will help me to make sound contributions to discussions on foundation design, construction and maintenance. This knowledge will help to prevent failure in structure and the consequences of death and asset losses. The fundamental right to life and own asset will therefore be guaranteed.

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