

**GIS APPLICATION IN THE IMPROVEMENT OF BEARING CAPACITY OF
SANDY SOIL BY CEMENT GROUTING**

BY

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CERTIFICATION

This is to certify that this work was carried out by IZEGBU CHUKWUDI SAMUEL with Matriculation Number, ENG1607979, of the Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

I dedicate this paper to God Almighty for His love and sustenance during my days as a student of the University of Benin, Benin City, Edo State.

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LIST OF NOMENCLATURE

AASHTO- American Association of State Highway and Transportation Officials

ASTM- American Society for Testing and Materials

BS 1377: Part 2: 1990 – British Standard Methods of Test for Soils for Civil Engineering Purposes.

W_L- Liquid Limit

CBR- California Bearing Ratio

MDD- Maximum Dry Density

OMC- Optimum Moisture Content

C_u- Uniformity Coefficient

C_c- Coefficient of Gradation

ABSTRACT

This study evaluated the impact of cement grout as a stabilizing agent for the improvement of the bearing capacity of sandy soil by grouting and the use of Geographic Information system (GIS) to provide the necessary geographical information.

This study was achieved by conducting the collection of soil sample in Iguoshodin community at a depth of 1.5m and the samples were taken to the University of Benin soil laboratory centre to conduct the necessary laboratory tests. These tests were natural moisture content test, specific gravity test, sieve analysis test, cone penetrometer test and standard proctor compaction test, all in accordance with the British Standard BS 1377: Part 2: 1990. The Geographic Information System (GIS) was used to carry out queries of the attributes of the soil samples in reference to the available soil standards. As a result, the time it takes to obtain the data is greatly reduced because it is constantly available.

Different percentages of the cement grout produced significant results. 2% cement grout with sample I gave an OMC and MDD of 13.38% and 1.67g/cm^3 respectively and 4% cement grout gave an OMC and MDD of 11.26% and 1.72g/cm^3 respectively and 6% cement grout gave an OMC and MDD of 12.3% and 1.75g/cm^3 respectively as compared to the natural state of sample I with OMC and MDD of 19.93% and 1.62g/cm^3 respectively. The result of 2% cement grout with sample II gave an OMC and MDD of 10.76% and 1.72g/cm^3 respectively and 4% cement grout gave an OMC and MDD of 8.32% and 1.77g/cm^3 respectively and 4% cement grout gave an OMC and MDD of 9.8% and 1.78g/cm^3 respectively as compared to the natural state of sample II with an OMC and MDD of 20.09% and 1.59g/cm^3 . The results of the samples shows that 4% cement is more effective than 2% and 6% cement grout and is in accordance with previous studies done in this area.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The construction of structures on weak ground often requires the soil to be improved in order to ensure the safety and the stability of surrounding buildings (Santhosh, 2007). Soil is one of the most important engineering materials. Determination of soil conditions is the most important first phase of work for every type of civil engineering facility. The knowledge of soil is necessary for the designing of foundation, pavement, underground structures, embankments, earth retaining structures, dams etc. As a result, various parameters like bearing capacity, stress distribution in the soil beneath the loading area, the probable settlement of the foundation, effect of ground water and effect of vibrations etc. are needed for the design of foundation (Gopalsamy, 2017). For any land-based structure, the foundation is very important and has to be strong to support the entire structure. In order for the foundation to be strong, the soil around it plays a very critical role. So, to work with soils, proper knowledge about their properties and factors which affect their behaviour is essential. The process of soil stabilization helps to achieve the required properties in a soil needed for the construction work. From the beginning of construction work, the necessity of enhancing soil properties has come to the light. Ancient civilizations of the Chinese, Romans and Incas utilized various methods to improve soil strength etc., some of these methods were so effective that their buildings and roads still exist (Murali et al, 2015).

In India, the modern era of soil stabilization began in early 1970's, with a general shortage of petroleum and aggregates, it became necessary for the civil engineers to look at the means to improve soil rather than replacing the entire poor soil at the building site. Soil stabilization was used but due to the use of obsolete methods and also due to the absence of

proper technique, soil stabilization lost favour. In recent times, with the increase in the demand for infrastructure, raw materials and fuel, soil stabilization has started to take a new shape. With the availability of better research, materials and equipment, it is emerging as a popular and cost-effective method for soil improvement. Different methods can be used to improve and treat the geotechnical properties of the problematic soils (such as strength and the stiffness) by treating it *in situ*. These methods include densifying treatments (such as compaction or preloading), pore water pressure reduction techniques (such as dewatering or electro-osmosis), the bonding of soil particles (by ground freezing, grouting, and chemical stabilization), and use of reinforcing elements (such as geotextiles and stone columns). Here, in this study, soil stabilization has been done with the help of cement grout. The improvement in the shear strength parameters has been stressed upon and comparative studies have been carried out using different methods of shear resistance measurement (Murali, 2015). The term ground improvement and ground modification are said to be the improvement or modification in the engineering properties of the soil that are carried out at a site where the soil in its natural state does not possess properties that are adequate for the proposed civil engineering activity. It is referred to as any procedure undertaken to increase the shear strength, reduce the permeability and compressibility or render the physical properties of soil more suitable for projected engineering use (Sherwood, 1993). Among the various soil stabilization procedure, the most suitable one is selected depending upon the type of soil available, time, and cost involved. The construction of structure on weak ground often requires the soil to be improved in order to ensure the safety and the stability of surrounding buildings. The selective of the most suitable method meant for the improvement of a particular soil sample depends on various factors such as: specific considerations available time for completion of the project, availability of equipment and soil conditions, required degree of compaction, types of structure to be supported, as well as site materials etc. (Abolusoro et al., 2019).

Grouting on the other hand is a process whereby stabilizers either in the form of suspension or solution is injected into sub surface soil. Sandy soil is the largest particle in the soil when you rub it, it feels rough. This is because it has sharp edges and it does not hold many nutrients (Abolusoro, 2019). GIS technology is used even in technical practice of civil engineering. In the preparatory phase it is focused on spatial allocation of the building structure, checking the best of its feasibility and usefulness, road structure projects worked out, variant more detailed solution of technical problems of the building structure are projected. In process of working on project various forms of basic source materials as well as the results of actual data capture, map documents previous resources photographs referring to the solved problem and appropriate legal and technical directions have been used (Bartonek et al., 2009; Bures, 2009). GIS technology is often interconnected with modern technologies of data capture on the base of geodetic methods making use of GPS, total station or other powerful electronic system. Innovative usage of GIS in civil engineering was published in (Bartonek et al., 2009; Bures, 2009). GIS is a very effective tool for capturing, displaying and analyzing geographically referenced data. It has shown a very important role in various aspects of geotechnical engineering including preliminary site investigations, identification of potential project barriers, interpolation for obtaining data at inaccessible locations, data visualization, data processing as well as preparation of post processing graphs and charts (Amardeep et al., 2018). This paper highlights soil survey of the case study using GIS.

1.2 STATEMENT OF THE PROBLEM

In the case of soil improvement and foundation construction, different soil type poses its own specific challenges. Sandy soil has naturally shifting characteristics; drainage through sandy soil further increases its shifting properties. Sandy soils is frequently seen as having

simple to define physical characteristics, such as weak with or no structure, high permeability, and a high sensitivity to compaction with numerous negative effects. However, analysis of the literature shows that their physical properties are far from simple. This poses a clear challenge for any structure to be built on this type of soil (Bruand et al., 2016). Loose sand can be subjected to large settlements, and these settlements tend to occur quickly due to the free draining granular nature of sands. Structures built on such soil displays movements which are detrimental and lead structural damages. The damage caused by these soil can be seen in many expensive ways, but it is especially clear in the pavement and structures. This can make it difficult to lay a foundation, so stabilizing the sand is necessary to give any structure better bearing capacity and adequate settlement management. Soil stabilization using various additives is one of the strategies or soil improvement that involves replacing the problematic soil with the acceptable soil (Afrin, 2017).

Cement as a stabilizing agent can be applied to any type of soil, except soil with organic content greater than 2% or having pH lower than 5.3 (ACI 230.1R-90, 1990). Because fewer cements are needed, using cement in granular soil has proven to be cost effective and efficient. Comparatively speaking to untreated soil, cement- treated soil has a brittle tendency.

During the field survey, knowing the exact location and having access to the field control's data updates are essential. The mobile Geographic Information System (GIS), a fast developing technology with the potential for use in a wide range of human activity fields, is made possible by all of these functionalities.

1.3 AIM AND OBJECTIVES

The aim of this study is to evaluate the impact of cement as a stabilizing agent for the improvement of the bearing capacity of a sandy soil by grouting. The objectives of this research include:

- i. determine the nature of the sandy soil particles.
- ii. determine the degree of soil compatibility.
- iii. perform the improvement process of sandy soil through grouting.
- iv. perform some essential laboratory tests on the sandy soil in comparing the effectiveness of the grouting process.
- v. use of geo-spatial data to create a model in the Geographic Information System (GIS) with the use of ArcGIS.

1.4 SCOPE OF THE STUDY

The scope of the study include the following.

- i. collection of the sandy soil samples.
- ii. use of the GPS device to obtain the co-ordinates of point of collection of the soil sample.
- iii. perform compaction test, liquid limit, specific gravity test and natural moisture content test.
- iv. improve the properties of the sandy soil by performing grouting.
- v. perform all the tests on the improved soil.

- vi. representation of the geo-spatial data in the GIS environment.

1.5 JUSTIFICATION OF STUDY

There is justification for seeking cheaper additives which may be used to alter the soil properties. Lime or calcium carbonate is oldest traditional chemical stabilizer used for soil stabilization. The study provides details of different types of soil stabilizing methods.

The relative density of sandy soil properties cannot be increased by compaction or by vibration, the best method is grouting. Grouting is mostly used in foundations of the structures. It is also used in seepage control in dams, rocks, cut-off walls and tunnels. The technique of grouting is to fill the voids between the medium by a grouting material in order, to improve the Engineering properties (Beenish, 2016).

Grout is basically a liquid solution or suspension that is injected into the soil under pressure in order to fill up the voids present between the soil particles and to bind them together. Grouts are available in two forms one is the suspension grout which is basically small sized particles suspended in a liquid (example is cement grout and bentonite grout both are made in water mostly cement grout is used with a mixing ratio of 10:1 or 2:1 and the other is grout solution, which consists of a variety of chemicals like sodium silicate acryl amide, lingo sulphates, amino and many more). Cement grout has a number of advantages it not only fills the voids but also sets with time, reduces the permeability and binds the soil particles. The grout properties are; stability, permanence, grout ability, toxicity and setting time. The following are some the grouting methods; permeation grouting, compaction grouting, hydro-fracture grouting and jet grouting (Beenish, 2016). Providing new more specific and detailed soil information, particularly suitable for analyses in geographic information systems (GIS), traditional soil survey is based on the recognition of soil properties at few sites and of their qualitative relation with landscape and environmental variables based on conceptual models.

The majority of GIS software system allow one to do spatial and attribute queries (Scianna et al., 2011). All engineering disciplines that focus on using soil as a construction material will benefit greatly from this research work, particularly in the use of stabilization to obtain desirable soil properties and the stabilizing agent from such soil to be utilized as a construction material.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HISTORY OF CEMENT GROUT

Ideas and methods of soil stabilization have been around for centuries. The concept of soil stabilization is that the soil is being altered in some form, whether it is mechanically or chemically to lock the soil in place and prevent it from moving (Substrata, 2019). Various material can be used for Grouting in which Cement is the most common material. Cement grout is widely used because it is in expensive, having high strength and readily available, but cement grout has poor injection ability (difficult to penetrate into tiny fractures and silty sand layers). In 1802, Mr. Berigny was the first person who successfully used injection technology for soil improvement. The credit for use of Portland cement as Grout is given to Marc Brunel in 1838 in England. Mr. Jeziorski introduced sodium silicate a first one chemical grout in 1887. In 1946, co-operative research by Texas Company Atchison, and Topeka & Santa Fe Railway discovered use of Cement grout with Asphalt emulsion for road bed stabilization. The use of Formaldehyde-based grouts started in 1950. In 1990, Levacic and Bravar started using Urea Formaldehyde for improving mechanical properties of soil. In 2014, same polymer resin used by Islam M. Abo Elnaga for improving natural Subgrade soil properties. In 2018, Research Paper published by Junxiang zhang and Yuning Sun (Korea) shows Self developed polymer foaming (PF) grouting materials gives better reinforcing effects on broken coal mass than that of Superfine cement (SC) & Aluminate cement (AC) (Kumar et al., 2020). Soil is one of the most important and primary media for any construction work. The strength and durability of any structure depends on the strength properties of the soil. It has been found from several

studies that, due to the detrimental characteristics of organic soil, the shear strength and bearing capacity of this soil are very low, while the compressibility is very high (Debnath et al., 2017).

Soil stabilization refers to the procedures in which a special soil, a cementing material, or other chemical or non-chemical materials are added to a natural soil or a technique use on a natural soil to improve one or more of its properties. One may achieve stabilization by physically mixing the natural soil and stabilizing materials together so as to achieve a homogenous mixture or by adding stabilizing material to an undisturbed soil deposits and obtaining interaction by letting it permeate through the soil voids (Abood et al., 2007). Deficient soils are regarded as soils which do not meet some or all the criterial required for their satisfactory performance as geotechnical structures. These could either be for base courses for road, embankment for dam or road, subsoil base for foundation, clay liners for containment of leachates and backfill for retaining walls (Alhassan et al., (2015). In the tropical region, these soils could be lateritic soils, black cotton soils, collapsible soils or any other tropical soil (Alhassan et al., 2017). Cement is one of the following additives used as a stabilizing agent for expansive soils. Extensive evaluations have been carried out on the cement stabilization of expansive soils. However, cement stabilization usually results in high stiffness, and makes the soil brittle, which is undesirable in dynamic loading conditions such as pavement systems (ScienceDirect, 2018).

2.2 SOIL STABILIZATION

Prior to the launch of a project, a site feasibility assessment for geotechnical projects is by far the most advantageous. Prior to starting the design phase, a site survey is typically conducted to better understand the subsoil properties and determine the best location for the project. When choosing a site, take into account the following geotechnical design requirements.

- Design load and function of the structure.
- Type of foundation to be used.
- Bearing capacity of subsoil.

In the past, the third bullet played a major in decision-making on-site selection.

Once the bearing capacity of the soil was poor, the following were options:

- Change the design to suit site condition.
- Remove and replace the in-situ soil.
- Abandon the site.

Abandoned sites due to undesirable soil bearing capacities dramatically increased, and the outcome of this was the scarcity of land and increased demand for natural resources. Affected areas include those which were susceptible to liquefaction and those covered with soft clay and organic soils. Other areas were those in a landslide and contaminated land. However, in most geotechnical projects, it is not possible to obtain a construction site that will meet the design requirements without ground modification. The current practice is to modify the engineering properties of the native problematic soils to meet the design specifications. Nowadays, soils such as, soft clays and organic soils can be improved to the civil engineering requirements. This state-of-the-art review focuses on soil stabilization method which is one of the several methods of soil improvement (Sherwood, 1993). There are various techniques for stabilizing soil. All these methods fall into two broad categories (FM 5-410) namely;

- **Mechanical stabilization**

Under this category, soil stabilization can be achieved through physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing. Mechanical stabilization is not the main subject of this review and will not be further discussed.

- **Chemical stabilization**

Under this category, soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. A chemical stabilization method is the fundamental of this review and, therefore, throughout the rest of this report, the term soil stabilization will mean *chemical stabilization*.

Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil (Keller brochure 32-01E). Note that, stabilization not necessary a magic wand by which every soil property can be improved for better (Ingles and Metcalf, 1972). The decision to technological usage depends on which soil properties have to be modified. The chief properties of soil which are of interest to engineers are volume stability, strength, compressibility, permeability and durability (Ingles and Metcalf, 1972; Sherwood, 1993; EuroSoilStab, 2002). Although laboratory testing might provide materials with higher strengths than similar materials from the field, they can still be used to gauge how well stabilized materials perform in the real world. Results from the laboratory tests, will enhance the knowledge on the choice of binders and amounts (EuroSoilStab, 2002).

2.3 COMPONENTS OF SOIL STABILIZATION

Soil stabilization involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The components of stabilization technology include soils and or soil minerals and stabilizing agent or binders (cementitious materials).

2.3.1 Soils

Most of stabilization has to be undertaken in soft soils (silty, clayey peat or organic soils) in order to achieve desirable engineering properties. According to Sherwood (1993) fine-grained granular materials are the easiest to stabilize due to their large surface area in relation to their particle diameter. A clay soil compared to others has a large surface area due to flat and elongated particle shapes. On the other hand, silty materials can be sensitive to small change in moisture and, therefore, may prove difficult during stabilization (Sherwood, 1993). Peat soils and organic soils are rich in water content of up to about 2000%, high porosity and high organic content. The consistency of peat soil can vary from muddy to fibrous, and in most cases, the deposit is shallow, but in worst cases, it can extend to several meters below the surface (Pousette, et al 1999; Cortellazzo and Cola, 1999; Åhnberg and Holm, 1999). Organic soils have high exchange capacity; it can hinder the hydration process by retaining the calcium ions liberated during the hydration of calcium silicate and calcium aluminate in the cement to satisfy the exchange capacity. In such soils, successful stabilization has to depend on the proper selection of binder and amount of binder added (Hebib and Farrell, 1999; Lahtinen and Jyrävä, 1999, Åhnberg et al, 2003).

2.3.2 Stabilizing Agents

These are hydraulic (primary binders) or non-hydraulic (secondary binders) materials that when in contact with water or in the presence of pozzolanic minerals reacts with water to form cementitious composite materials. The commonly used binders are:

- i. cement
- ii. lime
- iii. fly ash
- iv. blast furnace slag

2.3.2.1 Cement

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993; EuroSoilStab, 2002). Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil (EuroSoilStab, 2002). This can be the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement. Usually the choice of cement depends on type of soil to be treated and desired final strength.

Hydration process is a process under which cement reaction takes place. The process starts when cement is mixed with water and other components for a desired application resulting into hardening phenomena. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil (EuroSoilStab, 2002). The hydration reaction is slow proceeding from the surface of the cement grains and the center of the grains may remain unhydrated (Sherwood, 1993). Cement hydration is a complex process with a complex

series of unknown chemical reactions (MacLaren and White, 2003). However, this process can be affected by

- i. presence of foreign matters or impurities
- ii. water-cement ratio
- iii. curing temperature
- iv. presence of additives
- v. specific surface of the mixture.

Depending on the factor(s) involved, the ultimate effect on setting and gain in strength of cement stabilized soil may vary. Therefore, this should be considered during mix design in order to achieve the desired strength. Calcium silicates, C_3S and C_2S are the two main cementitious properties of ordinary Portland cement responsible for strength development (Al-Tabbaa and Perera, 2005; EuroSoilStab, 2002). Calcium hydroxide is another hydration product of Portland cement that further reacts with pozzolanic materials available in stabilized soil to produce further cementitious material (Sherwood, 1993). Normally the amount of cement used is small but sufficient to improve the engineering properties of the soil and further improved cation exchange of clay. Cement stabilized soils have the following improved properties:

- i. decreased cohesiveness (Plasticity)
- ii. decreased volume expansion or compressibility
- iii. increased strength (PCA-IS 411, 2003).



Figure 2.1: Cement Grouting (Shanko, 2017)

2.3.2.2 Lime

Lime provides an economical way of soil stabilization. The method of soil improvement in which lime is added to the soil to improve its properties is known as lime stabilization. The types of lime used to the soil are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, dolomite lime. The quantity of lime is used in most soil stabilizer is in the range of 5% to 10%. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction (Sherwood, 1993). In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes (Roger et al, 1993). Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds (Sherwood, 1993, EuroSoilStab, 2002). The effect can be brought by either quicklime, CaO or hydrated lime, $\text{Ca}(\text{OH})_2$. Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction

(Hicks, 2002). Quicklime is the most commonly used lime; the followings are the advantages of quicklime over hydrated lime (Rogers et al, 1996);

- i. higher available free lime content per unit mass
- ii. denser than hydrated lime (less storage space is required) and less dust
- iii. generates heat which accelerate strength gain and large reduction in moisture content according to the reaction equation below



Quicklime when mixed with wet soils, immediately takes up to 32% of its own weight of water from the surrounding soil to form hydrated lime; the generated heat accompanied by this reaction will further cause loss of water due to evaporation which in turn results into increased plastic limit of soil i.e. drying out and absorption (EuroSoilStab, 2002; Sherwood, 1993). Sherwood (1993) investigated the decrease in plasticity as brought about in first instance by cation exchange in which cations of sodium and hydrogen are replaced by calcium ions for which the clay mineral has a greater water affinity. The addition of lime will improve pH and boost the exchange capacity even in soils (such as calcareous soils) where clay may be saturated with calcium ions. Similar to cement, when lime reacts with moist clay minerals, the pH rises, favoring the solubility of siliceous and aluminous chemicals. These substances combine with calcium to produce calcium silica and calcium alumina hydrates, cementitious materials that resemble cement paste. Materials used in the natural pozzolanas that contain silica and alumina, such as clay minerals, pulverized fly ash (PFA), and blast furnace slag, have a high potential for reacting with lime

Lime stabilizations technology is mostly widely used in geotechnical and environmental applications. Some of applications include encapsulation of contaminants, rendering of backfill (e.g. wet cohesive soil), highway capping, slope stabilization and

foundation improvement such as in use of lime pile or lime-stabilized soil columns (Ingles and Metcalf, 1972). However, presence of Sulphur and organic materials may inhibit the lime stabilization process. Sulphate (e.g. gypsum) will react with lime and swell, which may have effect on soil strength.

2.3.2.3 Fly ash

Fly ash stabilization is gaining more importance recent times since it has wide spread availability. This method is inexpensive and takes less time than any other methods. It has a long history of use as an engineering material and has been successfully employed in geotechnical applications. Fly ash is a by-product of coal fired electric power generation facilities; it has little cementitious properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil. Fly ashes are readily available, cheaper and environmentally friendly. There are two main classes of fly ashes; class C and class F (Bhuvaneshwari et al, 2005, FM 5-410). Class C fly ashes are produced from burning subbituminous coal; it has high cementing properties because of high content of free CaO. Class C from lignite has the highest CaO (above 30%) resulting in self-cementing characteristics (FM 5-410). Class F fly ashes are produced by burning anthracite and bituminous coal; it has low self-cementing properties due to limited amount of free CaO available for flocculation of clay minerals and thus require addition of activators such as lime or cement.

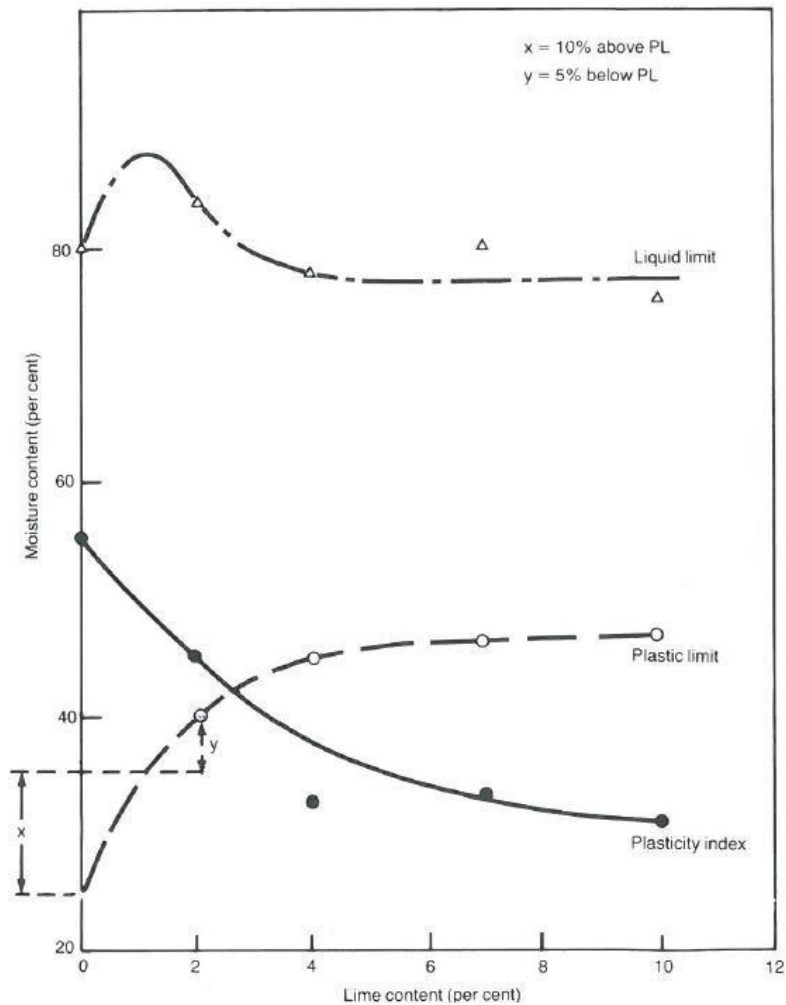


Figure 2.2: Effect of the addition of the lime on plasticity properties of London clay (Sherwood, 1993)

The reduction of swell potential achieved in fly ashes treated soil relates to mechanical bonding rather than ionic exchange with clay minerals (Mackiewicz and Ferguson, 2005).

However, soil fly ash stabilization has the following limitations (White, 2005):

- i. soil to be stabilized shall have less moisture content; therefore, dewatering may be required.
- ii. soil-fly ash mixture cured below zero and then soaked in water are highly susceptible to slaking and strength loss.
- iii. sulphur contents can form expansive minerals in soil-fly ash mixture, which reduces the long-term strength and durability.

2.3.2.4 Blast Furnace Slags

The manufacturing of pig iron results in this as a by-product. The chemical makeup is comparable to that of cement. It is however, not cementitious compound by itself, but it possesses latent hydraulic properties which upon addition of lime or alkaline material the hydraulic properties can develop (Sherwood, 1993; Åhnberg et al, 2003). Depending on cooling system, Sherwood (1993) itemized slag in three forms, namely:

- Air-cooled slag

Hot slag after leaving the blast furnace may be slowly cooled in open air, resulting into crystallized slag which can be crushed and used as aggregate.

- Granulated (merit 5000) or Pelletized slag

Quenching (i.e. sudden cooling with water or air) of hot slag may result into formation of vitrified slag. The granulated blast furnace slag or Merit 5000 (commonly known in Sweden) is a result of use of water during quenching process, while, the use of air in the process of quenching may result into formation of pelletized slag.

- Expanded slag

Under certain conditions, steam produced during cooling of hot slag may give rise to expanded slag.

2.3.2.5 Pozzolanas

Pozzolanas are siliceous and aluminous materials, which in itself possess little or no cementitious value, but will, in finely divided form and in the presence of moisture,

chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (ASTM 595). When water is used in the quenching process, the outcome is granulated blast furnace slag, also known as merit 5000 (often used in Sweden), however when air is used, the result can be pelletized slag. Rice husk ash and rice straw and bagasse are rich in silica and make an excellent pozzolana (Sherwood, 1993).

2.3 Factors Affecting the Strength of a Stabilized Soil

Presence of organic matters, sulphates, sulphides and carbon dioxide in the stabilized soils may contribute to undesirable strength of stabilized materials (Netterberg and Paige-Green, 1984, Sherwood, 1993).

2.3.1 Organic Matter

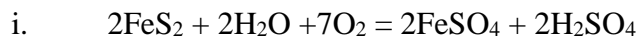
In many cases, the top layers of most soil constitute large amount of organic matters. However, in well drained soils organic matter may extend to a depth of 1.5 m (Sherwood, 1993). Soil organic matters react with hydration product e.g. calcium hydroxide ($\text{Ca}(\text{OH})_2$) resulting into low pH value. The resulting low pH value may retard the hydration process and affect the hardening of stabilized soils making it difficult or impossible to compact.

2.3.2 Sulphates

When sulfate-rich soils are stabilized with calcium-based stabilizers, the reaction results in calcium sulphoaluminate (ettringite) and/or thamausite, which takes up more spaces than the sum of the reactants. However, excess water to one initially present during the time of mixing may be required to dissolve sulphate in order to allow the reaction to proceed (Little and Nair, 2009; Sherwood, 1993).

2.3.3 Sulphides

In many of waste materials and industrial by-product, sulphides in form of iron pyrites (FeS_2) may be present. Oxidation of FeS_2 will produce sulphuric acid, which in the presence of calcium carbonate, may react to form gypsum (hydrated calcium sulphate) according to the reactions (i) and (ii) below



The hydrated sulphate so formed, and in the presence of excess water may attack the stabilized material in a similar way as sulphate (Sherwood, 1993). Even so, gypsum can also be found in natural soil (Little and Nair, 2009).

2.3.4 Compaction

In practice, the effect of addition of binder to the density of soil is of significant importance. Stabilized mixture has lower maximum dry density than that of un-stabilized soil for a given degree of compaction. The optimum moisture content increases with increasing binders (Sherwood, 1993). In cement stabilized soils, hydration process takes place immediately after cement comes into contact with water. This process involves hardening of soil mix which means that it is necessary to compact the soil mix as soon as possible. Any delay in compaction may result in hardening of stabilized soil mass and therefore extra compaction effort may be required to bring the same effect. That may lead to serious bond breakage and hence loss of strength. Stabilized clay soils are more likely to be affected than other soils due to alteration of plasticity properties of clays (Sherwood, 1993). In contrary to cement, delay in compaction for lime-stabilized soils may have some advantages (Sherwood, 1993).

2.3.5 Moisture Content

In stabilized soils, enough moisture content is essential not only for hydration process to proceed but also for efficient compaction. Fully hydrated cement takes up about 20% of its own weight of water from the surrounding (Sherwood, 1993); on other hand, Quicklime (CaO) takes up about 32% of its own weight of water from the surrounding (Roger et al, 1993; Sherwood, 1993). Insufficient moisture content will cause binders to compete with soils in order to gain these amounts of moisture. For soils with great soil-water affinity (such as clay, peat and organic soils), the hydration process may be retarded due to insufficient moisture content, which will ultimately affect the final strength.

2.3.6 Temperature

Pozzolanic reaction is sensitive to changes in temperature. In the field, temperature varies continuously throughout the day. Pozzolanic reactions between binders and soil particles will slow down at low temperature and result into lower strength of the stabilized mass. In cold regions, it may be advisable to stabilize the soil during the warm season (Sherwood, 1993; Maher et al., 1994).

2.4 SANDY SOIL

Soil is the basic foundation for any civil engineering structures. It is required to bear the loads without failure. In some places, soil may be weak which cannot resist the oncoming loads. In such cases, soil stabilization is needed (Subzar et al, 2018). Sandy soils characteristically consist of loose soil particles because the cohesion between them is weak (Shepherd *et al.*, 2002). The soil is uniform in texture and contains more than 75% sand. Further-more, sandy soils contain low proportions of clay and silt particles, hindering

aggregation (Oades, 1993). In contrast, soils dominated by clay form fine granular aggregates because the clay particles are electrically charged and the oppositely charged surfaces provide the basis of a greater aggregation (Shepherd *et al.*, 2001). For a range of soil analyses, the properties of sandy soils (especially soil biomass C) are generally lower than those of clay soils. One way to increase aggregation in sandy soil may be to increase both clay and organic matter levels (Edwards and Bremner, 1967; Tisdall and Oades, 1982).

Sand has large spaces between the particles, which allow air and water to move easily, so sand has good aeration and drainage. Clay packs down with only tiny spaces between particles so there is poor aeration and drainage. However, clay has about 100 times the surface area as the same volume of sand. More surface area means that clay will hold more water and more nutrients. Silt has some of the qualities of both sand and clay. Loam combines the best features of all three: aeration, drainage and storage capacity for water and nutrients. Often, soil particles are clumped together into crumbs, which create large spaces between the crumbs for aeration and drainage. Pebbles and rocks also increase drainage; sometimes so much that plants wilt from lack of water (Rana et al, 2019).

Sandy soils are often considered as soils with physical properties that are easily defined however they are far from being simple. This is particularly the case for sandy soils in the tropics where they are subjected to a cycle of wetting and drying associated with seasonality. In this respect small changes in composition lead to significant differences of physical properties. One of the major soil characteristics to be considered is the size distribution of the sand grains. Fine sand induces greater porosity, water retention and resistance to penetration than coarse sand, they exhibit lower permeability. Porosity decreases when the heterogeneity of the sand grain distribution increases leading to an increase in resistance to penetration and decreases in permeability. The presence of silt particles leads to similar consequences. Thus, silty sands are more compact than sandy soils, most silt particles occupying the voids between

sand grains thereby reducing porosity and consequently permeability. Size distribution and mineralogy of silt and clay sized particles that are associated with sand grains are also responsible for variations in physical properties of tropical sandy soils. Under tropical environments, sandy soils undergo significant weathering to depth thus resulting in a mineralogy where quartz is the dominant mineral in the sand and silt fraction and forms a significant proportion of the clay sized fraction. On the other hand, sandy soils can be present in the lower part of the landscape where clays or salts form during the dry season. As a consequence, sandy soils with similar particle size distribution but due to differences in mineralogy of the clay sized fraction that represents not more than a few percent of the soil mass, show very different physical properties. Finally, in sandy soils unlike other soils, the elementary fabric is easily affected by tillage practices. If greater porosity can be produced through tillage operations, the stability of these systems is very weak and compaction by wheels or other actions can in return produce a dense structure. Thus, compaction results from a variation of the structure at all scales, i.e. from the macroscopic to microscopic scales (Bruand, 2005).

Sandy soils are characterized by less than 18% clay and more than 68% sand in the first 100 cm of the solum. In the World Reference Base (WRB) soil classification system (ISSS Working Group, 1998), sandy soils may occur in the following Reference Soil Groups: Arenosols, Regosols, Leptosols and Fluvisols. These soils have developed in recently deposited sand materials such as alluvium or dunes. They are weakly developed and show poor horizonation. Soils characterized by a high proportion of sand in the first 100cm can also correspond to the upper part of highly developed soils formed in weathered quartz-rich material or rock, as evidence by the development of a highly depleted horizon.. This is particularly true in the tropics where sandy soils are subjected to a cycle of wetting and drying that greatly affects the soil with small differences in composition leading to significant differences of

physical properties. Sandy soils are characterized by a lack of structure or that it is weakly development. Coquet (1995) measured the shrinkage properties of two soils in Senegal with different texture. On the sandy soil, results obtained in the field and in the laboratory (on cores originating from the same horizons), showed very small shrinkage: bulk volume variation was only 0.05%. When they dried, sandy soils develop very few thin cracks organized in a loose network. The meagre shrinkage properties of these soils are related to the low clay content and the high proportion of low activity clays of many tropical sandy soils.

Sandy soils in the tropics show a large range of porosities and consequently bulk density (D_b). Porosity ranges from 33% ($D_b = 1.78 \text{ g cm}^{-3}$) to 47% ($D_b = 1.40 \text{ g cm}^{-3}$) are commonly recorded (Figure 1). The porosity in sandy soils is usually smaller than in clayey and silty soils.

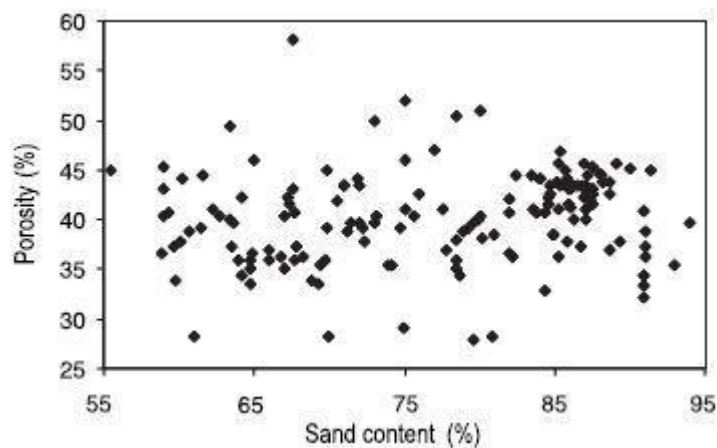


Figure 2.3: Variation of porosity according to the sand to increase. An increase in the silt-sand ratio would content in tropical sandy soils. (Nyamangara *et al.*, 2001)

Sandy soils retain little water at high water potentials and water content decreases rapidly with the water potential. Panayiotopoulos and Mullins (1985) studied the water retention properties of pure sand materials varying in size. They showed that most water was released between -0.1 and -1kPa for a coarse sand (2,000 - 710 μm) and between -15 and -30

kPa for a very fine sand (125 - 45 μm). The limited water release observed for the very fine sand between saturation and -0.5 kPa was not discussed by Panayiotopoulos and Mullins (1985). Mullins and Panayiotopoulos (1984) showed that the water retention curve was only very slightly affected by the clay content for a clay content $< 20\%$. The clay used was a kaolinite. With sandy soils, two thirds of the water present at saturation is usually released at -30 kPa as recorded by Obi and Ebo (1995) in a sandy soil in Southern Nigeria. Water contents ranging from 0.20 to 0.30 $\text{cm}^3 \text{cm}^{-3}$ and from 0.04 to 0.12 $\text{cm}^3 \text{cm}^{-3}$ are often recorded at -33 and -1500 kPa, respectively.

Unlike other soils, the structure of sandy soils can be easily affected by mechanical compaction over a large range of scales. Usually mechanical compaction preferentially affects large pores (i.e. macropores that result from tillage and biological activity) but in sandy soils it affects these large pores down to the small pores that result from the arrangement of the skeleton particles (sand and silt) within the clay fraction. That re-arrangement when submitted to mechanical compaction is possible because of the small cohesion between the skeleton particles. For narrowly graded pure sand materials, Panayiotopoulos and Mullins (1985) showed that these air-dry and nearly saturated sands were always found to pack more closely under a given load than the same sand at any water content. Increases in bulk density invariably results in an increase in the penetration resistance with significant consequences for root development although there no clear relationship with the penetration resistance (Mullins *et al.*, 1987; Bengough and Mullins, 1991). Indeed, the penetration resistance varies within a large range of values according to the soil water content without any variation of the other soil characteristics (e.g. particle size distribution, mineralogy, porosity, assemblage of the elementary particles). This large range of resistance to penetration would result from the contribution of cohesion forces that are partly related to the water content. Thus, a decrease in water content would increase frictional and cohesion forces from field capacity to intermediate

water content, smaller water contents increasing the frictional forces alone, the cohesion forces disappearing, thus explaining the results recorded in Nigeria by Ley *et al.*, (1995) on a large range of soils including sandy soils. Many tropical sandy soils are potentially hard setting soils, i.e. they can become compact, hard with apparently a pedal condition prevailing on drying (Northcote, 1979). Indeed, according to these authors, compaction that reduces the volume and continuity of large pores, would increase water retention and reduce water infiltration and saturated hydraulic conductivity in highly permeable deep sandy soils.

2.5 THE STABILIZING AGENT

2.5.1 CEMENT

Cement is a powdery substance made with calcined lime and clay as major ingredients. Clay used provides silica, alumina, and iron oxide, while calcined lime basically provides calcium oxide. In cement manufacturing, raw materials of cement are obtained by blasting rock quarries by boring the rock and setting off explosives (Powers and Brownyard, 1946). These fragmented rocks are then transported to the plant and stored separately in silos. They are then delivered, separately, through chutes to crushers where they are then crushed or pounded to chunks of 1/2 inch-sized particles. Depending on the type of cement being produced, required proportions of the crushed clay, lime stones, and any other required materials are then mixed by a process known as pre-homogenization and milled in a vertical steel mill by grinding the material with the pressure exerted through three conical rollers that roll over a turning milling table. Cement is an extremely fine material having adhesive and cohesive properties which provide binding medium for the discrete ingredients, it is a product obtained by pulverizing clinker formed by calcinating raw materials primarily consisting of lime (CaO), silicate (SiO₂), alumina (Al₂O₃), and iron oxide (Fe₂O₃). When cement is mixed with water it

forms a paste which hardens and bind aggregates (fine coarse) together to form a hard durable mass called concrete. Cements used in the construction industry can be classified as hydraulic and non-hydraulic.

The hydraulic cement set and hardens extremely fast in the presence of water (Due to the chemical action between cement and water known as hydration) and results in water resistance product which is stable. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack (MPSC, 2019). Non-hydraulic cements are derived from calcination of gypsum or limestone because their products of hydration are not resistant to water. However, the addition of pozzolanic materials can render the gypsum and make cement hydraulic. Thus, it will not set in condition or underwater, rather it sets as it dries and reacts with carbon-dioxide in the air. It can be attacked by some aggressive chemicals after setting.

2.5.1 CHEMICAL COMPOSITION OF CEMENT

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding (Schneider et al, 2011). Table 2.1 shows the approximate oxide composition limits of ordinary Portland cement.

Table 2.1 Approximate Oxide Composition Limits of Ordinary Portland Cement (Schneider et al, 2011).

Oxide	Per cent content
CaO	60-67
SiO ₂	17-25
Al ₂ O ₃	3.0-8.0
Fe ₂ O ₃	0.5-6.0
MgO	0.1-4.0
Alkalies (K ₂ O, Na ₂ O)	0.4-1.3
SO ₃	1.3-3.0

2.5.3 TYPES OF CEMENT

The properties of cement during hydration vary according to:

- i. Chemical composition.
- ii. Degree of fineness

It is possible to manufacture different types of cement by changing the percentages of their raw materials (De Vries et al, 1997).

2.5.3.1 TYPES OF PORTLAND CEMENT

- i. Ordinary Portland cement - Type I
- ii. Modified cement - Type II
- iii. Rapid-hardening Portland cement - Type III

- iv. Sulfate-resisting Portland cement - Type

It is possible to add some additive to Portland cement to produce the following types:

- i. Portland blast furnace cement - Type IS
- ii. Pozzolanic cement - Type IP
- iii. Air-entrained cement - Type IA
- iv. White Portland cement
- v. Colored Portland cement

2.5.3 SETTING AND HARDENING OF CEMENT

Setting Process: The process of losing plasticity with time and becoming dense, which is formed by mixing the cement and water. It happened in two stage initial setting and final setting.

Hardening Process: The process of forming hardening cement paste, which loses plasticity and its strength increases with time. Factors such as fineness and types of cement, blend of gypsum, age, water content, temperature and humidity which influence setting and hardening of Portland cement. Setting is important in concrete work to keep fresh concrete plastic for enough time which helps the processes of transporting, casting, and compaction (Nakatsu et al., 1999).

2.6 GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographical Information System is a very effective tool for capturing, displaying and analyzing geographically referenced data. GIS is different from other Information Systems insofar as it contains geographically referenced data consisting of spatial data component

which defines location, and attribute data component which defines characteristics (Chang, 2006). GIS has shown a very important role in various aspects of geotechnical engineering including preliminary site investigations, identification of potential project barriers (like mines etc.), interpolation for obtaining data at inaccessible locations, data visualization, data processing as well as preparation of post processing graphs and charts. Geotechnical information acquired from site and laboratory tests are vital for a safe and economical design of building and infrastructure works especially in land development projects (Mohamad et al, 2011). Hence GIS finds its applications at all the stages of a geotechnical engineering project. Today, GIS is rapidly changing by powerful computing, lots of data, internet capacity, web mapping and mobile devices (Sutton, 2021).

2.6.1 GIS COMPONENTS

- i. hardware.
- ii. software.
- iii. data.
- iv. methods.
- v. networks.
- vi. people.

2.6.1.1 GIS HARDWARE

Components of Geographic Information Systems hardware includes;

- i. powerful computers.
- ii. output devices.
- iii. printing.
- iv. plotting.

- v. monitors.
- vi. input devices.
- vii. storage space.

2.6.1.2 GIS SOFTWARE

Geographic Information Systems software allows users to;

- i. manipulate.
- ii. store.
- iii. query.
- iv. analyze.

2.6.1.3 GIS DATA

The most important GIS component includes;

- i. spatial data.
data with a locational context.
- ii. non-spatial data.
all other data (also called a-spatial data) (Dr. Sutton, 2021).

2.6.2 GIS APPLICATION IN GEOTECHNICAL ENGINEERING

In geotechnical practice, GIS can be used in at least four ways: data integration, data visualization and analysis, planning and summarizing site activities, and data presentation (Player, 2006).

2.6.2.1 DATA INTEGRATION

In geotechnical practice, the conventional approach to data integration for working site model creation can be an arduous task. Existing data sources are found in a variety of hard copy, electronic, and paper formats such as maps, plans, reports, books, aerial photos, etc. Integrating these data together with photos, notes, borings, and other site-specific data can require a significant effort. GIS provides tools for integrating these multiple data types such as raster format data (e.g. photos and scanned maps) and vector format data (e.g. computer-aided drafting (CAD) files, northing and easting point files, drainage lines, etc.). This data may consist of readily available existing information such as soil surveys and topographic maps, or project specific information such as proposed centerlines, project extents, survey points, aerial photos, and site investigation results (Amardeep et al., 2018).

2.6.2.2 DATA VISUALIZATION AND ANALYSIS

After data has been integrated into a working site model, the model can be used to visualize site data and analyze the site. This model is continually refined as more information is gathered and integrated into the existing model. One of the primary benefits of using GIS in this effort is its flexibility. Data layers can be combined and turned on and off as needed. Data can be symbolized to graphically represent relationships and queried to filter out extraneous information. Spatial queries can be performed to identify the relationships between features and help to determine engineering conclusions. GIS can be used to identify project constraints and potential barriers to successful project completion early in the design process (Amardeep et al., 2018).

2.6.2.3 PLANNING AND SUMMARIZING SITE ACTIVITIES

GIS can be used for both planning site activities and to integrate data collected during these activities into the site model, thus further refining it. In the GIS site model, boring and test pit locations can be planned, field reconnaissance locations noted, and maps, layouts, and figures can be created for use by field personnel. Global Positioning System (GPS) coordinates and/or project specific coordinates for investigation locations can be exported to guide surveyors and field staff in locating features and laying out investigation programs. During field work the locations of features can be captured using GPS, swing ties, offset distances from known features, etc., which can then be imported to GIS for integration into the site model. Digital photos taken during field activities can be linked to map features. Descriptive database tables can be created and linked to boring location maps to provide searchable features or scanned boring logs can be linked for retrieval through GIS (Amardeep et al., 2018).

2.6.2.4 DATA PRESENTATION

Another benefit of using GIS is data presentation. Layouts can be created for use in reports, papers, posters, and presentations in varying page sizes and formats. Labels, symbols, scale bars, north arrows, and text can be added to maps to provide clarity and improve information transfer.

This capability provides an excellent communication tool between office and field staff, consultants and their clients, field crews and utility locators, etc. Professional looking figures can be created for reports that are editable and reproducible (Player, 2006). In the present study some of the case studies ranging from soil survey planning to soil management, and furthermore, hydrologic response unit generation using GIS have been illustrated (Amardeep et al., 2018).

GIS technology in civil engineering is widely used at present. It is mainly due to the accessibility of modern measuring and information technologies. GIS phenomenon consists in data presentations through web portals on the internet. GIS products are accessible to the general public. GIS and records of electronic documents working on the database principle enable to make use of information more effectively. In the state administration and self-rule authority the usage of GIS leads to the simplification of decision processes and thus lowering the administration bureaucracy (Bartonek et al., 2010).

2.7 PREVIOUS RELATED STUDIES

- i. Ganta (2017) carried out his research on stabilizing sandy soil with sodium silicate as the grout to increase the bearing capacity of the soil. Through the process of injection model, he was able to apply the grout under low pressure by hand pressure. He concluded that the grouted soil had good liquid limit and the compaction and bearing ratio are high when compared to ordinary sandy soil. The cost of sodium silicate is low when compared to other grouting materials.
- ii. Beenish (2016) conducted studies on stabilizing sandy soil using cement grout as well. The grout was made by using water cement ratio by weight. Additionally, four pipes were used to inject the grout. He concluded that the cement content increase the angle of internal friction and 4% cement grout is effective as compared to 2% and 6%, the shear strength of the sandy soil increases with the increase in cement content.
- iii. Santhosh et al., (2018) did similar studies on bearing capacity of loose sandy soil through cement grouting. Samples were obtained and thoroughly mixed with grouting material with hand. With an increase in cement content, it was obtained that the shear strength of the sandy soil increased. He concluded that cement grouting is an effective technique to improve the bearing capacity and reducing the settlement of loose sandy soil.

CHAPTER THREE

3.0 METHODOLOGY

3.1 STUDY AREA

Any proposed construction cannot be supported by sandy soil since the soil's engineering characteristics are inappropriate for such structure. Most of this type of soil has been located in Ighosodin in Benin–City; in bar beaches across Lagos State; in Ughelli, Warri in Delta State and many more. However, there has been an increase in the pertinent use of sandy soil in engineering works as a result of the discovery of sandy soil in numerous sites.

Sandy soil drains fast and does not hold water very well because of their light texture and loose structure. The texture of soil is dependent on the size of the component particles. Large sand particles are encircled by air pockets, which creates lots of gaps for water to pass through.

The study was conducted in Iguoshodin Community, from Okun Junction of Ovia North East Local Government, Edo State. Latitude $6^{\circ}26'40''$ N and Longitude $5^{\circ}31'50.3''$ E are the two coordinates that make up the geographic coordinates. Figure 3.1 is a satellite view of the research area's map. A significant amount of the sample were collected disturbed by manual excavation to carry out all the required testing. The study area was populated with sandy soil in its natural form.

The type of granular medium and the intended use of the grouting will determine the correct grouting materials to use. The grouting materials typically utilized for grouting a granular medium are cement, bentonite, clay and lime. Sandy soil was used as the grouting media and cement as the grouting material in this current paper.



Figure 3.1: Schematic representation of Iguoshodin Community showing the study area (Adapted from Google map).

3.2 FIELD DATA COLLECTION

Two samples of soil were taken from the study area. A drilling auger was used to take soil samples. In order to drill, excesses of soil sample left on the auger was scrapped off. The samples were then obtained with the auger. The hole was dug using the auger drilling method, which involved rotating the auger to drive into the ground. The auger was then withdrawn, and the dug up soil was emptied into the sample bags. The disturbed samples were collected at a standard depth of 1.5 meters below the ground surface and stored in sample sack bags and identified according to the point of collection.

3.3 LABORATORY EXPERIMENTAL PROCEDURES

The soil were brought to the Geotechnical Laboratory of the University of Benin, where they were processed in accordance with BS 1377, part 2, 1990, and compacted in accordance with West African Standard. In order to the soil ready for the various experimental procedures, the soil sample had to be spread out in trays allowed to air dry.

3.3.1 Natural Moisture Content Test

An electronic weighing scale was used to weigh an empty container before it was filled with a representative portion of the soil sample. Then the container and soil were weighed and the results were recorded in grams. The weights of the containers when they were both empty and full were noted as W1 and W2, respectively. The samples were then oven dried for 24 hours at 105 to 110°C, put in a desiccator to cool, weighed, and recorded as W3 after that. This is done for the two samples obtained from the site. The following calculation was then used to determine the natural moisture content of the sample as a percentage of the dry weight using the equation below:

$$\text{Moisture Content} = \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Weight of dry sample}}$$

But numerical values are usually quoted as percentage i.e.

$$\text{Moisture Content} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (3.1)$$

Where:

W1= Weight of empty container

W2= Weight of Container and wet soil sample

W3= Weight of Container and dry soil sample

Details of the procedures adopted are contained in BS 1377:1990 TEST 1(A), ASTM D 2216.

3.3.1 Specific Gravity Test

The specific gravity was calculated using a bottle of 50ml density. First, the bottle was dried before being weighed as W1 on an automated weighing scale. The bottle was then filled with some of the oven dried sample, and the contents were weighed as W2. Following the addition of distilled to the soil, which was agitated with a glass rod to liberate any trapped air,

he bottle was fully filled with water and weighed as W3. The bottle was then thoroughly emptied of all its contents, cleansed and filled with fresh distilled water. This weight of water was then recorded as W4. The specific gravity of the soil was then determined as follows:

$$\text{Specific Gravity} = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \quad (3.2)$$

Where:

W1= Weight of bottle

W2= Weight of bottle and dry soil sample

W3= Weight of bottle plus soil and water

W4= Weight of bottle and water

Details of the procedures adopted are contained in BS 1377, ASTM D8541, and AASHTO T100.

3.3.2 Sieve Analysis

After being dried, the soil sample was divided into smaller sizes and run through a BS 4.75mm sieve. Sedimentation analysis was then performed because the particle were fine grains. The samples were sieved through sieves with openings of 32.36mm, 2mm, 1.18mm, 600, 425, 300, 212, 150, and 75 microns. On any particular sieve, the percentage of the soil sample retained is obtained from:

$$\frac{\text{Weight of soil retained}}{\text{Total weight taken}} \times 100 \quad (3.3)$$

The cumulative percentage retained on any sieve is the sum of the percentage retained on all coarser sieves. The percentage finer than any sieve size (or the percentage passing) is given as:

$$100 - \text{Cumulative percentage retained}$$

Details of the procedures adopted are contained in BS 1377 -2, 1990 sub-clause 9.2.

3.3.3 Cone Penetrometer Test

A piece of the soil sample is passed through the 425 micron IS filter and has been well combined, yields around 300g of air dried soil. Distilled water is added to the soil to create a consistent paste that has been obtained in a mixing disc. Making sure that no air is trapped during this procedure, the wet soil paste is next transferred to the cylindrical cup of the cone penetrometer equipment. The wet soil is finally leveled to the top of the cup and set on the base of the cone penetrometer. The penetrometer is setup such that the cone point barely contacts the soil paste on the surface of the cup before the first reading is obtained. The cone can then enter the space by releasing the vertical clamp.

3.3.4 Standard Proctor Compaction Test

The dried soil sample was weighed after being run through the 4.75mm sieve to get a soil weight of 3 kg. Then, an approximated amount of water was added in 2%, 4%, 6%, 8% and 10% to get a value of the relatively low moisture content. After that, the sample was put into the compaction mould in three layers, with each layers being compacted with 25 blows from a standard 2.5kg hammer that dropped free fall after calculating the weight of the empty mould. The weight of the mould and moist soil was then measured after the top of the compacted earth was leveled with the top of the mould using a straight edge. After measuring the moisture contents of the representative soil samples, the procedure was repeated with increase in the amount of water in percentages. Thereafter, the bulk density against moisture content plotted from which the optimum moisture content (OMC) of the sample was obtained. The dry density (unit weight) pd can be calculated fro, the equation:

$$pd = \frac{W}{V\left(1 + \frac{M}{100}\right)} \quad (3.4)$$

Where:

V= Volume of mould

M= Water content of moist compacted soil

W= Total weight of moist compacted soil in cylinder

3.3.5 California Bearing Ratio Test

A mass 5kg of sample soil was sieved through a 2.75mm mesh before the water from the OMC was added. Three layers of compacted dirt were present (55 blows per layers). Each layer received equal amounts of blows. After the process of compaction, the collar was taken off and the mould was trimmed using the straight edge. The sample was placed in the CBR machine, and readings were made of the plunger weight at 0:5 up to 12.5mm, after which the sample was spun and the plunger set to the bottom. The sample containing CBR mould was withdrawn from the machine and soaked for 24 hours the CBR values were measured using the same procedure. The CBR was plotted and the top and bottom CBR values were determined for both the unsoaked and soaked at 2.5m and 5.0mm.

CHAPTER FOUR

4.0 PRESENTATION AND ANALYSIS OF DATA

4.1 RESULTS FOR THE TESTS

4.1.1 SPECIFIC GRAVITY

The experiment is conducted as per the procedure laid down in BS 1377: Part 2: 1990. The specific gravity for sample I is 2.67 and sample II is 2.64. The value falls in the range 2.63 to 2.67 according IS 2386 Part 3 (1963). The results falls within this standard range. This is shown in appendix.

4.1.2 GRAIN SIZE ANALYSIS

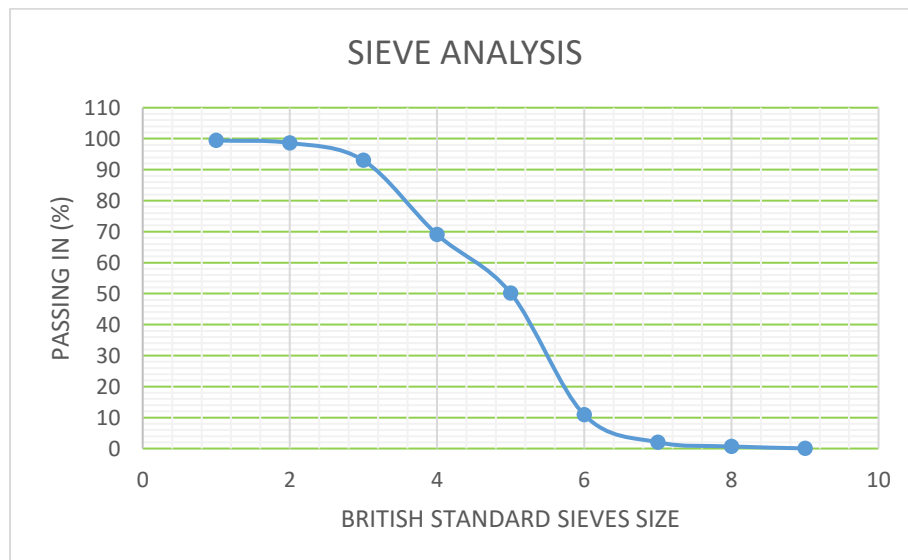


Figure 4.1 Grain analysis of sample I

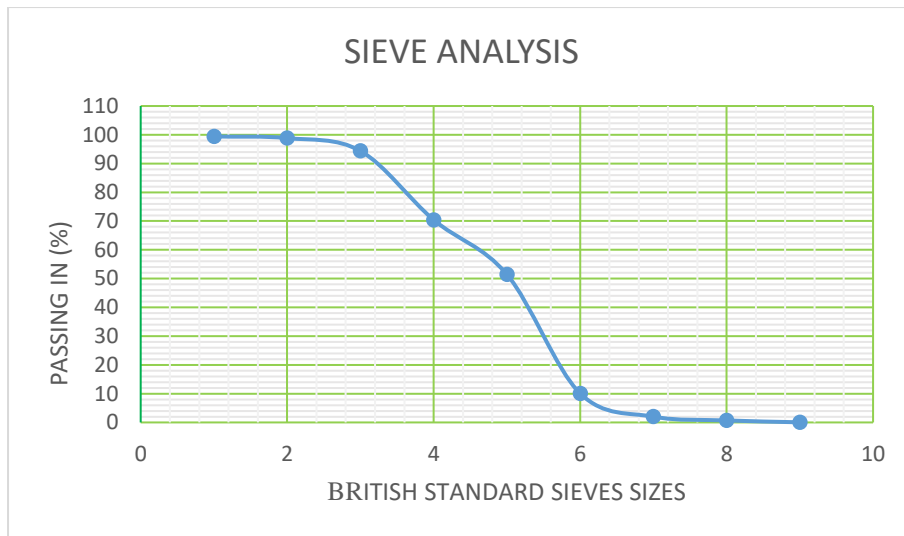


Figure 4.2 Grain analysis of sample II

According to ASTM D6913, Figure 4.1 shows the gradation of sample I and sample II. It can be concluded that the soil sample is classified as fine sand. This grain meets the gradation of fineness, shape, surface smoothness, texture and consistency making it the ideal sand for construction, offering better strength to the concrete. It is free from salt and other impurities making it a conventional selection for concreting.

From the sieve analysis chart, the obtained parameters for sample I are D10, D30 and D60 which are 0.31mm, 0.42mm and 0.52mm respectively. For sample II, D10, D30 and D60 are 0.32mm, 0.41mm and 0.52mm. These are used to obtain the Uniformity Coefficient (Cu) and Coefficient of Gradation (Cc).

$$Cu = \frac{D_{60}}{D_{10}} \quad (4.1)$$

$$Cc = \frac{(D_{30})^2}{(D_{10} \times D_{60})} \quad (4.2)$$

Inputting the obtained parameters into the formula, Cu = 1.68 and Cc = 1.09 for sample I and Cu = 1.63 and Cc = 1.01 for sample II. According to the British Standard System (BS 1990),

when C_u is greater than or equal to 4 and C_c between the range of 1 to 3 classify the soil as well graded gravel or soil. Therefore, this classify the soil sample as a well graded soil.

4.1.3 LIQUID LIMIT

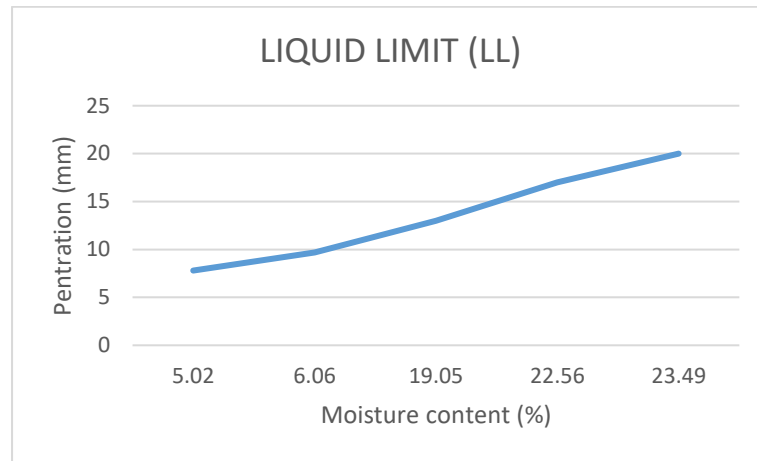


Figure 4.3 Liquid limit of sample I

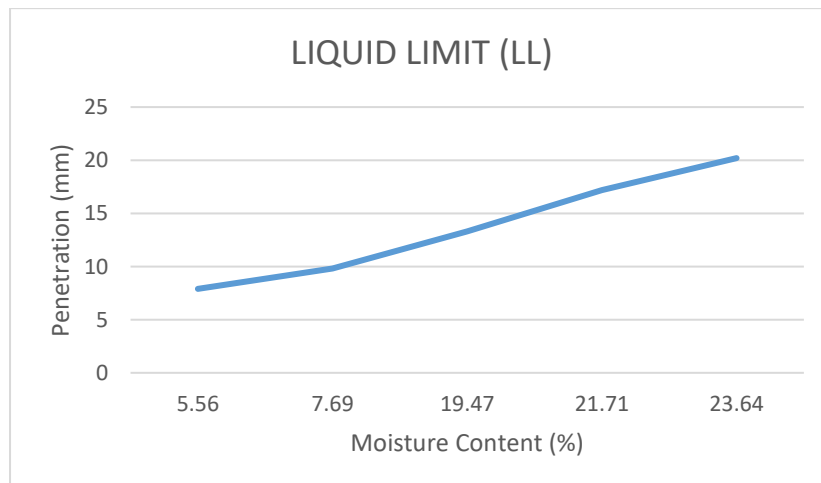


Figure 4.4 Liquid limit of sample II

According to BS 1377: Part 2: 1990 standard, from the result shown on the graph, the liquid limit (W_L) of sample I at 20mm is 23.64% and the liquid limit (W_L) of sample II is

23.50%. This shows that the sample has high moisture and low shear strength which makes it not suitable to support any form of structure. Therefore, stabilizing is needed. The results are shown in the appendix.

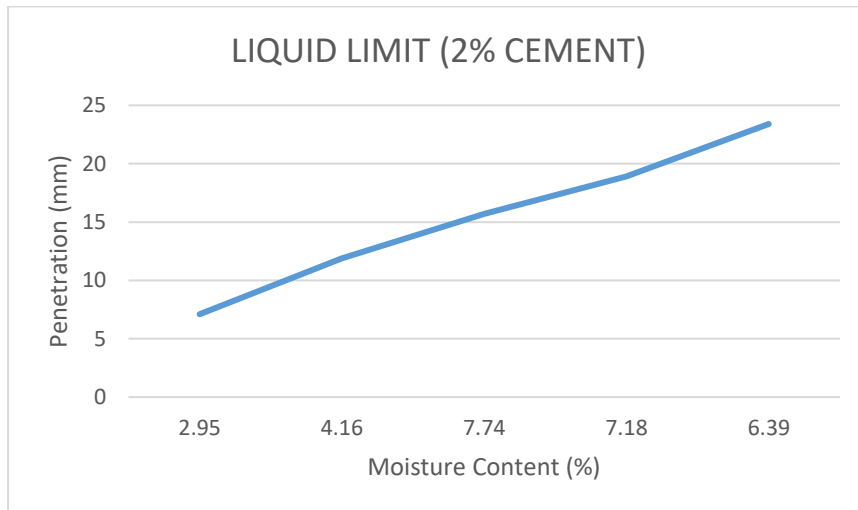


Figure 4.5 Liquid limit of sample I with 2% cement

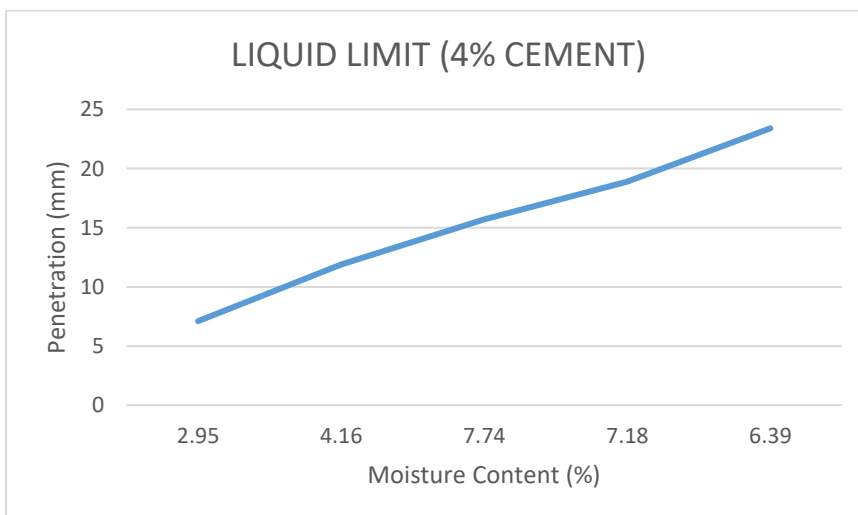


Figure 4.6 Liquid limit of sample I with 4% cement

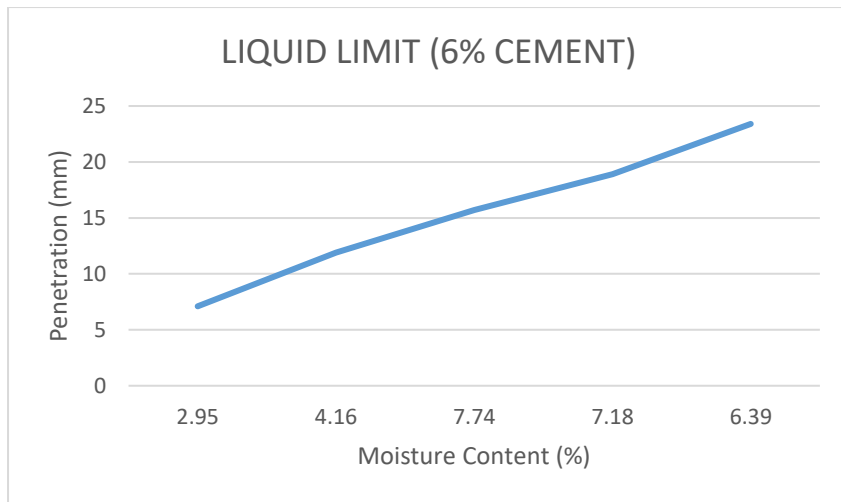


Figure 4.7 Liquid limit of sample I with 6% cement

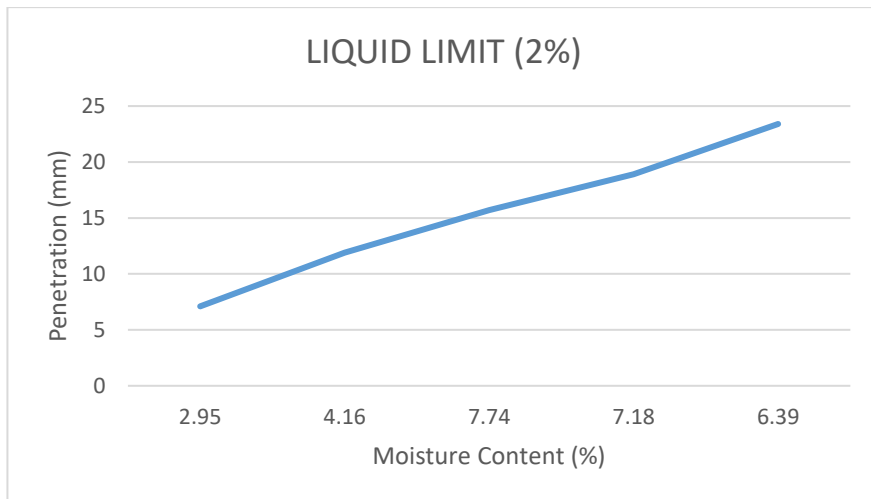


Figure 4.8 Liquid limit of sample II with 2% cement

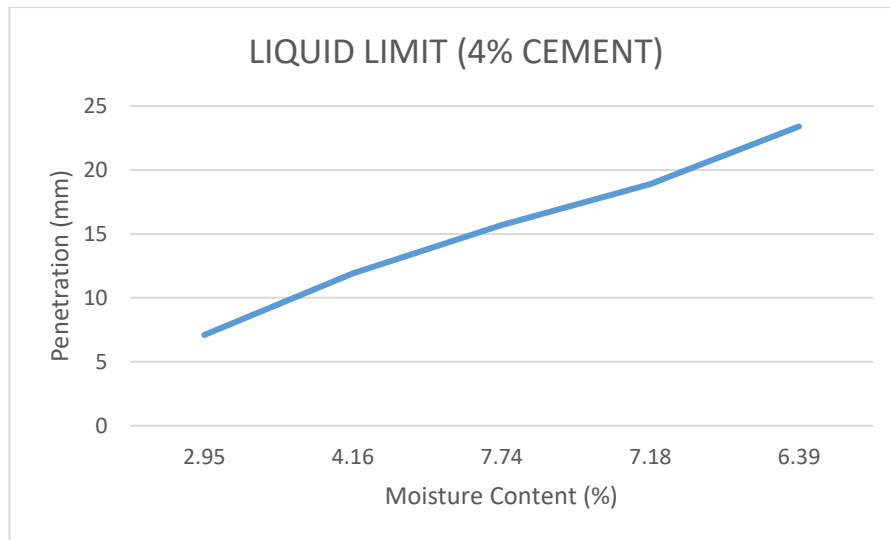


Figure 4.9 Liquid limit of sample II with 4%

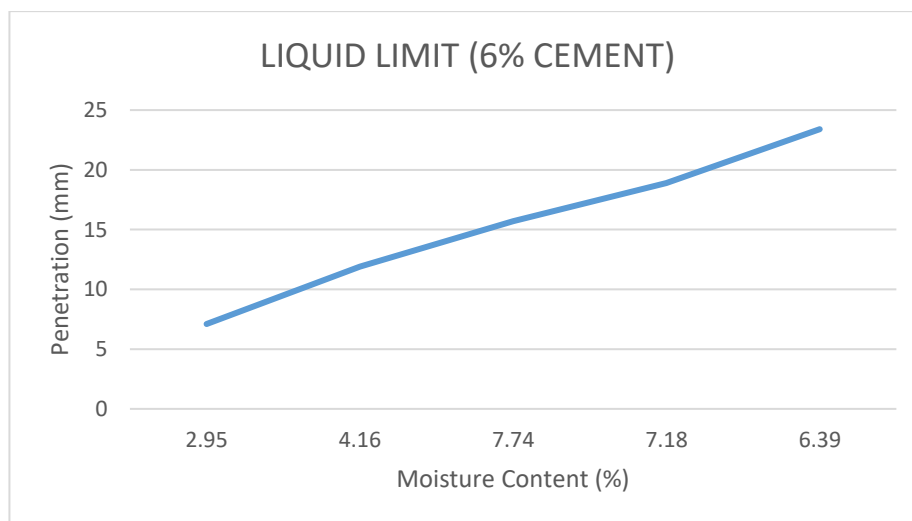


Figure 4.10 Liquid limit of sample II with 6%

According to BS 1377: Part 2: 1990 standard, from the results shown on the graphs, the liquid limit (W_L) of sample I at 20mm stabilized with 2% cement is 8.76%, 4% is 6.99%, and 6% cement is 6.99% and the liquid limit (W_L) of sample II at 20mm stabilized with 2% is 9.53%, 4% cement is 6.60% and 6% cement is 5.14%. It is observed from the figures that the liquid limit of the soil sample is reduces and the shear strength increases with an increase of

the cement grout. This shows that both samples are improved. Test results table is shown in appendix 1.

4.1.4 COMPRESSIVE STRENGTH RESULT

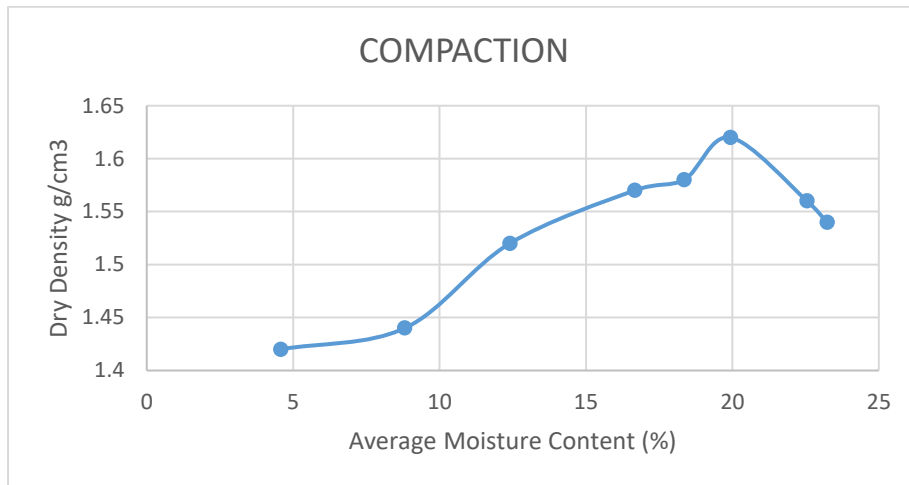


Figure 4.11 Compressive test graph of sample I

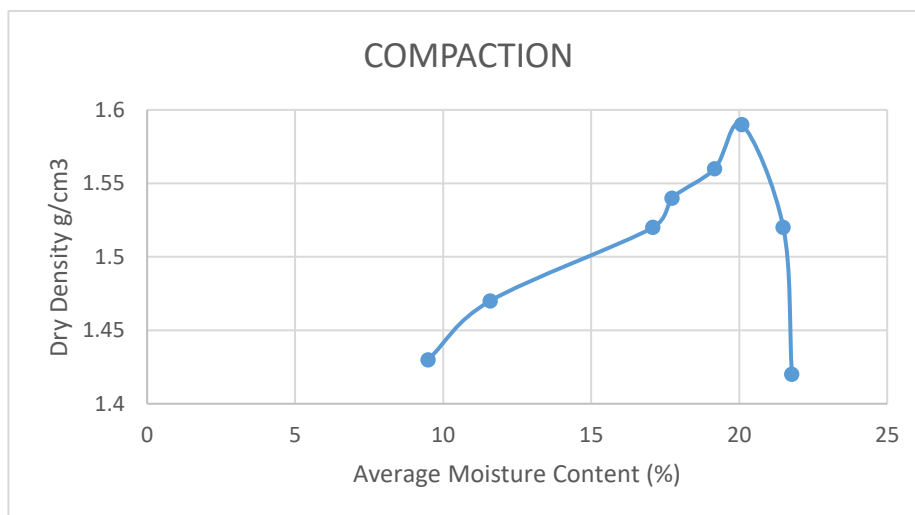


Figure 4.12 Compressive test graph of sample II

The test results are shown in tables as shown in the appendix for the two samples respectively. The figures 4.7 and 4.8 shows the average compressive strength without

stabilization. The results shows that the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of sample I is 19.93% and 1.62 g/cm³ and the OMC and MDD for sample II is 20.09% and 1.59 g/cm³. This reduces the compressive strength and cohesion of the soil sample causing it not to meet the required properties of a good soil. Hence, it needs stabilization.

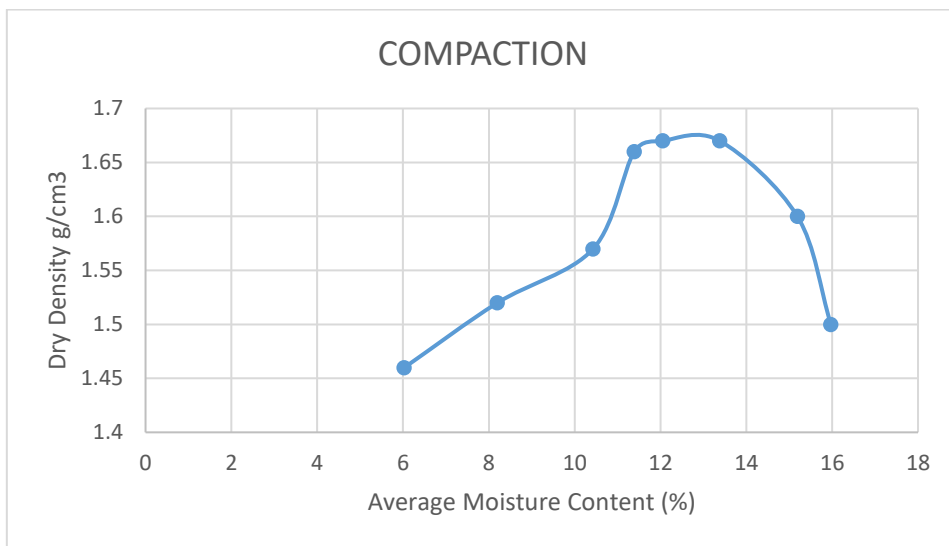


Figure 4.13 Compressive test graph of sample I with 2% cement

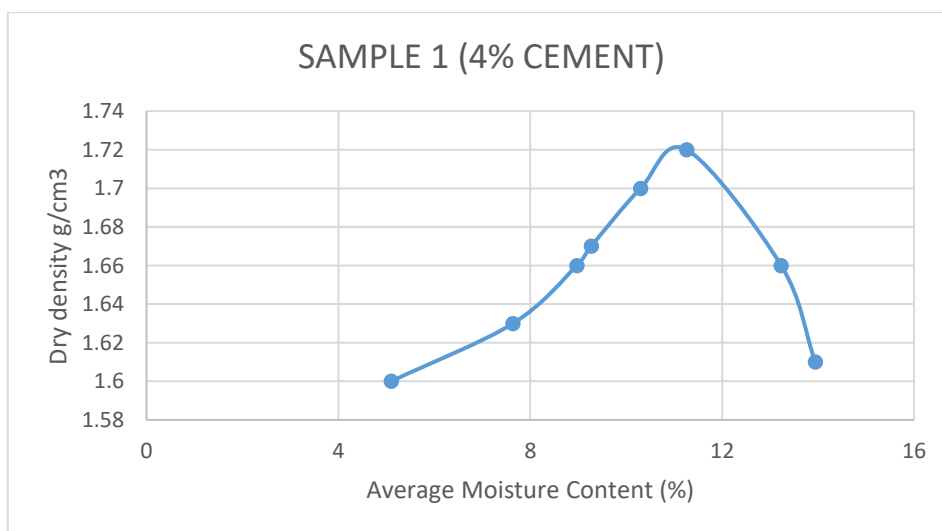


Figure 4.14 Compressive test graph of sample I with 4% cement

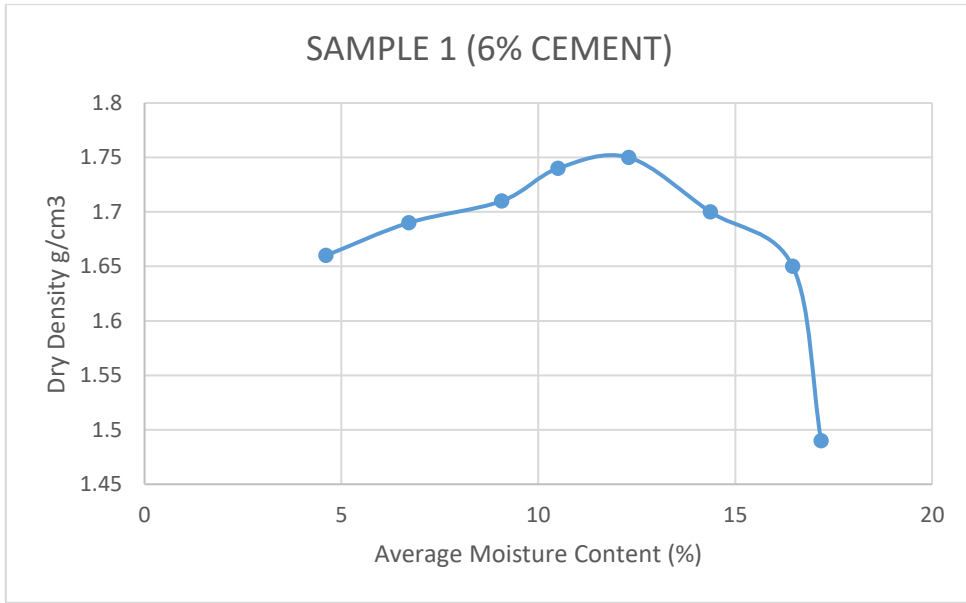


Figure 4.15 Compressive test graph of sample I with 6% cement

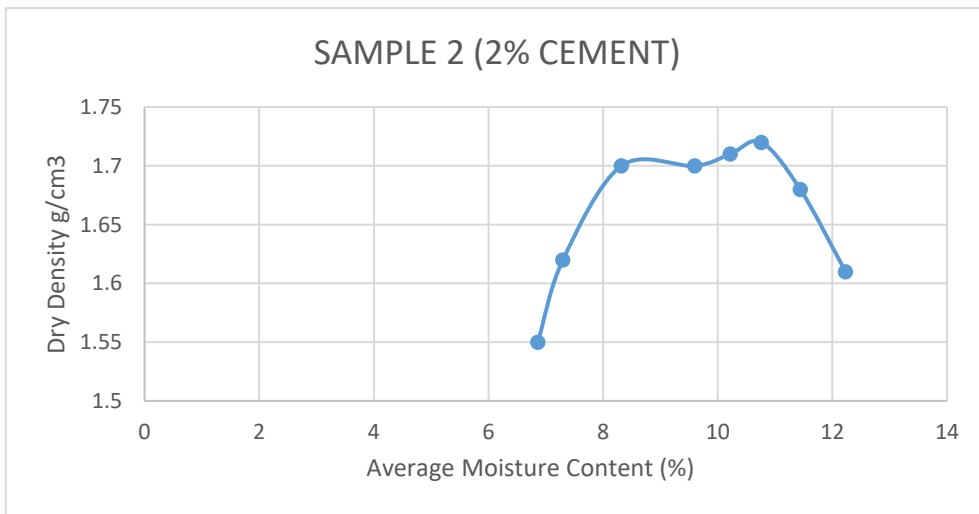


Figure 4.16 Compressive test graph of sample II with 2% cement

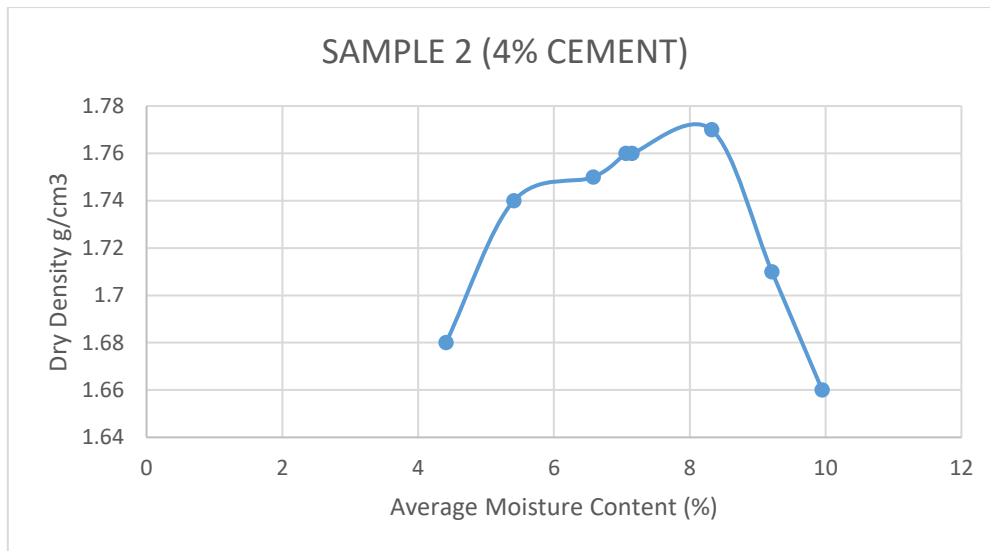


Figure 4.17 Compressive test graph of sample II with 4% cement

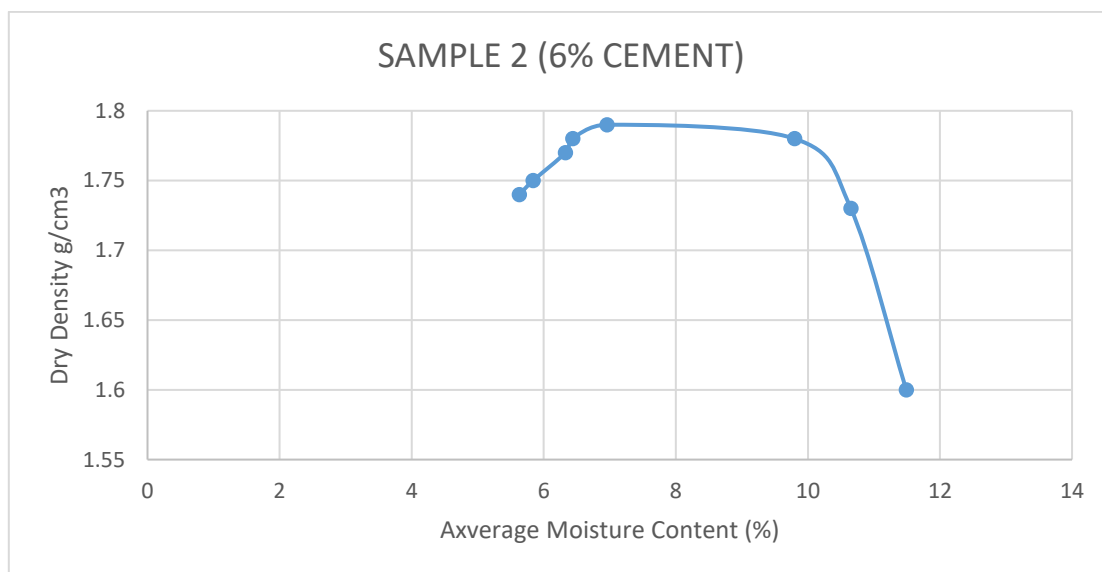


Figure 4.18 Compressive test graph of sample II with 6% cement

The figures shows the effect of cement grout on the soil sample in percentages of 2%, 4% and 6%. From the figure, the OMC and MDD of sample 1 at 2% cement grout is 13.38% and 1.67 g/cm³, at 4% cement grout is 11.26% and 1.72 g/cm³ and 12.3% grout and 1.75 g/cm³. The OMC and MDD of sample II at 2% cement grout is 10.76% and 1.72 g/cm³, at 4% cement grout is 8.32% and 1.77 g/cm³ and at 9.8% and 1.78 g/cm³. It shows stabilizing the well graded

soil with cement grout, it causes a reduction in the moisture content, an increase in the shear strength and cohesion.

4.2 QUERY OF SOIL ATTRIBUTE DATA WITH ARCGIS

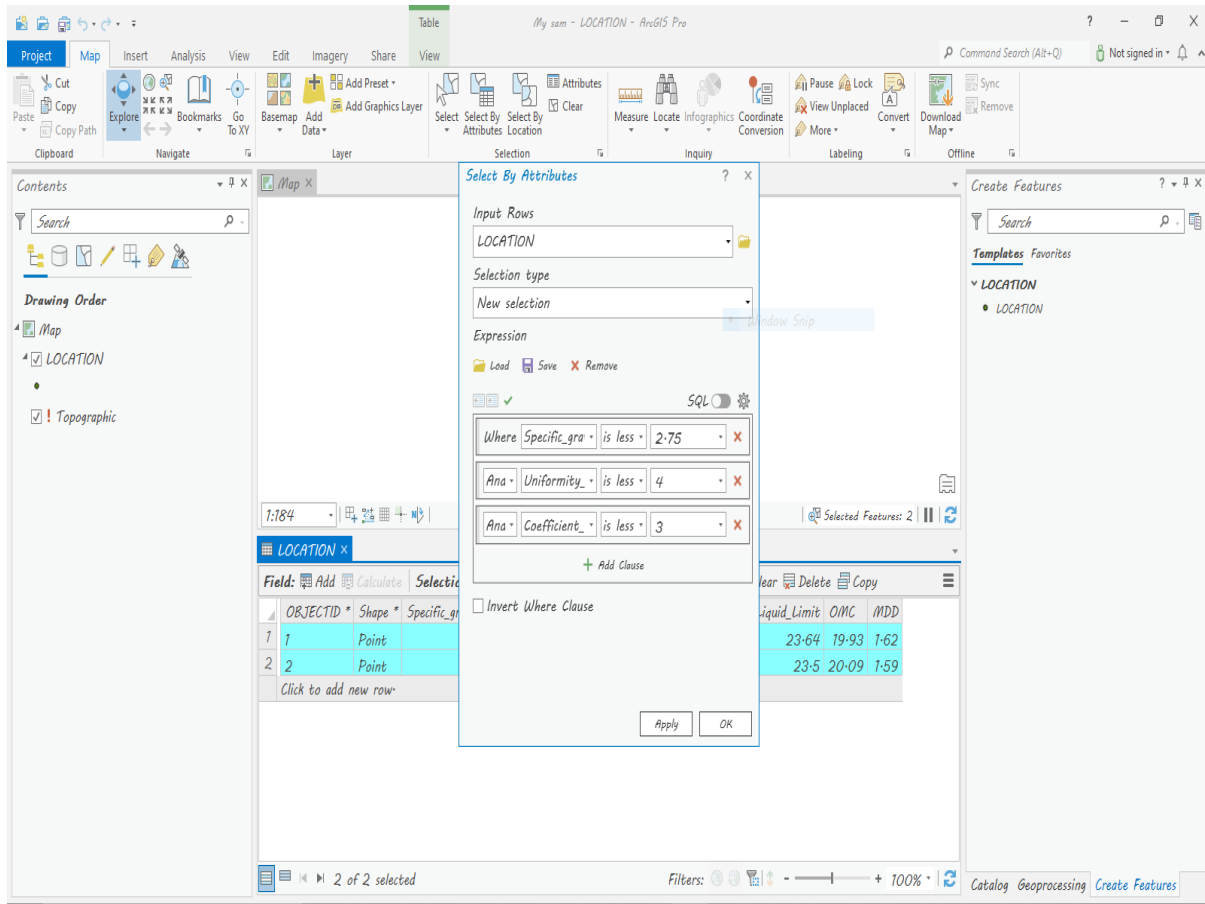


Figure 4.19 Query of soil attribute data using ArcGIS

Attribute data of the soil sample from the point of collection is queried to know to obtain the required information about that point.

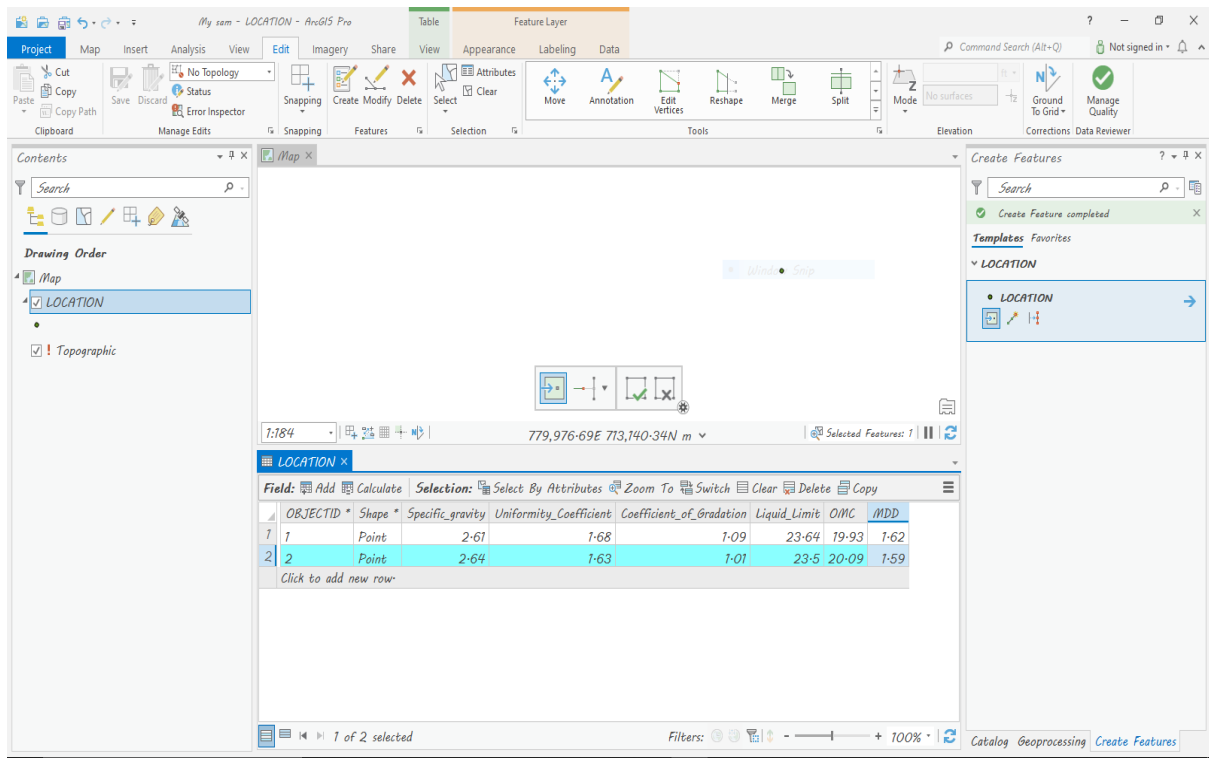


Figure 4.20 Result of query using ArcGIS

Results of query shows the highlighted sample as it meets the required data to be obtained.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the results of this experimental study the following conclusions are made.

- i. As the cement content increases the load settlement decreases. Thus, the bearing capacity of grouted soil is higher than natural sandy soil.
- ii. The strength behavior of the grouted sandy soil with 4% cement grout is significantly higher than at the loosest. As opposed to 2% and 6% cement grout, the 4% cement grout is more effective in improving the soil.
- iii. The fact that grouted sandy soil has a higher dry density than ungrouted soil suggests that it is very cohesive. Thus, the grouted soil has a better than a natural sandy soil.
- iv. Increment of cement content increases the shear strength of the sandy soil.
- v. This study demonstrates that cement grouting is an effective technique to enhance the shear strength of sandy soil and increase the bearing capacity of sandy soil.

5.2 RECOMMENDATIONS

From the results, it is recommended that:

- i. The sandy soil at Iughosodin is stabilized with 4% cement grout before using it for any structural work.
- ii. After investigating the structural characteristics of this stabilizing agents on the sandy soil at Iughosodin, more research is required to determine the geotechnical characteristics of the stabilizing agent on the same soil.

- iii. Since the unstabilized compressive strength of the soil does not meet the requirements of the Federal Ministry of Works and Housing, a monitoring unit should be established to make sure that the soil is properly stabilized as stated above.
- iv. The improvement may be carried out prior to, during, or after building an engineering project.

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APPENDIX I
UNIBEN GEOTECH RESEARH
MOISTURE CONTENT ANALYSIS

(Standard Laboratory Method)

OPERATOR:

JOB: SANDY SOIL

SOIL NO: SAMPLE I

LOCATION: UGHOSODIN

TEMP OF TEST

DEPTH: 1.5m

S/N	Dpt	Can wt.	Can wt.	Can wt. + dry soil	Can wt. + wet soil
	1.5	0.35	15.95	58.3	96.4
		JA5	17.35	56.2	95.9

DETERMINATION OD SPECIFIC GRAVITY OF SOIL PARTICLES

(Standard Laboratory Method)

OPERATOR:

JOB: SANDY SOIL

SOIL NO: SAMPLE I

LOCATION: UGHOSODIN

TEMP OF TEST

DEPTH: 1.5m

S/N	DPT	BN	B+W	B+S+W	B+S	B	Ad. W	WWAS	WS	WOWDS	Gs	AGs
		EE	72.9	96.4	58.3	20.6	52.3	38.1	37.7	14.2	2.65	2.67
		TQ	74.4	95.9	56.2	21.9	52.5	39.7	34.3	12.8	2.68	

SOIL NO: SAMPLE II

LOCATION: UGHOSODIN

TEMP OF TEST

DEPTH: 1.5m

S/N	DPT	BN	B+W	B+S+W	B+S	B	Ad. W	WWAS	WS	WOWDS	Gs	AGs
		NO	73.4	92.9	53.5	22.1	51.3	38.3	32.5	12.7	2.5	2.64
		JT 1	72.5	95.0	56.5	20.1	52.4	38.5	36.4	13.9	2.62	

B+W = Wt. of Bottle + Water (full) W4

B+S+W = Wt. of Bottle + Soil + Water W3

B+S = Wt. of Bottle + Soil W2

B = Wt. of Bottle W1

Ad. W = Wt. of Added Water (full) (W4-W1)

WWAS = Wt. of Water added to the soil (W3-W2)

WS = Wt. of soil (W2-W1)

WOWDS = Wt. of Water Displaced by Soil (W4-W1)-(W3-W2) = W

GS = Specific Gravity (W2-W1)/W

UNIBEN GEOTECH RESEARH
GRAIN SIZE ANALYSIS BY SIEVES

Size: _____

Lab NO: ____

Location: _____

Sample: I

Depth: _____1.5m_____

Tested By: ____

Weight of Dry Material and Container in Gram: _____

Weight of Container in Gram: _____

Weight of Dry Material in Gram: _____

BRITISH STANDARD SIEVES SIZES	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
2.36	0.59	0.59	99.41
2.00	0.77	1.36	98.64
1.18	5.65	7.01	92.99
600m	23.91	30.92	69.08
425	18.89	49.81	50.19
300	39.28	89.09	10.91
212	8.89	97.98	2.02
150	1.34	99.32	0.68
75	0.63	99.95	0.05

UNIBEN GEOTECH RESEARH
GRAIN SIZE ANALYSIS BY SIEVES

Size: _____ Job: _____ Lab NO: ____
 Location: _____ Sample: II
 Depth: _____ Tested By: ____
 Weight of Dry Material and Container in Gram: _____
 Weight of Container in Gram: _____
 Weight of Dry Material in Gram: _____

BRITISH STANDARD SIEVES SIZES	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
2.36	0.59	0.59	99.41
2.00	0.57	1.16	98.84
1.18	4.45	5.61	94.39
600m	23.97	29.58	70.42
425	18.95	48.53	51.47
300	41.38	89.91	10.09
212	8.08	97.99	2.01
150	1.32	99.31	0.69
75	0.65	99.96	0.04

CONE PENETROMETER TEST

SAMPLE NO: I

DESCRIPTION: SANDY SOIL

Penetration	7.8	9.7	13.0	17.0	20.0
Can no	A	5	RT4	PA6	0.7
Can Wt.	21.5	21.2	17.54	17.46	17.64
Can + Wet soil	47.04	43.41	47.16	49.84	46.76
Can + Dry soil	45.82	42.14	42.42	43.88	41.22
Moisture content (%)	5.02	6.06	19.05	22.56	23.49

CONE PENETROMETER TEST

SAMPLE NO: II

DESCRIPTION: SANDY SOIL

Penetration	7.9	9.8	13.3	17.2	20.2
Can no	PZO	PAI	M	RMG	RT4
Can Wt.	17.64	17.46	22.90	21.62	18.99
Can + Wet soil	39.85	33.00	36.77	34.40	37.45
Can + Dry soil	38.68	31.89	34.51	32.12	33.92
Moisture content (%)	5.56	7.69	19.47	21.71	23.64

CONE PENETROMETER TEST

SAMPLE NO: I

DESCRIPTION: SANDY SOIL WITH 2% CEMENT GROUT

Penetration	7.4	11.3	15.5	18.2	22.8
Can no	DD	PA7	T3	RT4	P6
Can Wt.	17.30	17.27	16.41	17.54	17.46
Can + Wet soil	46.60	41.52	34.64	40.29	38.82
Can + Dry soil	45.41	40.30	32.72	38.42	37.15
Moisture content (%)	4.23	5.30	11.77	8.96	8.48

DESCRIPTION: SANDY SOIL WITH 4% CEMENT GROUT

Penetration	7.5	11.8	15.8	18.8	23.1
Can no	4	11.0	5	NN	R1
Can Wt.	21.5	21.7	21.2	21.3	21.2
Can + Wet soil	33.18	39.61	39.91	39.20	40.53
Can + Dry soil	32.54	38.61	38.52	37.92	38.68
Moisture content (%)	5.80	5.91	8.03	7.70	5.17

DESCRIPTION: SANDY SOIL WITH 6% CEMENT GROUT

Penetration	7.1	11.9	15.7	18.9	23.4
Can no	ITV	PAI	0.7	PZO	HNZ
Can Wt.	16.73	17.46	17.64	17.58	18.38
Can + Wet soil	34.52	36.99	33.37	40.88	44.51
Can + Dry soil	34.01	36.21	32.24	39.32	42.94
Moisture content (%)	2.95	4.16	7.74	7.18	6.39

CONE PENETROMETER TEST

SAMPLE NO: II

DESCRIPTION: SANDY SOIL WITH 2% CEMENT GROUT

Penetration	7.6	11.5	15.7	18.3	22.9
Can no	M	5	0.51	M	0.9
Can Wt.	21.82	21.2	21.8	22.9	22.8
Can + Wet soil	37.1	41.09	40.15	37.52	34.50
Can + Dry soil	36.49	39.99	38.64	36.21	32.31
Moisture content (%)	4.16	5.85	11.82	9.84	8.48

DESCRIPTION: SANDY SOIL WITH 4% CEMENT GROUT

Penetration	7.7	11.9	15.9	18.7	23.2
Can no	SE	O	0.13	VI	Z
Can Wt.	24.4	26.0	21.0	24.7	23.3
Can + Wet soil	34.22	40.15	39.18	40.32	39.68
Can + Dry soil	33.74	39.16	37.65	39.29	38.83
Moisture content (%)	5.14	7.52	9.19	7.06	5.47

DESCRIPTION: SANDY SOIL WITH 6% CEMENT GROUT

Penetration	7.4	12.0	15.8	19.0	23.5
Can no	KE	LJ	PT	GE	0.21
Can Wt.	14.51	20.15	18.36	21.3	23.2
Can + Wet soil	40.44	42.08	44.37	41.62	39.51
Can + Dry soil	39.68	40.99	42.58	40.54	38.96
Moisture content (%)	3.02	5.23	7.39	5.61	3.49

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL.

Sample: I

Site..... Depth: 1.5m. Date PERCENTAGE: MDD: 1.62 g/cm³

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC: 19.93%

B.S / C.B.R Mould: 3125g

Wt. of mould & wet soil (W2)g	4602	4691	4836	4950	4998	5063	5034	5027								
Wt. of mould (W1)g	3125	3125	3125	3125	3125	3125	3125	3125								
Wt. of wet soil (W2-W1)g	1477	1566	1711	1825	1873	1938	1909	1902								
Bulk Density (Pb) (W2-W1)/x g/cm	1.48	1.57	1.71	1.83	1.87	1.94	1.91	1.90								
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm³																
Container no	111	A	11.0	SE	5	SE	GE	0.51	O	NN	0.5	R1	0.21	M	0.13	RM G
Wt. of wet soil & container (g)	47.0 2	43.3 2	55.1 9	43.5 0	47.6 8	46.8 9	45.7 9	47.1 3	54.8 6	41.6 7	53.1 7	49.9 0	44.7 5	43.9 5	45.1 2	46.8 5
Wt. of dry soil & container (g)	45.9 1	42.3 7	52.6 2	41.7 3	44.8 7	44.2 7	42.2 1	43.6 0	50.3 6	38.5 3	47.9 3	45.3 5	40.6 8	40.1 8	40.3 2	42.3 8
Wt. of container (g)	21.7	21.5	23.3	21.7	24.4	21.2	21.3	21.8	26.0	21.3	23.0	21.2	23.2	22.9	21.0	21.7
Wt. of dry soil (Wd) g	24.2 1	20.8 7	29.3 2	20.0 3	20.4 7	23.6 7	20.9 1	21.8 0	24.3 6	17.2 3	24.9 3	24.1 5	17.4 8	17.2 8	19.3 2	20.6 8
Wt. of moisture (Wm) g	1.11	0.95	2.57	1.77	2.81	2.62	3.58	3.53	4.5	3.14	5.24	4.55	4.07	3.77	4.8	4.47
Moisture content 100(Wm/Wd) %	4.58	4.55	8.77	8.84	13.7 3	11.0 7	17.1 2	16.1 9	18.4 7	18.2 2	21.0 2	18.8 4	23.2 8	21.8 2	24.8 4	21.6 2
Average moisture content (m) %	4.57		8.81		12.4		16.66		18.35		19.93		22.55		23.23	
Dry density = Pb/1 + (m/100) (g/cm ³)	1.42		1.44		1.52		1.57		1.58		1.62		1.56		1.54	
C.B.R. (mseen of top & bottom) %																

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL.

Sample: II

Site..... Depth.... Date PERCENTAGE:

MDD: 1.59 g/cm³

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC: 20.09%

B.S / C.B.R Mould: 3125g

Wt. of mould & wet soil (W2)g	4697	4768	4918	4931	4982	5032	4977	4851									
Wt. of mould (W1)g	3125	3125	3125	3125	3125	3125	3125	3125									
Wt. of wet soil (W2-W1)g	1572	1643	1793	1806	1857	1907	1852	1726									
Bulk Density (Pb) (W2-W1)/x g/cm	1.57	1.64	1.79	1.81	1.86	1.91	1.85	1.73									
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm³																	
Container no	DD	LJ	P20	PA 7	OZ2	RE T	T3	Hnz	RT 4	KE	PA E	0.7	PT	PAI	JA8	ITV	
Wt. of wet soil & container (g)	33.49	39.80	35.23	39.67	33.00	36.12	33.64	33.93	36.77	32.52	30.17	33.81	34.44	35.76	35.51	37.47	
Wt. of dry soil & container (g)	32.01	38.19	33.45	37.46	30.72	33.41	31.05	31.60	33.70	29.60	28.20	30.91	31.58	32.44	32.26	33.72	
Wt. of container (g)	17.30	20.15	17.58	17.27	17.42	17.63	16.41	18.38	17.54	14.51	17.46	17.64	18.36	17.46	17.48	16.73	
Wt. of dry soil (Wd) g	14.71	18.04	15.50	19.51	13.38	15.82	14.64	13.11	16.16	15.09	10.74	13.27	13.55	15.19	14.96	17.18	
Wt. of moisture (Wm) g	1.48	1.61	1.78	2.21	2.28	2.71	2.59	2.33	3.07	2.92	1.97	2.90	2.86	3.32	3.25	3.75	
Moisture content 100(Wm/Wd) %	10.06	8.92	11.84	11.33	17.04	17.13	17.69	17.77	18.99	19.35	18.34	21.85	21.11	21.86	21.72	21.83	
Average moisture content (m) %	9.49		11.59		17.09		17.73		19.17		20.09		21.49		21.78		
Dry density = Pb/1 + (m/100) (g/cm ³)	1.43		1.47		1.52		1.54		1.56		1.59		1.52		1.42		
C.B.R. (mseen of top & bottom) %																	

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL WITH CEMENT GROUT. Sample: I

Site..... Depth.... Date PERCENTAGE: 2% MDD:

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC:

B.S / C.B.R Mould: 4574g

Wt. of mould & wet soil (W2)g	6126	6222	6303	6419	6448	6463	6412	6311								
Wt. of mould (W1)g	4574	4574	4574	4574	4574	4574	4574	4574								
Wt. of wet soil (W2-W1)g	1552	1648	1729	1845	1874	1889	1838	1737								
Bulk Density (Pb) (W2-W1)/x g/cm	1.55	1.65	1.73	1.85	1.87	1.89	1.84	1.74								
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm³																
Container no	11	111	0	2	0.13	SE	RM O	0.5	0.51	R1	GE	5	NN	M	0.36	PA 9
Wt. of wet soil & container (g)	43.86	46.71	44.55	41.01	32.76	31.48	30.02	32.38	34.17	34.76	40.39	31.36	35.05	38.82	34.58	31.33
Wt. of dry soil & container (g)	42.08	45.91	43.16	40.18	31.71	30.89	29.22	31.46	32.93	33.36	38.34	30.23	36.81	36.77	32.52	29.44
Wt. of container (g)	21.72	21.81	26.19	23.41	21.33	24.44	21.78	23.11	21.86	21.24	21.38	21.24	21.34	22.90	18.34	17.34
Wt. of dry soil (Wd) g	20.36	24.10	17.02	10.09	10.16	5.61	7.05	8.05	10.31	11.60	15.18	8.53	11.56	13.52	12.89	11.84
Wt. of moisture (Wm) g	1.78	0.8	1.39	0.83	1.05	0.59	0.80	0.92	1.24	1.40	2.05	1.13	1.76	2.05	2.06	1.89
Moisture content 100(Wm/Wd) %	8.74	3.32	8.17	8.23	10.33	10.52	11.35	11.43	12.02	12.07	13.50	13.25	15.22	15.16	15.98	15.96
Average moisture content (m) %	6.03	8.20	10.43	11.39	12.05	13.38	15.19	15.97								
Dry density = Pb/1 + (m/100) (g/cm ³)	1.46	1.52	1.57	1.66	1.67	1.67	1.60	1.50								
C.B.R. (mseen of top & bottom) %																

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL WITH CEMENT GROUT. Sample: I

Site..... Depth.... Date PERCENTAGE: 4% MDD:

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC:

B.S / C.B.R Mould: 4574g

Wt. of mould & wet soil (W2)g	6251	6322	6386	6397	6440	6483	6457	6399									
Wt. of mould (W1)g	4574	4574	4574	4574	4574	4574	4574	4574									
Wt. of wet soil (W2-W1)g	1677	1748	1812	1823	1866	1909	1883	1825									
Bulk Density (Pb) (W2-W1)/x g/cm	1.68	1.75	1.81	1.82	1.87	1.91	1.88	1.83									
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm³																	
Container no	L	0.32	2	XS	SE	0.0	XP	IX	GM 10	0.1 8	SA	RA J	FO	B10	OM I	BO D	
Wt. of wet soil & container (g)	33.2 4	33.1 8	34. 48	39. 71	38. 46	39. 28	39. 55	39. 61	39.9 1	34. 91	39. 20	40. 53	34. 45	35. 59	31. 60	30. 83	
Wt. of dry soil & container (g)	32.6 4	32.6 4	33. 80	38. 76	37. 25	37. 94	38. 36	38. 48	38.3 4	33. 73	37. 60	38. 70	33. 22	34. 17	30. 10	29. 39	
Wt. of container (g)	21.6 2	21.2 9	23. 43	24. 77	24. 45	21. 57	24. 25	21. 54	21.5 2	21. 45	21. 87	21. 43	23. 01	22. 81	18. 25	18. 34	
Wt. of dry soil (Wd) g	11.0 2	11.3 5	9.0 6	12. 25	13. 45	14. 97	12. 85	12. 18	15.2 7	11. 44	14. 26	16. 21	9.2 8	10. 75	10. 77	10. 32	
Wt. of moisture (Wm) g	0.6	0.54	0.6 8	0.9 5	1.2 1	1.3 4	1.1 9	1.1 3	1.57	1.1 8	1.6 0	1.8 3	1.2 3	1.4 2	1.5 0	1.4 4	
Moisture content 100(Wm/Wd) %	5.44	4.76	7.5 1	7.7 6	8.9 9	8.9 5	9.2 6	9.2 8	10.2 8	10. 31	11. 22	11. 29	13. 25	13. 21	13. 93	13. 95	
Average moisture content (m) %	5.1		7.64		8.97		9.27		10.30		11.26		13.23		13.94		
Dry density = Pb/1 + (m/100) (g/cm ³)	1.60		1.63		1.66		1.67		1.70		1.72		1.66		1.61		
C.B.R. (mseen of top & bottom) %																	

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL WITH CEMENT GROUT. Sample: I

Site..... Depth.... Date PERCENTAGE: 6% MDD:

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC:

B.S / C.B.R Mould: 4574g

Wt. of mould & wet soil (W2)g	6312	6378	6437	6490	6529	6517	6497	6325									
Wt. of mould (W1)g	4574	4574	4574	4574	4574	4574	4574	4574									
Wt. of wet soil (W2-W1)g	1738	1804	1863	1916	1955	1943	1923	1751									
Bulk Density (Pb) (W2-W1)/x g/cm	1.74	1.80	1.86	1.92	1.96	1.94	1.92	1.75									
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm³																	
Container no	0.21	B	GP E	0.25	VT	N	0.10	U	0.15	GM 2	XA	0.9	0.1	GM 8	PL U	PA 5	
Wt. of wet soil & container (g)	34.5 3	36.5 3	36.9 4	35.6 2	36.6 5	33.3 7	40.8 8	34.7 5	40.7 7	44.4 1	42.4 4	44.5 1	40.5 1	41.6 3	35.2 9	35.6 2	
Wt. of dry soil & container (g)	34.0 4	35.8 8	36.2 4	34.8 3	35.6 7	32.4 3	39.3 2	33.5 2	38.8 4	42.5 2	40.1 9	41.9 4	36.9 2	38.3 5	32.8 8	33.0 6	
Wt. of container (g)	23.2 6	21.5 0	25.0 7	22.7 8	23.6 2	21.6 8	22.8 6	21.2 5	21.4 3	26.5 1	23.5 6	22.7 8	21.6 2	21.3 7	18.0 4	17.5 1	
Wt. of dry soil (Wd) g	10.5 5	14.1 9	10.6 8	11.5 2	11.0 0	10.1 9	14.9 9	11.6 1	15.9 3	15.1 6	15.3 2	18.2 9	15.3 0	16.9 8	14.0 6	14.8 7	
Wt. of moisture (Wm) g	0.49	0.65	0.70	0.79	0.98	0.94	1.56	1.23	1.93	1.89	2.25	2.57	2.53	2.78	2.41	2.56	
Moisture content 100(Wm/Wd) %	4.64	4.58	6.55	6.86	8.91	9.22	10.4 1	10.5 9	12.1 2	12.4 7	14.6 9	14.0 5	16.5 4	16.3 7	17.1 4	17.2 2	
Average moisture content (m) %	4.61		6.71		9.07		10.5		12.30		14.37		16.46		17.18		
Dry density = Pb/1 + (m/100) (g/cm ³)	1.66		1.69		1.71		1.74		1.75		1.70		1.65		1.49		
C.B.R. (mseen of top & bottom) %																	

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL WITH CEMENT GROUT. Sample: II

Site..... Depth.... Date PERCENTAGE: 2% MDD:

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC:

B.S / C.B.R Mould: 4574g

Wt. of mould & wet soil (W2)g	6234	6312	6409	6438	6459	6471	6443	6381								
Wt. of mould (W1)g	4574	4574	4574	4574	4574	4574	4574	4574								
Wt. of wet soil (W2-W1)g	1660	1738	1835	1864	1885	1897	1869	1807								
Bulk Density (Pb) (W2-W1)/x g/cm	1.66	1.74	1.84	1.86	1.89	1.90	1.87	1.81								
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm³																
Container no	0.51	RI	u	124	NN	XP	11.0	m	0.25	Rm o	0.1	0.18	0.9	SE	PA 5	BO D
Wt. of wet soil & container (g)	42.9 6	45.7 1	40.6 2	41.0 9	39.6 1	42.5 2	37.4 2	37.1 1	40.1 2	38.4 1	38.1 5	40.1 5	37.4 6	38.1 1	34.5 6	33.6 9
Wt. of dry soil & container (g)	41.5 2	44.2 4	41.9 3	39.7 4	38.1 6	41.1 o	36.0 1	35.8 9	38.5 4	36.9 3	36.7 3	38.3 6	36.0 1	36.5 5	32.7 4	32.0 7
Wt. of container (g)	21.8 6	21.2 4	21.2 5	21.9 8	21.3 4	24.2 5	21.7 2	22.9 0	22.7 8	21.7 8	22.8 6	21.4 2	22.7 8	22.4 5	17.5 1	18.3 4
Wt. of dry soil (Wd) g	19.6 6	23.0 0	17.8 6	18.5 8	17.1 0	17.4 2	14.2 9	13.0 9	15.3 1	14.4 4	13.1 6	16.6 4	12.6 7	13.6 4	14.8 2	13.3 1
Wt. of moisture (Wm) g	1.44	1.47	1.31	1.35	1.45	1.42	1.41	1.22	1.58	1.48	1.42	1.79	1.45	1.56	1.82	1.62
Moisture content 100(Wm/Wd) %	7.32	6.39	7.33	7.27	8.48	8.15	9.87	9.32	10.3 2	10.1 1	10.7 9	10.7 6	11.4 4	11.4 4	12.2 8	12.1 7
Average moisture content (m) %	6.86	7.30	8.32	9.60	10.22	10.76	11.44	12.23								
Dry density = Pb/1 + (m/100) (g/cm ³)	1.55	1.62	1.70	1.70	1.71	1.72	1.68	1.61								
C.B.R. (mseen of top & bottom) %																

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL WITH CEMENT GROUT. Sample: II

Site..... Depth.... Date PERCENTAGE: 4% MDD:

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC:

B.S / C.B.R Mould: 4574g

Wt. of mould & wet soil (W2)g	6323	6405	6429	6453	6468	6492	6460	6389								
Wt. of mould (W1)g	4574	4574	4574	4574	4574	4574	4574	4574								
Wt. of wet soil (W2-W1)g	1749	1831	1855	1879	1894	1918	1886	1815								
Bulk Density (Pb) (W2-W1)/x g/cm	1.75	1.83	1.86	1.88	1.89	1.92	1.87	1.82								
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm ³																
Container no	IX	0.21	0.10	GM 10	B	0.5	XS	N	GR E	B10	F0	XA	L	111	PL U	0.36
Wt. of wet soil & container (g)	34.12	32.09	40.15	42.17	38.02	34.96	39.18	40.05	41.65	42.68	38.17	40.32	40.59	42.44	39.68	34.97
Wt. of dry soil & container (g)	33.63	32.38	39.26	41.13	37.01	34.28	38.26	38.80	40.57	41.37	37.09	39.09	38.35	40.72	37.73	33.55
Wt. of container (g)	21.54	19.69	22.86	21.52	21.50	23.11	24.77	21.68	25.07	22.81	23.01	23.56	21.62	21.81	18.04	18.34
Wt. of dry soil (Wd) g	11.53	11.37	16.15	19.61	15.57	10.21	13.30	17.35	15.15	18.29	13.11	14.65	16.73	18.57	19.52	14.35
Wt. of moisture (Wm) g	0.49	0.52	0.89	1.04	1.01	0.68	0.92	1.25	1.08	1.31	1.08	1.23	1.53	1.72	1.95	1.42
Moisture content 100(Wm/Wd) %	4.25	4.57	5.51	5.30	6.49	6.66	6.92	7.20	7.13	7.16	8.24	8.40	9.15	9.26	9.99	9.90
Average moisture content (m) %	4.41	5.41	6.58	7.06	7.15	8.32	9.21	9.95								
Dry density = Pb/1 + (m/100) (g/cm ³)	1.68	1.74	1.75	1.76	1.76	1.77	1.71	1.66								
C.B.R. (mseen of top & bottom) %																

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL

USING STANDARD/HEAVY COMPACTION

Job...STABILIZATION OF SANDY SOIL WITH CEMENT GROUT. Sample: II

Site..... Depth.... Date PERCENTAGE: 6% MDD:

Amount retained on 20mm B.S. Sieve..... Total weight of sample..... OPT. MC:

B.S / C.B.R Mould: 4574g

Wt. of mould & wet soil (W2)g	6412	6423	6449	6461	6484	6522	6487	6356								
Wt. of mould (W1)g	4574	4574	4574	4574	4574	4574	4574	4574								
Wt. of wet soil (W2-W1)g	1838	1849	1875	1887	1910	1948	1913	1782								
Bulk Density (Pb) (W2-W1)/x g/cm	1.84	1.85	1.88	1.89	1.91	1.95	1.91	1.78								
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X= 915.3cm ³																
Container no	GM 8	0.0	0.32	2	0.13	GE	LT	0.17	SA	0.15	0	RA J	5	A	PA 9	OM I
Wt. of wet soil & container (g)	40.44	43.15	38.19	42.06	43.72	45.61	43.21	44.37	38.51	39.60	43.11	40.56	41.67	40.89	39.51	38.23
Wt. of dry soil & container (g)	39.45	41.97	37.27	41.03	42.40	44.27	42.02	42.92	37.46	38.44	41.09	38.88	39.65	39.13	37.26	36.14
Wt. of container (g)	21.37	21.57	21.29	23.41	21.33	21.38	23.62	23.20	21.87	21.39	20.19	21.43	21.24	21.62	17.34	18.25
Wt. of dry soil (Wd) g	17.95	20.56	15.79	17.61	21.20	20.83	18.54	20.01	15.16	16.60	20.90	16.92	18.41	17.06	19.98	17.83
Wt. of moisture (Wm) g	0.99	1.18	0.92	1.03	1.32	1.34	1.19	1.29	1.05	1.16	2.02	1.68	2.02	1.76	2.25	2.09
Moisture content 100(Wm/Wd) %	5.52	5.74	5.83	5.85	6.23	6.43	6.42	6.45	6.93	6.99	9.67	9.93	10.97	10.32	11.26	11.72
Average moisture content (m) %	5.63	5.84	6.33	6.44	6.96	9.80	10.65	11.49								
Dry density = Pb/1 + (m/100) (g/cm ³)	1.74	1.75	1.77	1.78	1.79	1.78	1.73	1.60								
C.B.R. (mseen of top & bottom) %																

APPENDIX II



Use of hand held GPS device to obtain co-ordinate of point of collection of sample



At the University of Benin soil lab carryout the required soil experiment