ASSESSING THE USE OF SEWAGE SLUDGE CAKE ASH IN THE STABILIZATION OF BLACK COTTON SOILS

AARON RACHKARA

S20B31/219

A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

April, 2025

UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

ABSTRACT

This research addresses the improvement of the engineering properties of black cotton soils treated with sewage sludge cake ash for use in the subgrade layer. The property of black cotton soils that this research banks on are heavily influenced by the high amount of montmorillonite clay mineral of upto about 70% to 80%. These soils fall under the order Vertic Cambisols usually formed from the weathering of basaltic rocks. It is noted that they are defined by a very low California Bearing Ration (CBR), high plasticity index and do not do well when subjected to loading in the unconfined compressive strength test (UCS). In addition to these physical properties, the chemical aspects also play a huge role since these soils have a high affinity for water. It is on these factors that the use of sewage sludge cake ash was proposed since the ash has a lot of pozzolanic compounds that when treated with the montmorillonite will produce a cementitious compound. The soil sample was picked from Kitgum Orom road. These tests were the Atterberg limits, particle size distribution, California bearing ratio, Unconfined compressive strength after treatment and the sewage sludge cake ash was subjected to an X-ray diffraction test. The tests confirmed it was indeed black cotton soil and that the ash had the necessary compounds to act as a pozzolan. The soil was treated with the black cotton soils at 5%, 10%, 15% and 20%, the optimum was found to be at 15% giving a CBR of 15.3%, plasticity index of 14.8% and a UCS of 0.33MPa. This deduced that the SSCA could improve the soil to the level of a G15 subgrade material with addition of some bio additives to improve its load bearing capacity.

DECLARATION

I RACHKARA AARON solemnly declare that this research proposal is based on information gained on my own from the literature reviewed and the research gap identified. I assert that the statements made, photographs attached and conclusions drawn are of my own effort and do not comprise any material previously published or written by another person except where due reference is made in text and the authors mentioned accordingly. I further certify that I prepared this research proposal for my academic requirements and not for any other purpose.

Signature: ………………………………………. Date: ……………………………………………….

DEDICATION

I dedicate this report to my mother who has seen me through school and has been a pillar of support, my family and my academic supervisor who guided me through the project.

ACKNOWLEDGEMENTS

I would like to thank the almighty God, the king of Glory for the grace He gave me during this period and the spirit of wisdom and understanding, indeed with God, all things are possible. I would love to appreciate the efforts of my project partner Mr. Luggya Anthony for the constant dedication and effort, in the same way, appreciation goes to my project supervisor Eng. Dr. Morris Oleng the expert guidance and support. My sincere gratitude goes to Stirling Laboratory for the technical support in carrying out the different tests. In addition, I would like to thank Mr. Rodgers Tayebwa for the technical guidance in carrying out engineering research and design projects.

APPROVAL

This research report by RACHKARA AARON was carried out under my supervision and guidance and he has finalized the final year and design project.

Signature……………………………………. Date…………………………………………

ENG. DR. MORRIS OLENG.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BCS - Black Cotton Soil

UCS - Unconfined Compressive Strength

CBR - California Bearing Ratio

ASTM - American Society for Testing of Materials

LL - Liquid Limit

PI - Plastic Index

PL - Plastic Limit

OMC - Optimum Moisture Content

ASCM - Alternative Supplementary cementitious material

MDD - Maximum Dry Density

AASHTO - American Association of State Highway and Transportation Officials

SSA - Sewage Sludge Ash

SSCA. - Sewage Sludge Cake Ash

MoWT. - Ministry of Works and Transport

BS - British Standards

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Black cotton soils are a type of soil usually identified by their dark color and high montmorillonite clay mineral content ranging from thirty percent to up to seventy percent this is the main factor that distinguishes it from other expansive soils, they usually have a minimum depth up to twenty-five centimeters. It is these unique properties that pose great risks, making them a great hindrance to the construction of structures and pavements (Feng et al., 2021). The characteristics of this soil that lead to failures are dominated by the behavior of the high montmorillonite clay mineral. This clay mineral has an unstable lattice structure which suffers from interlayer expansion during wetting cycles and in drying cycles release these same hydroxyl ions. This produces what we call the swelling and shrinking behavior as a result of variations in the moisture content, leading to stress on roads and pavements, causing cracks and potholes (Guru Prasada and Alireza Bahrami, 2023). During dry seasons, the soils, the soils contract significantly causing cracks in foundations and infrastructure. Conversely, during wet seasons, they expand considerably, exerting enormous pressure on structures and leading to potential failures. The high expense of rebuilding damaged structures has highlighted the need for more reliable analysis of such soils, as well as techniques to eliminate or at least lessen the effect of volume change in the soil while increasing strength. As a result of the recent increasing industrialization and living standard, the amount of sewage sludge produced all over Uganda is exponentially increasing day by day. According to the World Bank, Uganda has an annual production of 292 million liters of sewage sludge. Sewage sludge can be defined as a waste material from the treatment of waste water. If disposed of poorly in the environment, sewage sludge poses significant health hazards such as harm to aquatic life, waterborne diseases and pollution.

However, this sludge has considerable potential and can be profitably used in stabilizing projects. Soil stabilization techniques are crucial for mitigating problematic characteristics of Vertic Cambisols by ensuring stability of pavements built on them. Traditional stabilization procedures, such as lime and cement treatment, while successful, are prone to shrinkage cracks, costly and have environmental consequences. Thus, there is a growing need for a more sustainable cost-effective stabilization material that will counter attack the setbacks of the existent stabilization materials without compromising the engineering properties of the soil. Sewage sludge cake ash (SSCA), a by-product generated during the incineration process of sewage sludge in wastewater treatment plants is a promising solution due to its mineral composition and ability to improve soil qualities. Valuable minerals found in SSCA include silica, alumina, calcium oxide and iron oxide, which contribute to the formation of cementitious compounds and enhance the strength and durability of soils.

This research aims to investigate the effectiveness of SSCA in stabilizing black cotton soils, focusing on its impact on soil strength, plasticity and swelling behavior. Through a series of laboratory tests, optimal dosages of sludge cake ash for effective stabilization of black cotton soils will be determined. The long-term behavior of the stabilized soils will also be analyzed to ensure their durability and performance over time. By understanding the benefits and limitations of SSCA, this study will contribute to the development of sustainable and cost-effective solutions for managing black cotton soils.

A MAP OF UGANDA SHOWING DIFFERENT SOIL TYPES

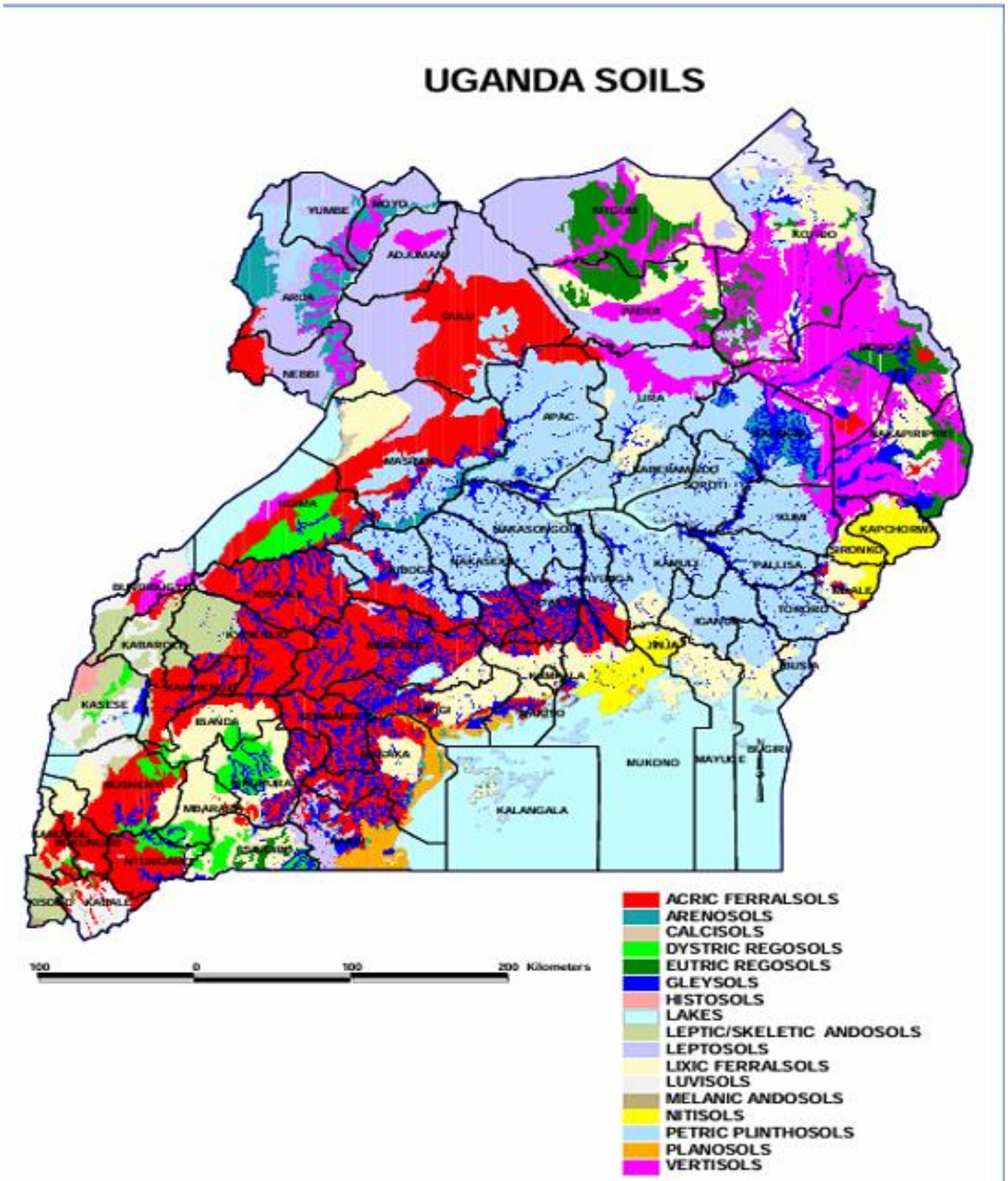


Figure 1 A Map of Uganda showing different sail types

1.2 PROJECT TITLE

The suitability of using sewage sludge cake ash in the stabilization of black cotton soils for subgrade construction.

1.3 PROBLEM STATEMENT

Highway and Structural engineers confront numerous challenges while in construction in Black Cotton Soil due to their swell and shrink behavior. The presence of montmorillonite is responsible for the swelling and shrinkage as a result of variations in the moisture content, leading to stress on roads and pavements, causing cracks and potholes (Guru Prasada and Alireza Bahrami, 2023). According to a study by Ocet, T. in 2020, Orom road in Kitgum district faces a challenge of cracks due to the presence of black cotton soils. The soil was tested and found to have a high plastic index of 43.2% which are above the limit of 25% for G15 material and 30% for G7 material. The soil was graded as A-7-6 indicating the high presence of clay and its unsuitability for subgrade construction. In order to improve the quality and durability, the soil can be stabilized however the traditional popular stabilizers like cement are prone to shrinkage cracks thus the use of sewage sludge cake ash, a by-product generated during the incineration of sewage sludge in wastewater treatment plants. Its pozzolanic properties contribute to its efficiency in reducing the plasticity of the soil and modifying the bearing capacity.

1.4 OBJECTIVES OF THE STUDY

1.4.1 MAIN OBJECTIVE

To assess the suitability of using sewage sludge cake ash in the stabilization of the black cotton soils.

1.4.2 SPECIFIC OBJECTIVES

1. To determine the engineering properties of the black cotton soil.

2. To examine the pozzolanic properties of the sludge cake ash.

3. To ascertain the performance of the black cotton soil treated with varying percentages of the sewage sludge cake ash.

1.5 RESEARCH QUESTIONS

1. What are the key engineering properties of the untreated black cotton soil that could contribute to its instability issues?

2. What are the essential chemical properties of the sewage sludge cake ash that make it suitable for stabilizing black cotton soil?

3. What is the appropriate sludge cake ash dosage for effective stabilization of black cotton soils?

1.6 JUSTIFICATION

Black cotton soils present adverse construction issues because of their tendency to shrink and expand drastically in response to moisture variations. Uncontrolled expansive soil movements cause cracking, heaving, and settling, requiring costly repairs and upkeep. A study by Chen, Z., published in 2023 found that expansive soil movements were responsible for 42% of foundation failures. Stabilizing these soils is crucial for ensuring the safety and durability of infrastructure.

Sludge cake ash is a byproduct generated from the incineration of dewatered sewage sludge at temperatures of 800 degrees Celsius (optimum temperature for the activation of the pozzolanic properties) in an electric furnace for a period of two hours. Sludge cake ash primarily consists of inorganic minerals that weren't burned during incineration, the main components being silicon, calcium, iron, phosphorus, and aluminum. This ash is able to reduce the plasticity and improve the strength of the soil due to its pozzolanic properties. Studies have reported that sludge cake ash possess pozzolanic properties similar to class C fly ash (Aparna, P., 2022). The pozzolanic reaction between sludge cake ash in the presence of water and the montmorillonite clay in black cotton soil leads to the formation of a calcium silicate hydrate ($C - S - H$) gel that binds the soils particles together increasing the strength and stability of the soil at the same time reducing its susceptibility to volume changes. Additionally, the gel, binds soil particles together to reduce space available for water to separate the clay particles which lowers the plasticity of the soil making it less prone to cracking.

<u>Ionic reactions for the formation of Calcium Silicate Hydrate Gel</u>

- $Ca(s) + H2O(l) \rightarrow Ca2+(aq) + 2OH-(aq)$

The solid calcium hydroxide present in the sludge cake ash is hydrolyzed to release Ca2+ and $OH-$

• $Ca2+(aq)$ + $Silicate(clay)$ +$2OH-(aq) \rightarrow C - S - H(gel)$ +$H2O(l)$

The Ca2+ and $OH-$ react with the silicate (clay) which represents the silicate tetrahedral units present in the montmorillonite clay structure. The resultant product is the calcium silicate hydrate gel.

1.7 HYPOTHESIS

Sewage sludge cake ash, with its pozzolanic capabilities, will improve the compressive strength and load bearing capacity of black cotton soil by making it less prone to cracking, lowering its swell potential and increasing its shear strength.

1.8 SIGNIFICANCE

Lime which is normally used as a chemical stabilizer is prone to agglomeration which leads to further cracking. With the current crisis of global warming, the traditional stabilizers increase carbon emissions which make them a danger to the environment. The proposed stabilizer when incinerated helps to combat the issue of waste management and this is because even though farmers and other parties utilize the sewage sludge, waste is still produced every day and hence managing it is still a problem.

1.9 RESEARCH SCOPE

1.9.1 CONTENT SCOPE

The potential of Sewage Sludge Cake Ash in stabilizing black cotton soil for construction is discussed in this paper. The objective is to assess the effect of SSCA on BCS with respect to different properties like bulk density, water absorption, efflorescence, plasticity, compressive strength, and shrink-swell behavior. The ultimate purpose of this paper is to determine whether SSCA can indeed enhance the engineering qualities of the soil, giving a more affordable, environmentally friendly alternative to other expensive conventional means of soil stabilization.

1.9.2 GEOGRAPHICAL SCOPE

The study is centered on black cotton soils from Kitgum-Orom road in Kitgum district, Northern Uganda

CHAPTER TWO: LITERATURE REVIEW

2.0 INTRODUCTION

This section addresses various studies done that are similar and relatable in the stabilization of black cotton soils. The different methods of soil stabilization are also discussed with the focal point on chemical stabilization using sewage sludge cake ash.

2.1 CLASSIFICATION, PHYSICAL AND CHEMICAL PROPERTIES OF BLACK COTTON SOILS

2.1.1 Black Cotton soils

These soils are generally dark in color and this is attributed to the to the minimal concentrations of titanium oxide (IRJET,2021). They can also be called Vertic Cambisols. They have a high montmorillonite content which is a clay mineral and it is this clay mineral that leads to the shrink-swell behavior, the cause of the challenges faced when used in construction. As it passes through wetting and drying cycles, the soil keeps expanding and cracks develop deeper and deeper causing failures. These soils are usually found in semi-arid regions. Another property that leads to failures are the high plasticity index and very low load bearing capacity and this necessitates stabilization when being used as a sub-grade (Amadi et al., 2021).

2.1.2 Classification of Black Cotton Soils

Various parameters like mineralogy, engineering behavior, and particle size distribution are used to classify black cotton soils. According to their mineralogy, montmorillonite mineral is the ruling constituent of the composition and character of black cotton soils. Kaolinite and illite are the other predominant constituents that sum up in the structural constituent in a minor sequence (Sharma & Reddy, 2020). Iron and magnesium compounds give black color to the soil, and mechanical strength is given by quartz, which occurs in trace amounts. Calcium carbonate is found in some locations, predominantly as lime nodules, which give alkalinity to the soil. Together, these minerals impart the typical chemical and physical characteristics to this soil, which vary in composition and behavior.

As per the American Association of State Highways and Transportation Officials (AASHTO), the soil is additionally classified as A-7-5 or A-7-6. It describes black cotton soils as very plastic with poor subgrade quality and not satisfactory as a material for road construction without being enhanced by stabilizing (Murthy, 2010).

According to the Unified Soil Classification System, this soil would be broadly categorized as CH (High Plasticity Clay) if its Plasticity Index (PI) is over 20 and Liquid Limit (LL) is over 50%. It would also be categorized as CL (Low Plasticity Clay), though this is extremely uncommon when the montmorillonite content in the soil is very low (Craig, 2012).

2.1.3 Physical Properties of Black Cotton Soils

CBR of Black Cotton Soil

One of the most common penetration tests used for determining the resistance of soils to be used as a subgrade in highway and pavement construction is the California Bearing Ratio. The California Transportation Department created the CBR test, which measures soil resistance to penetration in a laboratory environment. The principle of the test is to compact the cylindrical mold with soil densely, and then impose a specified force by a plunger through a uniform penetration rate. CBR value represents the percentage value of resistance provided by standard crushed stone material, and a test of resistance of two different soil depths (5 mm and 2.5 mm) is performed.

$$\text{CBR\%} = \left(\frac{Measured\ Load}{Standard\ Load}\right) * \ 100\%$$

In order to determine the effect of moisture on strength, the test is usually carried out under humid conditions (Arora, 2023). These soils possess low values of CBR between 2% and 6% when wet. This is because the particles have high density, including clays like montmorillonite. This clay is normally known to have high water affinity as well as high swelling capacity, which reduces the bearing capacity of the soil significantly.

Plasticity of Black Cotton Soil

The liquid limit and plasticity index are commonly used to measure plasticity. The British Standards 1377-2:1990 for the Atterberg Limits can be used to determine these parameters in a laboratory. Testing of these factors is crucial since the data obtained can be used to determine if the soil can flow freely in drained conditions, cannot be molded into a particular shape, or even breaks easily under dry conditions.

Black cotton soils have a high level of potential deformation on moisture intake since their liquid limit is above 40% and their plasticity index may be high, typically greater than 20 (Das & Roy, 2022). Swelling clays, primarily montmorillonite, with the ability to absorb are the cause of such high plasticity.

Black cotton soil with a higher plasticity index of more than 20 is highly cohesive and doesn't change shape even when subjected to an external force of a moderate degree. under addition refers to the fact that such soil is difficult to work with when the conditions are very wet and non-compacting (Verma et al., 2021). Highly plastic soils are often not suitable for construction unless they are treated or modified to become more stable.

2.1.4 CHEMICAL PROPERTIES OF BLACK COTTON SOIL.

Black cotton soils contain 30% to 70% montmorillonite clay minerals, according to Aminu et al. (2023). Montmorillonite results from the breakdown of basic igneous rocks and has a lattice structure that allows water molecules to be absorbed between layers as volume expands. Illite is a common mineral found in black cotton soil, an intermediate mineral between montmorillonite and kaolinite that has a medium swelling capacity (Mitchell, 1993).

Relative to illite and montmorillonite, kaolinite is less susceptible to volume alteration and more stable despite being found in small amounts. The engineering properties of the soil are based on the quantities and occurrence of the various clay minerals.

Though geographically varying in chemical composition, black cotton soil commonly contains the following major oxides:

Table 1 A Table Showing Varying

MINERAL	COMPOSITION
Silica	45% to 65%
Alumina	10% to 25%
Iron Oxide	5% to 15%
Calcium Oxide	1% to 5%
Potassium Oxide	Trace amounts

2.2 SOIL STABILIZATION

Increasing the shear strength parameters of the soil to increase its bearing capacity is another definition of soil stabilization. It means applying additional components to enhance its characteristics. Binding agents are used in soil stabilization to increase major geotechnical characteristics like durability, permeability, strength, and compressibility. Particularly when the original soil lacks sufficient support to withstand structural stresses, it is a crucial procedure. The soil behavior, such as responsiveness to moisture change, Atterberg's limitation, and stability, is improved by incorporating materials with natural binding properties (Ellappan, Arumugam, & Muthukumaran, 2020).

The two main modes of soil stabilizing techniques—mechanical and chemical stabilizing—are elaborated further below;

2.2.1 MECHANICAL STABILIZATION

The aim of mechanical stabilization is to improve stability by physically changing the soil characteristics by compaction or adding additional material. This may be done by mixing two or more natural soils together to form a composite whose qualities are better than those of its separate parts. During the improvement in strength and load-carrying capacity of soil, voids are reduced and its density is increased by utilizing mechanical energy in the form of machines such as rammers and rollers. Material like geotextiles, geogrids, and geomembranes stiffen soil layers. Geosynthetics improve the structural stability of soil by distributing loads and minimizing excess deformation.

2.2.2 CHEMICAL STABILIATION

Chemical stabilization is treatment in which the chemical and physical characteristics of the soil are changed by introducing chemicals or additives. This increases the strength, endurance, and water resistance of the soil along with changing its plasticity. In order to change the character of the soil, cement, lime, fly ash, and other waste materials from agriculture are employed as additives. The additives work by substituting cations with the weaker soil for the purpose of making cementitious compounds.

1. **Cement Stabilization**

One of the most prevalent techniques that have been very effective in achieving the desired strength of the soils is cement stabilization, which is generally used when lime cannot be used for the soil to be stabilized by it. Cement stabilization is used by techniques such as deep mixing or jet grouting to improve the engineering behavior of weak soils. When water is mixed in cement, there is a hydration reaction to form a hydrate silicate gel, which packs soil grains together, hugely increasing the load bearing capacity of the soil.

Thus, the subgrade is more resistant and tougher to external forces like variations in moisture and loadings due to traffic. Once fine-grained soils (sils and clays) have been cement stabilized, their plasticity index declines, which limits the possibility for them to swell when exposed to water.

Stabilized subgrades exhibit greater resistance against water penetration and erosion caused by weathering. By preventing the entry of water, the horizon of cement stabilizing creates a hard, impermeable surface that prolongs pavement life while minimizing erosion.

It is possible by reducing the total thickness of pavement construction without compromising performance because the cement-stabilized subgrade is much stronger than un-stabilized soilin addition, Material costs and construction time are conserved.

Limitations of cement stabilization

• Cement stabilization can be done using not all, but some of the soil types. For instance, various stabilization treatments might be necessary to stabilize extremely organic soils or to stabilize sulfate-rich soils.

• Because inadequate curing conditions (too high temperatures or too low humidity) can lead to insufficient strength development, curing needs to be watched carefully.

• Because of the brittle cement soil matrix formed, cement-stabilized layers can crack if the subgrade undergoes large volume changes.

2. **Lime stabilization**

This technique, which consists of the addition of different types of lime like hydrated high calcium lime, dolomite lime, and calcite fast lime, is an economic method of stabilizing soil. It triggers a range of chemical reactions such as flocculation, pozzolanic reactions, and cation exchange, apart from clayey soils. The elasticity and swelling property of the soil decrease when calcium ions from lime displace sodium and other ions. Through making finer particles of the soil agglomerate, workability is enhanced and the plasticity of the soil is reduced (Kamon & Nontananandh, 2012).

Improved compressive strength in lime-stabilized soils improves the load-carrying capacity of the subgrade and provides a more stable road base and pavement (Dash & Hussain, 2012).

It can be converted into biogas and electricity for household use and even large-scale utilization. The end product is fed back into the national grid in some areas.

They are used to make building materials; research mentions that twenty percent by weight of dry sludge in clay bricks did not have a significant impact on functional characteristics. (Liew et al.2004)

2.3 SEWAGE SLUDGE CAKE ASH (SSCA)

The final by-product of wastewater treatment is sewage sludge, which is dried in sludge beds before being incinerated to create sewage sludge ash. The large amounts of sludge created are greatly reduced by this process to around 70% of their initial make-up (Chen et al., 2022).

The daily production of sludge is increased by urban population growth, requiring sustainable management practices. With its high population and rapid urbanization, the capital city of Uganda, Kampala, generates a large volume of sewage sludge (Nyende & Okot-Okumu, 2015).

The environment becomes polluted when sewage sludge is discarded in landfills after cleansing with lagoon systems and biological treatment. However, if Uganda invests in incineration technology, it can generate SSA on an enormous scale. With the advancement of urbanization and environmental sewage sludge cake ash can be a good resource in various areas of science.

2.3.1 CHEMICAL PROPERTIES OF SSCA

Apart from trace heavy metals like lead, zinc, and copper, the major composition of sewage sludge cake ash includes inorganic phases like silica, alumina, calcium oxide, and phosphorus (Wang et al., 2018). Such chemical makeup of the ash can be explained by its source, chemicals used for treatment, and incineration conditions.

A non-destructive analytical method called the X-ray fluorescence test can be used to ascertain the chemical content of the sludge ash. Through this, the existence and quantities of major oxides that are the foundation of its pozzolanic activity can be determined. Specifically, when SSA is irradiated with X-rays, the present elements emit secondary X-rays, which are measured and quantified to generate a detailed report on the chemical composition of SSA. SSA's ability to produce cementitious compounds is primarily founded on the presence of SiO2, Fe2O3, and Al2O3. Based on ASTM C618, the pozzolanic material should contain at least 70% by weight of silicon dioxide, aluminum (III) oxide, and iron II oxide. The oxides, in total, should exhibit a suitable level of ash content. Furthermore, the ash's pozzolanic activity is restricted by the temperature with which it is burned, by its rate of cooling, and by the particle size.

2.3.2 BURNING TEMPERATURE OF SEWAGE SLUDGE

The sewage sludge, when it is burnt within the range of 600 to 1000°C, modifies its chemical composition and thus influences the pozzolanic behavior. The sludge can produce different proportions of reactive ash when burnt at individual temperatures, e.g., 700°C, 800°C, or 850°C. This can impact the workability of cement products.

Particularly, amorphous ash is preserved during incineration of sewage sludge at 800°C, whereas amorphous silica more readily crystallizes at a temperature exceeding 800°C. In order to investigate the influence of combustion temperature on the microstructure and pozzolanic activity of the generated sewage sludge ash, M. A. Tantawy et al. (2012) conducted the Chappelle test. Although crystallization is promoted at elevated temperatures, amorphous silica will deposit residual carbon from incomplete combustion below 800°C. Burning SSA at about 800°C is necessary to maintain ideal pozzolanic activity; temperatures over this point cause more amorphous silica to crystallize, which lowers pozzolanic activity.

2.3.3 APPLICATIONS IN CONSTRUCTION MATERIALS

SSCA has immense potential to be used in the construction sector, particularly for brick, mortar, and concrete production. To assess SSCA's potential as an environmentally friendly alternative, scientists have investigated its use as a replacement for conventional aggregates or cementitious materials.

According to research carried out by Chimenos et al. (2019), the addition of SSCA in place of some Portland cement improved the compressive strength of the concrete as well as reducing the material's carbon footprint in general. The pozzolanic nature of SSCA forms calcium silicate hydrates (C-S-H), further adding to the strength of the material. While it is effective to replace conventional aggregates, there is still a research gap to reduce the impact of the heavy metals in the sludge. These metals' possible leaching creates environmental issues.

2.3.4 CHALLENGES AND LIMITATIONS RELATED TO THE USE OF SEWAGE SLUDGE CAKE ASH

• Sewage sludge ash usually contains heavy metals like lead, cadmium, mercury, and arsenic, which can cause serious damage to public health and the environment if not given proper treatment before use. These contaminants can either settle in the water table or percolate into the ground, reducing soil fertility and possibly causing damage to agriculture and wildlife production.

•The possibility of toxic substances from SSA leaching into the environment is one drawback. It is possible to immobilize some of the pollutants in the ash structure by stabilization techniques, but other environmental processes like acid rain can leach the pollutants and guide them into water bodies, thereby contaminating water sources.

• The application of SSA in soil changes the pH values, which could be detrimental to the health of soil and restrict plant growth. SSA has been seen to increase the alkalinity of soil in some cases, which could lead to nutrient imbalance. For example, increased pH would make essential nutrients like iron, manganese, and phosphorus less accessible, which would influence plant growth (Singh & Agrawal, 2010).

2.4 SUBGRADE LAYER

Subgrade is the foundation of a road pavement structure, which provides the road with the capacity to sustain traffic loads and gives support to all the layers below it. The long-term road performance, strength, and durability are all directly influenced by its quality. The stability and load-carrying capacity of the subgrade depend upon the available type of soil, which can be clay, silt, sand, or gravel. In order to avoid pavement failure that results in costly maintenance in terms of cracks, rutting, and potholes, the subgrade should be properly prepared. The road engineers achieve a more resistant and stronger pavement structure by providing a good foundation.

This is done to reduce the water content in the sludge for volume reduction.

Table 2 A Table Showing standards for a G15 material

Material properties	**Accepted values**
CBR (%) BS1377 part4	>15 (after 4 days of soaking)
CBR swell (%) BS1377 part4	<1.5 measured at BS- heavy compaction
Atterberg limits	
Liquid limit BS1377 part2	<41
Plasticity index BS1377 part2	<25

2.5 FURTHER RESEARCH

A great deal of research study on the chemical and mechanical stabilization of soil has been conducted over the years, considering the use of waste materials for a sustainable and economic approach. Focusing on the pozzolanic nature of sewage sludge ash (SSA), various research studies over the past few decades have explored its potential as a sustainable material for construction. Below is a literature review of previous research focused on the pozzolanic properties of SSA.

a) Monzo et al. (1999). The study assessed the feasibility of using SSA as a pozzolanic admixture in blended cement by applying dosages of 10%,15%, and 20% thereof as a partial cement substitution. Compressive strength of mortar cubes was determined after 7-day cured, 28 days cured and 90 days cured. The 10% SSA mixture attained 20% of the compressive strength as compared to the control by the 90th day only, though the 15% and 20% SSA mixtures gave slightly low values because of dilution of cementitious material. Observations made in the present work revealed that SSA could be successfully incorporated in to cement matrix to improve concrete durability in terms of the long-term compressive strength. The study identified the availability of silica SiO_2 and alumina Al_2O_3, as factors that play a role in enhancing the pozzolanic activity of the ash. However, the research stressed the need to control SSA chemical content in every aspect since heavy metals as well as unburned organic matter could their presence may even be detrimental to the performance of the material in question.

b) In 2003, Ilic et al. Investigated the impact of thermal treatment on the pozzolanic characteristics of sewage sludge ash (SSA). They compared untreated SSA with treated samples that incorporated dosages of 0%, 5%, 10%, and 20% in blended cement formulations. The results indicated that untreated SSA displayed low pozzolanic activity, yielding compressive strengths of approximately 15 MPa after 28 days of curing. Conversely, SSA that underwent thermal treatment showed enhanced reactivity, with compressive strengths rising to around 25 MPa when used at a 10% replacement level. At a 20% incorporation of SSA, the compressive strength further improved to nearly 30 MPa, highlighting the significant benefits of heat treatment. Their findings indicated that incinerating sewage sludge at elevated temperatures, approximately 800°C, facilitated the crystallization of silicates and aluminates, which in turn substantially modified its chemical structure, rendering it more effective as a pozzolanic material for construction purposes.

c) The following research by Pan et al. (2017), to assess the pozzolanic characteristics of sewage sludge ash (SSA) in comparison to conventional fly ash within blended cement formulations. The findings indicated that although SSA exhibited pozzolanic activity, its reactivity was inferior to that of fly ash, a result of its more intricate chemical makeup. However, SSA was found to facilitate strength development in concrete during the later stages of curing (28 to 56 days), a phenomenon the authors linked to the generation of secondary calcium silicate hydrate (C-S-H) gels. The study underscored the potential of SSA as a partial replacement for fly ash, while also suggesting that pre-treatment could be beneficial in enhancing its reactivity.

Generally, various studies by different researchers pinpoint the effectiveness of partially replacing cement with SSA in mortar plus concrete ratios and its efficacy in the chemical and mechanical stabilization of Sandy soils. However, sewage sludge cake ash can be used to improve the physical and chemical properties of black cotton soils due to its pozzolanic properties which have been tested in various research papers.

CHAPTER THREE: METHODOLOGY

This chapter explains how the objectives of my project are going to be attained, the steps involved sample collection, material used and the tests that will be done on the soil samples.

3.1 MATERIALS

Black cotton soil

The black cotton soil was obtained from Orom road in Kitgum district at the coordinates 3.2625616136579 longitude: 33.0375100672245 at a depth of 1.5m to avoid contamination of organic matter and ensure a variety of different soil layers. The soil samples will be put in airtight polythene bags to retain the moisture content of the soil and then transported to a laboratory for testing. The soil sample was then airdried for 48 hours then riffled in preparation for the tests.

GEO REFERENCING COORDINATES WITH GIS MAP SYSTEM

The map showing different soil types in Uganda was georeferenced using ArchGis pro with the decimal degree coordinates latitude: 3.2625616136579 and longitude: 33.0375100672245 for Kitgum Orom road that we obtained from the field. This confirms that the sample point lies in the region that has Vertic Cambisols in the country, hence further confirming that the sample was black cotton when added to the results from the lab tests.

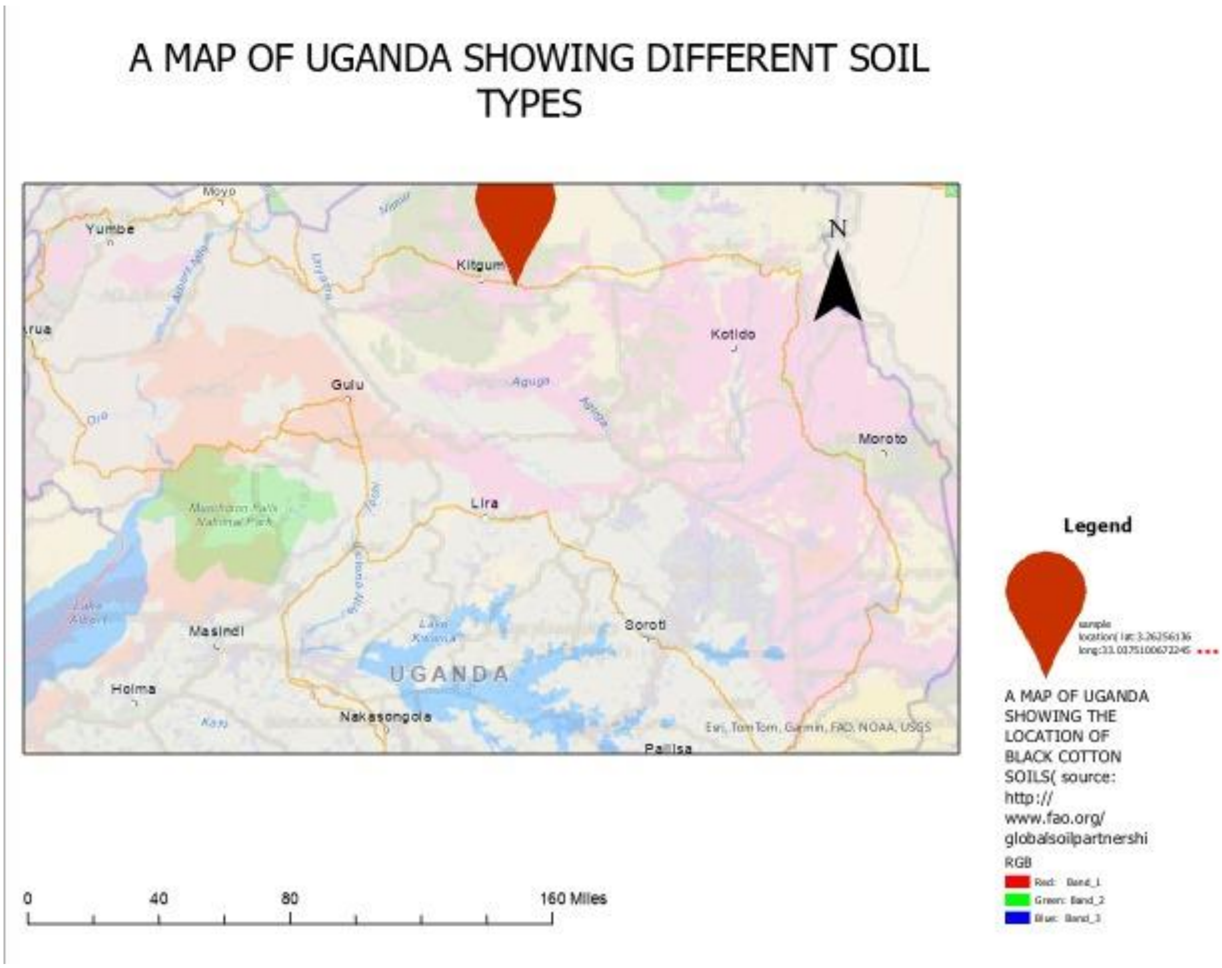


Figure 2 A GIS Map of Uganda Showing the location of black cotton soils

Sewage Sludge Cake Ash

The Gulu Sewage Treatment Plant provided the sewage sludge cake. It was a weight of 250 kg after it was collected in sacks. It was then burned for two hours at 800°C in an electric burning furnace. This was carried out in an effort to activate its pozzolanic properties. According to a 2020 research study of Abdalla Elham, incineration of sludge ash at 8000C has higher pozzolanic activity than other temperatures of incineration of sludge ash. The pozzolanic character of the ash is denatured by amorphous silica that grows at higher temperatures.

3.2 TESTS

3.2.1 DETERMINATION OF THE CLASSIFICATION, OHYSICAL AND CHEMICAL PROPERTES OF THE BLACK COTTON SOIL.

a) **Proctor compaction test as per BS 1924: Part 2: 1990**.

Objective: To determine the relationship between the moisture content and the dry density of the compacted soil sample.

These results provide the optimum moisture content at which the soil should be compacted for the CBR test.

Method: A soil sample underwent a drying process, followed by compaction in a cylindrical mold adhering to either the standard Proctor or modified Proctor method. The maximum dry density, along with the associated moisture content, was determined by graphing the outcomes of the compacted samples. This results in the formation of a moisture-density curve, which facilitates the identification of both the optimum moisture content and the maximum dry density.

b) Sieve analysis test using dry sieving as BS: 1377 part2:1990

Objective: Sieve analysis, also known as gradation test was done to assess the particle size distribution of granular materials. From this test it was possible to determine whether the soil consists of predominantly gravel, clay or silt.

Method: Soil samples are sieved through a range of standard sieves, measuring the mass retained on each sieve. From a particle size distribution curve, the soil was classified.

Grading modulus = $\frac{[300 - (\text{percentage retained on 2mm} + 0.425\text{mm} + 0.075\text{mm})]}{100}$

c) California Bearing Ratio as per BS 1377 Part 4 1990.

Objective: The primary objective of the CBR test is to determine the California Bearing Ratio value of a soil sample. It represents the ratio of the force required to penetrate the soil sample at a specific depth to the force required to penetrate a standard crushed rock material at the same depth.

Equipment

- Test sieves 20mm and 5mm
- Three cylindrical molds (150mm inner diameter and height of 127mm).
- Two metal rammers, 2.5 kg and 4.5 kg.
- Perforated baseplates
- Perforated swell plates with adjustable stems to provide seating for a dial gauge
- A dial gauge with 25 mm travel and reading to 0.01 mm
- CBR compression machine
- Soaking pit

Method: The one-point method was used in determining the CBR % of the soil due to limited availability of the material during the time of testing, however, the three-point method provides more reliable results. The test was carried out on the sample passing through the 20mm test sieve of about 6 kgs. Using results from the OMC, the sample was thoroughly mixed thereafter sealed and soaked for at least 24 hours before tests were carried out.

- The sample at optimum moisture content was compacted into a standard mold in five layers, applying 62 evenly distributed blows per layer using a 4.5 kg rammer.
- The sample was then trimmed and fitted with a perforated baseplate. A filter paper was then placed on top of the sample, followed by perforated swell plates.
- Annular surcharge discs weighing about 4.5 kg were then placed on the stem of the perforated swell plates. A dial gauge was thereafter mounted on the extension collar and adjusted to give a convenient zero reading.
- The mold was then placed in the soaking tank with the water level just below the mold extension and left to soak for 4 days.
- After 4 days of soaking, the sample was then taken for penetration using a CBR testing machine.

Calculations

Density calculations

1. The volume of the mold V_m (cm^3) was obtained
2. Bulk density was calculated from;

$$\text{bulk density} = \left(\frac{\text{mass of soil}}{\text{volume of the mould}}\right) \times 1000$$

Mass of the soil was obtained from the mass of soil, mold, and baseplate – mass of mold and baseplate.

3. Dry density was then calculated from;

$$\text{dry density} = \left(\frac{100}{100 + \text{moisture content}}\right) \times \text{bulk density}$$

Swell calculation

1. Swell in percentage was calculated from the equation below;

$$\text{swell} = \left(\frac{\text{F} - \text{B}}{127}\right) \times 100$$

Where

F is the dial gauge reading after 4 days of soaking

B is the dial gauge reading before soaking

Calculation for California bearing ratio.

1. Penetration of 2.5 mm and 5.0 mm were used to calculate the CBR value.
2. CBR at 2.5 mm penetration was calculated from;

$$\text{CBR}(\%) = \frac{\text{P} \times 100}{13.2}$$

Where

P is the plunger force at 2.5 mm penetration in kN

3. CBR at 5.0mm penetration was calculated from;

$$\mathrm{CBR}(\%) = \frac{\mathrm{P} \times 100}{20.0}$$

Where

P is the plunger force at 5.0 mm penetration in kN.

NB: CBR at 2.5mm penetration was used for assessing the quality of the material

d) Atterberg limit test as per BS 1377: Part 2: 1990.

Objective: Provides a solid basis for classifying soil and obtaining its plastic and cohesive behavior.

Liquid Limit

Apparatus Required:

- Test sieve (425 μm size)
- Flat glass platform
- Two spatulas
- Cone penetrometer
- Metal cup (55 mm diameter, 40 mm depth, rim parallel to the flat base)

Method: The test was conducted on a soil sample that passed through a 425 μm sieve weighing approximately 400 g. The sample was placed on a glass plate and water was added followed by thorough mixing with spatulas until a thick uniform paste was formed. The mixture was then sealed in an airtight bag and allowed to rest for 24 hours to ensure the water fully penetrated the soil.

After the sample was soaked, its moisture content was adjusted, and the soil was penetrated with the cone penetrometer for five seconds. Penetrations within a range of 15.0 mm to 27.0 mm were recorded, and representative samples were taken for moisture content determination by oven-drying at 105ºC for 24 hours.

e) Plastic limit

Method: The sample was rolled on a glass plate into threads 3 mm in diameter until they started to break. The particles were then placed in an oven at 105ºC for 24 hours to determine the moisture content.

The average of the moisture contents for the portions of the sample was taken as the plastic limit. The value was rounded off to the nearest whole number.

Plasticity index was obtained by: PI = Liquid Limit – Plastic Limit

f) Linear shrinkage

Method: The sample was placed in a lubricated brass mold for linear shrinkage determination. The sample was then placed in an oven at about 105ºC for 24 hours.

The linear shrinkage was calculated from;

$$linear\ shrinkage(\%) = \left(1 - \frac{l}{d}\right) \times 100$$

Given that

l is the length of the oven-dried sample

d is the original length of the specimen

3.2.2 EXAMINATION OF THE POZZOLANIC PROPERTIES OF SEWAGE SLUDGE CAKE ASH.

a) **X-ray Fluorescence Test as per ASTM 48438-23.**

Objective: The purpose of this test was to determine the chemical compounds present in the black cotton soil.

Method: The ash is exposed to X-rays, generating a diffraction pattern based on scattered rays. This pattern is analyzed to identify minerals by comparing peaks to standard reference databases. Results are summarized to report the mineral composition.

3.2.3 TO ASCERTAIN THE PERFORMANCE OF THE BLACK COTTON SOIL TREATED WITH VARYING PERCENTAGES OF SEWAGE SLUDGE CAKE ASH.

The treated sample will be subjected to the same tests as were done on the untreated sample under the same conditions. This will serve as a control to compare the test results and ascertain whether the sewage sludge ash was effective in stabilizing the black cotton soil. It was then treated with various percentages by composition of the sewage sludge cake ash as shown below.

MIX DESIGN

Table 3: Summary of the Mix design for the stabilization of black cotton soils with varying percentages of sewage sludge cake ash

Percentage of soil	Percentage of sewage sludge cake ash	Composition by weight of the stabilizer (Kg)	Composition by weight of the soil(kg)
100	0	0	80
95	5	4	76
90	10	8	72
85	15	12	68
80	20	16	64

a) **Maximum dry density and optimum moisture content (British Standard 1377 part 2).**

This test helped to obtain the relationship between the compacted dry density and moisture content. This was majorly important in identifying the optimum moisture content to be used when compacting the sample for the California Bearing Ratio Test.

b) **CBR test (British Standard 1377 part 4).**

This test aided in gauging the strength and bearing capacity of the soil. The strength of a subgrade, subbase, and base course material are expressed as a percentage in terms of their CBR value.

c) **Atterberg Limits (British Standard 1137 part 2) i.e. Liquid limit, Plastic limit, and linear shrinkage.**

The main objective of these tests was to provides a solid basis for classifying soil and obtaining its plastic and cohesive behavior.3

d) **Unconfined Compressive Test (BS 1924: Part 2: 1990)**

Equipment

- CBR compaction mold
- 4.5Kg metal rammer
- Large metal tray
- Sieves (20mm and 37.5mm)
- Galvanized mixing baths
- Compression testing machine
- Platter knife or spatula

Method: Using 20mm and 37.5mm sieve, the soil sample was sieved and divided into three similar lots of approximately 21kg by oven dried weight. The sewage sludge ash was mixed with the soil following the mix design. Using the respective optimum moisture content, the soil was mixed with the ash and water and treated for 4 hours. The samples were then compacted using a 4.5kg rammer applying 62 evenly distributed blows to each of the 5 equally thick layers. The new weight of the molds was taken before taking the samples for curing and testing with the compression testing machine. The testing process included crushing the specimens in the compression testing machine, applying a constant load of 140kPa/s.

UCS was calculated from the following formula; $\frac{LOAD)/KN}{0.01824(KN/m^2}$

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This section explains the results obtained from the various tests i.e. the physical characteristics of the black cotton soil, the chemical analyses of the sewage sludge ash and thereafter the performance of the stabilized sample. It also elaborates on the laboratory findings and compares the different soil properties with set standards for application in sub grade construction.

4.2 ENGINEERING PROPERTIES OF THE NEAT SOIL SAMPLE

4.2.1 Particle Size Distribution

This involved the use of sieve analysis with reference to BS 1377 Part 2:1990, which was done to determine the grading of the neat soil sample. On conducting this particular test, it was found that clay takes the greater percentage of composition with an average of 70.08% passing the 75 micro meter sieve and the lesser percentage in the sand and gravel.

The shape of the curve clearly illustrates the distribution of the different articles, gravel, silt and clay, where we see the 50% passing the 75-micrometer sieve and a lack of well-distributed coarser fractions. A well-graded soil sample should have a uniform distribution of particles over the course and fine range to provide better compaction properties and improve drainage resulting to a stronger durable foundation performance.

From the values, a computation of the grading modulus was a done sample to determine the coarse particles to fine particles in the soil. The following result was obtained on the three test samples, 0.59, 0.65, and 0.62, giving an average of 0.62. This clearly showed that fine particles in the clay soil sample were in great quantity compared to the coarse material.

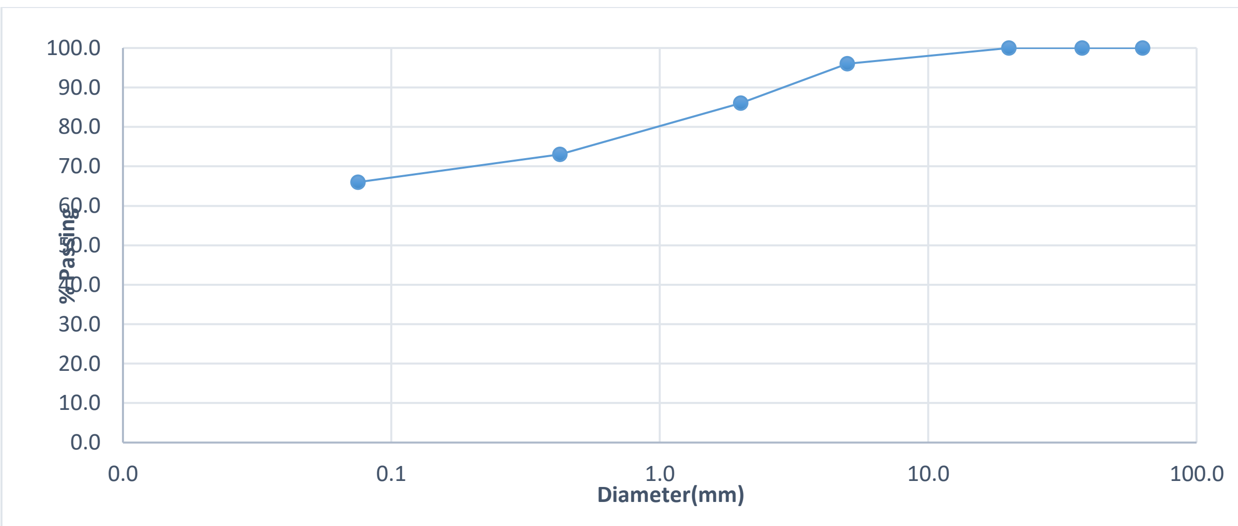


Figure 3 Particle Size Distribution curve

4.2.2 Atterberg Limits

The moisture content at which the soil turns from plastic to liquid and develops a moderate shear strength is known as the "Liquid Limit." First, second, and third neat samples taken directly from the cone penetrometer registered liquid limits of 66.8%, 67.2%, and 67.7%, respectively. Their mean recorded 67.0%, more than the maximum requirement of the MOWT manual standard requirement of 41% for the subgrade material. The reason the neat sample contains a *high liquid limit is due to the fact* that the amount of fine material within the soil is proportional to its abundance as it can absorb more water and flow. Consequently, there was a necessity to make sure that the liquid limit of the soil sample was decreased.

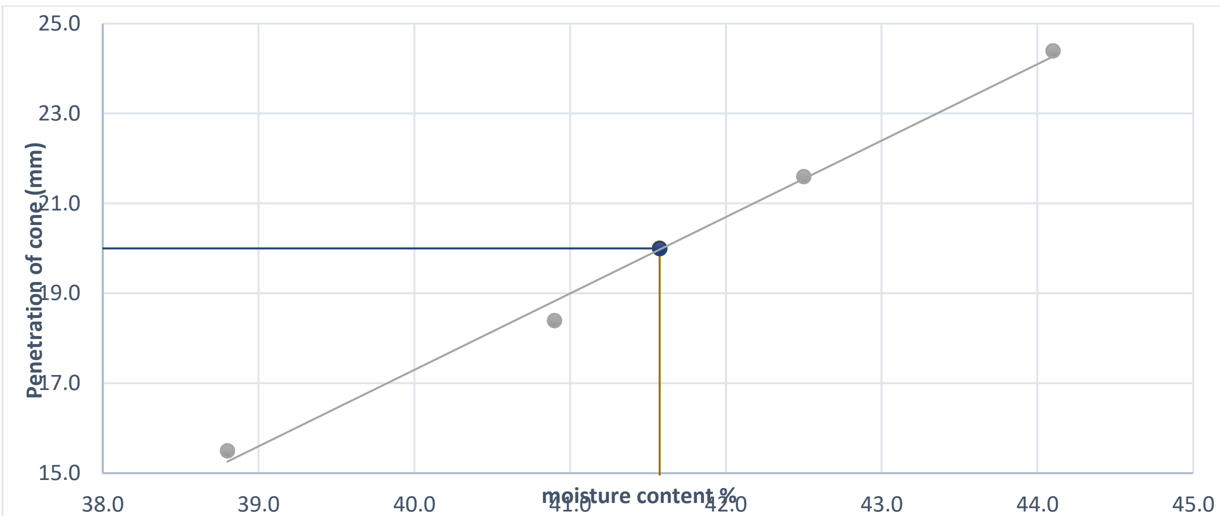


Figure 4 Liquid Limit Penetration Curve

The percentage of water in which the soil changes from plastic to semi-solid state, when it becomes non-moldable and begins to degrade, is called the plastic limit (Mitchell & Soga, 2020). 22.5%, 28.0%, and 27.9% plastic limits were determined using the cone penetrometer, averaging 27.6%.

plasticity index is a significant parameter that influences the behavior of a soil, that is, the capacity of the soil to withstand deformation without failing. Plasticity index is the difference between the liquid and plastic limits of the soil. High plasticity index in a soil sample means that the sample is prone to large volume changes when the moisture content varies.

Because of their susceptibility to changes in volume, such soils with a high plasticity index are less stable in construction applications.

Regulation by MOWT prescribes a limiting plasticity of 25% for subgrade material; the mean plasticity index of black cotton soil is 39.4%. Since the material is under this, stabilization would be required.

The large silt and montmorillonite content, which offer a significant surface area for the retention of water, is responsible for the high plastic index (Kumari & Ramaswamy, 2021).

The first and second neat soil samples had linear shrinkage limits of 20%, 19.3%, and 19.9% at 0.5 meters, averaging 19.6%. Linear shrinkage is the method by which soil changes from a part to a whole solid state without volume change. Black cotton soil experiences linear shrinkage when it loses moisture, and the soil shrinks as water is lost through evaporation. Shrinkage is a function of the kind and quantity of clay minerals, particularly montmorillonite, which swells when wet and shrinks when dry. Particle size, soil structure, initial water content, and the presence of organic matter or salts control the degree of shrinkage.

4.2.3 CLASSIFICATION OF THE SOIL

According to the average findings of the particle size distribution and Atterberg tests, the clean research soil samples are A-7-6 according to the AASHTO soil classification for highways. This is because they have a plasticity index of 39.4% and over 35% passing sieve No. 200.

According to the Unified Soil Classification System, the soil sample is CH soils, fine-grained inorganic clays, as the percentage passing sieve No. 200 is 70.08%>50% with plasticity index 39.4%.

4.2.4 MDD AND OMC OF THE NEAT SOIL

Proctor compaction test was used to find OMC and MDD. The provided data set obtained from this test is extremely crucial in determining the optimal treatment techniques to enhance the soil and make foundations long-lasting enough. The Proctor Compaction test, as a whole, provides a complete indication of the maximum weight at which a specific type of soil can be compacted at a particular moisture content.

The test results are shown in the graph above and are 24.4% for OMC and 1.465 gm/cc for MDD. These test results show that the maximum compactness of the soil is obtained with the best 24% moisture content. The reason behind the high OMC and low MDD is the fine-grained nature of the soil, which requires more water to reach the optimum moisture content. This creates a structure with elevated void ratio that deteriorates dry density despite compaction (Pindir and Sharma, 2020).

The low dry density of 1.465g/cm3 was produced by the low moisture content of 24.4% close to the beginning of the curve. This is due to the fact that there is not enough moisture to lubricate the soil particles so that they can move easily and enclose each other in a dense pack. As water is added, the dry density rises uniformly until it reaches its maximum, or in other words, the MDD. Beyond this point, adding more water decreases the dry density as the excess water fills the pores, displacing the soil particles from and away from one another (Saha Kumar 2023).

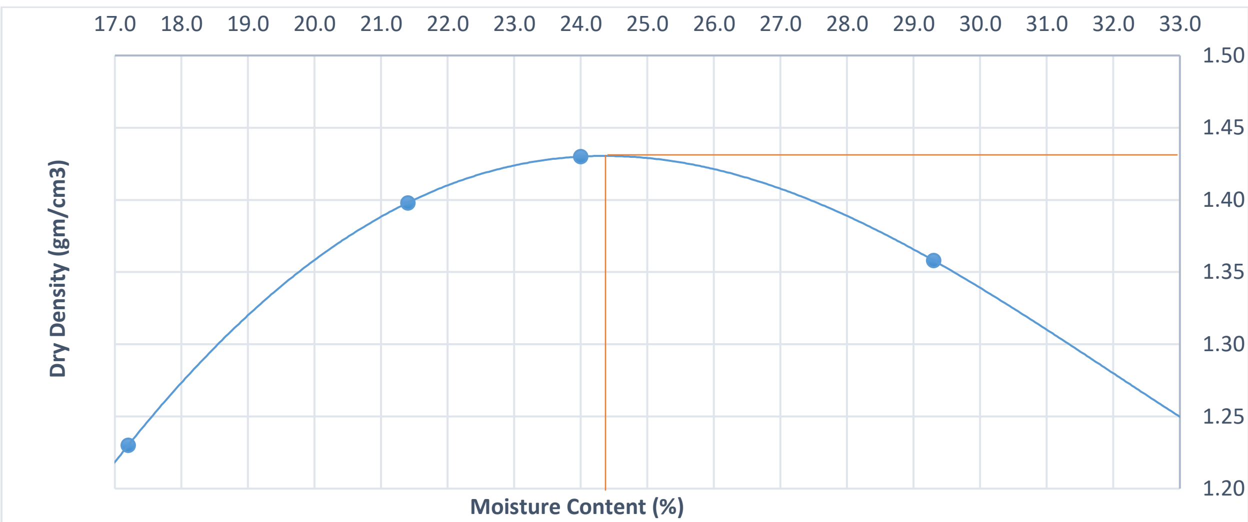


Figure 5 MDD curve for the neat soil sample

4.2.5 CALIFORNIA BEARING RATIO OF THE NEAT SAMPLE

The CBR test determines how much force soil can withstand before it starts to fail under a specific load of a standard material. This means that soils with a high CBR have a higher load-bearing capacity to sustain loads as opposed to those with a low CBR.

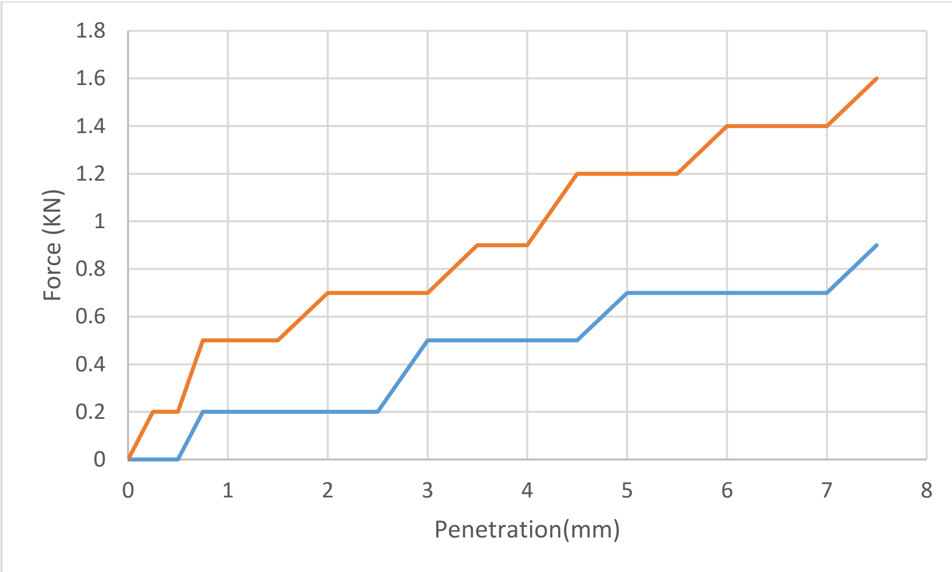


Figure 6 CBR Curve

After soaking for four days, the neat soil samples generated CBR values of 5.5%, 4.1%, and 4.9%, averaging 4.8%. The strength of the soil, relatively low and likely to be weak for load-bearing purposes, was reflected in its CBR of 4.8%. Based on the MOWT general specification for road and bridge works 2005 manual, this CBR is 15% below minimum level for a subgrade material. To improve its capacity to carry heavy loads and withstand deformation, stabilization has to be carried out.

The most important explanation for the black cotton soil's low CBR is that it possesses a high Plasticity Index, making it more flexible and causing it to lose cohesiveness when it comes in contact with water (Singh and Chawala, 2020).

SUMMARY OF RESULTS OBTAINED FOR THE PROPERTIES OF THE NEAT SOIL

Table 3 Summary of results obtained for the neat soil

Test	Result	General Specifications
Plasticity index	39.4%	Maximum 25%
Liquid Limit	67%	Maximum 41%
Linear Shrinkage	19.6%	-
Plastic Limit	27.6%	-
CBR	4.8%	Minimum 15%
CBR swell	1.30%	Maximum 1.5
Optimum Moisture Content	24.4%	-
Maximum Dry Density	1.465g/cm3	-
Classification(AASHTO)	A-7-6	-
Classification(USCS)	CH	-
Grading modulus	0.62	-

4.3 CHEMICAL ANALYSIS OF THE SEWAGE SLUDGE CAKE ASH

4.3.1 X-RAY FLUORESCENCE TEST

Chemical stabilization of soil to be used in road pavements is mainly accounted to the composition of the additives, which are required to have a fair percentage of calcium oxide, silicon dioxide, aluminum (III) oxide, and iron (II) oxide that contribute to the pozzolanic reactions, improving soil strength (Chen et al, 2023).

Parameter	Unit	Results for DFD 040\2025 Sewage sludge sample
Loss on Ignition	%m\m	38.71
	Elemental Composition	
Silicon dioxide	%m/m	51.78
Calcium oxide	%m/m	20.19
Aluminium oxide	%m/m	13.33
Iron III Oxide	%m/m	8.93
Phosphorus pent oxide	%m/m	2.63
Magnesium II Oxide	%m/m	1.43
Potassium Oxide	%m/m	1.16
Zinc Oxide	%m/m	0.64
Titanium dioxide	%m/m	0.12
Nickel Oxide	%m/m	0.063
Manganese Oxide	%m/m	0.03
Copper Oxide	%m/m	0.02

Table 4 A Table showing percentage composition of different elements in the SSCA

The XRF test result showed that the sludge ash consisted of the following percentage of calcium oxide, silicon dioxide, aluminum (III) oxide, and iron II oxide in order: 20.19, 51.78, 13.33, and 8.93. The ASTM C618 demands that pozzolanic materials consist of not less than 70% silicon dioxide, aluminum (III) oxide, and iron II oxide combined. The sludge ash meets this condition with a total percentage of 74.04%, and hence it can be blended with the black cotton soil to form cementitious compounds.

Calcium-Silicate-Hydrate gel, which is responsible for the durability and strength of soil, is formed partially because of the availability of silicon dioxide and calcium oxide. The presence of a high amount of calcium oxide also provides a sufficient quantity of lime that can trigger pozzolanic reactions instantly, reducing need for extra lime.

The source of the sludge is the reason for the variation in the composition of the sludge ash. The majority of waste products and feces that have calcium oxide are treated at the Gulu sewage treatment plant. The addition of calcium hydroxide in coagulation, the use of hard water with Ca2+, and the consumption of foods like milk and green vegetables that are eliminated through feces and urine are the sources of calcium. Lastly, calcium salts break down to yield calcium oxide, e.g., CaCO3 to CaO, when the cake of sludge is burned at temperatures between 8000c.

4.4 ENGINEERING PROPERTIES OF THE TREATED SOIL

4.4.1 VARIATION IN THE MDD

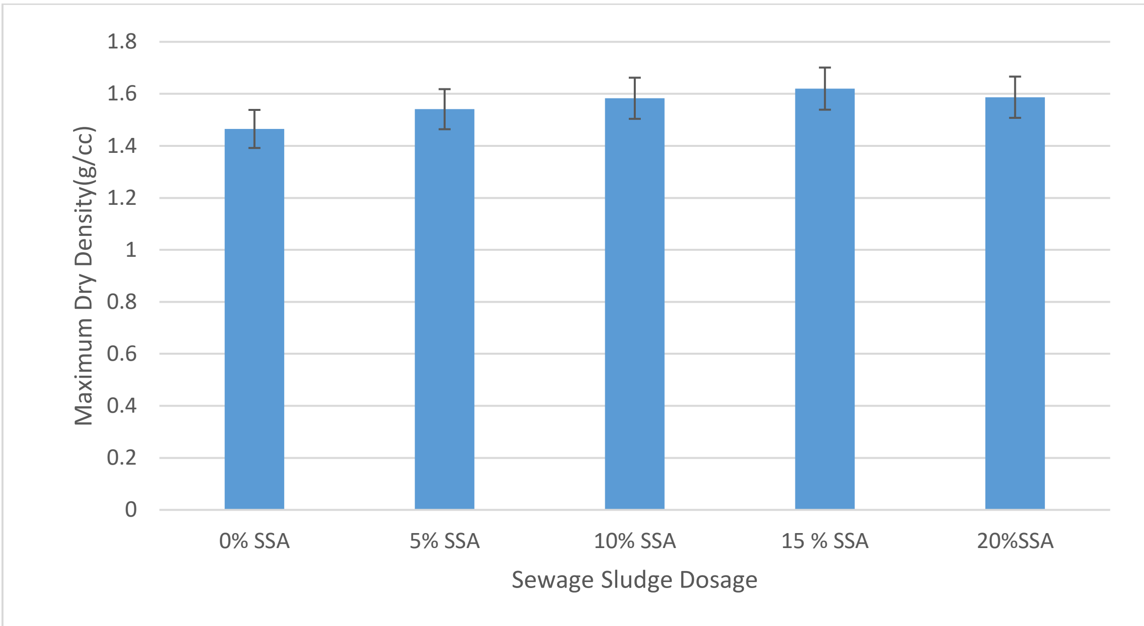


Figure 7 A Graph showing variation of MDD on addition of SSCA

With the addition of the sewage sludge cake ash in the various compositions of 5%,10% and 15%, the MDD of the soil always increased to a high rate of 1.620g/cc at a composition of the SSCA at 15% as shown by figure 6 above. This is due to the chemical reaction between the water, CaO in the sludge ash and the clay minerals to form binding compounds that hold soil particles tighter, decreasing the holes between them. To achieve maximum dry density, the soil not only compresses but also gets sealed in a consistent, stronger, and denser framework when compacted. The adhesive holds the soil particles together more tightly, sealing the gap between them. Subsequently, the MDD drops to 1.590g/cc when the SSCA dosage was raised to 20%, which signaled that the soil was now oversaturated with stabilizer. The agglomeration and flocculation of the particles were initiated by the increased water requirement of the soil to attain its MDD as a result of the new surplus of fines within the soil structure. Even in the compaction phase, this form of construction is described to contain greater vacant spaces, which in turn impacts the dry density.

4.4.2 VARIATION IN THE OMC

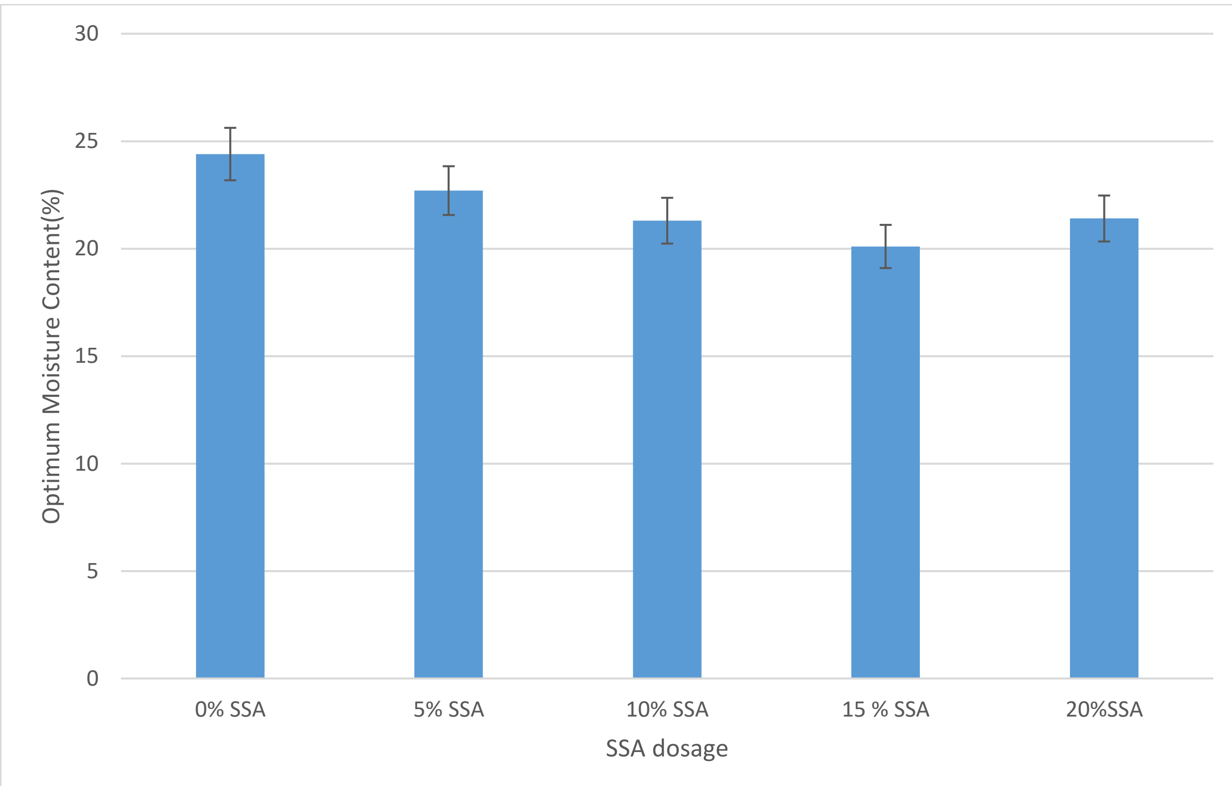


Figure 8 A Graph Showing Variation in OMC

The OMC is decreased by 6.6%, 12.7%, and 18% when 5%, 10%, and 15% composition is added with SSCA, respectively, as noted in figure 7 above.

Because the particles are better rearranged and less water is required to attain maximum density, the chemical reactions described above enhance the soil structure

(Gautam et al., 2021). With the addition of 20% SSCA, there is a slight rise in the OMC from 20% to 21.5%. This is because the extra sewage sludge ash particles have a higher surface area, hence they can retain more water.

4.4.3 VARIATION IN THE ATTERBERG LIMITS

Liquid Limit

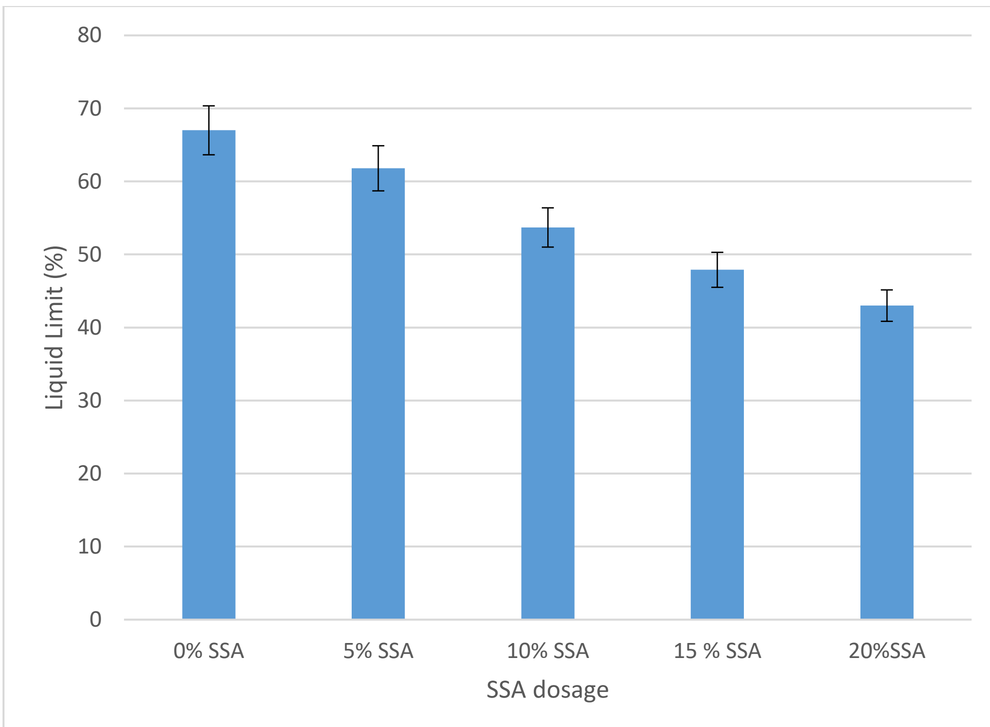


Figure 9 A Graph Showing Variation in Liquid Limit

Liquid limit decreases with the increase of SSCA composition, and the figure 8 above indicates a minimum of 43%. Agglomeration of particles and cation exchange are to blame. Owing to the presence of Na +, the montmorillonite clay mineral which was initially at 0% sludge ash is the cause of the high affinity of the soil. By minimizing electrostatic repulsion between clay particles, the available Ca 2+ replaces the Na +

via cationic exchange when the SSCA is added in equal dosages. The result is that the clay particles then aggregate into larger units with a smaller surface area exposed to water (Sheng-quan Zhou, 2019). A lower liquid limit is ultimately achieved when less water is required in order to reach saturation.

Plasticity index

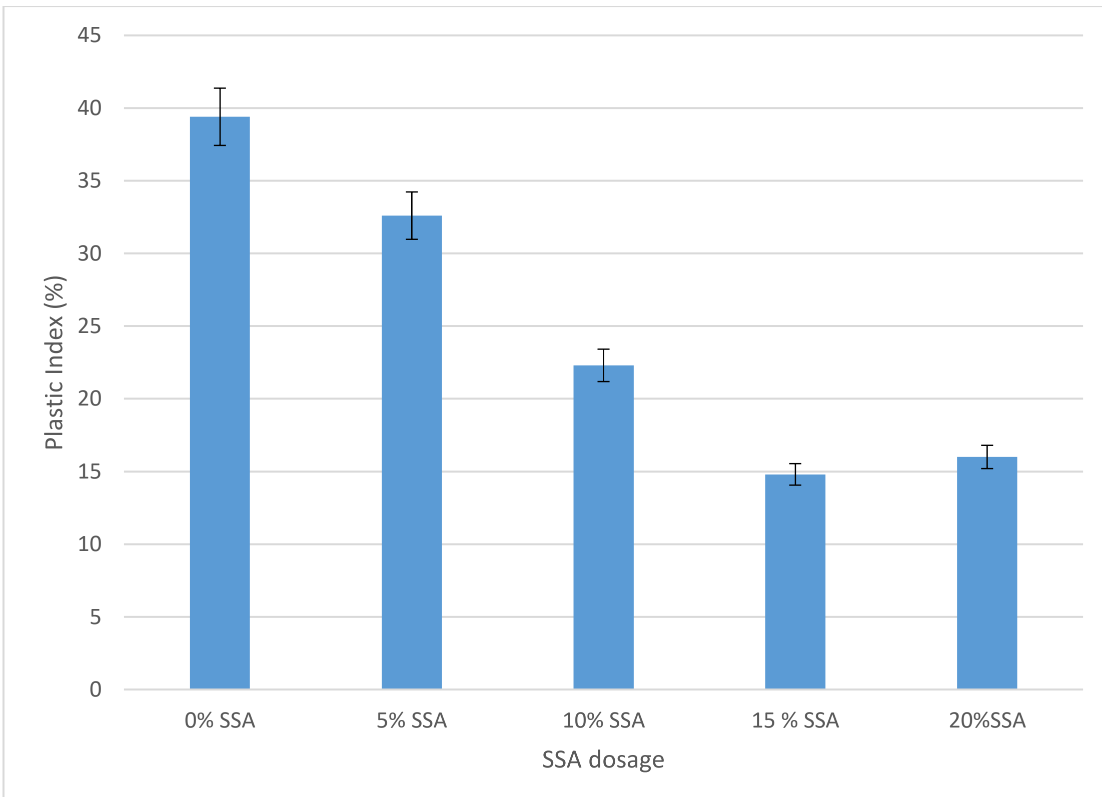


Figure 10 A Graph Showing Variation in Plastic Index

The plasticity index of the soil reduces from 39.8% to a value as low as 14.8%, which is within the range acceptable for a G15 subgrade material. With the increase in the amount of sewage sludge cake ash added to the 15% composition, the plasticity index reduces. This can be accounted for by a series of cation exchange reactions that substitute for singly charged cations in the clay doubly charged cations from the SSCA

(Bello et al., 2021). The new cations have a stable structure with lower affinity for water lowering their plasticity. In addition, the alkaline nature of the sewage sledge cake ash constituents such as calcium oxide forms cementitious compounds

Linear Shrinkage

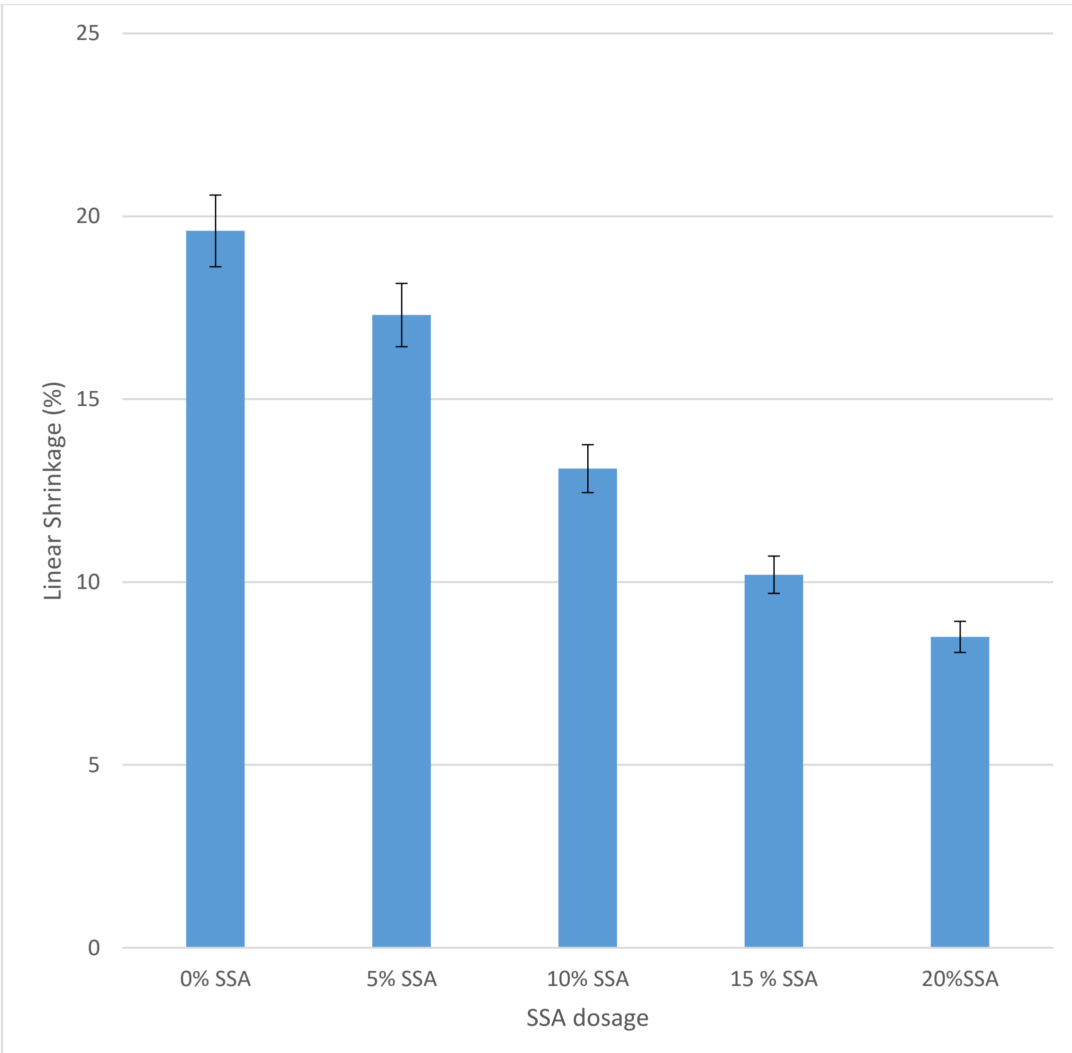


Figure 11 A Graph showing Variation in Linear Shrinkage

With the increase in the content of sludge, the linear shrinkage in the above figure 10 continually reduces to a minimum of 8.5%. The main reason for this is that the sludge ash retains water in the soil, preventing the drying and shrinking of the soil. Apart from this, the sludge ash controls the plasticity of the soil, thereby rendering the soil less prone to shrinking and drying.

4.4.4 VARIATION WITH THE CBR

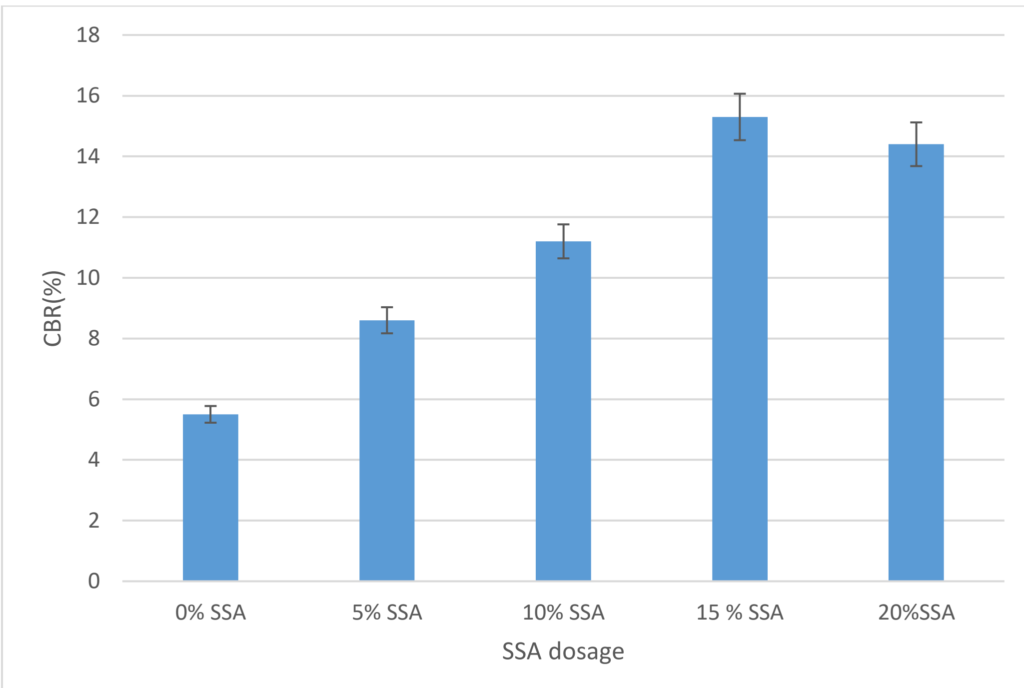


Figure 12 A Graph Showing variation of the CBR

With stabilization of the soil using 15% sewage sludge cake ash, the CBR increased from 4.8% to 15.3%, i.e., a drastic improvement. The significant increase is due to the chemical reaction of the clayey soils with the activated CaO in the ash. Fewer weak monovalent ions, i.e., sodium (Na^+), originally adsorbed on the clay particles are replaced by the calcium ions. By lowering the repulsive forces between particles and the thickness of the diffuse water layer, this substitution draws soil particles towards each other. By creating larger, interlocking soil clumps, this process—flocculation—allows the soil to support increased loads (Manzoor & Yousuf, 2020). Nevertheless, in the presence of 20% of the sewage sludge cake ash, the CBR decreased However, at a composition of 20% of the sewage sludge cake ash, the CBR reduced to 14.8% because the of the presence of the excess fines that rather limit particle bonding leading to a less dense, weaker soil structure.

4.4.5 VARIATION WITH THE UCS

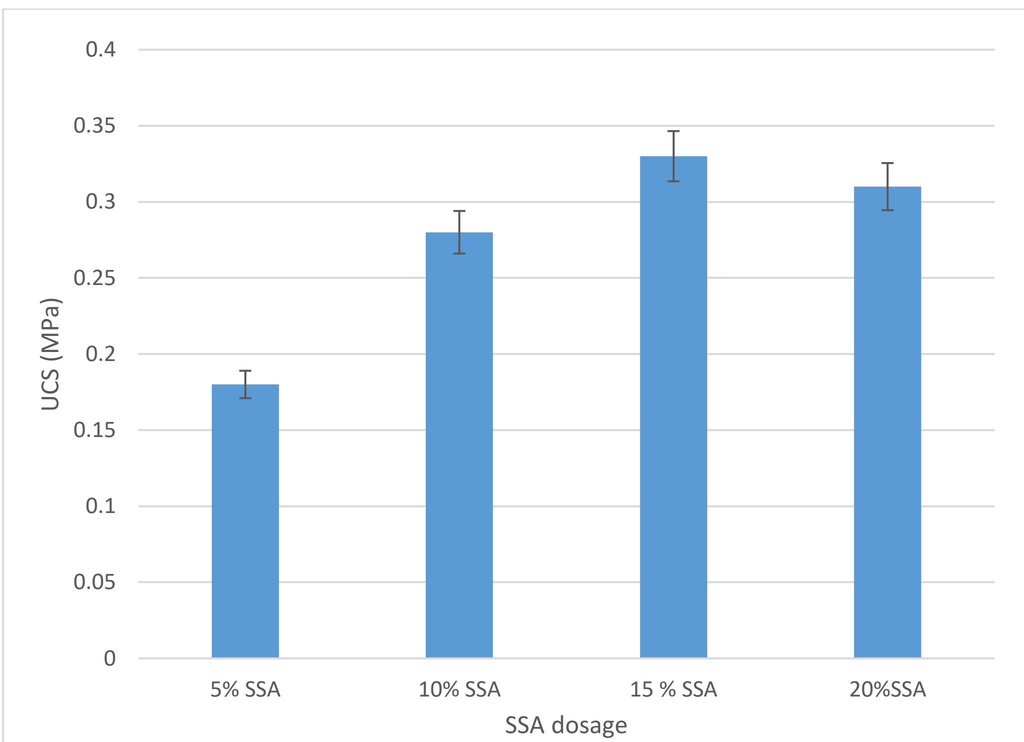


Figure 13 A Graph Showing Variation of the UCS

The UCS of the soil increased to a peak value of 0.33MPa when 15% of the sewage sludge cake ash was added. The pozzolanic reaction between the silica that is released from the clay and the Ca2+, which occurs because of the alkaline nature of the CaO that gets activated when burned, produces a calcium-silicate hydrate gel with a nature similar to Portland cement. As a result, the soil matrix becomes denser, tougher, and more resistant to vertical loads. In 2017, Firoozi et al. When 20% additional stabilizer was added, UCS decreased to 0.31MPa, which could be because of a state of non-equilibrium in the chemical structure of the soil.

CBR swell

The addition of sewage sludge came ash led to a decrease in the CBR. This change is primarily due to the shift in the structure of the clay minerals particularly montmorillonite that aid swelling. On reaction with the sewage sludge cake ash, they form structures that are more stable less prone to swelling under wet conditions.

Conclusion

According to the test results, the engineering characteristics of black cotton soil were partly improved by adding 15% sewage sludge cake ash, which was close to MoWT's G15 subgrade material standards. The improved load-bearing capacity of the soil was validated by the CBR value, which rose from 4.8% to 15.3%, more than the standard level of 15%. Besides, the plasticity index declined from 39.8% to 14.8%, which is closer to the 25% bench, and suggests a decline in shrink-swell tendency of soil. Between 1.3% and 0.37%, CBR-swell decreased below the allowable limit of 0-1.5%. Nevertheless, UCS of 0.33 MPa fell below the requirement of 0.5 MPa for a G15 subgrade material. This suggests that while the addition of sewage sludge cake ash has provided some stability and strength to the soil, further additional stabilization methods may be needed to fully meet the necessary standards. The A-6 classification by AASHTO indicates that the soil is fine grained and comprises mostly of clay with an average plasticity with a fair performance as a subgrade in subgrade construction.

RESEARCH DESIGN

Material preparation

Sewage sludge cake ash

- Obtain sewage sludge cake from a waste water treatment plant.
- Ensure that the sludge is completely dried from the sludge drying beds.
- Incinerate the sewage sludge cake at temperatures of 800^{o} C at phased heating over a period of two hours.

Parameter	Unit	Results for DFD 040\2025 Sewage sludge sample
Loss on Ignition	%m\m	38.71
	Elemental Composition	
Silicon dioxide	%m/m	51.78
Calcium oxide	%m/m	20.19
Aluminium oxide	%m/m	13.33
Iron III Oxide	%m/m	8.93

Stabilizing the subgrade material along Orom road

Take a stretch of 1km

7m wide and 250 mm subgrade thickness.

Volume = length * width * thickness

V= 1000 * 7 * 0.25 = 1750m^3

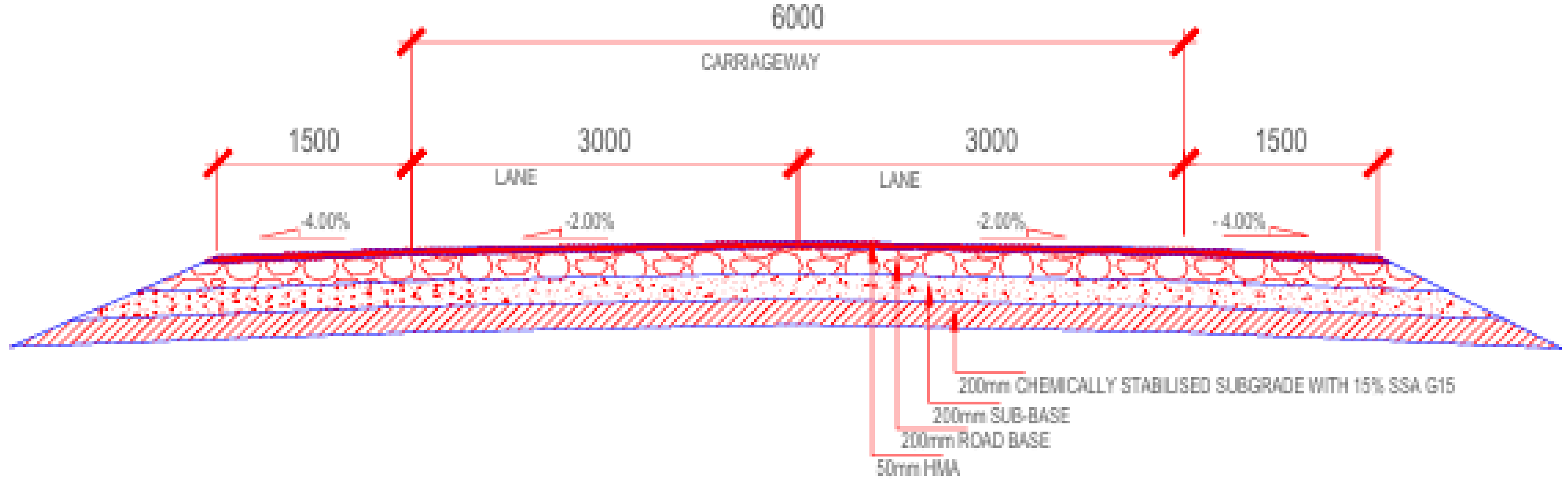
For 15% SSA content; Quantity of SSA = volume of soil * SSA content Quantity = 1750 * 0.15 = 262.5m^3

Therefore, weight of SSA = quantity of SSA * density of SSA

Weight= 262.5* 1100 = 288,750 Kg.

Thus, for 1km stretch, 288.75 tons of SSA would be needed.

RESEARCH DESIGN



CROSS SECTION

TYPICAL CROSS SECTION	
PROJECT TITLE	STABILIZATION OF BLACK COTTON SOILS WITH SEWAGE SLUDGE CAKE ASH
AUTHOR	RACHKARA AARON
REG NUMBER	S20B32/219
SCALE	1:50 A3

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

According to the result of the first objective, the black cotton soil has to be stabilized to improve its load carrying capacity and stabilize its swell and shrink behavior when in contact with water. This is because the low CBR of 4.8%, plasticity index of 39.8%, liquid limit of 67%, and CBR swell of 1.3% are lower than the requirements of a G15 material according to the MoWT general specifications.

According to the XRF test results under objective 2, the sludge ash has the percentage of calcium oxide, silicon dioxide, aluminum (III) oxide, and iron II oxide as 20.19, 51.78, 13.33, and 8.93, respectively. According to ASTM C618 pozzolanic materials must have a minimum of 70% silicon dioxide, aluminum (III) oxide, and iron (II) oxide combined. The sludge ash meets this specification with a total of 74.04%, indicating its potential to blend with the soil and produce cementitious material that will contribute to the overall strength and stability of the soil against loading and harsh environmental conditions.

From the results of the third objective, the finding was that 15% addition of sewage sludge cake ash improved the engineering properties of black cotton soil to some extent and made it superior as per the MoWT's G15 subgrade material requirements. The improved load-bearing capacity of the soil was confirmed by the CBR value, which rose from 4.8% to 15.3%, which is beyond the advised 15%. Also, the plasticity index fell from 39.8% to 14.8%, closer to the 25% bench, indicating the shrink-swell capacity of the soil decreased. Between 1.3% and 0.37%, the CBR-swell fell below the permissible limit of 0-1.5%. The 0.33 MPa UCS, however, was less than the standard.

This implies that even while adding sewage sludge cake ash has given the soil some stability and strength, other stabilization techniques could be required to completely satisfy the requirements.

RECOMMENDATIONS

Various studies need to be conducted on potential stabilizers such as bio-based additives or even utilizing fiber reinforcements to blend with the ash of sewage sludge cake to impart strength and stability to the soil, though the CBR, Plasticity index, and CBR swell were within the requirement, the liquid limit was still relatively high, and the UCS was less than the minimum required strength.

REFERENCES

Mitchell, J. K., & Soga, K. (2020). Fundamentals of Soil Behavior. 4th Edition. Wiley.

Das, B. M. (2019). Principles of Geotechnical Engineering (9th ed.). Cengage Learning, Stamford, CT.

Kumar, R., Ramaswamy, M., & Reddy, K. (2022). Stabilization of Expansive Soils for Road Construction: A Review. International Journal of Geotechnical Engineering, 23(4), 345-359.

Pindir and Sharma, (2020). Soil stabilization techniques and their application in Civil Engineering. Springer.

Sahar, S., & Kumar, A. (2023). Soil stabilization Techniques for expansive soils. A review International Journal of Civil Engineering, 12(3) ,114-125.

Singh, (2020), Effect of moisture content on the compaction behavior of black cotton soil Journal of Engineering and Technology, 31(04), 104-115.

Mukasa, S., Kyeyune, G., and Okullo, P. (2022). Assessment of the influence of soil properties on pavement performance in Mpigi district, Uganda. International Journal of Civil Engineering and Technology, 13(8), 2449-2459.

Guru Prasada Panda, Alireza BahramT.Vamsi Nagaraju, Haytham F. (2023), Response of High Swelling Montmorillonite Clays with

Aqueous Polymer, MDPI., 13(7), Available at https://www.mdpi.com.

Dwarakanath Ravikumar, Duo Zhang, Victor Li (2021), Carbon dioxide utilization in concrete curing or mixing might not produce a net climate benefit, Natural Journal, Article 855, Available at www.nature.com.

Samuel Juuko, Dennis Kalumba, Umaru Bagampade (2011), The use of locally available sand in stabilization of Ugandan clayey soils: Case study of clayey soil from Busega area, Available at https://www.researchgate.net.

Alazigha, I.J., Yushau,A. A., A and Abdullahi,S.S.(2022). Experimental study on expansive soil improved by lignin and its derivatives. Sustainability, 14(11),8784.

Bordbar, M., Bazaz, M. R., & Karimiazar, S. H. (2021). Evaluation of the effect of expansive soil on rigid pavements performance using 3D finite element modeling. Acta Geotechnical, 16(5), 1729-1742.

Chen, C., Wang, Q., Li, J., & Xiao, Y. (2022). Effects of modified sewage sludge ash on engineering properties of soft clay. Environmental Science and Pollution Research, 29(23), 18222-18233.

Pan, S. Y., Chiang, P. C., & Lin, Y. P. (2017). Comparative analysis of the properties of sewage sludge ash and fly ash as supplementary cementitious materials. Journal of Hazardous Materials, 335, 157-164.

Brito, J. D., & Saikia, N. (2010). Recycled aggregate in concrete: use of industrial, construction and demolition waste. Springer Science & Business Media.

Ribeiro, A. B., Mateus, E., Silva, M., & Castro, F. (2018). Leaching Behaviour of Sewage Sludge Ash in Soil Stabilization. Environmental Science and Pollution Research, 25(2), 177-185.

Singh, R. P., & Agrawal, M. (2010). Environmental Impacts of Sewage Sludge on Soil and Plant Growth: A Review. Waste Management, 30(4), 362-373.

Ocet,T.(2020). Improving engineering properties of Black Cotton soils.

Makerere University Available at http://makir.mak,ac.ug

Patel, A. (2020). A review on expansive soil and its stabilization techniques. Journal of Civil Engineering Research, 11(5), 151-158.

Chen, Z., Zhou, Y., & Li, J. (2023). Analysis of foundation failure modes in expansive soil areas: A case study in Xi'an City, China. Bulletin of Engineering Geology and Environment, 82(2), 1223-1232.

Aminu, M., Wali, F. & Sani, S., 2023. Comparative analysis of black cotton soil stabilization using sewage sludge ash and lime. Geotechnical Engineering Journal, 21(1), pp.45-53.

Amadi, A.A., Onwukwe, N. & Udo, I.M., 2021. Stabilization of expansive soils with sewage sludge ash: Environmental and engineering considerations. Sustainable Construction Materials and Technologies, 13(4), pp.102-112.

Anwar, M., Al-Taie, A., & Ajayi, O., 2023. Sewage sludge ash and fly ash blend for soil stabilization: A sustainable approach. Environmental Geotechnics, 12(2), pp.56-65.

Mutuku, G. & Wanjiku, P., 2021. Engineering properties of black cotton soils stabilized with sewage sludge ash in Kenya. African Journal of Civil Engineering, 14(3), pp.50-58.

Ogunbode, E.B., Mohammed, S.M. & Nuhu, S.M., 2022. A review of sewage sludge ash stabilization of expansive soils. Journal of Geotechnical Engineering, 23(2), pp.91-103.

Nyende, M., & Okot-Okumu, J. (2015). Wastewater Treatment and Sludge Management in Uganda. Water Practice and Technology, 10(2), 357-364.

Wang, Z., Li, J., & Zhu, D. (2018). Characterization and Utilization of Sewage Sludge Ash for Sustainable Development in Construction Industry. Journal of Cleaner Production, 203, 1027-1036.

Chimenos, J. M., Segarra, M., & Muga, L. (2019). Sewage Sludge Ash as an Alternative Binder for Portland Cement: Strength and Environmental Performance. Construction and Building Materials, 229, 116854.

Kamon, M., & Nontananandh, S. (2012). Stabilization of Expansive Soils Using Lime and Cement. Transportation Geotechnics, 1(4), 250-256.

Kehrein, P., van Loosdrecht, M., Osseweijer, P., Garfí, M., Dewulf, J., & Posada, J. A. (2020). A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks. Environmental Science: Water Research & Technology, 6(4), 877-910.

Mitchell, J. K. (1993). Fundamentals of Soil Behavior (2nd ed.). John Wiley & Sons.

APPENDIX A: PICTURES

Figure 14 Preparation of CBR mold

Figure 15 Kitgum Orom Road Sign post

Figure 16 sludge on sludge drying beds

Figure 17 Penetration of the CBR molds

Figure 18 Sewage Sludge Ash

Figure 19 Cone Penetrator

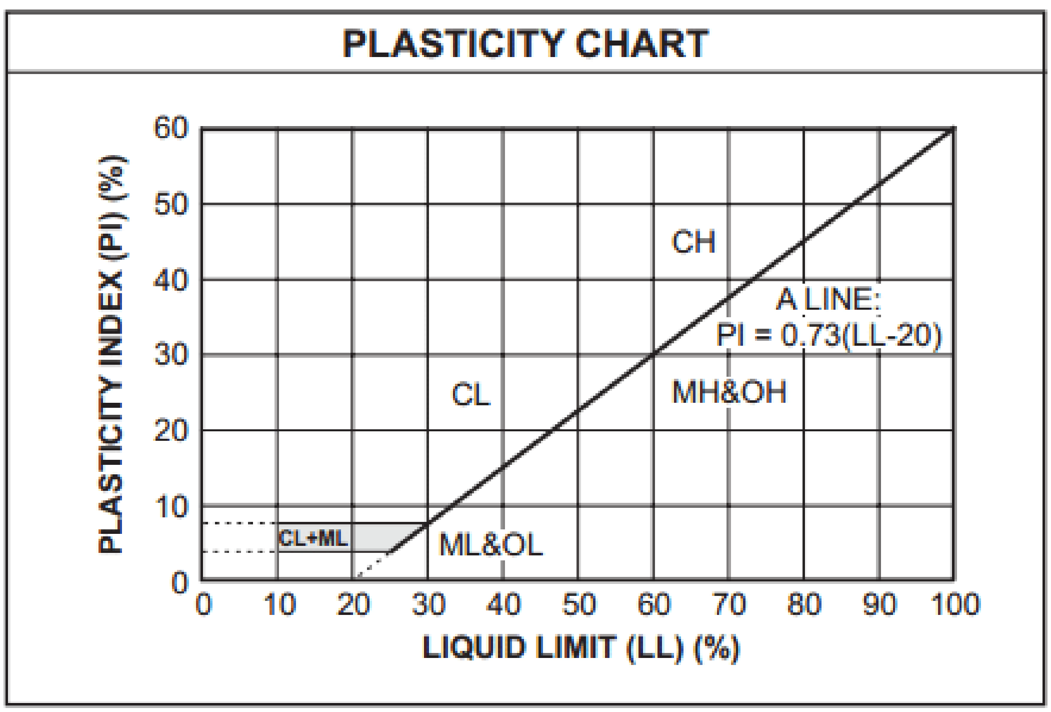


Figure 20 figure showing plasticity chart

Table 5 A Table showing the AASHTO Classification system

Table 5.1. AASHTO Classification System

General Classification	*Granular materials (35% or less passing No. 200 Sieve (0.075 mm))*							*Silt-clay Materials More than 35% passing No. 200 Sieve (0.075 mm)*			
Group Classification	*A—1*		*A—3*	*A—2*				*A—4*	*A—5*	*A—6*	*A—7*
	A—1—a	*A—1—b*		*A—2—4*	*A—2—5*	*A—2—6*	*A—2—7*				*A—7—5* *A—7—6*
(*a*) Sieve Analysis: Percent Passing											
(*i*) 2.00 mm (No. 10)	50 max										
(*ii*) 0.425 mm (No. 40)	30 max	50 max	51 min								
(*iii*) 0.075 mm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
(*b*) Characteristics of fraction passing 0.425 mm (No. 40)											
(*i*) Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
(*ii*) Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min*
(*c*) Usual types of significant Constituent materials	Stone Fragments Gravel and sand		Fine Sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils	
(*d*) General rating as subgrade.	Excellent to Good							Fair to Poor			

* If plasticity index is equal to or less than (liquid Limit—30), the soil is A—7—5 (*i.e.* PL > 30%)
If plasticity index is greater than (Liquid Limit—30), the soil is A—7—6 (*i.e.* PL < 30%)

APPENDIX B: LABORATORY RESULTS

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT:	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH			
Test Reference No	Lab Reference No	Date Sampled	Date Tested	Technician
Mix	NEAT	25/Jan/25	31/Jan/25	Lab team
Material description:	BLACK COTTON SOIL	Natural moisture (%)	11.0	

TEST DATA

Weight of rammer (Kg)	No of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm^3)
4.5	27	3	457	100	1,000

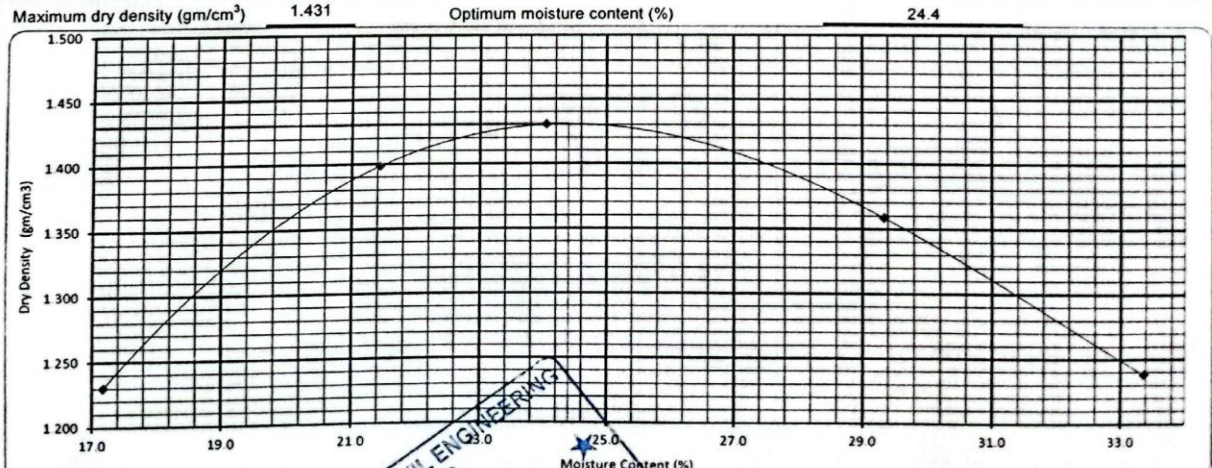
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	110	170	230	290	350
Mass of Compacted soil + mould	gm	4,943	5,200	5,276	5,259	5,153
Mass of Mould	gm	3,502	3,502	3,502	3,502	3,502
Mass of Compacted soil	gm	1441	1698	1774	1757	1651
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.441	1.698	1.774	1.757	1.651

DATA FOR PROCTOR CURVE

Container No.		BKX	KAU	FDC	YY	RWE
Mass of wet soil + Container	gm	2,301.0	2,519.0	2,761.0	2,522.0	2,261.0
Mass of dry soil + container	gm	2,081.0	2,215.0	2,382.0	2,128.0	1,899.0
Mass of container	gm	800.0	797.0	806.0	785.0	814.0
Mass of water added	gm	220	304	379	394	362
Mass of dry soil	gm	1281	1418	1576	1343	1085
Moisture content	%	17.2	21.4	24.0	29.3	33.4
Dry density	g/cm^3	1.230	1.398	1.430	1.358	1.238

Maximum dry density (gm/cm^3) 1.431 Optimum moisture content (%) 24.4



Remarks:

FOR TESTING LAB

Lab Technician	Materials Engineer	

STIRLING CIVIL ENGINEERING LTD 11 FEB 2025 P.O. BOX ..., KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference:	Laboratory Reference No.:	Sampling Date:	25/Jan/25
Location	NEAT	Casting date	1/Feb/25
		Testing Date	5/Feb/25
		Technician	Lab team
Sample Description	BLACK COTTON SOIL	**Volume of Mould used (m³)**	2305

Natural moisture of air dried sample		Volume of water added	
Tin No	LDD	Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1671	MDD (Mg/m³)	1.431
Tin + oven dry soil sample (g)	1651	N.M.C (%)	1.6
Tin (g)	419	OMC (%)	24.4
Dry soil sample	1232	Added OMC (%)	22.8
Water (g)	20	Calculated dry wt of soil (g)	5902.6
N.M.C (%)	1.6	Water added (g)	1345
Average (%)	1.6	**Water added (mL)**	1345

Number of blows		62			
Number of layer		5			
Water Content Determination		Before Soaking		After Soaking	
Tare No		BAR	-	HY	-
Mass of wet sample + Tare	g	1581	-	1255	-
Mass of dry sample + Tare	g	1490	-	1115	-
Mass of Tare	g	803	-	158	-
Mass of water	g	91	-	140	-
Mass of dry sample	g	687	-	957	-
Water content	%	13.2	-	14.6	-
Average water Content	%	13.2		14.6	
Density determination					
Mould No		I8			
Mass of mould + soil	g	11255		11310	
Mass of mould	g	7289		7289	
Mass of soil	g	3966		4021	
Volume of the mould	cm3	2305		2305	
Moist density	g/cm3	1.721		1.744	
Dry density	g/cm3	1.519		1.522	
Swell Determination					
Date		Hour		D Gauge Reding	
Initial reading		96 hrs		14.26	
Final reading				16	
Height of the specimen				127	
Height of swell				1.74	
		Swelling(%)		1.37	

Observations

For the Lab

Lab. Technician	Materials Engineer

STIRLING CIVIL ENGINEERING LTD P.O. BOX KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Laboratory Reference No.	Sampling Date	25/Jan/25
Location		Penetration Date	5/Feb/25
Depth		Technician	Lab team
Sample Description	BLACK COTTON SOIL		

	Specimen 1	Specimen 2	Specimen 3
Number of blows per layer	62		
Number of layers	5	5	5
Mould No	18		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2312	0.2312	0.2312
Speed mm/min.			

Penetration of the plunger (mm)	Time (S)	Top Reading $*10^{3}$mm	Top Force (KN)	Bottom Reading $*10^{3}$mm	Bottom Force (KN)
0	0	0	0.0	0	0.0
0.25	12	0	0.0	1	0.2
0.5	24	0	0.0	1	0.2
0.75	35	1	0.2	2	0.5
1	47	1	0.2	2	0.5
1.5	71	1	0.2	2	0.5
2	94	1	0.2	3	0.7
2.5	118	1	0.2	3	0.7
3	142	2	0.5	3	0.7
3.5	165	2	0.5	4	0.9
4	189	2	0.5	4	0.9
4.5	213	2	0.5	5	1.2
5	236	3	0.7	5	1.2
5.5	260	3	0.7	5	1.2
6	283	3	0.7	6	1.4
6.5	307	3	0.7	6	1.4
7	331	3	0.7	[illegible]	[illegible]
7.5	354	4	[illegible]	7	1.6

Observations

For the Contractor

STIRLING CIVIL ENGINEERING LTD
FEB 2025
P. O. BOX ..., KAMPALA (U)

Lab. Technician

Materials Engineer

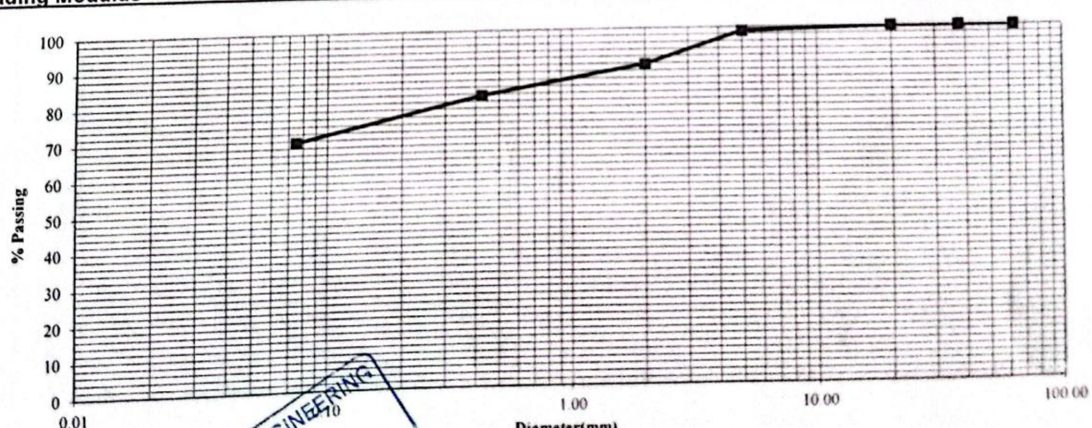
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT : STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:			Lab. Refernece No.:		
Location :(km)	NEAT		Dry wt. of sample before washing: (g)		3445.9
Depth: (m)			Dry wt. of sample after washing: (g)		1290.0
Material description:	BLACK COTTON SOIL		Date Sampled:	Date Tested:	Technician
			25/Jan/2025	31/Jan/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	0.0	0.0	**100**	80	100
20.0	0.0	0.0	**100**	60	95
5.0	40.3	1.2	**99**	30	65
2.00	313.9	9.1	**90**	20	50
0.425	280.1	8.1	**82**	10	30
0.075	414.7	12.0	**70**	5	15
Total fines	2396.9	69.6			
Bottom Pan	241.0				
Extracted fines	2155.9				
Total sample	3445.9				
Grading Modulus		**0.59**			



FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 2... KAMPALA (U)

Lab Technician *Materials Engineer*

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT:	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

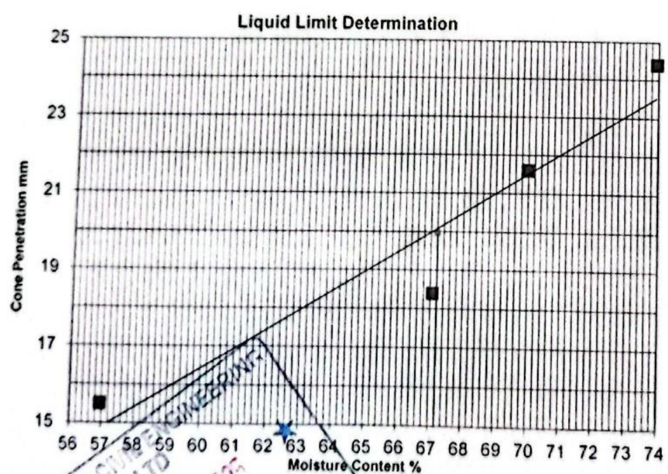
ATTERBERG LIMITS

Liquid limit (cone penetrometer) and plastic limit

Test Reference No		Lab Reference No	Technician	Lab Team
Location	NEAT	SAMPLE 2	Sample Date	25/Jan/2025
Test method	BS 1377, Part 2, 1990 4.3/4.4		Test Date	28/Jan/2025
LAYER	BLACK COTTON SOIL			

PLASTIC LIMIT	Test No	PNU	OO		Average
Mass of wet soil + container (g)		40.9	33.37		37.135
Mass of dry soil + container (g)		36.98	30.79		33.885
Mass of container (g)		22.84	21.66		22.25
Mass of moisture (g)		3.92	2.6		3.25
Mass of dry soil (g)		14.14	9.13		11.635
Moisture content %		27.7	28.3		28.0
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.5	18.4	21.6	24.4
penetration (mm)		15.5	18.4	21.6	24.4
AVERAGE		15.5	18.4	21.6	24.4
Container No		PI45	PI811	FORD	PI82
Mass of wet soil + container (g)		65.07	57.47	68.81	76.85
Mass of dry soil + container (g)		44.00	37.27	43.35	47.19
Mass of container (g)		7.00	7.15	6.96	7.08
Mass of moisture (g)		21.07	20.2	25.46	29.66
Mass of dry soil (g)		37	30.12	36.39	40.11
Moisture content (%)		56.9	67.1	70.0	73.9
AVERAGE		56.9	67.1	70.0	73.9



Liquid limit (%)	67.2
Plastic limit (%)	28.0
Plasticity Index (%)	39.2
Linear shrinkage	
Trough No.	K
Trough length (cm)	14.0
Specimen length (cm)	11.3
L shringage =	2.7
% L.shrinkage =	19.3

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STIRLING CIVIL ENGINEERING LTD — FEB 2025 — P.O. BOX 786, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT:	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

Test Reference No		Lab Reference No	Date Sampled	Date Tested	Technician
Mix	NEAT (SAMPLE 2)		25/Jan/25	31/Jan/25	Lab team
Material description:		BLACK COTTON SOIL	Natural moisture (%) :	11.0	

TEST DATA

Weight of rammer (Kg)	No. of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm^3)
4.5	27	3	457	100	1,000

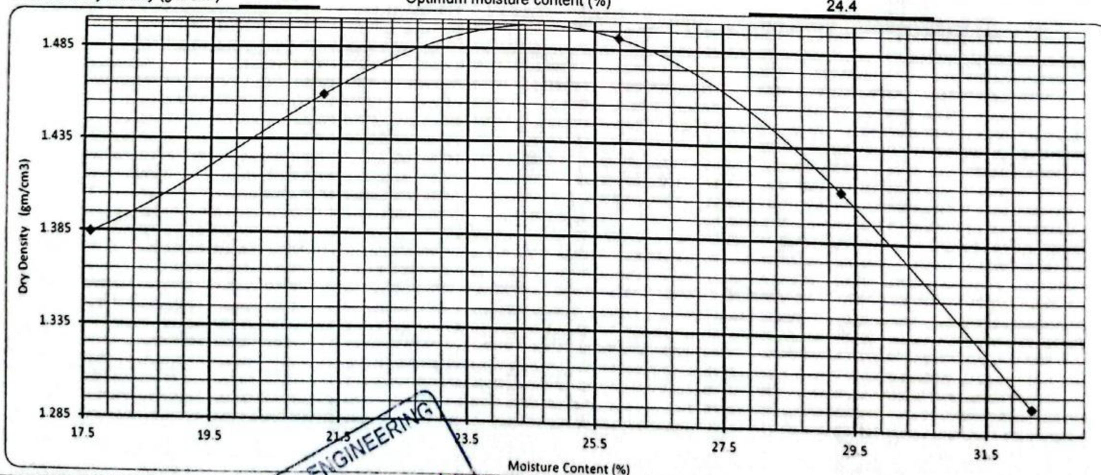
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	90	150	210	270	330
Mass of Compacted soil + mould	gm	5,383	5,524	5,632	5,580	5,472
Mass of Mould	gm	3,755	3,755	3,755	3,755	3,755
Mass of Compacted soil	gm	1628	1769	1877	1825	1717
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.628	1.769	1.877	1.825	1.717

DATA FOR PROCTOR CURVE

Container No.		MU	LU	AXE	JK	KO
Mass of wet soil + Container	gm	1,568.0	968.0	2,235.0	1,856.0	1,158.0
Mass of dry soil + container	gm	1,356.0	808.0	1,940.0	1,550.0	913.0
Mass of container	gm	152.0	55.0	800.0	505.0	152.0
Mass of water added	gm	212	160	295	306	245
Mass of dry soil	gm	1204	753	1140	1045	761
Moisture content	%	17.6	21.2	25.9	29.3	32.2
Dry density	g/cm^3	1.384	1.459	1.491	1.412	1.299

Maximum dry density (gm/cm^3) 1.498 Optimum moisture content (%) 24.4



Remarks:

FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD 11 FEB 2025

Lab Technician Materials Engineer

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference	Laboratory Reference No.:	Sampling Date	25/Jan/25
Location	NEAT (SAMPLE 2)	Casting date	1/Feb/25
		Testing Date	5/Feb/25
		Technician	Lab team
Sample Description	BLACK COTTON SOIL	**Volume of Mould used (m³)**	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	AU		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	532		MDD (Mg/m³)	1.498
Tin + oven dry soil sample (g)	500		N.M.C (%)	7.2
Tin (g)	54		OMC (%)	24.4
Dry soil sample	446		Added OMC (%)	17.2
Water (g)	32		Calculated dry wt of soil (g)	5569.5
N.M.C (%)	7.2		Water added (g)	964
Average (%)	7.2		**Water added (mL)**	**964**

Number of blows		62			
Number of layer		5			
Water Content Determination		Before Soaking		After Soaking	
Tare No		MU	-	JP	-
Mass of wet sample + Tare	g	1708	-	640	-
Mass of dry sample + Tare	g	1577	-	565	-
Mass of Tare	g	548	-	60	-
Mass of water	g	131	-	75	-
Mass of dry sample	g	1029	-	505	-
Water content	%	12.7	-	14.9	-
Average water Content	%	12.7		14.9	
Density determination					
Mould No		KAU			
Mass of mould + soil	g	11314		11400	
Mass of mould	g	7262		7262	
Mass of soil	g	4052		4138	
Volume of the mould	cm3	2305		2305	
Moist density	g/cm3	1.758		1.795	
Dry density	g/cm3	1.559		1.563	
Swell Determination					
Date		Hour		D.Gauge Reding	
Initial reading		96 hrs			
Final reading				3.55	
Height of the specimen				127	
Height of swell				1.55	
		Swelling(%)		1.22	

Observations

For the Lab

Lab. Technician	*Materials Engineer*

STIRLING CIVIL ENGINEERING LTD 11 FEB 2025 KAMPALA (U)

UGANDA CHRISTIAN UNIVERSITY

A Centre of Excellence in the Heart of Africa

RACHKARA AARON & LUGGYA MARK

Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No :	Sampling Date	25/Jan/25
Location:		Penetration Date	5/Feb/25
Depth :		Technician	Lab team
Sample Description :	BLACK COTTON SOIL		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	KAU		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2312	0.2312	0.2312

Speed .... mm/min

Penetration of the plunger (mm)	Time (s)	Top Reading *10³mm	Top Force (KN)	Bottom Reading *10³mm	Bottom Force (KN)
0	**0**	0	0.0	0	0.0
0.25	**12**	0	0.0	0	0.0
0.5	**24**	0	0.0	1	0.2
0.75	**35**	1	0.2	1	0.2
1	**47**	1	0.2	1	0.2
1.5	**71**	1	0.2	1	0.2
2	**94**	2	0.5	2	0.5
2.5	**118**	2	0.5	2	0.5
3	**142**	2	0.5	2	0.5
3.5	**165**	3	0.7	3	0.7
4	**189**	3	0.7	3	0.7
4.5	**213**	3	0.7	3	0.7
5	**236**	4	0.9	4	0.9
5.5	**260**	4	0.9	4	0.9
6	**283**	4	0.9	4	0.9
6.5	**307**	4	0.9	5	1.2
7	**331**	4	0.9	[illegible]	1.2
7.5	**354**	4	[illegible]	5	1.2

Observations

For the Contractor

Lab Technician | Materials Engineer

STIRLING CIVIL ENGINEERING LTD 11 FEB 2025 P.O. BOX 7... KAMPALA (U)

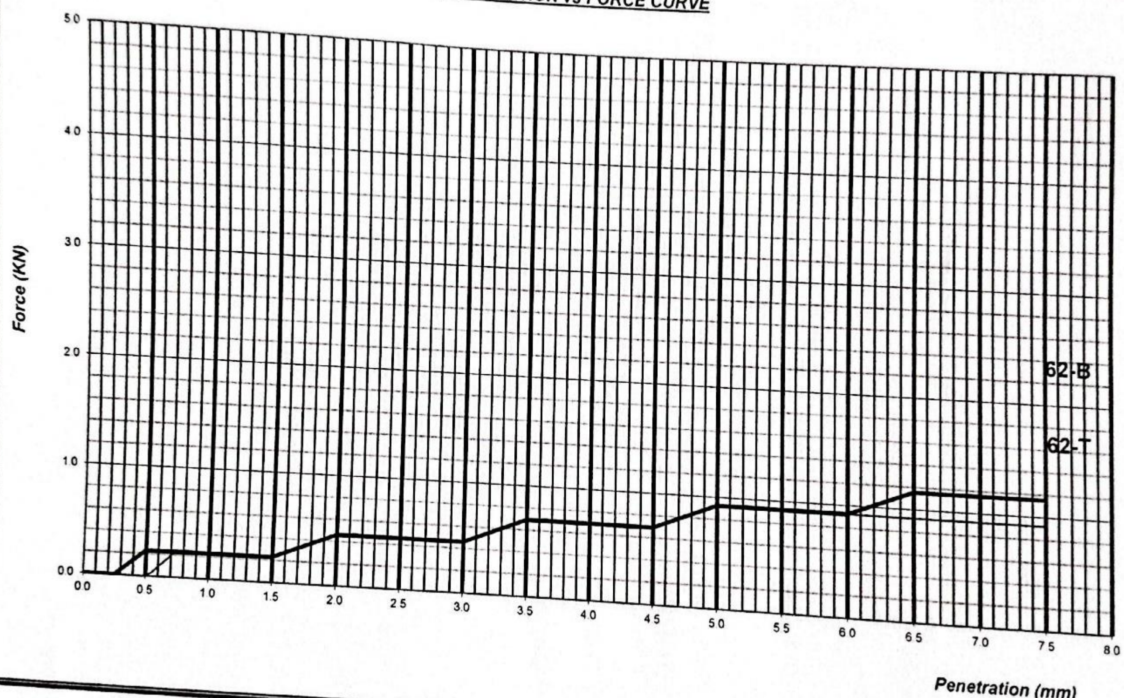
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:		
Location:		Sampling Date :	25/Jan/25
Depth:		Testing Date :	5/Feb/25
Sample Description:	BLACK COTTON SOIL	Technician	: Lab team

PENETRATION vs FORCE CURVE



	62 blows													
	Force		CBR											
	Bottom	Top	Bottom	Top										
2.5 mm Penetration	0.5	0.5	3	3										
5.0 mm Penetration	0.9	0.9	5	5										
Average	0.7		4.1	4.1										
Retained CBR	4.1													
Observations														

CBR = 4.1

For the Lab.

Lab. Technician	Materials Engineer		

STIRLING CIVIL ENGINEERING LTD
11 FEB 2025
P.O. BOX 786, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	RACHKARA AARON & LUGGYA MARK	**Stirling**

PROJECT:	**STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH**

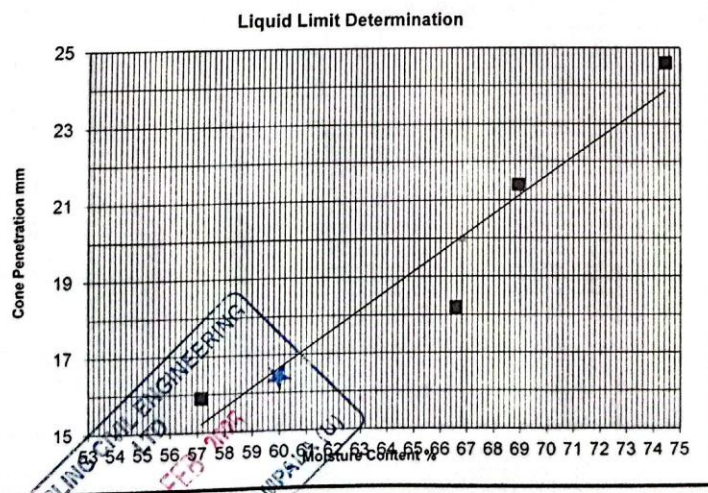
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.	Lab. Reference No.	Technician	Lab Team
Location	NEAT	Sample Date	25/Jan/2025
Test method	BS 1377: Part 2, 1990 4 3/4 4	Test Date	28/Jan/2025
LAYER	BLACK COTTON SOIL		

PLASTIC LIMIT	Test No.	Q	OG		Average
Mass of wet soil + container (g)		37.51	33.15		35.33
Mass of dry soil + container (g)		34.28	30.53		32.405
Mass of container (g)		21.68	21.41		21.545
Mass of moisture (g)		3.23	2.6		2.925
Mass of dry soil (g)		12.6	9.12		10.86
Moisture content %		25.6	28.7		27.2
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.9	18.2	21.4	24.6
penetration (mm)		15.9	18.2	21.4	24.6
AVERAGE		15.9	18.2	21.4	24.6
Container No.		A4	A3	PI33	6E
Mass of wet soil + container (g)		73.70	58.79	73.15	76.74
Mass of dry soil + container (g)		49.42	38.05	46.20	47.04
Mass of container (g)		6.92	6.90	7.09	7.15
Mass of moisture (g)		24.28	20.74	26.95	29.7
Mass of dry soil (g)		42.5	31.15	39.11	39.89
Moisture content (%)		57.1	66.6	68.9	74.5
AVERAGE		57.1	66.6	68.9	74.5



Liquid limit (%)	66.8
Plastic limit (%)	27.2
Plasticity Index (%)	39.6
Linear shrinkage	
Trough No.	I
Trough length (cm)	14.0
Specimen length (cm)	11.2
L.shringage =	2.8
% L.shrinkage =	20.0

Remarks:

TESTING LAB:

Materials Engineer

Lab Technician

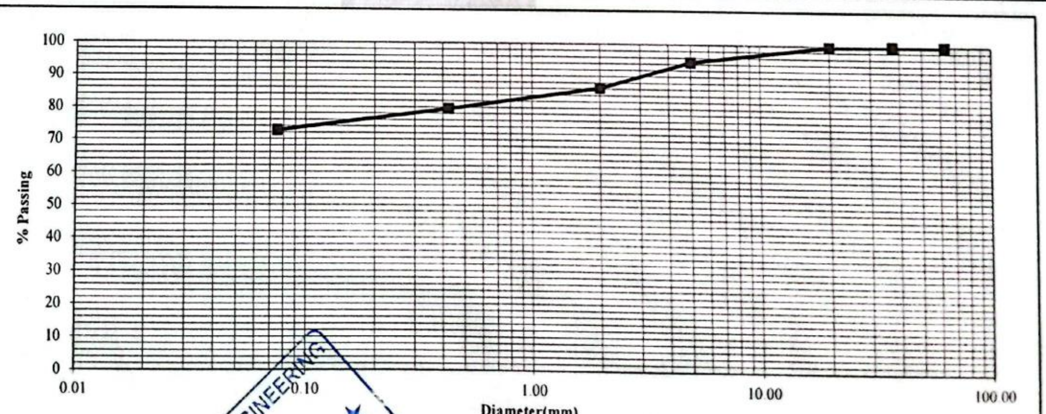
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT : STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	NEAT SAMPLE 3	Dry wt. of sample before washing (g)		3112.8
Depth: (m)		Dry wt. of sample after washing (g)		1036.0
Material description:	BLACK COTTON SOIL	Date Sampled:	Date Tested:	Technician
		25/Jan/2025	31/Jan/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	0.0	0.0	**100**	80	100
20.0	11.0	0.4	**100**	60	95
5.0	158.9	5.1	**95**	30	65
2.00	257.3	8.3	**86**	20	50
0.425	210.2	6.8	**80**	10	30
0.075	214.7	6.9	**73**	5	15
Total fines	2260.7	72.6			
Bottom Pan	183.9				
Extracted fines	2076.8				
Total sample	3112.8				
Grading Modulus		**0.62**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD P. O. BOX 75...

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT:	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH				
Test Reference No		Lab Reference No	Date Sampled	Date Tested	Technician
Mix	NEAT (SAMPLE		25/Jan/25	31/Jan/25	Lab team
Material description:		BLACK COTTON SOIL	Natural moisture (%)	6.8	

TEST DATA

Weight of rammer (Kg)	No of blows per layer	No of layers	Height of drop (mm)	Diameter of mould(mm)	Volume of mould (cm³)
4.5	27	3	457	100	1.000

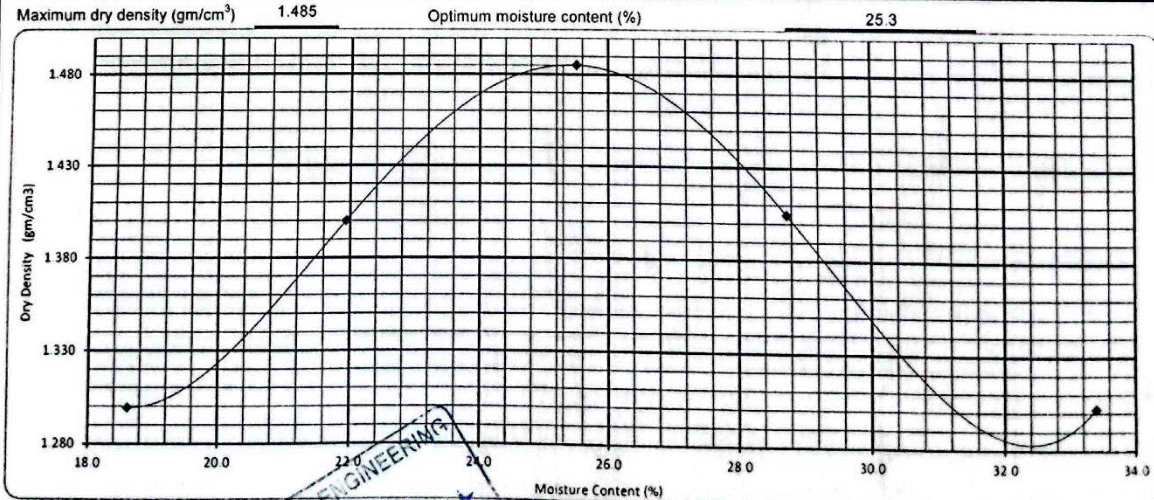
MOISTURE CONTENT DATA

Test No		1	2	3	4	5
Tin No		A	A	A	A	A
Water Added	cm^3	120	180	240	300	360
Mass of Compacted soil + mould	gm	5,333	5,499	5,656	5,600	5,529
Mass of Mould	gm	3,792	3,792	3,792	3,792	3,792
Mass of Compacted soil	gm	1541	1707	1864	1808	1737
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.541	1.707	1.864	1.808	1.737

DATA FOR PROCTOR CURVE

Container No.		LD	KCR	ZION	YT	NQ
Mass of wet soil + Container	gm	1,650.0	1,518.0	1,547.0	1,568.0	799.0
Mass of dry soil + container	gm	1,457.0	1,319.0	1,322.0	1,310.0	616.0
Mass of container	gm	420.0	412.0	440.0	412.0	68.0
Mass of water added	gm	193	199	225	258	183
Mass of dry soil	gm	1037	907	882	898	548
Moisture content	%	18.6	21.9	25.5	28.7	33.4
Dry density	g/cm^3	1.299	1.400	1.485	1.404	1.302

Maximum dry density (gm/cm^3) 1.485 Optimum moisture content (%) 25.3



Remarks:

FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD

11 FEB 2025

Lab Technician	Materials Engineer		

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT:	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

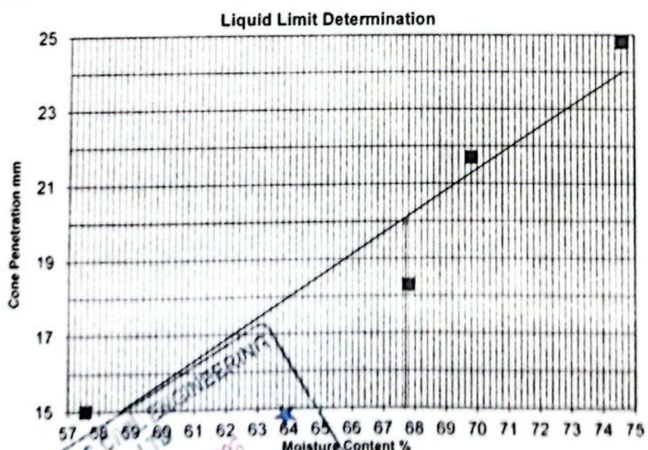
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No	Lab Reference No	Technician	Lab Team
Location	NEAT SAMPLE3	Sample Date	25/Jan/2025
Test method	BS 1377 Part 2 1990 4 3/4 4	Test Date	28/Jan/2025
LAYER	BLACK COTTON SOIL		

PLASTIC LIMIT	Test No	D	KK		Average
Mass of wet soil + container (g)		46 44	38 98		42 71
Mass of dry soil + container (g)		41 3	35 32		38 31
Mass of container (g)		22 76	22 24		22 5
Mass of moisture (g)		5 14	3 7		4 4
Mass of dry soil (g)		18 54	13 08		15 81
Moisture content %		27 7	28 0		27 9
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15 0	18 3	21 7	24 8
penetration (mm)		15 0	18 3	21 7	24 8
AVERAGE		15 0	18 3	21 7	24 8
Container No		PP	PIH	PPP	OI
Mass of wet soil + container (g)		46 14	43 21	46 48	50 42
Mass of dry soil + container (g)		31 79	28 49	30 22	31 86
Mass of container (g)		6 86	6 77	6 93	6 99
Mass of moisture (g)		14 35	14 72	16 26	18 56
Mass of dry soil (g)		24 93	21 72	23 29	24 87
Moisture content (%)		57 6	67 8	69 8	74 6
AVERAGE		57 6	67 8	69 8	74 6



Liquid limit (%)	67 7
Plastic limit (%)	27 9
Plasticity Index (%)	39 8
Linear shrinkage	
Trough No	P
Trough length (cm)	14 0
Specimen length (cm)	11 2
L shringage =	2 8
% L shrinkage =	19 9

Remarks

TESTING LAB		
Materials Engineer		
Lab Technician		

STIRLING CIVIL ENGINEERING LTD 11 FEB 2025 P.O. BOX 786, KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference : | Laboratory Reference No : | Sampling Date 25/Jan/25

Location: | Penetration Date 5/Feb/25

Depth : | Technician : Lab team

Sample Description : BLACK COTTON SOIL

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	YT		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0 2312	0 2312	0 2312

Speed :..........mm/min.		Top		Bottom									
Penetration of the plunger (mm)	Time (s)	Reading $*10^3$mm	Force (KN)	Reading $*10^3$mm	Force (KN)								
0	0	0	0.0	0	0.0								
0.25	12	0	0.0	0	0 0								
0.5	24	1	0.2	1	0 2								
0.75	35	1	0.2	1	0 2								
1	47	1	0.2	1	0 2								
1.5	71	1	0.2	2	0 5								
2	94	2	0.5	2	0 5								
2.5	118	3	0.7	2	0.5								
3	142	3	0.7	3	0.7								
3.5	165	4	0.9	3	0 7								
4	189	4	0.9	4	0 9								
4.5	213	4	0.9	4	0.9								
5	236	4	0.9	4	0 9								
5.5	260	5	1.2	5	1 2								
6	283	5	1.2	5	1 2								
6.5	307	5	1 2	5	1.2								
7	331	5	1 2		1 4								
7.5	354	5		6	1 4								

Observations

For the Contractor

Lab. Technician

STIRLING CIVIL ENGINEERING LTD
11 FEB 2025
Materials Engineers
P.O. BOX ... KAMPALA (U)

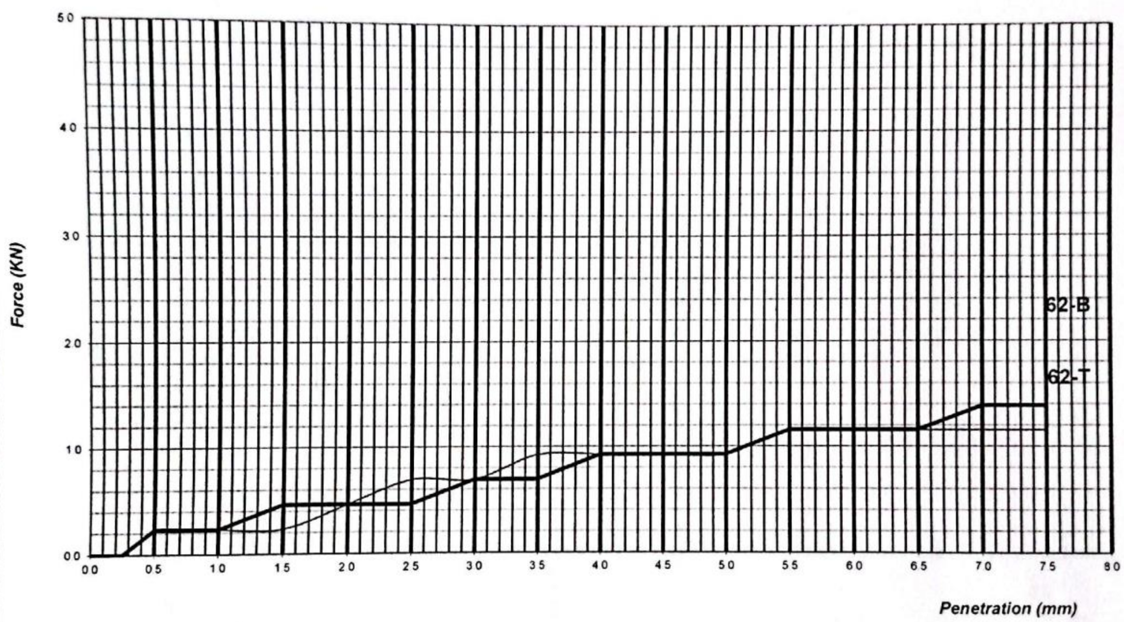
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date : 25/Jan/25
Location:		Testing Date : 5/Feb/25
Depth:		Technician : Lab team
Sample Description: BLACK COTTON SOIL		

PENETRATION vs FORCE CURVE



	62 blows			
	Force		CBR	
	Bottom	Top	Bottom	Top
2.5 mm Penetration	0.5	0.7	3	5
5.0 mm Penetration	0.9	0.9	5	5
Average	0.7	0.8	4.1	4.9
Retained CBR		4.9		
Observations	CBR= 4.9			

For the Lab

Lab. Technician | *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD
11 FEB 2025
P.O. BOX

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference	Laboratory Reference No.:	Sampling Date	25/Jan/25
Location	NEAT (SAMPLE 3)	Casting date	1/Feb/25
		Testing Date	5/Feb/25
Sample Description	BLACK COTTON SOIL	Technician	Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No	KT		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1642		MDD (Mg/m^3)	1.485
Tin + oven dry soil sample (g)	1588		N.M.C (%)	6.8
Tin (g)	799		OMC (%)	25.3
Dry soil sample	789		Added OMC (%)	18.5
Water (g)	54		Calculated dry wt of soil (g)	5589.4
N.M.C (%)	6.8		Water added (g)	1036
Average (%)	6.8		**Water added (mL)**	**1036**

Number of blows		62				
Number of layer		5				
Water Content Determination		Before Soaking		After Soaking		
Tare No		D	-	KI	-	
Mass of wet sample + Tare	g	856	-	1970	-	
Mass of dry sample + Tare	g	764	-	1728	-	
Mass of Tare	g	58	-	82	-	
Mass of water	g	92	-	242	-	
Mass of dry sample	g	706	-	1646	-	
Water content	%	13.0	-	14.7	-	
Average water Content	%	13.0		14.7		
Density determination						
Mould No		YT				
Mass of mould + soil	g	9964		10044		
Mass of mould	g	5152		5152		
Mass of soil	g	4812		4892		
Volume of the mould	cm3	2305		2305		
Moist density	g/cm3	2.088		2.123		
Dry density	g/cm3	1.847		1.850		
Swell Determination						
Date		Hour		D Gauge Reding		
Initial reading		96 hrs		13.58		
Final reading				15.36		
Height of the specimen				127		
Height of swell				1.78		
		Swelling(%)		**1.40**		

Observations

For the Lab

Lab. Technician	*Materials Engineer*

STIRLING CIVIL ENGINEERING LTD 11 FEB 2025 KAMPALA (U)

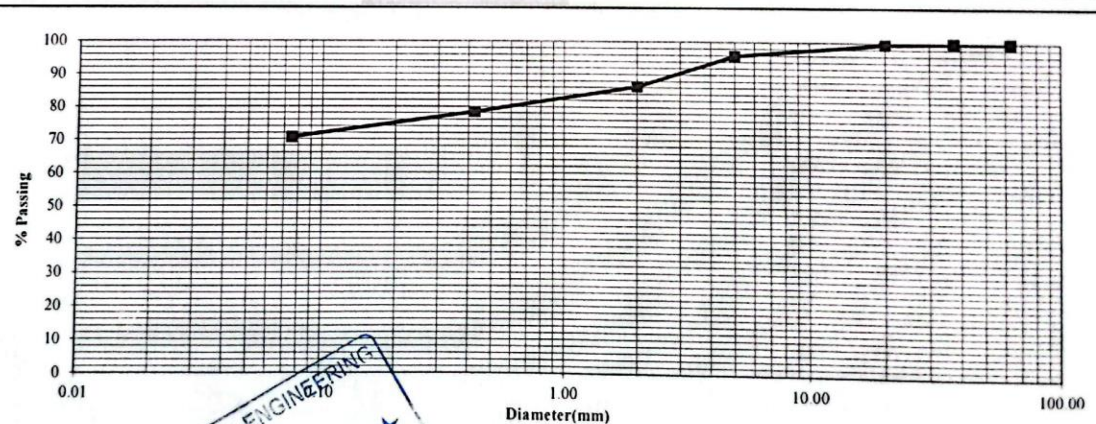
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT : STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab Refernece No.:		
Location (km)	NEAT SAMPLE 2	Dry wt. of sample before washing (g)		4102.7
Depth: (m)		Dry wt. of sample after washing (g)		1320.4
Material description:	BLACK COTTON SOIL	Date Sampled:	Date Tested	Technician
		25/Jan/2025	31/Jan/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	0.0	0.0	**100**	80	100
20.0	20.0	0.5	**100**	60	95
5.0	151.7	3.7	**96**	30	65
2.00	389.8	9.5	**86**	20	50
0.425	330.0	8.0	**78**	10	30
0.075	314.7	7.7	**71**	5	15
Total fines	2896.5	70.6			
Bottom Pan	114.2				
Extracted fines	2782.3				
Total sample	4102.7				
Grading Modulus		**0.65**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD P.O. BOX ... KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT: STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

SUMMARY OF TEST RESULTS FOR BLACK COTTON STABILISED WITH 10% ASH

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62 BLOWS OF COMPACTION	62	AVERAGE
STABILISED WITH 10% ASH	Black cotton soil stabilised with 10% sewage sludge Ash	25/01/2025	100	100	100	98	94	83	63	0.60	53.3	31.1	22.2	13.1	1.583	21.3	11.3	0.55	0.55
			100	100	100	98	95	84	59	0.62	53.8	31.4	22.4	13.1					
			100	100	100	98.09	94.39	83.28	61.11	0.61	53.6	31.3	22.3	13.1	1.583	21.3	11.3	0.55	0.55
	AVERAGE		100	[illegible]	100	98	94	83	61	0.612	53.6	31.4	22.3	13.1	1.583	21.3	11.3	0.55	0.55

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 736, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT: STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

SUMMARY OF TEST RESULTS FOR BLACK COTTON NEAT

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62 BLOWS OF COMPACTION	62	AVERAGE
NEAT	BLACK COTTON SOIL	25/01/2025	100	100	100	99	90	82	70	0.59	66.8	27.2	39.6	20.0	1.431	24.4	5.5	1.37	1.37
			100	100	100	96	86	78	71	0.65	67.2	28.0	39.2	19.3	1.498	24.4	4.1	1.22	1.22
			100	100	100	95	86	80	73	0.62	67.7	27.9	39.8	19.9	1.485	25.3	4.9	1.40	1.40
			100	100	99.76	97.32	88.02	79.93	70.08	0.62	67.0	27.6	39.4	19.6	1.465	24.4	4.8	1.30	1.30
	AVERAGE		100	100	100	97	88	80	70	0.620	67.2	28.0	39.4	19.7	1.465	24.4	4.8	1.30	1.30

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
11 FEB
P.O. BOX

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT: STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

SUMMARY OF TEST RESULTS FOR BLACK COTTON STABILISED WITH 5% ASH

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62 BLOWS OF COMPACTION	62	AVERAGE
STABILISED WITH 5% ASH	Black cotton soil stabilised with 5% sewage sludge Ash	25/01/2025	100	100	100	98	95	82	62	0.60	61.8	29.3	32.5	17.3	1.541	22.7	8.4	1.37	1.37
			100	100	100	100	97	83	67	0.53	62.1	29.4	32.7	19.3					
			100	100	100	98.78	96.31	82.59	64.76	0.56	62.0	29.3	32.6	18.3	1.541	22.7	8.4	1.37	1.37
	AVERAGE		100	100	100	99	96	83	65	0.563	62.0	29.4	32.6	18.3	1.541	22.7	8.4	1.37	1.37

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT: STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

SUMMARY OF TEST RESULTS FOR BLACK COTTON STABILISED WITH 15% ASH

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62 BLOWS OF COMPACTION	62	AVERAGE
STABILISED WITH 15% ASH	Black cotton soil stabilised with 15% sewage sludge Ash	25/01/2025	100	100	100	99	94	83	65	0.58	48	33.3	14.7	10.2	1.620	20.1	15.4	0.37	0.37
			100	100	100	99	96	84	67	0.53	47.8	32.9	14.9	10.2					
			100	100	100	98.88	94.71	83.58	65.97	0.56	47.9	33.1	14.8	10.2	1.620	20.1	15.4	0.37	0.37
	AVERAGE		100	100	100	99	95	84	66	0.557	47.9	32.9	14.8	10.2	1.620	20.1	15.4	0.37	0.37

FOR LAB

Lab Technician

STIRLING CIVIL ENGINEERING LTD

Materials Engineer

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling

PROJECT: STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH

SUMMARY OF TEST RESULTS FOR BLACK COTTON STABILISED WITH 20% ASH

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62 BLOWS OF COMPACTION	62	AVERAGE
STABILISED WITH 20% ASH	Black cotton soil stabilised with 20% sewage sludge Ash	25/01/2025	100	100	100	98	93	85	69	0.52	43.2	34.7	8.5	5.0	1.587	21.4	14.5	0.55	0.55
			100	100	100	98	95	88	68	0.49	43.5	35.0	8.5	5.0					
			100	100	100	97.93	93.97	86.63	68.88	0.51	43.4	34.8	8.5	5.0	1.587	21.4	14.5	0.55	0.55
	AVERAGE		100	100	100	98	94	87	69	0.505	43.4	35.0	8.5	5.0	1.587	21.4	14.5	0.55	0.55

FOR LAB

STIRLING CIVIL ENGINEERING LTD
Materials Engineer
P.O. BOX ... KAMPALA (U)

Lab Technician

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling
PROJECT	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH	

STABLISED CBR

(BS 1924 PART 2 1)

BLACK COTTON SOIL STABILIZED WITH 5% SEWAGE SLUDGE ASH

M/c of air dried sample				M/c After Mixing			
Tin No	CR7			Stabliser	5% OF SEWAGE SLUDGE ASH		
Tin + Wet soil gm	2489			Content	5.0		
Tin + Dry Soil gm	2310			Tin No	BAR		
Tin gm	769			Tin + Wet Soil	1581		
Water gm	179.0			Tin + Dry Soil	1490		
Dry Soil gm	1,541.0			Tin	803		
M/c %	11.6			Water	91.0		
Av. M/c %	11.6			Dry Soil	687.0		
				M/c	13.2		

(a)MDD	1.541	kg/m3	(b)Air Dry M/c	11.6	%
(c)WD	3.498	kg/m3	(e)M/c to add	11.1	%
(d)OMC	22.7	%	(F) volume	2.305	

Date prepared 25/Feb/25 Date immerse 4/Mar/25 Date tested 11/Mar/25

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	8,063.1		
(j) Wt of air dried soil	6,000		
Air dry M/c	11.6		
(k) soil dry wt (100j/100+b)	5,375.6		
Stabliser	5% OF SEWAGE SLUDGE ASH		
(m)Stablisers content %	5.0		
(n) Stabliser to add k x(m/100)	268.8		
Water Addition((j+n)x(d-b))/(100+b)	622.5		
Wt. per layer CBR Only h/3			

SPECIMEN WEIGHT CHECK			
No. of blows	62.0	62.0	AVERAGE
Mould No.	7 DAYS AIR TIGHT, 7 DAYS SOAKED	7 DAYS AIR TIGHT, 7 DAYS SOAKED	
Stabliser	5% OF SEWAGE SLUDGE ASH	5% OF SEWAGE SLUDGE ASH	
Content %	5.0	5.0	
Mould g	A	B	
Wet Soil g	4,469.0	4,877.0	
Compaction M/c %	13.2	13.2	
Dry density kg/m3	1.712	1.868	
%Compaction	111.1	121.2	
FORCE	3.5	3.2	
UCS	0.190	0.178	0.18

STIRLING CIVIL ENGINEERING P.O. BOX 96, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling
PROJECT	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH	

STABLISED CBR

(BS 1924 PART 2 1)

BLACK COTTON SOIL STABILIZED WITH10% SEWAGE SLUDGE ASH

M/c of air dried sample		
Tin No	KAU	
Tin + Wet soil gm	2225	
Tin + Dry Soil gm	2060	
Tin gm	799	
Water gm	165.0	
Dry Soil gm	1,261.0	
M/c %	13.1	
Av. M/c %	13.1	

M/c After Mixing			
Stabliser	10% OF SEWAGE SLUDGE ASH		
Content	10.0		
Tin No	ACB		
Tin + Wet Soil	1842		
Tin + Dry Soil	1654		
Tin	781		
Water	188.0		
Dry Soil	873.0		
M/c	21.5		

(a)MDD 1.583 kg/m3

(c)WD 3,371 kg/m3

(d)OMC 21.3 %

(b)Air Dry M/c 13.1 %

(e)M/c to add 8.2 %

(F) volume 2.305

Date prepared 25/Feb/25 Date immerse 4/Mar/25 Date tested 11/Mar/25

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	7,769.5		
(j) Wt of air dried soil	6,000		
Air dry M/c	13.1		
(k) soil dry wt (100j/100+b)	5,305.8		
Stabliser	10% OF SEWAGE SLUDGE ASH		
(m)Stablisers content %	10.0		
(n) Stabliser to add k x(m/100)	530.6		
Water Addition((j+n)x(d-b))/(100+b)	474.4		
Wt. per layer CBR Only h/3			

SPECIMEN WEIGHT CHECK

No. of blows	62.0	62.0	AVERAGE
Mould No.	7 DAYS AIR TIGHT	7 DAYS AIR TIGHT, 7 DAYS SOAKED	
Stabliser	10% OF SEWAGE SLUDGE ASH	10% OF SEWAGE SLUDGE ASH	
Content %	10.0	10.0	
Mould g	A	B	
Wet Soil g	4,285.0	4,423.0	
Compaction M/c %	21.5	21.5	
Dry density kg/m3	1.530	1.579	
%Compaction	96.7	99.8	
FORCE	5.1	5.1	
UCS (F/A)	0.279	0.279	0.28

STIRLING CIVIL ENGINEERING LTD
24 MAR 2025
P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling
PROJECT	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH	

STABLISED CBR

(BS 1924 PART 2 1)

BLACK COTTON SOIL STABILIZED WITH1 5% SEWAGE SLUDGE ASH

M/c of air dried sample		
Tin No	KJT	
Tin + Wet soil gm	2368	
Tin + Dry Soil gm	2230	
Tin gm	811	
Water gm	138.0	
Dry Soil gm	1,419.0	
M/c %	9.7	
Av. M/c %	9.7	

M/c After Mixing			
Stabliser	15% OF SEWAGE SLUDGE ASH		
Content	5.0		
Tin No	KT		
Tin + Wet Soil	1640		
Tin + Dry Soil	1508		
Tin	799		
Water	132.0		
Dry Soil	709.0		
M/c	18.6		

(a)MDD 1.620 kg/m3

(c)WD 3,256 kg/m3

(d)OMC 20.1 %

(b)Air Dry M/c 9.7 %

(e)M/c to add 10.4 %

(F) volume 2.305

Date prepared 25/Feb/25 Date immerse 4/Mar/25 Date tested 11/Mar/25

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	7,505.5		
(j) Wt of air dried soil	6,000		
Air dry M/c	9.7		
(k) soil dry wt (100j/100+b)	5,468.2		
Stabliser	15% OF SEWAGE SLUDGE ASH		
(m)Stablisers content %	5.0		
(n) Stabliser to add k x(m/100)	273.4		
Water Addition((j+n)x(d-b))/(100+b)	593.2		
Wt. per layer CBR Only h/3			

SPECIMEN WEIGHT CHECK			
No. of blows	62.0	62.0	AVERAGE
Mould No.	7 DAYS AIR TIGHT	7 DAYS AIR TIGHT, 7 DAYS SOAKED	
Stabliser	15% OF SEWAGE SLUDGE ASH	15% OF SEWAGE SLUDGE ASH	
Content %	5.0	5.0	
Mould g	A	B	
Wet Soil g	4,652.0	4,588.0	
Compaction M/c %	18.6	18.6	
Dry density kg/m3	1.701	1.678	
%Compaction	105.0	103.6	
FORCE	6.2	5.8	
UCS	0.342	0.317	0.33

STIRLING CIVIL ENGINEERING LTD
24 MAR 2025
P.O. BOX 96, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	RACHKARA AARON & LUGGYA MARK	Stirling
PROJECT	STABILISING BLACK COTTON SOIL USING SEWAGE SLUDGE ASH	

STABLISED CBR

(BS 1924 PART 2 1)

BLACK COTTON SOIL STABILIZED WITH 20% SEWAGE SLUDGE ASH

M/c of air dried sample

Tin No.	UH	
Tin + Wet soil gm	2152	
Tin + Dry Soil gm	2031	
Tin gm	799	
Water gm	121.0	
Dry Soil gm	1,232.0	
M/c %	9.8	
Av. M/c %	9.8	

M/c After Mixing

Stabliser	20% OF SEWAGE SLUDGE ASH		
Content	3.0		
Tin No	ACB		
Tin + Wet Soil	1842		
Tin + Dry Soil	1654		
Tin	781		
Water	188.0		
Dry Soil	873.0		
M/c	21.5		

(a)MDD	1.587	kg/m3	(b)Air Dry M/c	9.8	%
(c)WD	21	kg/m3	(e)M/c to add	10.3	%
(d)OMC	20.1	%	(F) volume	2.305	

Date prepared 25/Feb/25 Date immerse 4/Mar/25 Date tested 11/Mar/25

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	7,354.5		
(j) Wt of air dried soil	6,000		
Air dry M/c	9.8		
(k) soil dry wt (100j/100+b)	5,463.4		
Stabliser	20% OF SEWAGE SLUDGE ASH		
(m)Stablisers content %	3.0		
(n) Stabliser to add k x(m/100)	163.9		
Water Addition((j+n)x(d-b))/(100+b)	576.9		
Wt. per layer CBR Only h/3			

SPECIMEN WEIGHT CHECK

No. of blows	62.0	62.0	AVERAGE
Mould No.	7 DAYS AIR TIGHT	7 DAYS AIR TIGHT, 7 DAYS SOAKED	
Stabliser	20% OF SEWAGE SLUDGE ASH	20% OF SEWAGE SLUDGE ASH	
Content %	3.0	3.0	
Mould g	A	B	
Wet Soil g	4,566.0	4,720.0	
Compaction M/c %	21.5	21.5	
Dry density kg/m3	1.630	1.685	
%Compaction	102.7	106.1	
FORCE	5.8	5.5	
UCS	0.317	0.304	0.31

STIRLING CIVIL ENGINEERING LTD
MAR 2025
P. O. BOX 796, KAMPALA (U)

Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No.............................

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DIRECTORATE OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 Lourdel Road
Wandegeya,
P.O. Box 105639
Kampala - Uganda

DFD 040/2025
10th February 2025

MR. LUGGYA MARK ANTHONY AND MR. RACHKARA AARON
REG NO. S21B32/114 & S20B32/219
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4, MUKONO-UGANDA
Tel: 256-709-870710

REPORT OF ANALYSIS

Description of the Samples

One sample in black polythene bag containing Brown soil sample was submitted by Mr. Luggya Mark Anthony, on 04th February 2025, and analysed on 07th February 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Brown powdered substances packed in a black polythene bag.	01	Sample "S" DFD 040/2025

Analysis Requested

Elemental analysis

Method of Analysis

Elemental analysis was done using the XRF Method while loss on ignition was done using the thermogravimetric method.

Results of Analysis

The above sample has been analyzed with the following results as below,

Parameter	Units	Results for DFD 040/2025 sewage sludge sample
Loss on Ignition	% m/m	38.71
Elemental Composition		
Silicon dioxide	% m/m	51.78
Calcium oxide	% m/m	20.19
Aluminium oxide	% m/m	13.33
Iron (III) Oxide	% m/m	8.93
Phosphorous pent oxide	% m/m	2.63
Magnesium (II)Oxide	% m/m	1.43
Potassium Oxide	% m/m	1.16
Zinc Oxide	% m/m	0.64
Titanium dioxide	% m/m	0.12
Nickel oxide	% m/m	0.063
Manganese Oxide	% m/m	0.03
Copper Oxide	% m/m	0.02

Remarks

1. Results relate to sample analyzed and are reported as on received basis.

10/02/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"