STABILISATION OF LATERITE SOILS WITH CEMENT AND METAKAOLIN

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S20B32/216

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, 2024

UGANDA CHRISTIAN UNIVERSITY

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ABSTRACT

The purpose of this research was to stabilize laterite soils using cement and metakaolin. The need for this research is driven from the problems experienced during cement stabilization particularly autogenous shrinkage that is associated with cement hydration. Metakaolin which is pozzolanic in nature has in previous research demonstrated the capacity to minimize this shrinkage by increasing the voids formed during hydration of cement. Metakaolin has also been found to improve the strength properties of concrete. Therefore, this research aimed at increasing the strength of laterite soil stabilized with cement and metakaolin. To achieve this, cement and metakaolin were mixed together with cement kept at a constant 3%, which is the optimum for this purpose according previous research and metakaolin increased from 0% to 8% in intervals of 2% in order to determine the suitable mix design for stabilization of the laterite soils. A design mix of 3% cement and 4% metakaolin was selected as the optimum since this soil gave the highest values for the strength properties of the laterite soil after stabilization that is 57% for CBR and 1.41MPa for UCS. The shrinkage characteristics of the soil that is PI, CBR swell and linear shrinkage were all found to be within the allowable range according to the MoWT general specifications for road and bridge works 2005.

DECLARATION

I hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

Signed: Date:

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AGABA JOEL

S20B32/216

APPROVAL

I certify that this report is for **AGABA JOEL** and I fully accept that he has been under supervision and so submitted to the Faculty of Engineering, Design and Technology Uganda Christian University in partial fulfillment of the requirements for an award of a Bachelor of science in civil and environmental engineering.

Signed; Date

………………………………………. …………………………………………………..

Ms. Josephine Ritah Nakyeyune

Academic Supervisor

DEDICATION

I dedicate this research to my parents Mr. & Mrs. Bataringaya who have been my biggest support throughout this my academic journey. Additionally, I dedicate this research to my siblings Arinda Joan, Ahabwe Joshua and Ankunda Jonathan as well for being a motivation to my life.

ACKNOWLEDGEMENT

I thank the Almighty God for enabling me to carry out this research project and seeing me through this entire duration.

I would also like to thank my parents as well as my siblings for their continued support financially and emotionally for their unwavering support allowed me to focus on this research project and it would not have been possible without this support.

I would like to extend my gratitude to Ms. Josephine Ritah Nakyeyune, my research supervisor for the guidance, assistance, advice and time that she dedicated to this research project.

Appreciation goes out to Mr. Kakooza Paul my project partner for being collaborative and active throughout this research process.

Finally, I would like to thank the faculty of engineering design and technology at Uganda Christian university for supporting us and allowing us to do this research under their guidance and supervision.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
C-A-H	Calcium Aluminate Hydrate
CBR	California Beating Ratio
CEM	Cement
C-S-H	Calcium Silicate Hydrate
LL	Liquid limit
MDD	Maximum Dry Density
MK	Metakaolin
MoWT	Ministry of works and transportation
OMC	Optimum Moisture Content
PI	Plasticity index
PL	Plastic limit
UCS	Unconfined Compressive strength

CHAPTER ONE: INTRODUCTION

1.1 Background

Laterite soils are heavily worn tropical or sub-tropical residual soils which contain varied ratios of clay size to gravel-sized particles (Oyelami and Van Rooy, 2018). Laterite soils are reddish yellow soils that result from the processes of weathering in tropical climatic conditions of alternate hot and wet weather (Santha Kumar et al., 2022). The reddish yellow color is due to the presence of large quantities of iron oxide in the form of hematite (Fe_2O_3) (Kamtchueng et al., 2015). Uganda being located in the tropics has got laterite soils available in abundance in many parts of the country (Kamanyire, 2000).

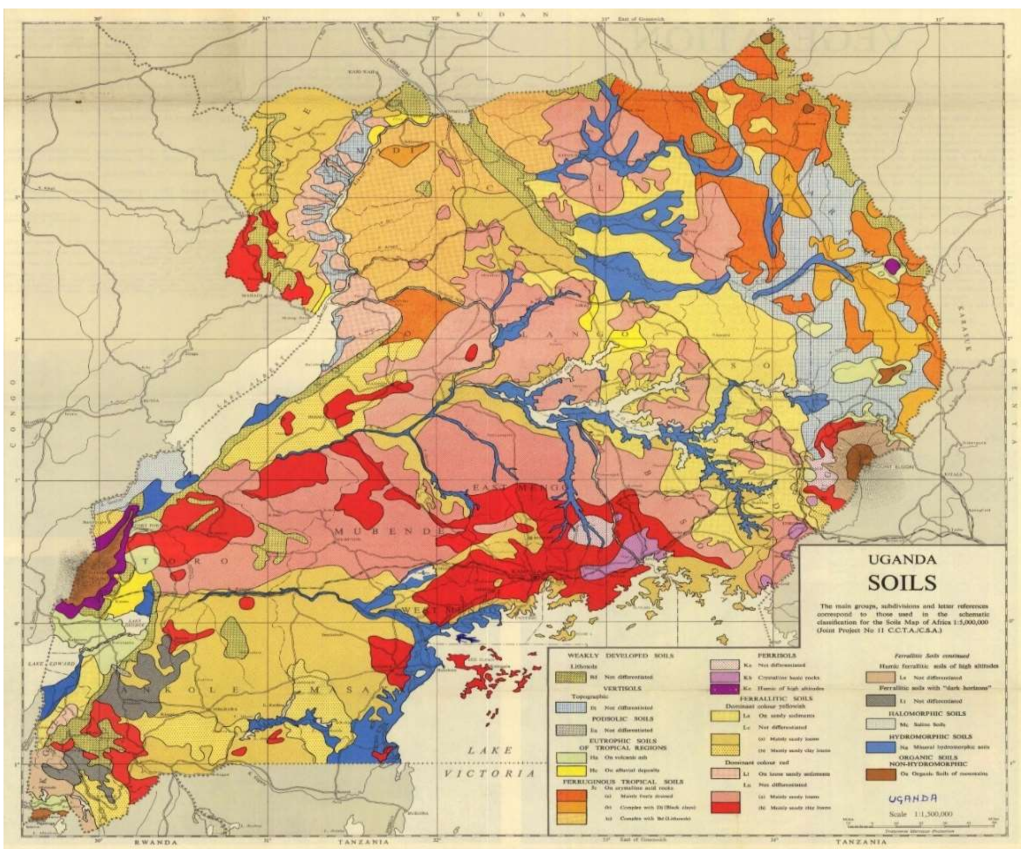

Figure 1: Showing distribution of soils in Uganda (Obtained from https://esdac.jrc.ec.europa.eu/content/uganda-soils)

From figure 1 above, it can be seen that majority of the soils in Uganda are ferralitic in nature. Ferrallitic soils are iron containing soils among which is laterite soil. This has led to the adaptation of these soils in many engineering activities. Uganda is highly dependent on laterite soils for road construction. These soils are most notably used in the subgrade and subbase layers of roads. However, these soils often have low bearing capacity. Laterite soils have also been found to contain quantities of clay minerals (Reda, Mohamad and Harris, 2021). Therefore, these soils are susceptible to volumetric changes which poses a challenge to motorists. This problem can be seen along Jambula road located in Akright city in Entebbe municipality where the presence of weak laterite soils in the subbase has left the road susceptible to damage from heavy traffic hence causing uneven settlement of the road surface and thus development of potholes in the road. This has caused problems for motorists that use the road (Richard, 2023). Various techniques have been developed to stabilize these soils like the use of cement as a chemical stabilizer. However, cement has got a challenge of shrinkage among others. Materials like meta-kaolin have been found to be effective in increasing the strength properties of cement-based concrete.

1.2 Problem statement

Laterite soils are a result of weathering in tropical conditions which is typical in most parts of Uganda(Smith et al., 2017). These types of soils are not suitable to be used as fill materials since they can't be compacted back to their natural density therefore being unable to offer enough resistance to traffic loads since they crush easily under loading (Tugume *et al.*, 2019). They are also greatly affected by water due to the presence of quantities of clay minerals in the soils which often fail during the rainy season (Bello Yamusa *et al.*, 2019). This problem can be seen along Jambula road located in Akright city in Entebbe municipality where the presence of weak laterite soils in the subbase has made the road susceptible to heavy traffic causing uneven settlement on the road surface leading to formation of potholes causing problems for motorists that use the road. A study conducted on the road concluded that the reason for failure of the road surface was because the laterite soils used in the subbase that did not offer enough resistance to traffic loading. The subbase material used was found to have a design soaked CBR (at 95% MDD; OMC) between 29-32%. The study concluded that subbase material with a minimum CBR of 45% be used on the road because of the traffic requirements of this road. Many researchers have tried to find materials that can be used to stabilize this type of soils. One of the materials that have been extensively researched is cement since it is able to increase their bearing capacity. However, the use of cement is marred by several problems particularly the shrinkage of cement-based materials that occurs during hydration. To solve this issue, the cement may be partially replaced with meta-kaolin. This study therefore aims to stabilize laterite soil using cement and metakaolin.

1.3 Objectives

1.3.1 Main objective

To stabilize laterite soils using cement and metakaolin.

1.3.2 Specific objectives

1. To determine the engineering properties of the neat laterite soil.
2. To determine the properties of meta-kaolin.

3. To determine the engineering properties of laterite soil stabilized with varying percentages of cement and meta-kaolin

1.4 Research questions

1. What are the engineering properties the laterite soils used on the road?
2. What are the properties of metakaolin?
3. What are the engineering properties of the soil when stabilized with different percentages of cement and metakaolin

1.5 Justification

Meta-kaolin ($Al_2Si_2O_7$) is produced from calcination of kaolinite clay at temperatures between 700^{0}C to 800^{0}C(Astutiningsih, Banjarnahor and Zakiyuddin, 2018). Meta-kaolin has pozzolanic properties (Branco and Angulski, 2018). This implies that meta-kaolin can react at room temperature in the presence of water to form substances that possess cementitious properties (Okitoi, 2021). Meta-kaolin itself is made up of (50-60) % silica and around (40-45) % alumina which are in active form. This silica and alumina will react with the calcium hydroxide ($Ca(OH)_2$) formed during hydration of cement leading to formation of calcium aluminum feldspars like calcium silicate hydrate and calcium aluminate hydrate which are components of the gel (Okitoi, 2021) that serves to bind the soil particles thus increasing the bearing capacity of the soil and reducing the plasticity index. (Kolovos et al., 2013) proved that the shrinkage associated with cement during hydration is reduced by (0-20) % by the use of meta-kaolin and reduction in the amount of cement used. From the MoWT General specifications for road and bridge works 2005, cement should be selected as a stabilizer of the PI of the soil is less than 20. This is because beyond a PI of 20, the fines in the soil are too high and lime would be more suitable for stabilization.

1.5 Scope

1.5.1 Geographical scope

The laterite soil that was used for the study was obtained from Jambula road in Akright city in Entebbe municipality in central Uganda. The metakaolin was got from Buwambo Parish in Gombe sub-county Wakiso subcounty in central Uganda. The cement was purchased from a hardware store in Mukono town.

1.5.2 Content scope

The scope of this research was be aimed but not limited at improving the engineering properties of laterite soils used on Jambula road in Entebbe municipality using cement and metakaolin.

1.5.3 Time scope

The research was carried out from August 2023 to March 2024.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter discusses the theoretical foundations upon which the research was built and centered and also highlights the important discoveries from analyzing different scholars' research findings.

2.1 Laterite soils

Laterite soils are a reddish-brown soil that are formed as a result of weathering in areas with tropical climate. Tropical climate implies alternate hot and wet weather (Trewin, 2014). In academic writing, the term "laterite" was originally used by geologist Francis Buchanan in 1807. He described the type of soil in the mountainous region of Malabar, India (Santha Kumar et al., 2022). The Latin word "Later," means "brick earth," and is the origin of the word "Laterite" originates (Rajashree, 2020). Laterite soil is a highly weathered soil rich in the secondary oxides of aluminum, iron, and or both. It is nearly void of primary silicates and bases, but it may include substantial amounts of kaolin and quartz (Quadri, Adeyemi and Olafusi, 2012). According to geomorphology, laterization involves the concentration of hydrated iron and aluminum oxides also known as "sesquioxide" as well as the leaching out or removal of silica, alkali, and alkaline earths (Prasad and Parthasarathy, 2018). It is either hard or capable of hardening on exposure (Quadri, Adeyemi and Olafusi, 2012). The reddish-brown color is due to the presence of these secondary oxides of iron and aluminum (Tiboti et al., 2021).

The properties of laterite soils greatly vary depending on the area in which the soils are found (Saing et al., 2017). These variations are caused by differences in the characteristics in the area in which the soils are found. The following are some of the factors that cause variations

- Parent rock- the characteristics of the soils will depend on the chemical composition of the rock from which the soils were formed (Oyelami and Van Rooy, 2018).
- Degree of weathering- when weathering occurs for a long time, the silica in the soil will almost be completely leached out and therefore only aluminum and iron oxides will be present in the soil which will influence its engineering properties (Santha Kumar et al., 2022)
- Geology in the area- the geology in the area has got a direct effect on the hydrology of the area and hence the flow of rain water. This will therefore influence how weathering in the area takes place and therefore affect the properties of soil formed (VALLERGA BA and VAN TIL CJ, 1970).
- Climate in the area- tropical climates with alternate hot and cold weather are the most favorable for the formation of laterite soils (McCauley, Jones and Jacobsen, 2005).

Laterite soils also contain very small quantities of clay minerals which cause a degree of volumetric changes with changes in moisture content of the soil (Adebisi *et al*., 2013).

Depending on the size of the soil's particles, the laterite soil may be cohesive or non-cohesive. While the sand -based laterite soil displays non-cohesive behavior, the silt and clay-based laterite soil displays cohesive behavior (Roshan et al., 2022).

Uganda is one of the countries in the tropics, this implies that Uganda has got an abundance of laterite soils. As such, these soils are readily available to be used in the construction industry because they are very economical. However, these soils often do not offer enough resistance to traffic loading and therefore will crush easily under traffic loading when used in road construction projects.

2.2 Soil stabilization

In the process of building roads, soil stabilization is an essential task. It is done when the local soils are soft and do not have enough bearing capacity, when the natural aggregates available locally are of not of good quality and expensive to import, or when it is expensive to remove the soils and replace with granular materials (Tan, Zahran and Tan, 2020). It is the process of adding together and combining different elements with soil to enhance specific engineering characteristics or properties of the soil. The procedure involves mixing additives to change the texture, gradation, and or the plasticity of the soil or to work as a binder for cementing the soil, or it may involve blending soils to produce the required engineering properties like gradation (Guyer, 2011).

Stabilization involves several techniques but they can broadly be classified into 2 types:

1. Mechanical stabilization
2. Chemical stabilization

2.2.1 Mechanical stabilization

Through physical processes, such as induced vibration, compaction, or the addition of additional physical elements like aggregates, barriers and nailing, it is possible to stabilize soil by changing the physical characteristics of the native soil particles. This process is known as mechanical stabilization (Makusa, 2012). Mechanical stabilization produces the required engineering properties by compaction of the soil aggregates particles hence producing a dense soil (Samuel, 2023).

Mechanical stabilization attempts to change the soil's engineering properties without changing its chemical make-up (Fondjo, Theron and Ray, 2021).

Mechanical stabilization techniques

(Fondjo, Theron and Ray, 2021) state the following as different mechanical stabilization techniques;

Pre wetting

The fundamental theory underlying this method is that saturating soil causes a swell prior to the commencement of construction, meaning that any additional wetting of the soil material will be too minimal to cause sufficient failure by maintaining a high water content (Schanz and Elsawy, 2015).

Compaction

The following are the reasons for which compaction of soil is carried out.

1. Reduction of the soil material's subsequent settling under loading.
2. Decrease in permeability stops rise in water stresses that would cause problems with liquefaction and water content.
3. Lastly, it raises the soil material's bearing limit and shear resistance.

Soil replacement

This technique involves excavating the weak soil from the area and replacing it with soil from a different area that demonstrates better strength characteristics.

Blending of various soils

This involves mixing the weaker soil with another soil with better engineering properties. This can be done with for example aggregates or sand and will generally improve the gradation in the soil to increase the properties of the soil.

Soil reinforcements

This technique involves addition of materials with a greater tensile strength as compared to the local soil. Such materials include geo-textiles as well as fibers (Sayyed *et al.*, 2012).

The scope of this research however is not mechanical stabilization.

2.2.2 Chemical stabilization

In chemical stabilization, the desired impact of soil stabilization is mostly achieved by chemical reactions between the stabilizing substance and the soil minerals (Makusa, 2012).

In this type of stabilization, a chemical compound is added to the soil and the chemical composition of the compound added will react with the elements in the soil to improve the soil.

Chemical stabilization is done by mixing materials like lime, cement, fly ash, rice husk ash and other pozzolanic materials or a mixture of these materials with the soil whose engineering properties are to be stabilized(Guyer, 2011). The subsequent chemical reactions are what lead to the soil's engineering properties improving (Patel et al., 2020).

Chemical stabilization can be divided into 2 broader categories (Fondjo, Theron and Ray, 2021);

i. Using traditional stabilizers for example cement, lime as well as fly ash.
ii. Using non- traditional stabilizers for example cement kiln dust, lime kiln dust, bitumen emulsion, silica fume and metakaolin.

Advantages of chemical stabilization

- (Okoko, 2014) reported significant monetary savings when using chemical stabilization rather than mechanical stabilization in the stabilization of soils.
- This method is also suitable for all different soil types regardless of the soil's characteristics (Chijioke and Donald, 2019).

Limitations of chemical stabilization

- Some of these chemical stabilizers may be toxic to the environments in which they are exposed. Moreover, due to limited research on the subject, knowledge of this toxicity is not known to many people (Chijioke and Donald, 2019).
- The production of some of these chemical stabilizers such as cement is an energy instance process and the energy used is often from non-renewable resources such as coal among others (Ohunakin *et al.*, 2013). Additionally, the production of these stabilizers often leads to production of particulates which contribute to global warming (Larr and Neidell, 2016).

2.2.2.1 Selecting a suitable chemical stabilizer for a soil

For a given type of soil, there may be more than one potential stabilizer that can be used, however there are some general rules that make certain stabilizers more desirable based on soil properties such as the granularity, fluidity, or texture of the soil (Guyer, 2011). Traditionally, the 2 mostly used chemical stabilizers are cement and lime. To determine which of the 2 is most suitable for a stabilization of a given soil, the MoWT General specifications for road and bridge works 2005 guide as follows;

Table 1: Requirements for cement stabilization

% passing the 0.075mm screen BS 1377-2	**Plasticity index (%) BS1377: Part 2**	**Best suited stabilizer**
Less than 25%	PI less than 6 or PI x (% passing 0.075mm) is less than 60	Cement only
	6-10	Cement is preferred
	More than 10	Cement and/ or lime
More than 25%	Less than 10	Cement is preferred
	10 – 20	Cement and/ or lime
	More than 20	Lime is preferred

From the table, it is concluded that cement is generally suitable for soils with a PI less than 20. For a PI above 20, then lime is more suitable.

Additionally, when the PI of the soil is between 10 and 20, then both cement and lime can be used.

For lime to be effective, it requires the presence of fine sized soil particles to react and is therefore used for soil material with a relatively high PI. A high PI indicates that the soil has a large capacity to swell. This is proof of presence of clayey particles in the soil (KeyStone, 2003)

Cement can be used to stabilize soils with a high PI, although lime is usually preferred in these cases. However, if cement must be used, the MoWT General specifications for road and bridge works 2005 suggest that the material be pre- treated with addition of 2% lime prior to cement stabilization so as to improve the workability of the soil.

2.3 Cement

Cement is a powdery substance bearing cohesive and adhesive qualities, and being able to bind objects such as building blocks, stones, and bricks. The main elements in cement are clay and calcined lime. While lime after calcination primarily gives calcium oxide, the clay used offers alumina, silica, as well iron oxide (Dunuweera and Rajapakse, 2018).

Cement composition depends on the purpose for which it was manufactured. However, ordinary Portland cement usually contains about 63% calcium oxide (CaO), 21.9% silicon oxide (SiO), 6.9% aluminium oxide (Al_2O_3), 3.9% iron oxide (Fe_2O_3) (Tan, Zahran and Tan, 2020). Some organic soil types, sandy soils with limited reactivity, soils with moderate to high SO levels and high plasticity clays are not appropriate for cement stabilization. Due to high organic content in organic soils and the lack of pozzolans and silts, cement alone will not be able to give the needed stabilization strengths unless cement is applied in significant dosages (ACI Committee 230 and American Concrete Institute., 2009). An unsuitable soil candidate for cement stabilization is one with a pH of less than 5.5 and more organic matter than 2%. The low pH will negatively affect hydration rate of the mixture and hence resulting in slower strength gain (Tan, Zahran and Tan, 2020).

2.3.1 Hydration of cement

Hydration is an exothermic chemical reaction happens between cement and water. This reaction is responsible for the ability of cement to bond particles. Hydration in actual sense is however not one reaction. It is rather is collective term used to refer to a series of reactions that take place either simultaneously as well as successively when anhydrous cement is mixed with water(Ridi, 2018).

Dicalcium silicate (C_2S),tricalcium silicate (C_3S), tetracalcium aluminoferrite (C_4AF) and tricalcium aluminate (C_3A) are phase compounds that can be found in cement (Ridi, 2018). The fastest reaction is that of C_3S, and the slowest is that of C_2S. C_3A plays a crucial role during the early stages of hydration because it reacts strongly with water, thereby stiffening the cement paste. It also reacts more quickly than C_3S. Gypsum is added during cement manufacture to delay this reaction, and stop the immediate stiffening. Ettringite is created when water reacts with C_3A and gypsum. Tricalcium aluminate hydrate (CAH), which is produced after gypsum is used up, is created when C_3A and water interact. A soil-cement matrix is created when the CSH and CAH combine to produce a gel that acts as a binder for the particles of the soil (Tan, Zahran and Tan, 2020). Once the cement paste has hardened, it gains strength. Crystallized calcium hydroxide (CH) and tricalcium silicate hydrate (CSH) which are byproducts of the hydration reaction between C_3S and C_2S and the water, are what give hardened cement paste its consistency (Ridi, 2018).

Cement is generally an adequate stabilizer in most engineering applications. An advantage of using cement is that there is minimal leaching of calcium when it is used (Tan, Zahran and Tan, 2020). Although, exclusive use of cement for soil stabilization is strongly discouraged, mostly because to the detrimental environmental effects of cement manufacture, which include significant energy consumption and carbon dioxide emissions (Firoozi et al., 2017).

2.3.3 Environmental cost of cement.

Although cement is a widely used and effective construction material, it is important to note its effect on the environment. It is estimated that the construction industry contributes about 8% of the annual CO_2 tonnage in the environment (Michael, Peter and David, 2022).

Cement is made by heating limestone, clay and other materials in a kiln at a very high temperature about 1450^0C to form cement clinker (Ohunakin *et al.*, 2013). Very high amounts of energy are required to produce these amounts of energy (Ohunakin *et al.*, 2013). Recent developments in renewable energy technologies are still not enough to produce the amount of energy required to cater for the world's cement needs in a manner that is economically sustainable (Larr and Neidell, 2016). As such, the only viable solution is the use of energy sources like coal and other hydrocarbons. These produce vast amount of carbon dioxide which is the major driver of global warming. Additionally calcium carbonate ($CaCO_3$) in the lime stone produces carbon dioxide as a by-product as it changes to lime (CaO) further contributing to the carbon dioxide load into the environment (Michael, Peter and David, 2022). The environmental cost of cement is therefore one of the major reasons why stabilization techniques like metakaolin that require less energy to produce is important. These chemicals can greatly reduce the carbon dioxide pollution by the construction industry.

2.4 Metakaolin

Metakaolin is a product of the thermal activation of kaolin clay (Rashad, 2015). Kaolin clay is a type of clay whose main clay mineral is kaolinite. Kaolinite is a hydrated aluminosilicate ($Al_2Si_2O_5(OH)_4$) (Survey, 2009). Thermal activation of the clay removes the water from the clay leaving behind a dehydrated aluminosilicate (Astutiningsih, Banjarnahor and Zakiyuddin, 2018).

The thermal activation involves heating the kaolin clay at a high temperature. This temperature generally varies depending on the intended use of the Metakaolin as well as the preference of the scholar. Generally, this temperature is between 600^0C- 800^0C (Rashad, 2015).

The period for which the clay is heated is also subject to variations similar to those for the temperature. The general duration is however between 2-12 hours (Soleil-Raynaut, 2018).

It is important to note that the temperature required for production of MK is about 55% less that that required to produce cement.

Metakaolin is a pozzolanic material (Okitoi, 2021). This implies that it will react at room temperature in when there is moisture to form materials that possess cementitious properties (Risdanareni et al., 2019).

2.4.1 Chemical composition of metakaolin.

The table below shows the composition of different oxides in samples of metakaolin by 3 different scholars

Table 2: The chemical composition of Metakaolin

Oxides	**Tosten Lorange** (Lorange, 2020).	**2** (Risdanareni et al., 2019).	**Ana Luisa VELOSA** (Velosa, Rocha and Veiga, 2009).
SiO_2	55.78	31	60.11
Al_2O_3	29.42	53.5	29.61
Fe_2O_3	0.55	6.58	1.28
CaO	0.68	1.1	0.05
MgO	0.21	0.12	0.15
SO_3	0.00	0.00	0.00
K_2O	2.22	5.79	3.32
Na_2O	0.02	0.04	1.94
Ti_2O_3	0.08	0.919	0.36

P_2O_5	0.01	-	-
Mn_2O_3	0.02	-	-
LOI	11.0	-	2.61

From the table, it can be seen that Silica (SiO_2) and alumina (Al_2O_3) are the predominant oxides in the Metakaolin. When used together with cement, this SiO_2 and Al_2O_3 will react with the calcium hydroxide formed during hydration forming substances that possess pozzolanic properties.

Sub-base.

The layer of aggregate material directly beneath the base course is known as the subbase, and it typically comprises of recycled materials, crushed aggregate, or gravel. This layer is directly above the subgrade. Subbases perform a number of functions, such as relieving the subgrade of stress and supplying drainage for the pavement structure (Transportation and Administration, 2016). In addition to providing drainage for the pavement on the lowest layer of the pavement, the granular subbase serves as a load-bearing layer and reinforces the structure of the pavement immediately under the pavement surface (Hein and Izevbekhai, 2018).

The ministry of works general specifications provide for the subbase layer of a road to be made of material of either G30 or G45 as specified by the engineer. The strength of this layer is very important in ensuring longevity of the road as it distributes the forces to the subgrade.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter discusses the procedures, methods and materials which were employed to meet the specific objectives of the project.

3.1 Materials and methods

3.1.1 Materials

Laterite soil

The soil was sampled from a borrow pit along Jambula road from 2 different locations at depths of 1.5m in disturbed form using a shovel and a hoe. This borrow pit was the source of the material used on the road. The total weight of the soil sample collected was about 350kg and it was placed in 5 airtight sacks and transported to Stirling laboratory in Mbalala for testing.

Upon arrival at the laboratory, the material was placed on large trays to air dry so as to bring the soil to a consistent moisture content and the soil tests carried out on it.

Cement

Cement was purchased from a hardware store in Mukono town and transported to the laboratory. Type II cement 32.5N was used for the stabilization as it is most suited for stabilizing laterite soils (Dunuweera and Rajapakse, 2018).

Meta-Kaolin

Kaolin clay was obtained from Buwambo from an already existent pile of the material. The kaolin was allowed to dry for 1 day and then subjected to temperatures of $750^{0}C$

for 2 hours using the electric furnace at Uganda Christian University Mukono campus at the Visual Arts Department. (Sánchez et al., 2020; Okitoi, 2021) note that this time and temperature is sufficient to allow removal of the water from the clay leaving behind a dehydrated aluminosilicate. After a period of cooling, the sample was crashed and sieved using sieve size 300μm to form a white powder. A sample of this was taken to the government analytical laboratory from where an XRF test was done to determine the chemical composition of the metakaolin.

3.1.2 Methods

To determine the engineering properties of the neat soil

3.1.2.1 Particle size distribution

This test was carried out in accordance with **BS1377: Part 2: 1990**.

The purpose of this test was to determine how much of each particle size was present in the sample.

After preparation of the sample, it was passed through the different sieve sizes and the weight retained on each sieve noted. From this, the cumulative percentage passing was calculated.

Sample retained = weight of the sieve with the sample - weight of the sieve without the sample

Percentage retained = (mass retained)/(initial sample mass)×100

cumulative % passing = 100-% percentage retained

The grading modulus of the sample was also obtained from

GRADING MODULUS= 3-(summation of % retained on 2+0.425+0.075/100)/100

3.1.2.2 Atterberg limit tests

They were done with reference to **BS1377: Part 2: 1990.**

The Atterberg limit tests were composed of 3 different soil tests that is: liquid limit, shrinkage limit and plastic limit. These tests were important because they informed the ability of the soil to expand. They helped to determine the PI of the soil.

Equipment

- Cone penetrometer
- 0.045mm Sieve
- Drying oven

Liquid limit (LL)

The moisture content at which the soil changed from plastic to liquid.

A sample of 200g of the air-dried sample that had passed the 0.0425mm sieve was obtained and the prepared in accordance with the standard.

A graph of penetration against moisture content was plotted and LL determined as the moisture content at a penetration of 20mm.

Plastic limit (PL)

This was carried out with reference to **BS1377: Part 2: 1990**.

This was the water content at which soil begun to behave plastically.

As water was added, the same material from the liquid limit test was molded with the hands. It started to crack when it was rolled to a thickness of around 3 mm. The rolled samples were weighed before being placed on a mold and dried in an oven for 24 hours. After oven drying, the final weight was measured, and the amount of water added computed and documented as the plastic limit.

Plasticity index (PI)

It can be defined as the stomach of the soil as it indicates the capacity of the soil to swell.

3.1.2.3 Proctor compaction test

This was carried out with reference to **BS1377: Part 4: 1990**

This test was used to obtain the optimum moisture content and the MDD that can be achieved upon compaction of the soil.

Equipment

- Proctor mold
- Oven
- Filter paper
- Weighing scale

Five layers of the sample were inserted into the mold, and each layer blown 27 times with a 4.5 kg rammer. The sample was taken out and dried in the oven for 24 hours. The dried sample's weight was noted, and the dry density computed for the given moisture content. The dry unit weight and water content were plotted on a graph after this is repeated multiple times. The optimum moisture content was identified as the moisture content when the dry density was maximum.

3.1.2.4 California bearing ratio

The test was done because it helps inform the soils ability to resist penetration and therefore it indicates the strength of the soil.

It was carried out with reference to **BS1377: Part 4: 1990**.

Equipment

- CBR mold
- Rammer
- Soaking pit
- CBR machine

Using the OMC from the proctor test a sample was prepared in a mold and compacted. The sample was then soaked in water for a duration of four days after which its surface was dried and prepared for penetration. The CBR machine was used to measure resistance of the soil to penetration and this is the CBR value. The swell of the sample was also calculated.

To determine the composition of the metakaolin.

3.1.2.5 Xrf test

It was done to determine the chemical composition of the metakaolin. The results of this test provided information on the percentage of different oxides in the material.

The sample was be subjected to x-rays using an x-ray spectrometer. The sample then emitted florescent x- rays where each element reacted by releasing a specific fluorescent print. An Xray analyzer then captured these signals and they were analyzed to determine the chemical composition of the sample.

To determine the engineering properties of laterite soil stabilized with varying percentages of cement and metakaolin.

3.1.2.6 Mix design

Previous researchers have determined the optimum amount of cement for stabilization of laterite soils to be 3% (Patel et al., 2020), (Ali Ashraf, 2018) and (Bilal et al., 2017).

With this, a mix design was developed such that the percentage of cement was kept at a constant 3% while the percentage of metakaolin was increased from 0 to 6%.

Previous research has shown that the optimum percentage for stabilization of soil using metakaolin alone was between 5 and 6% (Rashad, 2015; Kolovos, Asteris and Tsivilis, 2016; Abdulkarim et al., 2022; Bharadwaj, Burkan Isgor and Jason Weiss, 2023)

Table 3: Mix design

Soil (%)	Cement (%)	Metakaolin (%)
100	0	0
95	0	5
97	3	0
95	3	2
93	3	4

91	3	6
89	3	8

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results from different tests that were done on the materials. The tests were done to achieve the different objectives that were stated in chapter one and they were done using the methods described in chapter 3.

4.1 Neat laterite soil

Table 4: Summary of the test results on the neat soil

Property	Neat soil	Standard as per MoWT General specifications for road and bridge works 2005
Liquid limit (%)	45.2	Maximum 40
Plastic limit (%)	29.5	-
Plasticity index	15.6	Maximum 14
Linear shrinkage	7.8	Maximum 7
MDD	2.159	-
OMC	10.7	-
CBR	33	Minimum 45
CBR swell	0.79	Maximum 0.5
Grading modulus	1.181	Minimum 1.5

The soils cannot be categorized as G45 material since some parameters are below those set in the MoWT manual.

4.1.1 Particle size distribution

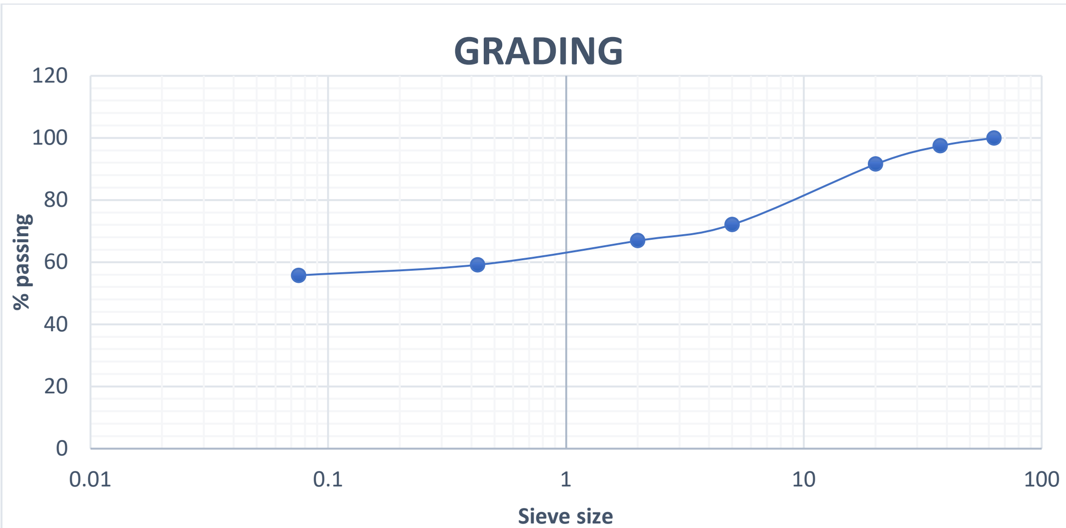

Figure 2: The grading curve for the neat soil

The grading curve for the soil was obtained as shown above.

The shape of the curve is such that it occupies almost all the particle sizes. This means that this soil can be classified as well graded based purely on the particle sizes occupied (Jebur, 2017).

Using the unified soil classification system (USC),

Since the percentage passing sieve No.200 is 55.76%>50%, then it is fine grained soil.

The liquid limit is 45.2<50, then it falls under silts and clays with low liquid limit.

The soil is made up of 27.86% gravel and 16.38% sand and since it plots below the A-line, the soil can be classified as a gravelly silt with sand.

55% of the soil passes sieve No. 200 and therefore there is a large percent of fine-grained soils as such, the soils have a PI of 15 which is above the requirement for the subgrade layer of G45 according the Ministry of works general specifications for roads and bridges 2005 and hence a need to improve the PI by stabilization.

The Grading modulus of the sample was calculated to be 1.181 which is below the 1.5 minimum for G45 material according to the MoWT manual for road and bridge works. Grading modulus gives a relationship between the fine grains and coarse grains with in a soils sample. The higher the grading modulus, the finer the soil. this indicates that the soil is too fine to be used as subbaseG45 material.

These fines contribute to the high PI of the sample and therefore lead to a low CBR of the soil since they hinder its ability to resist loading (Kevin, 2021).

4.1.2 Atterberg limit tests

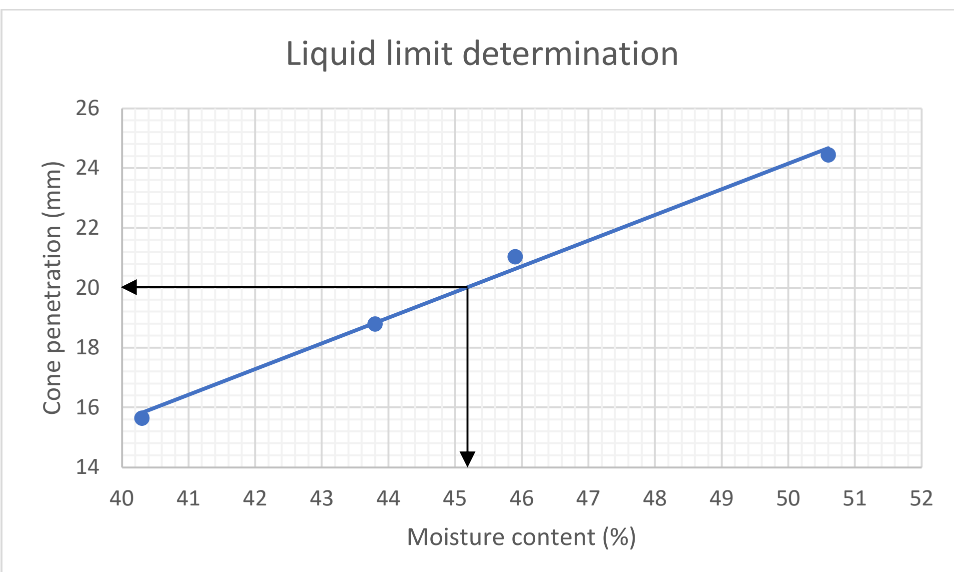

Figure 3: Determination of liquid limit for the neat soil

Liquid limit is the moisture content at which the soil turns to plastic from liquid state. It is the lowest moisture content at which a soil will flow when very little shear force is applied (Shakya, 2024). The liquid limit of the sample was found to be 45.2%. The higher the liquid limit, the finer the particles in the soil because the soil is able to absorb more water before it flows. That is why Sandy soils will easily flow when water is added as compared to clay soils which expand before they flow.(James, 1990)

The plastic limit is the moisture content at which it becomes impossible to remold fine-grained soil without it splitting (KeyStone, 2003). The plastic limit of the soil was found to be 29.5% and hence the plasticity index was found to be 15.6%.

Plasticity index describes the ability of the soil to absorb water. It is obtained by the difference between Liquid limit and plastic limit. The higher the PI of the soil, the more the soil changes in volume due to changes in moisture content (Ahmed and Agaiby, 2020).

The PI of the sample is 15.6% which is above the minimum PI for G45 material according to the MoWT General specifications for Roads and bridge works. The high PI can be attributed to the percentage of fines in the sample which indicates that the soil has a high percentage of clay and silt which significantly increase its PI (James, 1990). Therefore, the soil needs to be stabilized to lower this PI and make it suitable for G45 material.

4.1.3 Proctor test

Proctor test was used to determine the optimum moisture content for compaction of a given soil and the maximum dry density of that soil for a given compaction effort.

The MDD and OMC were obtained from the proctor curve as shown below.

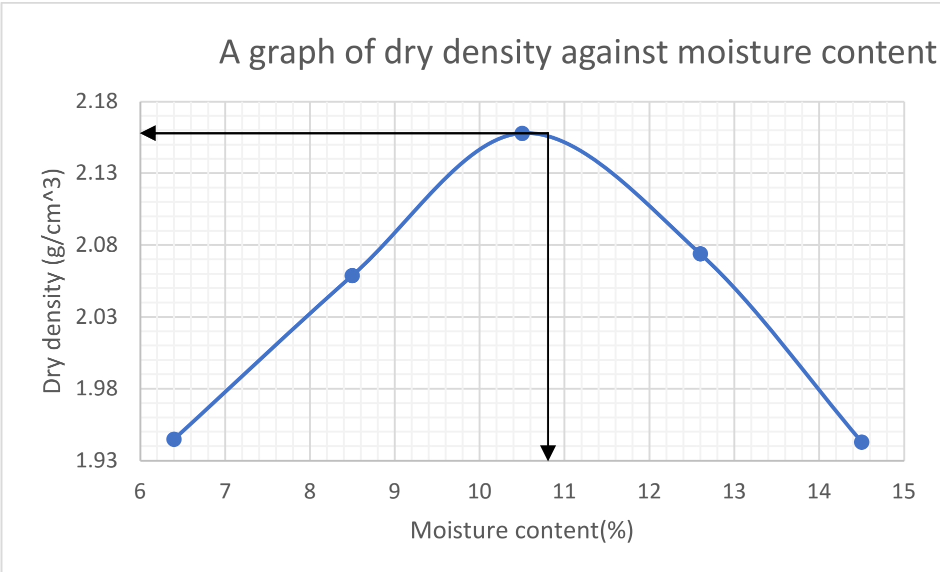

Figure 4: MDD curve for the neat soil

The soil particles in dry soil are not in contact with each other and therefore the soil when compacted becomes stiff and cracks hence forming gaps (Violah, 2020). The addition of water to soil at low moisture content during compaction forms a thin film around each soil particle which causes the particles to be close to each other by acting as a lubricant thereby making the soil denser (Connelly et al., 2008). Therefore, low void ratios are produced when water is added to soil at a low moisture content, allowing the soil particles to move freely during compaction. As such, as the volume of air in the sample decreases and the dry density of the soil reaches its maximum. (Jongpradist, 2011). The moisture content at this point is the optimum moisture content.

Further addition of water beyond the Optimum moisture content leads to a decrease in the dry density. This is because the water no longer serves a s a lubricant but rather occupies the void spaces and forces the soil particles to separate from one another which leads to a decrease in the dry density of the soil (Violah, 2020).

The OMC of the soil was found to be 10.7% and the Maximum dry density 2.159m/cm^3. This implied that the best compaction of this soil is achieved at a moisture content of 10.7%.

4.1.4 California bearing ratio

CBR is a measure of the strength of the soil. it is obtained by measuring the resistance of a soil sample to penetration.

The soil did not meet the requirements for G45 subbase material as per the MoWT General specifications for road and bridge works 2005. The specifications require the material to have a CBR of 45 while the sample had a CBR of 33. This soil therefore needs to be stabilized before it can be used to construct the subbase.

The CBR swell was also found to be 0.79 which is above the 0.5 maximum for G45 material according to ministry of works and transportation general specifications indicating that the soil swells a lot when exposed to moisture.

The reason for this low value in CBR may be associated with the large amount of fines in the soil which cause volumetric changes of the soil with changes in moisture content thus making the soil weak (Bilal et al., 2017).

Therefore, the neat properties of the soil highlight that it is not suitable to be used as G45 subgrade material according to the requirements of the MoWT General specifications for road and bridge works 2005. Also considering the PI of the soil 15.6 is less than 20%, and the percentage of fines of 55.56%, cement is a better stabilizer than lime since lime requires a large quantity of fines for stabilization according to the general specifications.

4.2 Chemical analysis of the metakaolin.

XRF analysis was performed on the metakaolin and the table shows the composition of the powder.

Table 5: Chemical composition of the Metakaolin sample

Chemical compound	Composition (%)
Silicon dioxide	57.459
Aluminum oxide	24.926
Calcium oxide	8.579
Iron (III) oxide	7.778
Potassium oxide	0.376
Titanium dioxide	0.261
Phosphorous pent oxide	0.249
Manganese (III) oxide	0.211

Figure 5 A graph shows the chemical composition of Metakaolin

The dominant oxides in the sample were found to be silicon dioxide and aluminum oxide which are the most important for the metakaolin to serve as a partial replacement for cement since they will react with the calcium hydroxide formed during hydration to form calcium aluminum feldspars that form the substance that bind the soil particles together (Lorange, 2020).

The metakaolin can also be classified as a class N pozzolan since the summation of silica, alumina and iron (III) oxide in the sample is greater than 70% according to ASTM standard.

4.3 Stabilized laterite soil

The following are the results of the stabilization on the properties of the neat soil.

4.3.1 Effect of the metakaolin on the Atterberg limits of the soil

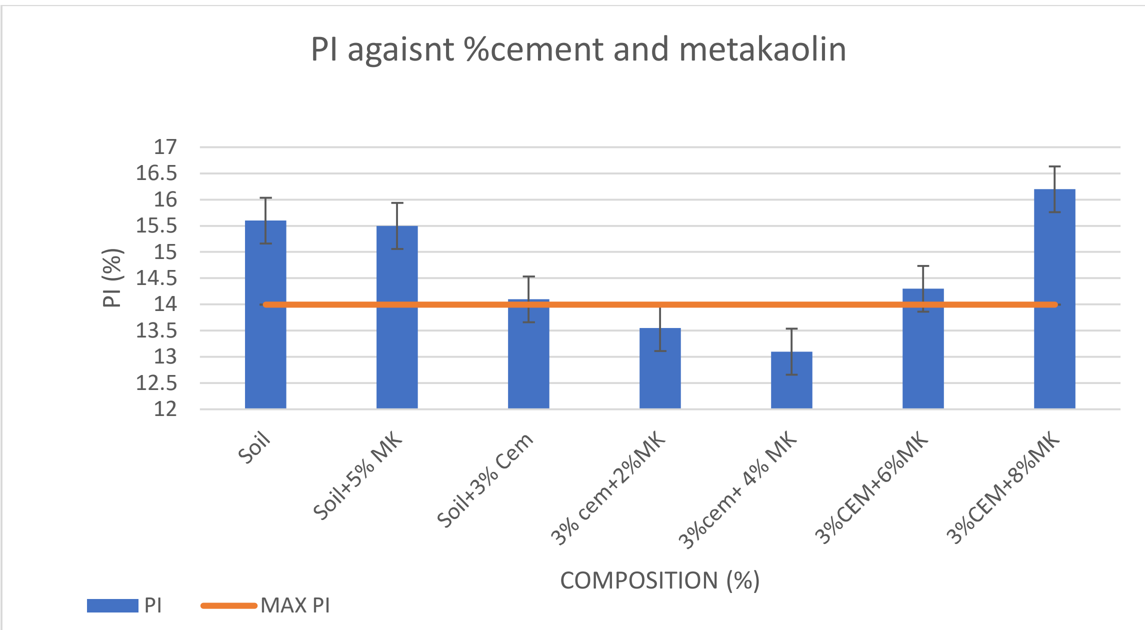

Figure 6: A graph showing changes in PI with % MK and cement

The PI initially reduces from 14.1 to 13.1 on increasing the amount of metakaolin from 0% to 4% because of the pozzolanic reaction that takes place between cement, metakaolin and the soil. This reaction causes formation of a gel that binds the particles of the soil together hence reducing the amount of fines in the sample (Bamwesigye, 2020). However, beyond 4% the PI of the soil no longer reduces but rather increases due to the excess metakaolin which implies some of the silicates will not react (Lorange, 2020). The lowest PI is obtained at 4% metakaolin and 3% cement.

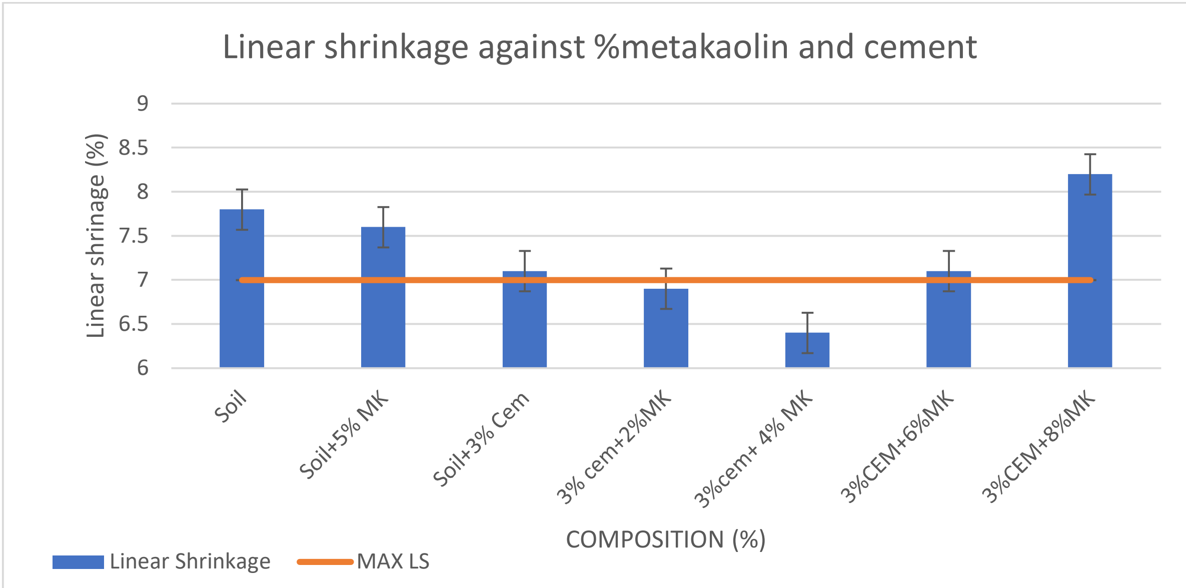

Figure 7: A graph showing variation in LS against %MK and cement

The same trend is observed in the linear shrinkage of the soil with a minimum linear shrinkage observed as 6.4 at 4% metakaolin. The initial decrease in Linear shrinkage is because of the formation of Calcium Aluminate Hydrate and Calcium Silicate hydrate which are the main components of the gel that binds the soil particles and reduces the amount of fines in the soil (Sanou et al., 2023). The amount of fines in the soil is directly proportional to the shrinkage of the soil. Beyond 4% MK, a decrease in the linear shrinkage is observed because the metakaolin is in excess. This implies that there will be excess silicates which influence the structure of the calcium silicate hydrate and lead to a weaker soil (Dao and Ebid, 2022).

4.3.2 Effect of the cement and metakaolin on proctor values of the soil

4.3.2.1 Maximum dry density

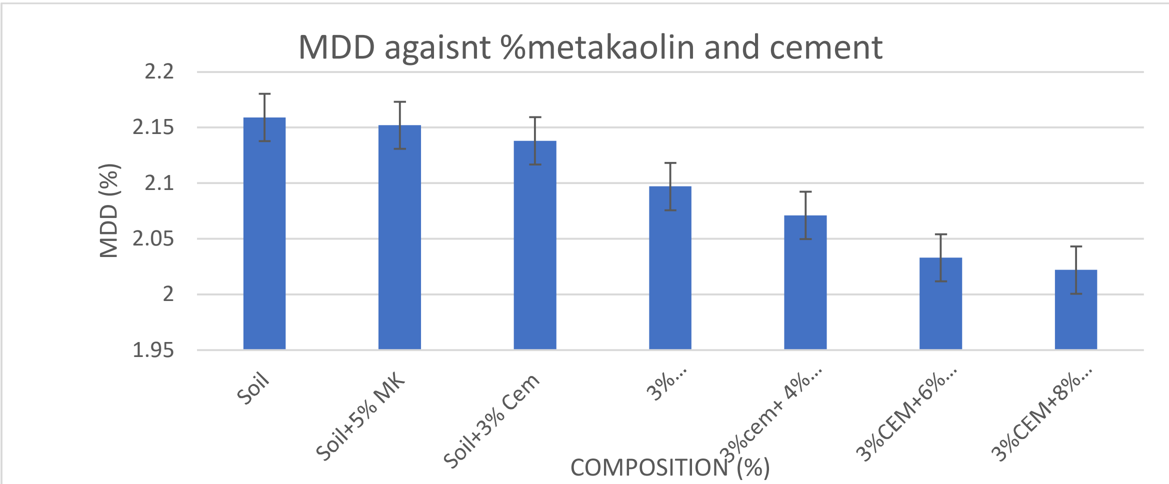

Figure 8 : A graph of MDD against %metakaolin and cement

Increasing the amout of metakaolin used led to a general decrease in the maximum dry density of the soil from 2.159g/cm^3 to 2.022g/cm^3 due to the heat generated during the hydration reaction. Since the cement and metakaoiln are fine grained, they lead to a higher water absorption capacity of the soil and hence reduction in MDD (Bamwesigye, 2020) as shown in the graphs above.

4.3.2.2 Optimum moisture content

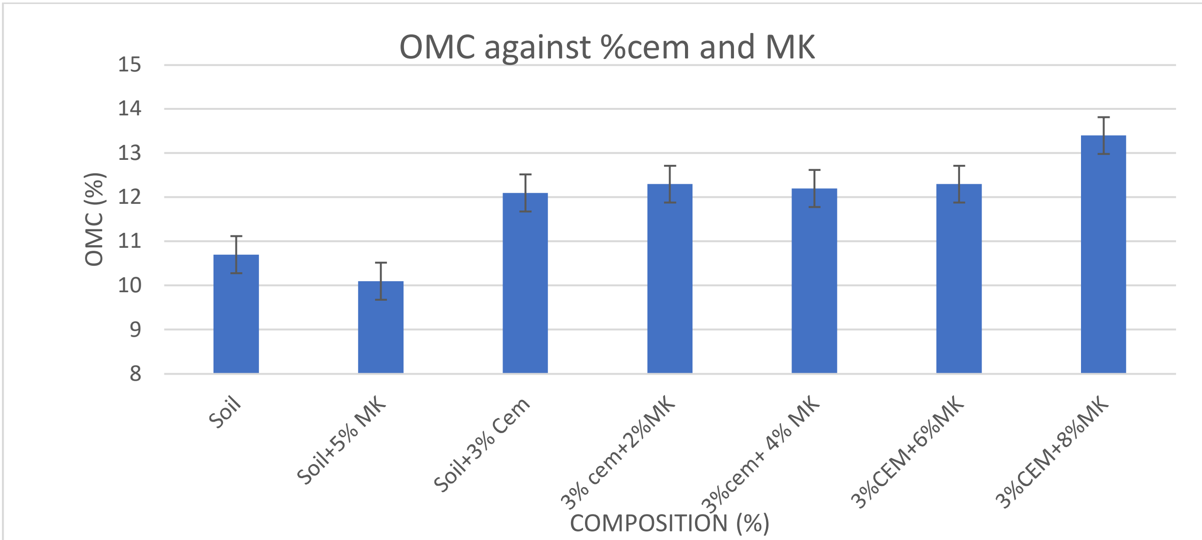

Figure 9: A graph of OMC against %cem and MK

The optimum moisture content increased from 10.7% to 13.4%. This increase was because hydration that takes place generates a lot of heat as water in the precence of the water (Bamwesigye, 2020).

4.3.3 Effect of cement and metakaolin on the CBR of the soil

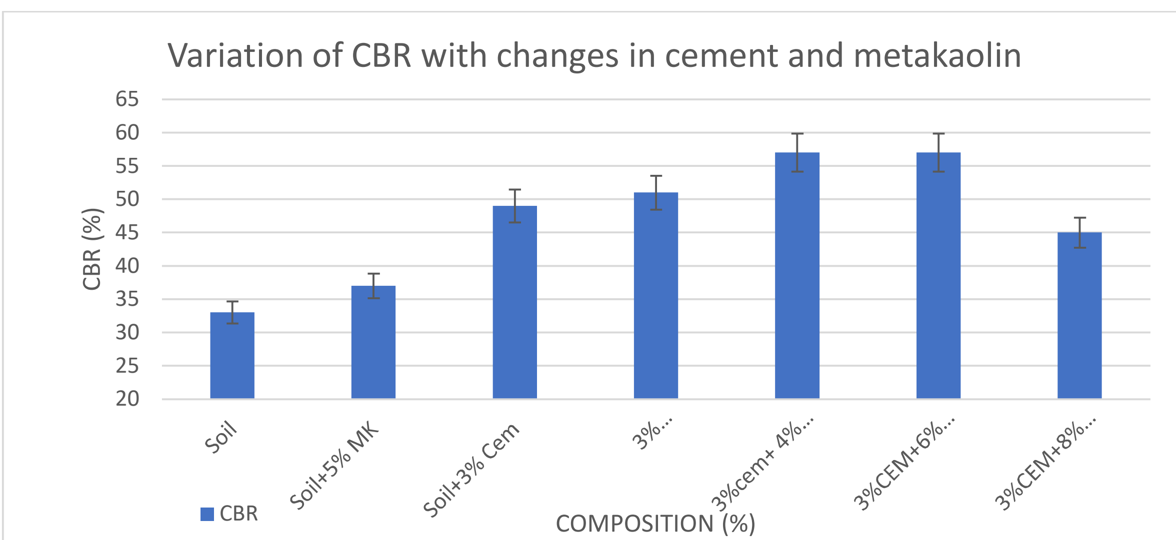

Figure 10: A graph of Variation of CBR with changes in cement and metakaolin

The CBR of the soil increased with addition of metakaolin from 0-4% with a maximum CBR value of 57% obtained between 4 and 6% metakaolin. This was because of the decrease in fine clay contents due to addition of cement and metakaolin. This decrease in fines is due to the pozzolanic reaction whereby calcium oxide from the cement reacts with silicates and aluminates from the laterite soil and metakaolin. During this reaction, the soil texture is changed and clay particles clamped together into larger particle sizes to form an inter-locking mass of soil (Tumuhimbise and Kahunza, 2018). The same process results in the formation of calcium silicate hydrates and calcium aluminate hydrates that are responsible for strength gain in chemical stabilization hence the increase in CBR(Kolovos et al., 2013). Beyond this, further addition of metakaolin leads to reduction in the CBR due to the presence of excess metakaolin. Excess metakaolin leads to presence of excess silicates that do not react (Lorange, 2020). The excess silicates alter the structure of the C-S-H hence a weaker soil (Brykov et al., 2002).

CBR SWELL

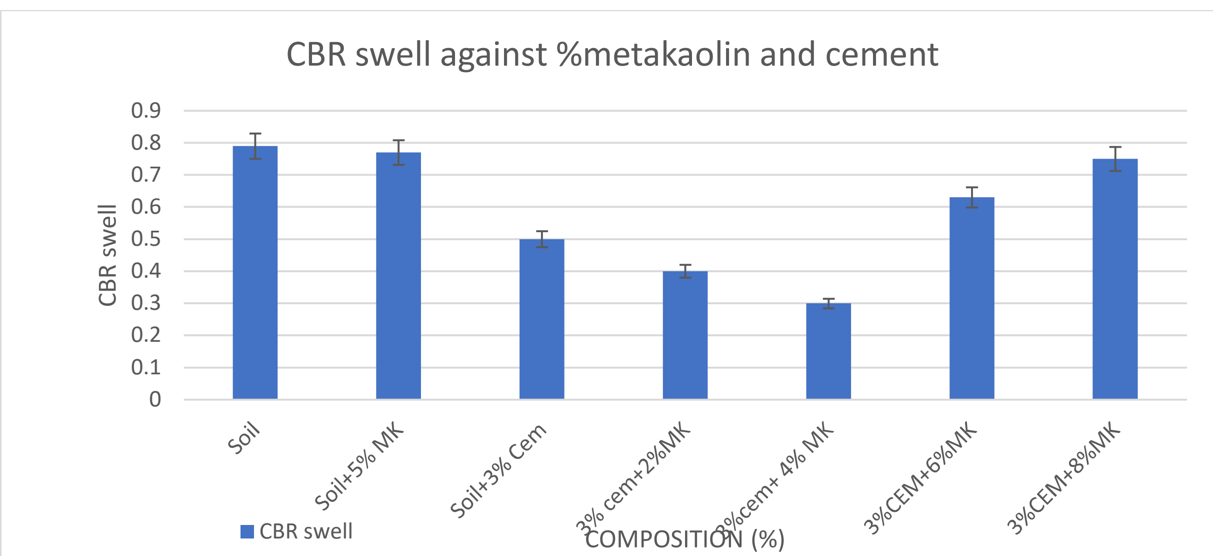

Figure 11: A graph of CBR swell against %metakaolin and cement

The CBR swell of the soil reduced with increase in metakaolin content up to 4% metakaolin since there was a gain in strength of the soil (Sorsa, 2022). However beyond 4% metakaolin, the CBR swell of the soil was seen to reduce to the excess silicates from excess metakaolin in the soil (Yu et al., 2015; Dao and Ebid, 2022).

4.3.4 Effect of cement and metakaolin on UCS of the soil

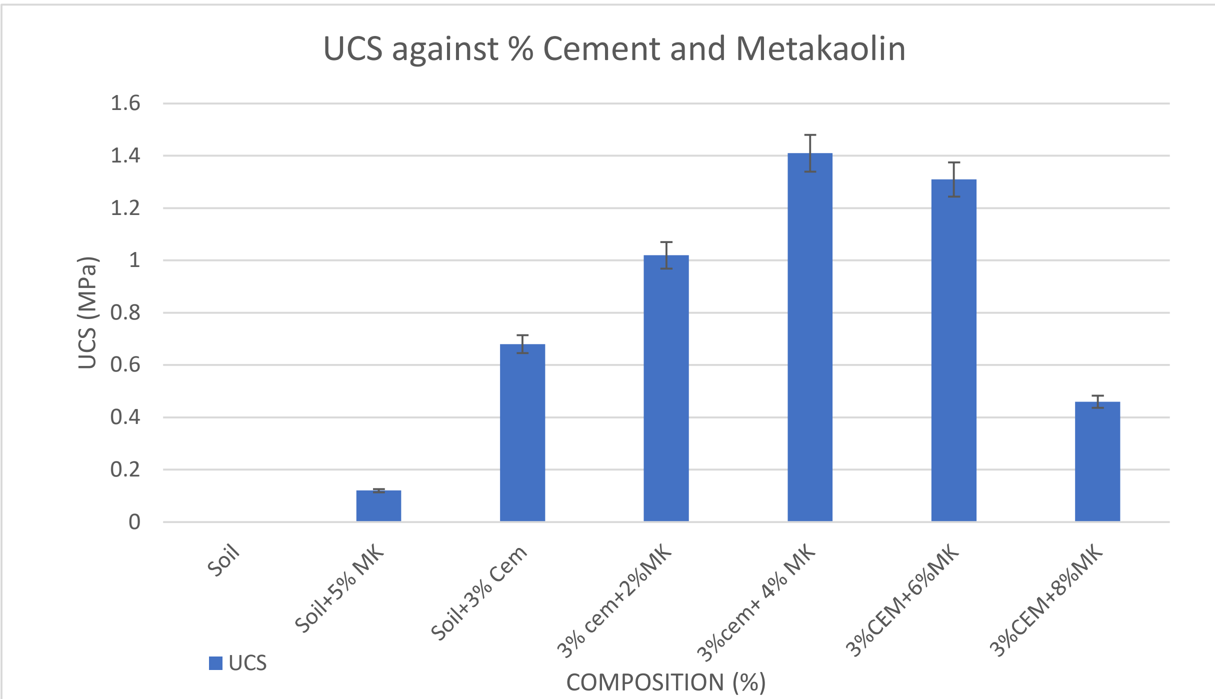

Figure 12: A graph of UCS against % Cement and Metakaolin

The above graph shows the variation of UCS of the soil with increase in Metakaolin content.

From 0% to 4% metakaolin, the UCS of the soil increases to a maximum of 1.41 at 4% metakaolin due to the pozzolanic reaction which causes the soil particles to clamp together to create an interlocking structure (Tumuhimbise and Kahunza, 2018). The reaction produces calcium aluminum feldspars, which are what give the soil its strength (Patel et al., 2020). Beyond this, the UCS value reduces with increase in metakaolin due to the excess silicates which do not react(Bharadwaj, Burkan Isgor and Jason Weiss, 2023).

Research design

Table 6: Summary of the results

Soil (%)	Cement (%)	Meta-kaolin (%)	PI	Linear Shrinkage	MDD (gm/mm^3)	OMC (%)	CBR (%)	CBR swell	UCS (MPa)
100	0	0	15.6	7.8	2.159	10.7	33	0.79	-
95	0	5	15.5	7.6	2.152	10.1	37	0.77	0.12
97	3	0	14.1	7.1	2.138	12.1	49	0.5	0.68
95	3	2	13.55	6.9	2.097	12.3	51	0.4	1.02
93	**3**	**4**	**13.1**	**6.4**	**2.071**	**12.2**	**57**	**0.3**	**1.41**
91	3	6	14.3	7.1	2.033	12.3	57	0.63	1.31
89	3	8	16.2	8.2	2.022	13.4	45	0.75	0.46

From the summary of the results shown in the table above, the optimum mix ratio is 93% laterite soil, 3% cement and 4% metakaolin.

This ratio was seen to have a CBR of 57% which is above the 45% for material class C0.7 according to the MoWT General specifications for road and bridge works 2005. The UCS of 1.41MPa is also above the 0.7MPa minimum for C0.7 cement stabilized material.

Additionally, the PI of 13.1% obtained at this ratio was below the minimum 14 for G45 subbase material.

The soil at this ratio also demonstrated a low linear shrinkage that is 6.4 below the maximum 8 as well as a low CBR swell of 0.3 which was below the maximum of 1.0.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was mainly focused on the use of cement and metakaolin to stabilize laterite soils and the following are the conclusions drawn from the tests carried out.

The following conclusions were made from the research;

It was found that the laterite soil sample collected from Jambula borrow pit was a silt-based laterite soil with 55.56% fines and had a PI of 15.6% which was above the minimum PI of 14 % for G45 material according to the General specifications for roads and bridges. The CBR of the neat soil was 33% which is below the required CBR in the MoWT general specifications that is 45%. The CBR swell of 0.79 and linear shrinkage of 7.8 were above the maximum allowable of 0.5 and 7 respectively. The soils properties were below the required standards for G45 mainly because of the amount of fines in the soil. Therefore, this soil required stabilization to improve its strength to be able to meet the traffic requirements of the road.

The composition of the metakaolin was such that the sum of the percentage of silicon dioxide, aluminum dioxide and iron (III) oxide was 90.163% which greater than 70% implying that metakaolin is a class N natural pozzolan according to the ASTM standard. The metakaolin sample was also dominated by silicon dioxide 57.46% and aluminum oxide 24.93% which are the most important for hydration and lead to formation of C-S-H and C-A-H that form the gel which binds the soil particles increasing the strength of the soil and reducing its PI.

The strength parameters of the laterite soil stabilized with cement at 3% and varying percentages of metakaolin that is 0%, 2%,4%, 6% and 8% were seen to initially increase with the maximum CBR and UCS values of 57 and 1.41 MPa respectively at 4% MK. Beyond 4%, there was a decrease in the strength parameters of the stabilized soil because of the excess silicates in the mix as a result of excess MK.

5.2 Recommendations

This research could be extended further to study the microstructure of the product formed after stabilization of the soil with metakaolin. This research could help understand the long-term characteristics and durability of stabilized soil.

Further research into other pozzolanic materials that may be used to enhance the usability of metakaolin to stabilize soils should also be carried out in order to expand the existing knowledge on metakaolin stabilization.

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APPENDIX

APPENDIX A: PICTORIAL

Figure 13: Washing the sample for Sieve analysis   Figure 14: Sampling the laterite soil

Figure 15: Liquid limit determination

Figure 16: Sampling the metakaolin

Figure 17: Sampling metakaolin

Figure 18: Crushing the metakaolin

Figure 19: Crushing the metakaolin sample

APPENDIX B: LABORATORY RESULTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 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	30 BLOWS 95% COMPACTION	62	AVERAGE
NEAT	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL	12/9/2023	100	98	93	74	68	58	54	1.19	45.3	29.6	15.7	7.8	2.159	10.7	33	0.79	0.79
			100	97	90	70	66	60	57	1.17	45.0	29.4	15.6	7.8	-	-	-	-	
			100	97.47	91.61	72.14	66.94	59.18	55.76	1.18	45.2	29.5	15.6	7.8	2.159	10.7	33	0.79	0.79
	AVERAGE		100	97	92	72	67	59	56	1.181	45.2	29.4	15.6	7.8	2.159	10.7	33	0.79	0.79

FOR LAB

Lab Technician

Materials Engineer

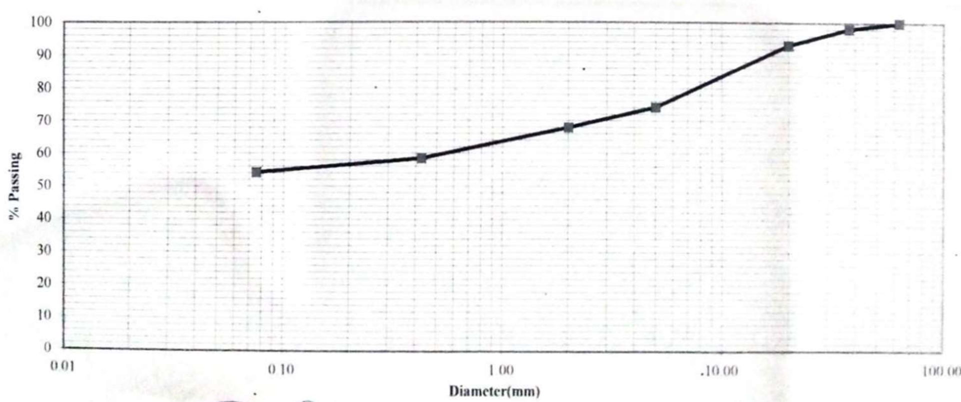
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	NEAT	Dry wt. of sample before washing: (g)		10039.9
Depth: (m)		Dry wt. of sample after washing: (g)		4608.4
Material description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	12/Dec/2023	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	184.4	1.8	**98**	80	100
20.0	498.6	5.0	**93**	60	95
5.0	1909.0	19.0	**74**	30	65
2.00	626.5	6.2	**68**	20	50
0.425	954.9	9.5	**58**	10	30
0.075	425.5	4.2	**54**	5	15
Total fines	5441.0	54.2			
Bottom Pan	9.5				
Extracted fines	5431.5				
Total sample	10039.9				
Grading Modulus		**1.19**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

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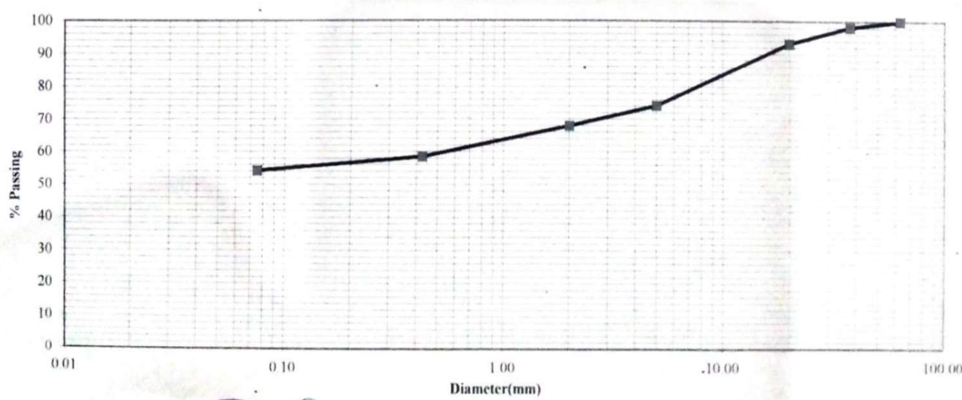


FOR TESTING LAB

Lab Technician *Materials Engineer*

P.O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

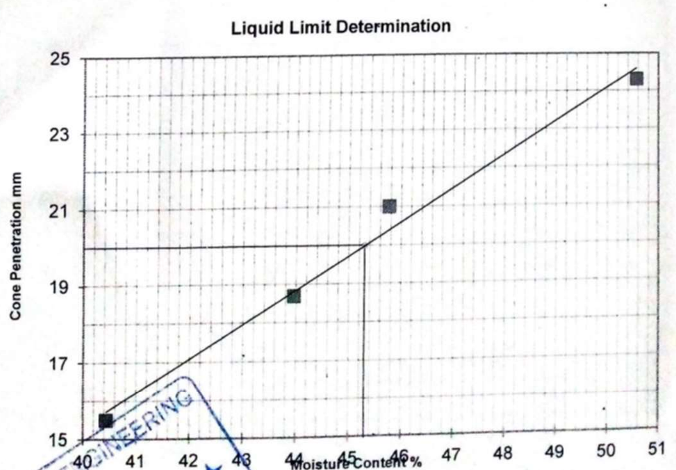
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	NEAT	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	12/Dec/2023
LAYER	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL		

PLASTIC LIMIT	Test No.	SO	OG		Average
Mass of wet soil + container (g)		38.43	35.23		36.83
Mass of dry soil + container (g)		34.9	32.05		33.475
Mass of container (g)		22.9	21.39		22.145
Mass of moisture (g)		3.53	3.2		3.355
Mass of dry soil (g)		12	10.66		11.33
Moisture content %		29.4	29.8		29.6
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.5	18.7	21	24.3
penetration (mm)		15.5	18.7	21.0	24.3
AVERAGE		15.5	18.7	21.0	24.3
Container No.		P135	P126	P157	A7
Mass of wet soil + container (g)		56.41	57.32	46.41	45.00
Mass of dry soil + container (g)		42.82	41.93	33.98	32.98
Mass of container (g)		9.21	6.92	6.82	9.21
Mass of moisture (g)		13.59	15.39	12.43	12.02
Mass of dry soil (g)		33.61	35.01	27.16	23.77
Moisture content (%)		40.4	44.0	45.8	50.6
AVERAGE		40.4	44.0	45.8	50.6



Liquid limit (%)	45.3
Plastic limit (%)	29.6
Plasticity Index (%)	15.7
Linear shrinkage	
Trough No.	I
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.1
% L.shrinkage =	7.8

Remarks:

TESTING LAB

Materials Engineer.

Lab Technician

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	**ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS**

ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
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Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	12/Dec/2023
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AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
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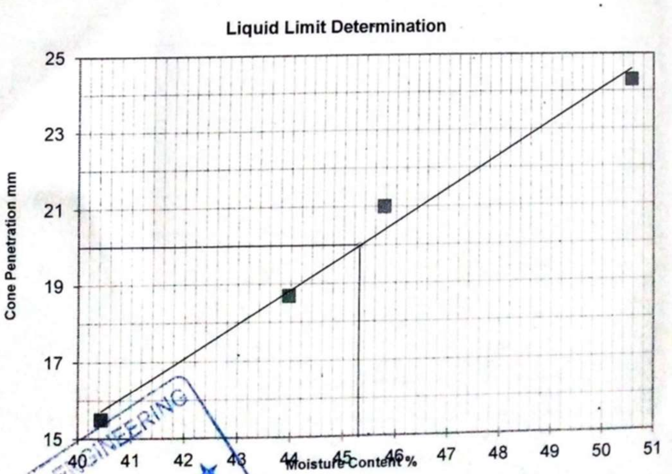
Moisture content (%)		40.4	44.0	45.8	50.6
AVERAGE		40.4	44.0	45.8	50.6



Liquid limit (%)	45.3
Plastic limit (%)	29.6
Plasticity Index (%)	15.7
Linear shrinkage	
Trough No.	I
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.1
% L.shrinkage =	7.8

Remarks:

TESTING LAB

Materials Engineer.

Lab Technician

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UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
Mix	NEAT	9/Dec/23	12/Dec/23	Lab team
Material description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL	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

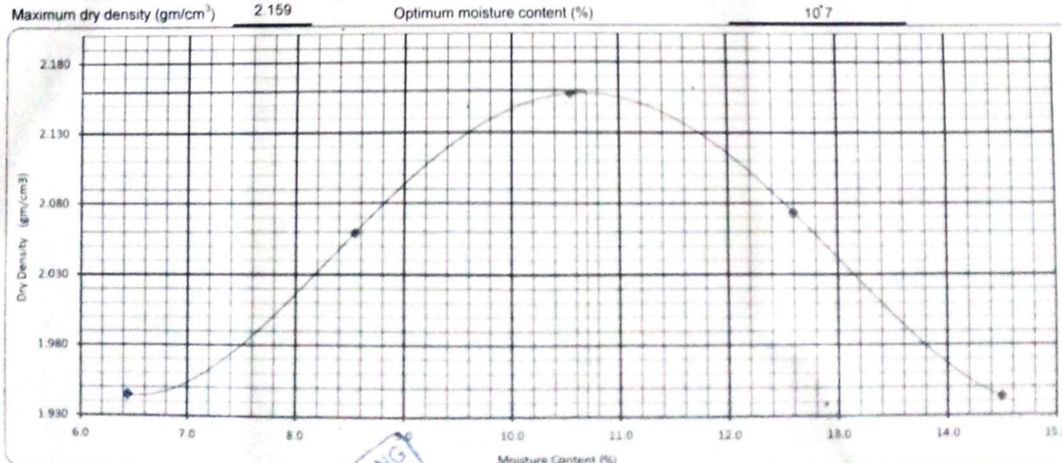
MOISTURE CONTENT DATA

Test No		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	10	110	210	310	410
Mass of Compacted soil + mould	gm	6,350	6,515	6,665	6,615	6,505
Mass of Mould	gm	4,280	4,280	4,280	4,280	4,280
Mass of Compacted soil	gm	2070	2235	2385	2335	2225
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	2.070	2.235	2.385	2.335	2.225

DATA FOR PROCTOR CURVE

Container No		CR7	FDC	CML	ACB	MJR
Mass of wet soil + Container	gm	2,165.0	2,325.0	2,060.0	2,205.0	2,325.0
Mass of dry soil + container	gm	2,080.0	2,205.0	1,936.0	2,045.0	2,130.0
Mass of container	gm	760.0	800.0	760.0	775.0	785.0
Mass of water added	gm	85	120	124	160	195
Mass of dry soil	gm	1320	1405	1176	1270	1345
Moisture content	%	6.4	8.5	10.5	12.6	14.5
Dry density	g/cm^3	1.945	2.059	2.158	2.074	1.943

Maximum dry density (gm/cm^3) 2.159 Optimum moisture content (%) 10.7



Remarks:

FOR TESTING LAB

Lab Technician	Materials Engineer	

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:		
Location:	NEAT	Sampling Date :	9/Dec/23
		Casting date :	13/Dec/23
Sample Description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL	Testing Date	17/Dec/23
		Technician :	Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No	BBC		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2690		MDD (Mg/m^3)	2.159
Tin + oven dry soil sample (g)	2579		N.M.C (%)	6.2
Tin (g)	800		OMC (%)	10.7
Dry soil sample	1779		Added OMC (%)	4.5
Water (g)	111		Calculated dry wt of soil (g)	5625.6
N.M.C (%)	6.2		Water added (g)	252
Average (%)	6.2		**Water added (mL)**	**252**

Number of blows		**62**							
Number of layer		5							
Water Content Determination		Before Soaking		After Soaking					
Tare No		CML	-	BOJ	-				
Mass of wet sample + Tare	g	1435	-	3050	-				
Mass of dry sample + Tare	g	1375	-	2758	-				
Mass of Tare	g	760	-	800	-				
Mass of water	g	60	-	292	-				
Mass of dry sample	g	615	-	1958	-				
Water content	%	9.8	-	14.9	-				
Average water Content	%	9.8		14.9					
Density determination									
Mould No		MM							
Mass of mould + soil	g	12205		12488					
Mass of mould	g	6720		6720					
Mass of soil	g	5485		5768					
Volume of the mould	cm3	2305		2305					
Moist density	g/cm3	2.380		2.502					
Dry density	g/cm3	2.168		2.178					
Swell Determination									
Date		Hour		D Gauge Reding					
Initial reading		96 hrs		14.25					
Final reading				15.25					
Height of the specimen				127					
Height of swell									
		Swelling(%)		0.79					
Observations									

For the Lab		
Lab. Technician	Materials Engineer	

STIRLING CIVIL ENGINEERING LTD P.O. BOX 795, KAMPALA

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:		Penetration Date	17/Dec/23
Depth :		Technician	: Lab team
Sample Description :	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	MM		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2052	0.2052	0.2052

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**	1	0.2	1	0.2								
0.5	**24**	1	0.2	2	0.4								
0.75	**35**	1	0.2	3	0.6								
1	**47**	2	0.4	6	1.2								
1.5	**71**	3	0.6	12	2.5								
2	**94**	5	1.0	16	3.3								
2.5	**118**	7	1.4	20	4.1								
3	**142**	9	1.8	24	4.9								
3.5	**165**	10	2.1	27	5.5								
4	**189**	12	2.5	30	6.2								
4.5	**213**	14	2.9	33	6.8								
5	**236**	16	3.3	35	7.2								
5.5	**260**	19	3.9	38	7.8								
6	**283**	21	4.3	40	8.2								
6.5	**307**	23	4.7	42	8.6								
7	**331**	25	5.1	44	9.0								
7.5	**354**	27	5.5	45	9.2								

Observations

For the Contractor		
Lab. Technician	*Materials Engineer*	

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

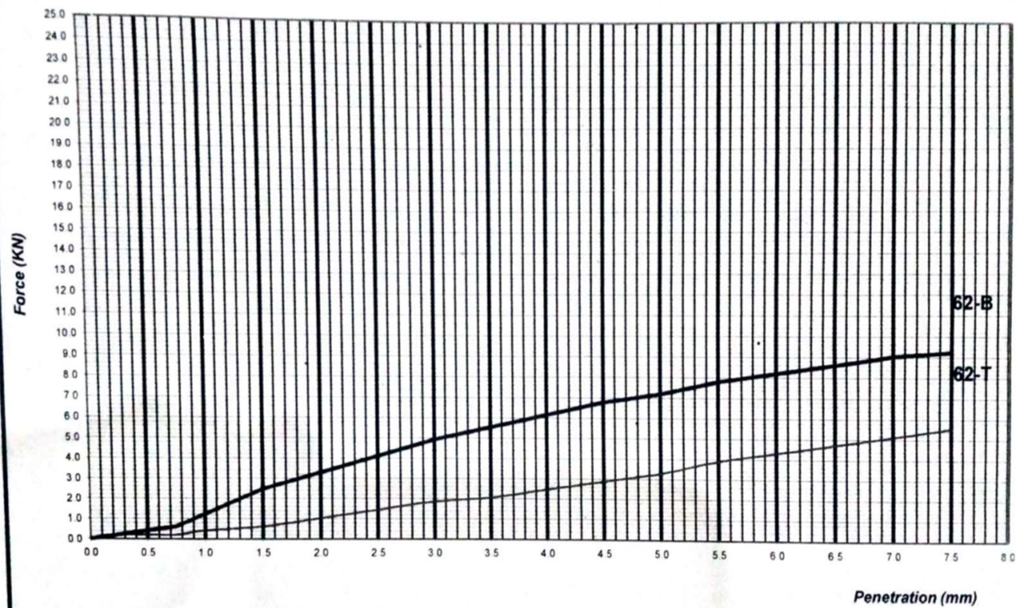
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

ASSESSING THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No :	Sampling Date :	9/Dec/23
Location		Testing Date	17/Dec/23
Depth		Technician	Lab team
Sample Description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL		

PENETRATION vs FORCE CURVE



	62 blows			
	Force		CBR	
	Bottom	Top	Bottom	Top
2.5 mm Penetration	4.1	1.4	31	11
5.0 mm Penetration	7.2	3.3	36	16
Average	5.6	2.4	33.5	13.6
Retained CBR	33.5			
Observations	CBR= 33.5			

For the Lab

Lab. Technician | Materials Engineer

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In any Correspondence on this subject please quote No........................
GE 032/2024
31st January 2024

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

MR. AGABA JOEL AND MR KAKOOZA PAUL
S20B32/216 / S20B32/228
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-786-819434

REPORT OF ANALYSIS

Description of the Samples
One sample in a black polythene bag containing Meta kaolin powder was submitted by Mr. Agaba Joel, on 19th January 2024, and analysed on 22nd February 2023. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Cream powdered sample packed in a black polythene bag.	01	Sample "A" GE 032/2024

Analysis Requested
Elemental analysis

Method of Analysis
Elemental analysis was done using the XRF Method.

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

Parameter	Units	Results Meta Kaolin sample GE 032/2024
Silicon dioxide	% m/m	57.459
Aluminum Oxide	% m/m	24.926
Calcium Oxide	% m/m	8.570
Iron (III) Oxide	% m/m	7.778
Potassium Oxide	% m/m	0.376
Titanium di oxide	% m/m	0.261
Phosphorous pent oxide	% m/m	0.249
Manganese (II)Oxide	% m/m	0.211

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

31/01/2024

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF ALL THE TEST RESULTS FOR LATERATIC GRAVEL MODIFIED WITH METAKAOLINE AND CEMENT

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	62Blows	62
0	NEAT LATERATIC GRAVEL	12/9/2023	100	98	93	74	68	58	54	1.19	45.3	29.6	15.7	7.8	2.159	10.7	33	0.79
			100	97	90	70	66	60	57	1.17	45.0	29.4	15.6	7.8	-	-	-	-
	STABILISED WITH 5% METAKAOLINE ONLY		100	100	93	60	54	46	40	1.604	43	27.5	15.5	7.6	2.152	10.1	37	0.66
			100	99	69	56	47	34	22	1.961	42.9	27.5	15.4	7.6	-	-	-	-
	3% CEMENT ONLY		100	98	80	48	42	32	26	2.005	42.9	28.8	14.1	7.1	2.138	12.1	49	0.5
			100	96	83	49	42	33	26	1.991	42.8	28.7	14.1	7.1	-	-	-	-
	3% CEMENT AND 2% METAKAOLINE		100.0	100.0	99.0	60.9	44.6	30.5	17.1	2.078	41.8	28.3	13.5	6.9	2.097	12.3	51	0.40
			100.0	100.0	98.7	59.7	43.9	30.9	18.3	2.068	41.5	27.9	13.6	6.9	-	-	-	-
	3% CEMENT & 4% METAKAOLIN		100.0	100.0	89.5	53.4	44.2	29.9	19.9	2.060	42.4	29.2	13.2	6.4	2.071	12.2	57	0.30
			100.0	100.0	89.4	57.3	46.7	29.5	18.0	2.058	42.3	29.3	13.0	6.4	-	-	-	-
	3% CEMENT & 6% METAKAOLIN		100.0	97.2	79.0	47.7	39.6	26.1	17.9	2.163	42.8	28.4	14.4	7.1	2.033	12.3	50	0.63
			100.0	96.7	82.9	50.1	41.6	27.4	18.5	2.126	43.0	28.7	14.2	7.1	-	-	-	-
	3% CEMENT & 8% METAKAOLIN		100.0	100.0	97.7	74.2	55.8	38.1	26.3	1.798	41.8	25.7	16.1	8.2	2.022	13.4	45	0.75
			100.0	100.0	99.7	66.3	51.3	37.9	30.8	1.799	41.7	25.4	16.3	8.2	-	-	-	-

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
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INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 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	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL	12/9/2023	100	98	93	74	68	58	54	1.19	45.3	29.6	15.7	7.8	2.159	10.7	33	0.79	0.79
			100	97	90	70	66	60	57	1.17	45.0	29.4	15.6	7.8	-	-	-	-	
			100	**97.47**	**91.61**	**72.14**	**66.94**	**59.18**	**55.76**	**1.18**	**45.2**	**29.5**	**15.6**	**7.8**	**2.159**	**10.7**	**33**	**0.79**	**0.79**
	AVERAGE		100	97	92	72	67	59	56	1.181	45.2	29.4	15.6	7.8	2.159	10.7	33	0.79	0.79

FOR LAB

Lab Technician

Materials Engineer

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P. O. BOX 796, KAMPALA (U)

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PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL STABILISED WITH 5% METAKAOLINE ONLY

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	62Blows	62	AVERAGE
STABILISED WITH 5% METAKAOLINE ONLY	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN	12/9/2023	100	100	93	60	54	46	40	1.60	43	27.5	15.5	7.6	2.152	10.1	37	0.66	0.66
			100	99	69	56	47	34	22	1.96	42.9	27.5	15.4	7.6	-	-	-	-	
			100	**99.53**	**80.81**	**57.96**	**50.66**	**40.09**	**31**	**1.78**	**43.0**	**27.5**	**15.5**	**7.6**	**2.152**	**10.1**	**37**	**0.66**	**0.66**
	AVERAGE		100	100	81	58	51	40	31	1.782	43.0	27.5	15.5	7.6	2.152	10.1	37	0.66	0.66

FOR LAB

Lab Technician

Materials Engineer

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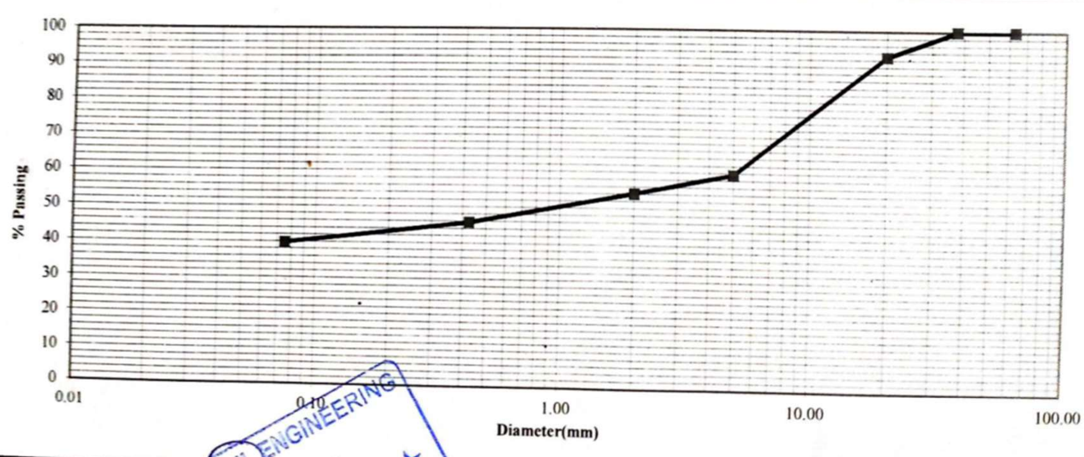
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	STABILISED WITH 5% METAKAOLINE ONLY	Dry wt. of sample before washing: (g)		5068
Depth: (m)		Dry wt. of sample after washing: (g)		3063.5
Material description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	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	362.0	7.1	**93**	60	95
5.0	1688.1	33.3	**60**	30	65
2.00	274.4	5.4	**54**	20	50
0.425	426.7	8.4	**46**	10	30
0.075	301.7	6.0	**40**	5	15
Total fines	2015.1	39.8			
Bottom Pan	10.6				
Extracted fines	2004.5				
Total sample	5068.0				
Grading Modulus		**1.60**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD
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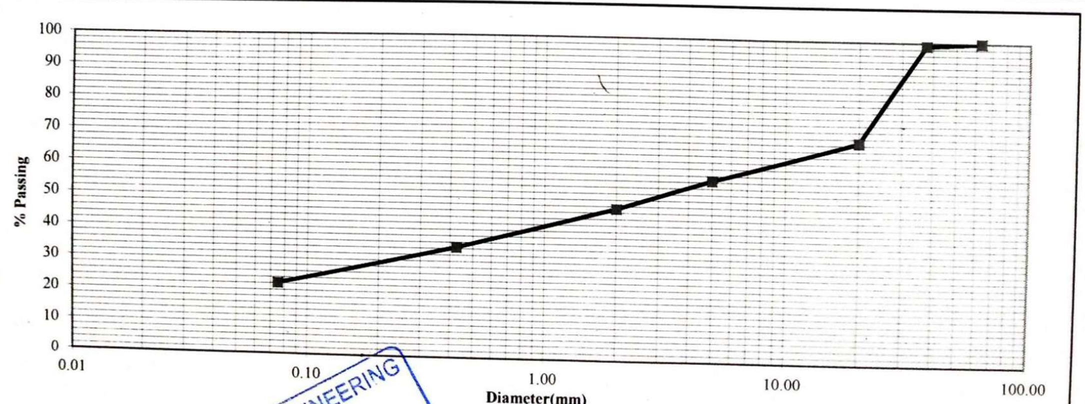
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	STABILISED WITH 5% METAKAOLINE ONLY	Dry wt. of sample before washing: (g)		5663.2
Depth: (m)		Dry wt. of sample after washing: (g)		4414.2
Material description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	52.8	0.9	**99**	80	100
20.0	1715.8	30.3	**69**	60	95
5.0	702.4	12.4	**56**	30	65
2.00	520.1	9.2	**47**	20	50
0.425	719.8	12.7	**34**	10	30
0.075	693.1	12.2	**22**	5	15
Total fines	1259.2	22.2			
Bottom Pan	10.2				
Extracted fines	1249.0				
Total sample	5663.2				
Grading Modulus		**1.96**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	**PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS**

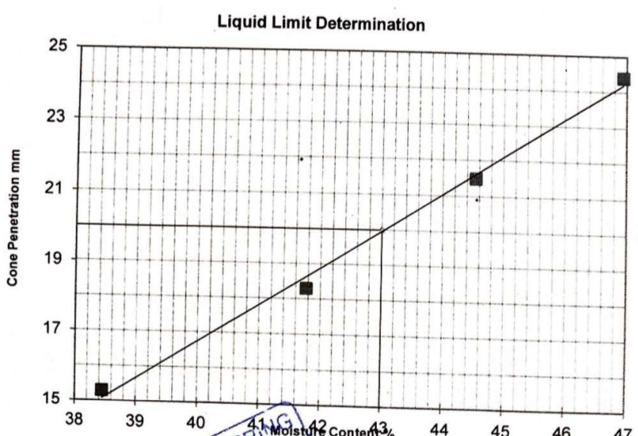
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	STABILISED WITH 5% METAKAOLINE ONLY	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN		

PLASTIC LIMIT	Test No.	D2	Q		Average
Mass of wet soil + container (g)		35.94	41.1		38.52
Mass of dry soil + container (g)		33.1	36.91		35.005
Mass of container (g)		22.75	21.69		22.22
Mass of moisture (g)		2.84	4.2		3.515
Mass of dry soil (g)		10.35	15.22		12.785
Moisture content %		27.4	27.5		27.5
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.3	18.3	21.5	24.4
penetration (mm)		15.3	18.3	21.5	24.4
AVERAGE		15.3	18.3	21.5	24.4
Container No.		AB	A7	PI6OO	PI2H
Mass of wet soil + container (g)		52.27	57.92	56.80	53.54
Mass of dry soil + container (g)		39.66	43.59	41.43	40.11
Mass of container (g)		6.86	9.28	6.92	11.50
Mass of moisture (g)		12.61	14.33	15.37	13.43
Mass of dry soil (g)		32.8	34.31	34.51	28.61
Moisture content (%)		38.4	41.8	44.5	46.9
AVERAGE		38.4	41.8	44.5	46.9



Liquid limit (%)	43.0
Plastic limit (%)	27.5
Plasticity Index (%)	15.5
Linear shrinkage	
Trough No.	J
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.1
% L.shrinkage =	7.6

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

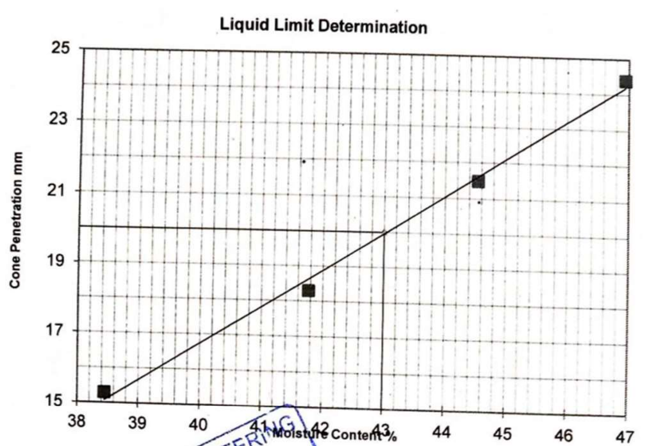
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	STABILISED WITH 5% METAKAOLINE ONLY	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN		

PLASTIC LIMIT	Test No.	D2	Q		Average
Mass of wet soil + container (g)		35.94	41.1		38.52
Mass of dry soil + container (g)		33.1	36.91		35.005
Mass of container (g)		22.75	21.69		22.22
Mass of moisture (g)		2.84	4.2		3.515
Mass of dry soil (g)		10.35	15.22		12.785
Moisture content %		27.4	27.5		27.5
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.3	18.3	21.5	24.4
penetration (mm)		15.3	18.3	21.5	24.4
AVERAGE		15.3	18.3	21.5	24.4
Container No.		AB	A7	PI6OO	PI2H
Mass of wet soil + container (g)		52.27	57.92	56.80	53.54
Mass of dry soil + container (g)		39.66	43.59	41.43	40.11
Mass of container (g)		6.86	9.28	6.92	11.50
Mass of moisture (g)		12.61	14.33	15.37	13.43
Mass of dry soil (g)		32.8	34.31	34.51	28.61
Moisture content (%)		38.4	41.8	44.5	46.9
AVERAGE		38.4	41.8	44.5	46.9



Liquid limit (%)	43.0
Plastic limit (%)	27.5
Plasticity Index (%)	15.5
Linear shrinkage	
Trough No.	J
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.1
% L.shrinkage =	7.6

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

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

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS				
Test Reference No.		Lab Reference No.	Date Sampled	Date Tested	Technician
Mix	STABILISED WITH 5% METAKAOLINE ONLY		9/Dec/23	24/Jan/24	Lab team
Material description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN		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

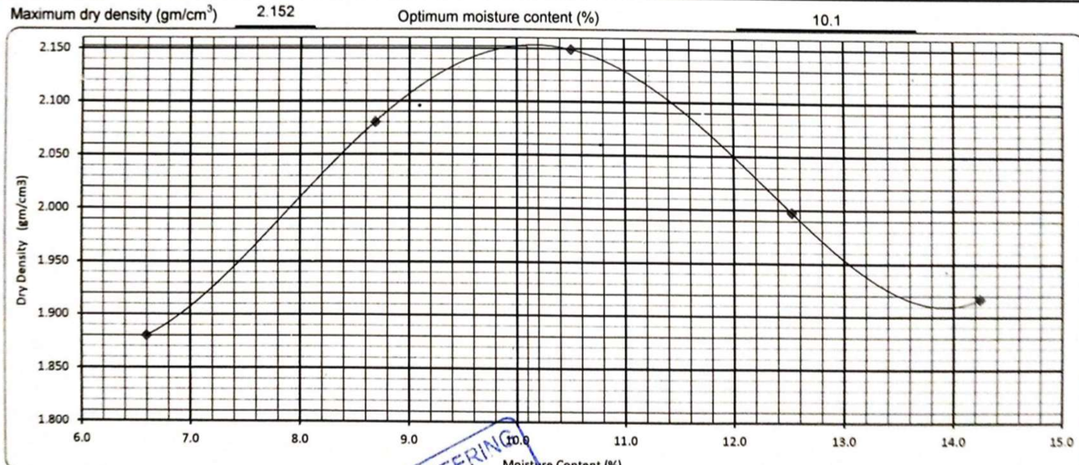
MOISTURE CONTENT DATA

Test No		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	200	300	400	500	600
Mass of Compacted soil + mould	gm	6,283	6,540	6,654	6,527	6,469
Mass of Mould	gm	4,279	4,279	4,279	4,279	4,279
Mass of Compacted soil	gm	2004	2261	2375	2248	2190
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	2.004	2.261	2.375	2.248	2.190

DATA FOR PROCTOR CURVE

Container No.		FDC	BOJ	Z6T	BBC	ACB
Mass of wet soil + Container	gm	2,518.0	2,378.0	2,700.0	2,471.0	2,563.0
Mass of dry soil + container	gm	2,412.0	2,252.0	2,485.0	2,286.0	2,341.0
Mass of container	gm	805.0	801.0	438.0	809.0	782.0
Mass of water added	gm	106	126	215	185	222
Mass of dry soil	gm	1607	1451	2047	1477	1559
Moisture content	%	6.6	8.7	10.5	12.5	14.2
Dry density	g/cm^3	1.880	2.080	2.149	1.998	1.917

Maximum dry density (gm/cm^3) 2.152 Optimum moisture content (%) 10.1



Remarks:

FOR TESTING LAB

Lab Technician Materials Engineer

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:	STABILISED WITH 5% METAKAOLINE ONLY	Casting date :	27/Jan/24
		Testing Date	10/Feb/24
Sample Description:	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN	Technician	Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	NBM		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1713		MDD (Mg/m^3)	2.152
Tin + oven dry soil sample (g)	1693		N.M.C (%)	2.2
Tin (g)	797		OMC (%)	10.1
Dry soil sample	896		Added OMC (%)	7.9
Water (g)	20		Calculated dry wt of soil (g)	5866.1
N.M.C (%)	2.2		Water added (g)	**462**
Average (%)	2.2		**Water added (mL)**	**462**

Number of blows		62					
Number of layer		5					
Water Content Determination		Before Soaking	After Soaking				
Tare No		BA -	KT -				
Mass of wet sample + Tare	g	2395 -	1874 -				
Mass of dry sample + Tare	g	2215 -	1753 -				
Mass of Tare	g	768 -	799 -				
Mass of water	g	180 -	121 -				
Mass of dry sample	g	1447 -	954 -				
Water content	%	12.4 -	12.7 -				
Average water Content	%	12.4	12.7				
Density determination							
Mould No		AS					
Mass of mould + soil	g	10662	10675				
Mass of mould	g	5264	5264				
Mass of soil	g	5398	5411				
Volume of the mould	cm3	2305	2305				
Moist density	g/cm3	2.342	2.348				
Dry density	g/cm3	2.083	2.083				
Swell Determination							
Date		Hour	D.Gauge Reding				
Initial reading		96 hrs	13.21				
Final reading			14.05				
Height of the specimen			127				
Height of swell			0.84				
		Swelling(%)	**0.66**				
Observations							

For the Lab		
Lab. Technician	*Materials Engineer*	

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:		Penetration Date	10/Feb/24
Depth :		Technician	: : Lab team
Sample Description :	: BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	AS		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2052	0.2052	0.2052
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**	1	0.2	4	0.8
0.5	**24**	1	0.2	6	1.2
0.75	**35**	2	0.4	9	1.8
1	**47**	4	0.8	13	2.7
1.5	**71**	5	1.0	16	3.3
2	**94**	6	1.2	18	3.7
2.5	**118**	8	1.6	22	4.5
3	**142**	10	2.1	28	5.7
3.5	**165**	12	2.5	31	6.4
4	**189**	14	2.9	34	7.0
4.5	**213**	17	3.5	37	7.6
5	**236**	19	3.9	39	8.0
5.5	**260**	21	4.3	42	8.6
6	**283**	23	4.7	44	9.0
6.5	**307**	25	5.1	46	9.4
7	**331**	27	5.5	48	9.8
7.5	**354**	28	5.7	50	10.3

Observations

For the Contractor		
Lab. Technician	*Materials Engineer*	

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

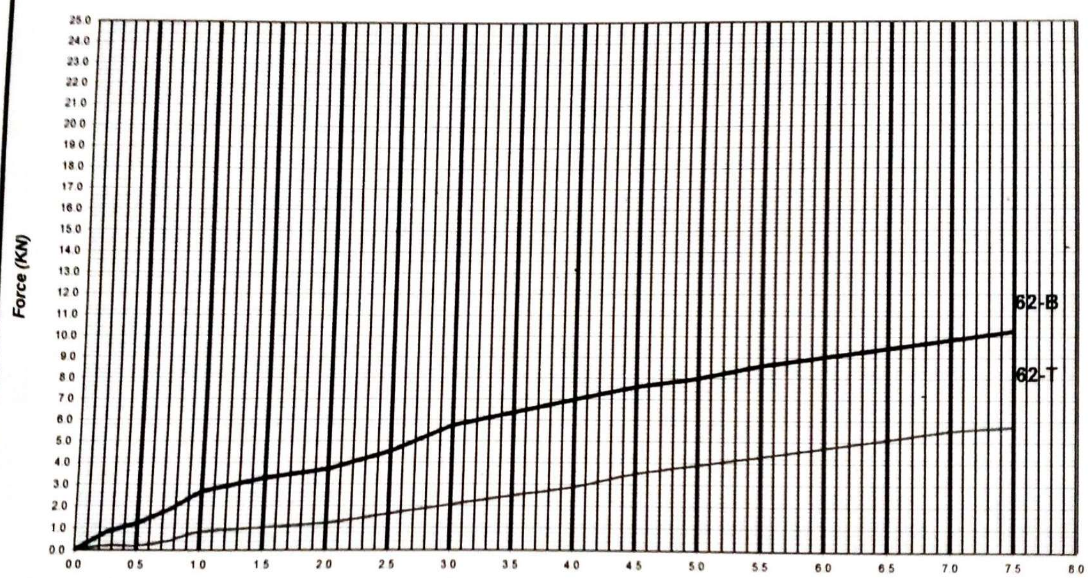
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Laboratory Reference No.	Sampling Date : 9/Dec/23
Location		Testing Date : 10/Feb/24
Depth		Technician : Lab team
Sample Description	BROWN YELLOWISH LATERITIC GRAVEL MATERIAL & 5% METAKAOLIN	

PENETRATION vs FORCE CURVE



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	4.5	1.6	34	12								
5.0 mm Penetration	8.0	3.9	40	20								
Average	6.3	2.8	37.1	16.0								
Retained CBR	37.1											
Observations	CBR= 37.1											

For the Lab		
Lab Technician	*Materials Engineer*	

STIRLING CIVIL ENGINEERING LTD P.O. BOX 795, KAMPALA

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 3% CEMENT ONLY

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 COMPACTION	62	AVERAGE
3% CEMENT ONLY	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY	12/9/2023	100	98	80	48	42	32	26	2.01	42.9	28.8	14.1	7.1	2.138	12.1	49	0.49	0.49
			100	96	83	49	42	33	26	1.99	42.8	28.7	14:1	7.1	-	-	- - -	-	
			100	**97**	**81.34**	**48.09**	**41.85**	**32.52**	**25.84**	**2.00**	**42.9**	**28.7**	**14.1**	**7.1**	**2.138**	**12.1**	**49**	**0.49**	**0.49**
	AVERAGE		**100**	**97**	**81**	**48**	**42**	**33**	**26**	**1.998**	**42.9**	**28.7**	**14.1**	**7.1**	**2.138**	**12.1**	**49**	**0.49**	**0.49**

FOR LAB

Lab Technician

Materials Engineer

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

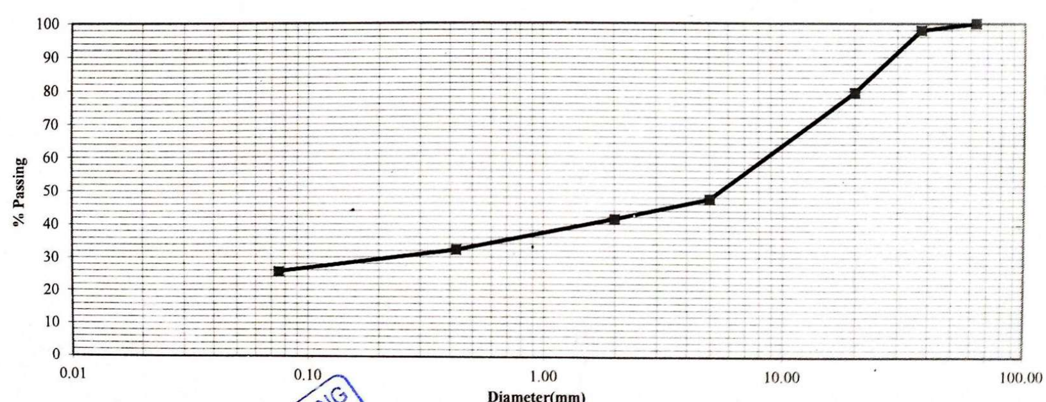
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	3% CEMENT ONLY	Dry wt. of sample before washing: (g)		4585.8
Depth: (m)		Dry wt. of sample after washing: (g)		3419.0
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	93.0	2.0	**98**	80	100
20.0	841.4	18.3	**80**	60	95
5.0	1471.2	32.1	**48**	30	65
2.00	274.4	6.0	**42**	20	50
0.425	426.7	9.3	**32**	10	30
0.075	301.7	6.6	**26**	5	15
Total fines	1177.4	25.7			
Bottom Pan	10.6				
Extracted fines	1166.8				
Total sample	4585.8				
Grading Modulus		**2.01**			



FOR TESTING LAB	
Lab Technician Materials Engineer	

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

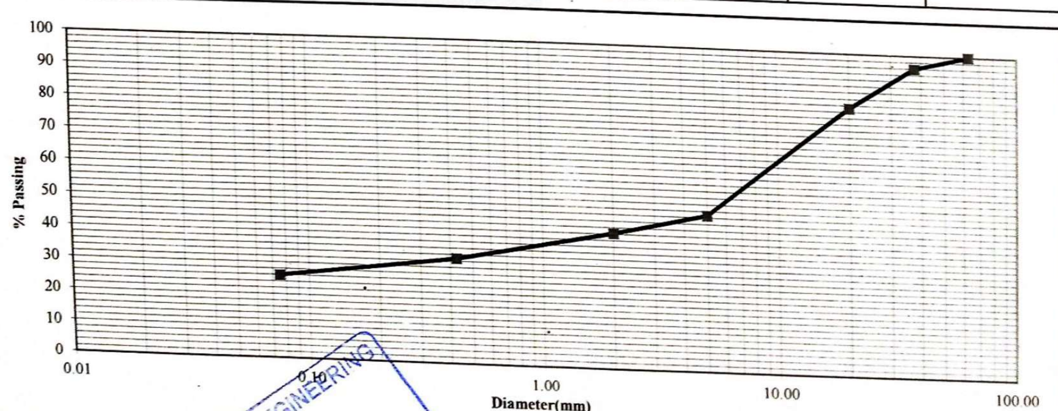
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	3% CEMENT ONLY	Dry wt. of sample before washing: (g)		4175.7
Depth: (m)		Dry wt. of sample after washing: (g)		3093.5
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	165.5	4.0	**96**	80	100
20.0	542.2	13.0	**83**	60	95
5.0	1437.4	34.4	**49**	30	65
2.00	270.8	6.5	**42**	20	50
0.425	390.6	9.4	**33**	10	30
0.075	283.3	6.8	**26**	5	15
Total fines	1085.9	26.0			
Bottom Pan	3.7				
Extracted fines	1082.2				
Total sample	4175.7				
Grading Modulus		**1.99**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	**PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS**

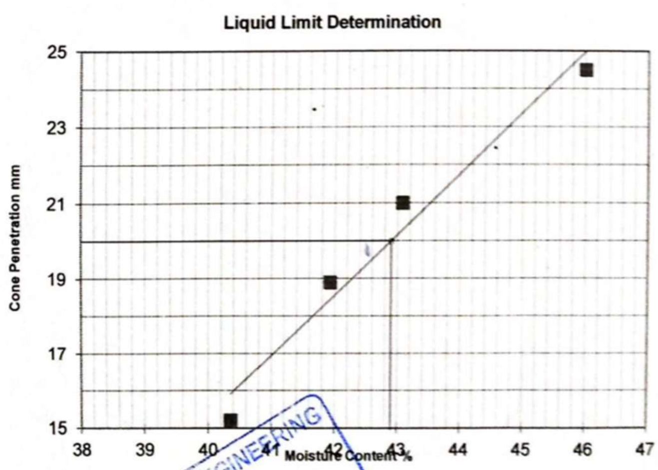
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT ONLY .	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY		

PLASTIC LIMIT	Test No.	SO	KK		Average
Mass of wet soil + container (g)		38.54	43.01		40.775
Mass of dry soil + container (g)		35.05	38.37		36.71
Mass of container (g)		22.93	22.25		22.59
Mass of moisture (g)		3.49	4.6		4.065
Mass of dry soil (g)		12.12	16.12		14.12
Moisture content %		28.8	28.8		28.8
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.2	18.9	21	24.5
penetration (mm)		15.2	18.9	21.0	24.5
AVERAGE		15.2	18.9	21.0	24.5
Container No.		PI45	PI82	PII2	PII9
Mass of wet soil + container (g)		46.01	50.26	42.94	52.93
Mass of dry soil + container (g)		34.82	37.48	32.06	38.44
Mass of container (g)		7.09	7.00	6.80	6.94
Mass of moisture (g)		11.19	12.78	10.88	14.49
Mass of dry soil (g)		27.73	30.48	25.26	31.5
Moisture content (%)		40.4	41.9	43.1	46.0
AVERAGE		40.4	41.9	43.1	46.0



Liquid limit (%)	42.9
Plastic limit (%)	28.8
Plasticity Index (%)	14.1
Linear shrinkage	
Trough No.	2
Trough length (cm)	14.0
Specimen length (cm)	13.0
L.shringage =	1.0
% L.shrinkage =	7.1

Remarks:

TESTING LAB		
Materials Engineer		
Lab Technician		

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 796, KAMPALA

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

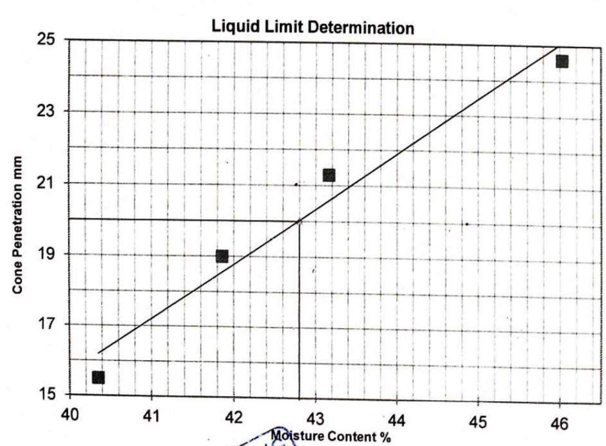
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT ONLY	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRÅVEL STABILISED WITH 3% CEMENT ONLY		

PLASTIC LIMIT	Test No.	SM	DT		Average
Mass of wet soil + container (g)		36.25	35.4		35.825
Mass of dry soil + container (g)		33.19	32.75		32.97
Mass of container (g)		22.5	23.52		23.01
Mass of moisture (g)		3.06	2.7		2.855
Mass of dry soil (g)		10.69	9.23		9.96
Moisture content %		28.6	28.7		28.7
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.5	19	21.3	24.6
penetration (mm)		15.5	19.0	21.3	24.6
AVERAGE		15.5	19.0	21.3	24.6
Container No.		A	P121	PI46	FOO
Mass of wet soil + container (g)		55.07	53.05	44.25	60.35
Mass of dry soil + container (g)		41.27	39.48	33.08	43.49
Mass of container (g)		7.07	7.06	7.20	6.86
Mass of moisture (g)		13.8	13.57	11.17	16.86
Mass of dry soil (g)		34.2	32.42	25.88	36.63
Moisture content (%)		40.4	41.9	43.2	46.0
AVERAGE		40.4	41.9	43.2	46.0



Liquid limit (%)	42.8
Plastic limit (%)	28.7
Plasticity Index (%)	14.1
Linear shrinkage	
Trough No.	2
Trough length (cm)	14.0
Specimen length (cm)	13.0
L.shringage =	1.0
% L.shrinkage =	7.1

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
Mix	3% CEMENT ONLY	9/Dec/23	24/Jan/24	Lab team
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY	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

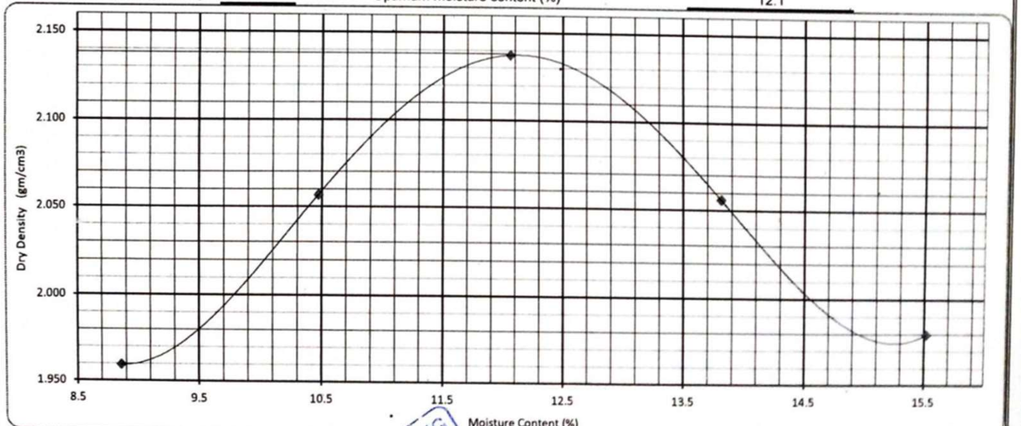
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	200	300	400	500	600
Mass of Compacted soil + mould	gm	6,412	6,551	6,674	6,619	6,566
Mass of Mould	gm	4,279	4,279	4,279	4,279	4,279
Mass of Compacted soil	gm	2133	2272	2395	2340	2287
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	2.133	2.272	2.395	2.340	2.287

DATA FOR PROCTOR CURVE

Container No.		LDU	OPD	XZM	EX	DJ
Mass of wet soil + Container	gm	1,781.0	1,986.0	2,747.0	1,735.0	2,273.0
Mass of dry soil + container	gm	1,670.0	1,850.0	2,538.0	1,589.0	2,041.0
Mass of container	gm	417.0	551.0	805.0	532.0	546.0
Mass of water added	gm	111	136	209	146	232
Mass of dry soil	gm	1253	1299	1733	1057	1495
Moisture content	%	8.9	10.5	12.1	13.8	15.5
Dry density	g/cm^3	1.959	2.057	2.137	2.056	1.980

Maximum dry density (gm/cm^3) 2.138 Optimum moisture content (%) 12.1



Remarks:

FOR TESTING LAB

Lab Technician	Materials Engineer	

STIRLING CIVIL ENGINEERING LTD P. O. BOX 796, KAMPALA

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	9/Dec/23
Location:	3% CEMENT ONLY	Casting date :	27/Jan/24
		Testing Date :	10/Feb/24
		Technician :	: Lab team
Sample Description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY	**Volume of Mould used (m^3)**	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	ZION		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2240		MDD (Mg/m^3)	2.138
Tin + oven dry soil sample (g)	2212		N.M.C (%)	1.6
Tin (g)	436		OMC (%)	12.1
Dry soil sample	1776		Added OMC (%)	10.5
Water (g)	28		Calculated dry wt of soil (g)	5905.4
N.M.C (%)	1.6		Water added (g)	**622**
Average (%)	1.6		**Water added (mL)**	**622**

Number of blows		62										
Number of layer		5										
Water Content Determination		Before Soaking		After Soaking								
Tare No		Y6Y	-	CML	-							
Mass of wet sample + Tare	g	2141	-	1946	-							
Mass of dry sample + Tare	g	1984	-	1809	-							
Mass of Tare	g	820	-	763	-							
Mass of water	g	157	-	137	-							
Mass of dry sample	g	1164	-	1046	-							
Water content	%	13.5	-	13.1	-							
Average water Content	%	13.5		13.1								
Density determination												
Mould No		AS										
Mass of mould + soil	g	10847		10826								
Mass of mould	g	5592		5592								
Mass of soil	g	5255		5234								
Volume of the mould	cm3	2305		2305								
Moist density	g/cm3	2.280		2.271								
Dry density	g/cm3	2.009		2.008								
Swell Determination												
Date		Hour		D.Gauge Reding								
Initial reading		96 hrs		5.9								
Final reading				6.52								
Height of the specimen				127								
Height of swell				0.62								
		Swelling(%)		**0.49**								
Observations												

For the Lab			
Lab. Technician	*Materials Engineer*		

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:		Penetration Date	10/Feb/24
Depth :		Technician	: : Lab team
Sample Description :	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	AS		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2052	0.2052	0.2052

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**	1	0.2	2	0.4						
0.5	**24**	2	0.4	6	1.2						
0.75	**35**	4	0.8	10	2.1						
1	**47**	6	1.2	13	2.7						
1.5	**71**	9	1.8	20	4.1						
2	**94**	13	2.7	25	5.1						
2.5	**118**	18	3.7	30	6.2						
3	**142**	25	5.1	34	7.0						
3.5	**165**	29	6.0	38	7.8						
4	**189**	38	7.8	43	8.8						
4.5	**213**	42	8.6	46	9.4						
5	**236**	46	9.4	50	10.3						
5.5	**260**	52	10.7	54	11.1						
6	**283**	56	11.5	59	12.1						
6.5	**307**	59	12.1	64	13.1						
7	**331**	62	12.7	66	13.5						
7.5	**354**	64	13.1	69	14.2						

Observations

For the Contractor			
Lab. Technician	*Materials Engineer*		

STIRLING CIVIL ENGINEERING
P.O. BOX 706, KAMPALA (U)

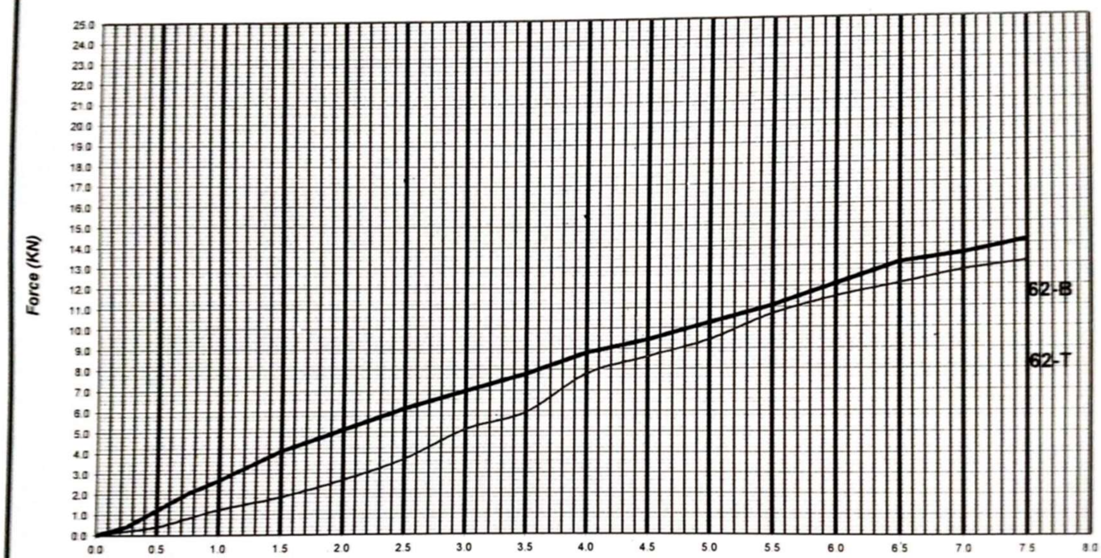
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	9/Dec/23
Location		Testing Date :	10/Feb/24
Depth		Technician	: Lab team
Sample Description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT ONLY		

PENETRATION vs FORCE CURVE



	62 blows			
	Force		CBR	
	Bottom	Top	Bottom	Top
2.5 mm Penetration	6.2	3.7	46	28
5.0 mm Penetration	10.3	9.4	51	47
Average	8.2	6.6	48.9	37.6
Retained CBR	48.9			
Observations	CBR= 48.9			

For the Lab		
Lab. Technician	Materials Engineer	

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 3% CEMENT AND 2% METAKAOLINE

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
3% CEMENT AND 2% METAKAO LINE	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE	12/9/2023	100	100	99	61	45	30	17	2.08	41.8	28.3	13.5	6.9	2.097	12.3	51	0.40	0.40
			100	100	99	60	44	31	18	2.07	41.5	27.9	13.6	6.9	-	-	-	-	
			100	**100**	**98.86**	**60.28**	**44.27**	**30.7**	**17.7**	**2.07**	**41.7**	**28.1**	**13.6**	**6.9**	**2.097**	**12.3**	**51**	**0.40**	**0.40**
	AVERAGE		100	100	99	60	44	31	18	2.073	41.7	27.9	13.6	6.9	2.097	12.3	51	0.40	0.40

FOR LAB

Lab Technician

Materials Engineer

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

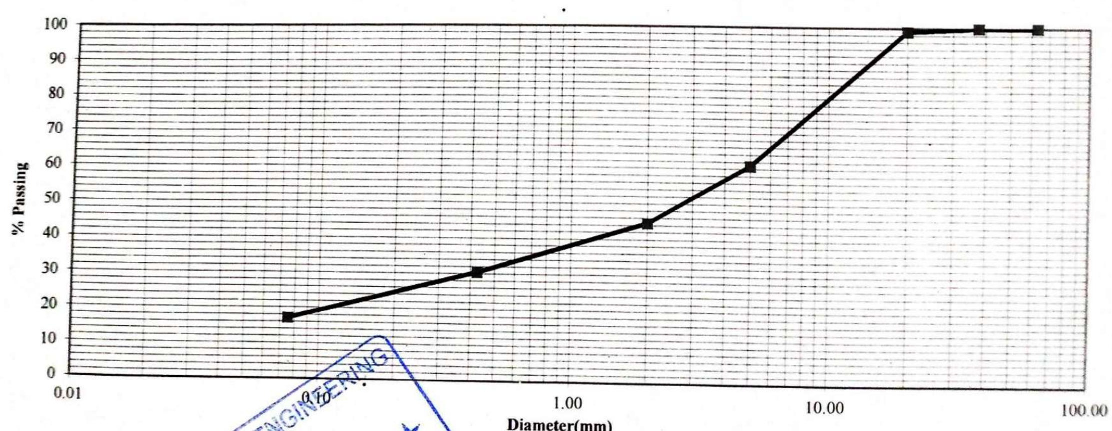
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:			
Location :(km)	3% CEMENT AND 2% METAKAOLINE	Dry wt. of sample before washing: (g)			3825.6
Depth: (m)		Dry wt. of sample after washing: (g)			3183.7
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE	Date Sampled:	Date Tested:		Technician
		9/Dec/2023	24/Jan/2024		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	38.4	1.0	**99**	60	95
5.0	1457.8	38.1	**61**	30	65
2.00	622.7	16.3	**45**	20	50
0.425	539.9	14.1	**30**	10	30
0.075	514.0	13.4	**17**	5	15
Total fines	652.8	17.1			
Bottom Pan	10.9				
Extracted fines	641.9				
Total sample	3825.6				
Grading Modulus		**2.08**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

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

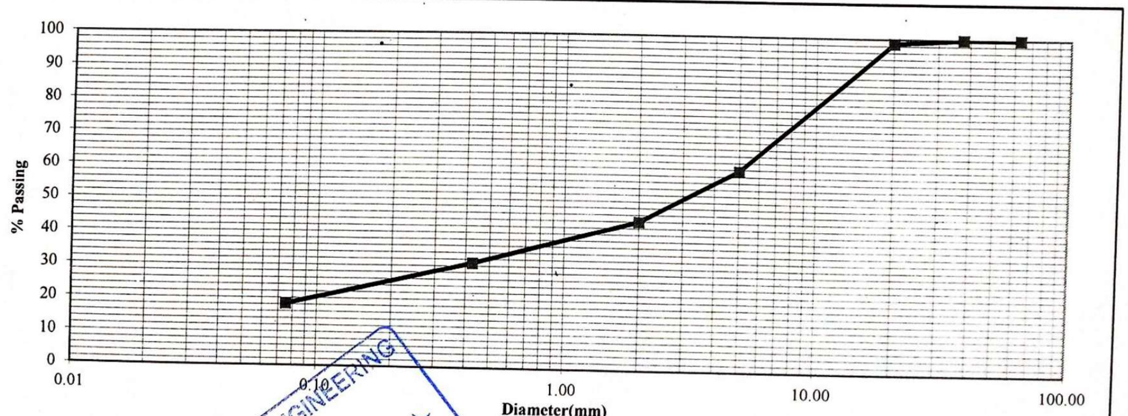
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:			
Location :(km)	3% CEMENT AND 2% METAKAOLINE	Dry wt. of sample before washing: (g)			4002.9
Depth: (m)		Dry wt. of sample after washing: (g)			3281.1
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE	Date Sampled:	Date Tested:		Technician
		9/Dec/2023	24/Jan/2024		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	50.8	1.3	**99**	60	95
5.0	1563.8	39.1	**60**	30	65
2.00	629.8	15.7	**44**	20	50
0.425	521.4	13.0	**31**	10	30
0.075	502.8	12.6	**18**	5	15
Total fines	734.3	18.3			
Bottom Pan	12.5				
Extracted fines	721.8				
Total sample	4002.9				
Grading Modulus		**2.07**			



FOR TESTING LAB

Lab Technician Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

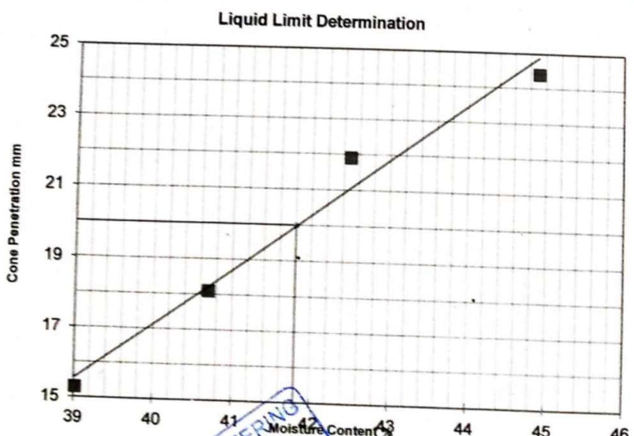
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT AND 2% METAKAOLINE	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE		

PLASTIC LIMIT	Test No.	OG	KK		Average
Mass of wet soil + container (g)		43.66	41.29		42.475
Mass of dry soil + container (g)		38.8	37.06		37.93
Mass of container (g)		21.42	22.26		21.84
Mass of moisture (g)		4.86	4.2		4.545
Mass of dry soil (g)		17.38	14.8		16.09
Moisture content %		28.0	28.6		
AVERAGE					28.3

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.3	18.1	21.9	24.4
penetration (mm)		15.3	18.1	21.9	24.4
AVERAGE		15.3	18.1	21.9	24.4
Container No.		P133	4B	A11	P119
Mass of wet soil + container (g)		59.81	61.91	62.56	64.80
Mass of dry soil + container (g)		44.98	45.99	46.05	46.99
Mass of container (g)		6.97	6.87	7.19	7.33
Mass of moisture (g)		14.83	15.92	16.51	17.81
Mass of dry soil (g)		38.01	39.12	38.86	39.66
Moisture content (%)		39.0	40.7	42.5	44.9
AVERAGE		39.0	40.7	42.5	44.9



Liquid limit (%)	41.8
Plastic limit (%)	28.3
Plasticity Index (%)	13.5
Linear shrinkage	
Trough No.	X
Trough length (cm)	14.0
Specimen length (cm)	13.0
L.shringage =	1.0
% L.shrinkage =	6.9

Remarks:

TESTING LAB

Materials Engineer.

Lab Technician

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

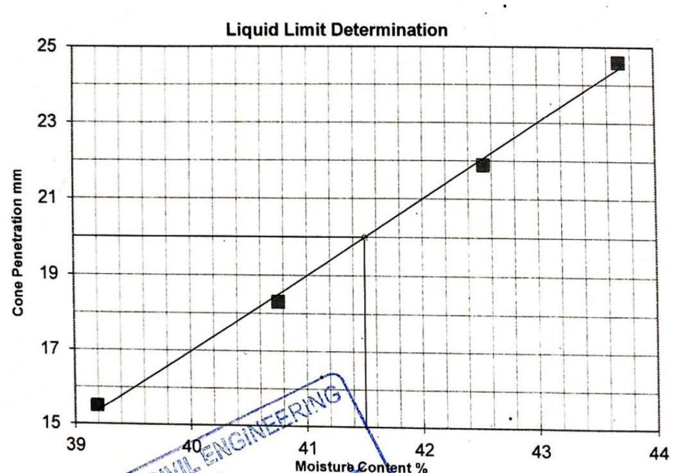
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT AND 2% METAKAOLINE	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE		

PLASTIC LIMIT	Test No.	SO	RAD		Average
Mass of wet soil + container (g)		47.86	44.87		46.365
Mass of dry soil + container (g)		42.42	39.92		41.17
Mass of container (g)		23.13	21.97		22.55
Mass of moisture (g)		5.44	5.0		5.195
Mass of dry soil (g)		19.29	17.95		18.62
Moisture content %		28.2	27.6		27.9
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.5	18.3	21.9	24.6
penetration (mm)		15.5	18.3	21.9	24.6
AVERAGE		15.5	18.3	21.9	24.6
Container No.		P115	P160	P182	A4
Mass of wet soil + container (g)		56.27	66.69	63.57	68.34
Mass of dry soil + container (g)		42.42	49.39	46.66	49.64
Mass of container (g)		7.08	6.94	6.90	6.85
Mass of moisture (g)		13.85	17.3	16.91	18.7
Mass of dry soil (g)		35.34	42.45	39.76	42.79
Moisture content (%)		39.2	40.8	42.5	43.7
AVERAGE		39.2	40.8	42.5	43.7



Liquid limit (%)	41.5
Plastic limit (%)	27.9
Plasticity Index (%)	13.6
Linear shrinkage	
Trough No.	X
Trough length (cm)	14.0
Specimen length (cm)	13.0
L.shringage =	1.0
% L.shrinkage =	6.9

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STIRLING CIVIL ENGINEERING LTD P.O. BOX 796, KAM...

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
Mix	3% CEMENT AND 2% METAKAOLINE	9/Dec/23	24/Jan/24	Lab team
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE	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

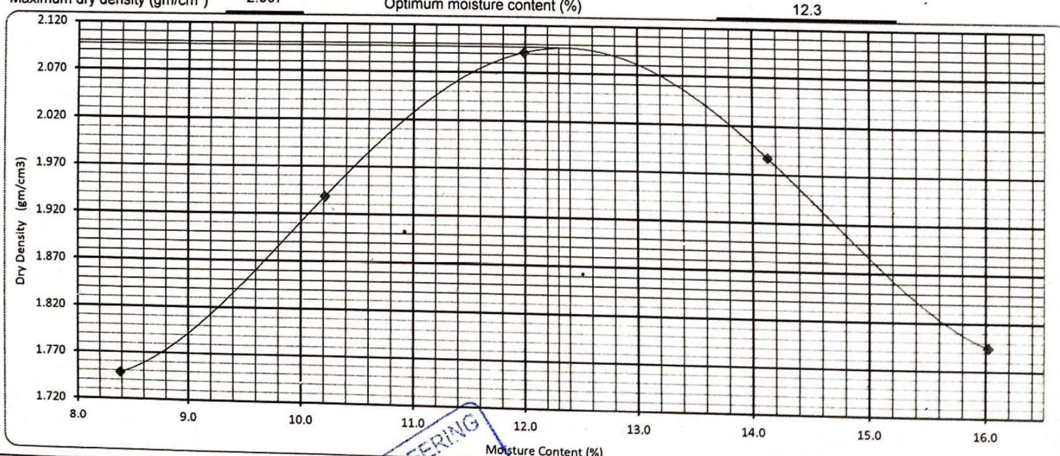
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	150	210	270	330	390
Mass of Compacted soil + mould	gm	5,115	5,356	5,562	5,488	5,302
Mass of Mould	gm	3,220	3,220	3,220	3,220	3,220
Mass of Compacted soil	gm	1895	2136	2342	2268	2082
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.895	2.136	2.342	2.268	2.082

DATA FOR PROCTOR CURVE

Container No.		XZM	NBM	BBC	CML	BXR
Mass of wet soil + Container	gm	2,785.0	2,691.0	2,595.0	2,546.0	2,608.0
Mass of dry soil + container	gm	2,632.0	2,516.0	2,399.0	2,326.0	2,360.0
Mass of container	gm	807.0	802.0	764.0	769.0	812.0
Mass of water added	gm	153	175	196	220	248
Mass of dry soil	gm	1825	1714	1635	1557	1548
Moisture content	%	8.4	10.2	12.0	14.1	16.0
Dry density	g/cm^3	1.748	1.938	2.091	1.987	1.795

Maximum dry density (gm/cm^3) 2.097 Optimum moisture content (%) 12.3



Remarks:

FOR TESTING LAB

Lab Technician	Materials Engineer	

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	9/Dec/23
Location:	3% CEMENT AND 2% METAKAOLINE	Casting date :	27/Jan/24
		Testing Date :	10/Feb/24
Sample Description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE	Technician :	: Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			Volume of water added	
Tin No.	K26		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	3125		MDD (Mg/m^3)	2.097
Tin + oven dry soil sample (g)	3026		N.M.C (%)	4.5
Tin (g)	805		OMC (%)	12.3
Dry soil sample	2221		Added OMC (%)	7.8
Water (g)	99		Calculated dry wt of soil (g)	5732.6
N.M.C (%)	4.5		Water added (g)	450
Average (%)	4.5		**Water added (mL)**	**450**

Number of blows		62								
Number of layer		5								
Water Content Determination		Before Soaking		After Soaking						
Tare No		BK	-	XZM	-					
Mass of wet sample + Tare	g	745	-	2540	-					
Mass of dry sample + Tare	g	669	-	2340	-					
Mass of Tare	g	55	-	805	-					
Mass of water	g	76	-	200	-					
Mass of dry sample	g	614	-	1535	-					
Water content	%	12.4	-	13.0	-					
Average water Content	%	12.4		13.0						
Density determination										
Mould No		HB								
Mass of mould + soil	g	10900		10935						
Mass of mould	g	5510		5510						
Mass of soil	g	5390		5425						
Volume of the mould	cm3	2305		2305						
Moist density	g/cm3	2.338		2.354						
Dry density	g/cm3	2.081		2.082						
Swell Determination										
Date		Hour		D.Gauge Reding						
Initial reading		96 hrs		3.59						
Final reading				4.1						
Height of the specimen				127						
Height of swell				0.51						
		Swelling(%)		**0.40**						
Observations										

For the Lab			
Lab. Technician	*Materials Engineer*		

STIRLING CIVIL ENGINEERING LTD P.O. BOX

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:		Penetration Date	10/Feb/24
Depth :		Technician	Lab team
Sample Description :	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	HB		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2052	0.2052	0.2052

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**	3	0.6	5	1.0
0.5	**24**	6	1.2	8	1.6
0.75	**35**	9	1.8	11	2.3
1	**47**	11	2.3	17	3.5
1.5	**71**	15	3.1	21	4.3
2	**94**	18	3.7	25	5.1
2.5	**118**	21	4.3	30	6.2
3	**142**	26	5.3	36	7.4
3.5	**165**	30	6.2	42	8.6
4	**189**	32	6.6	46	9.4
4.5	**213**	34	7.0	50	10.3
5	**236**	36	7.4	54	11.1
5.5	**260**	37	7.6	56	11.5
6	**283**	38	7.8	58	11.9
6.5	**307**	39	8.0	61	12.5
7	**331**	40	8.2	63	12.9
7.5	**354**	41	8.4	66	13.5

Observations

For the Contractor

Lab. Technician	Material Engineer	

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

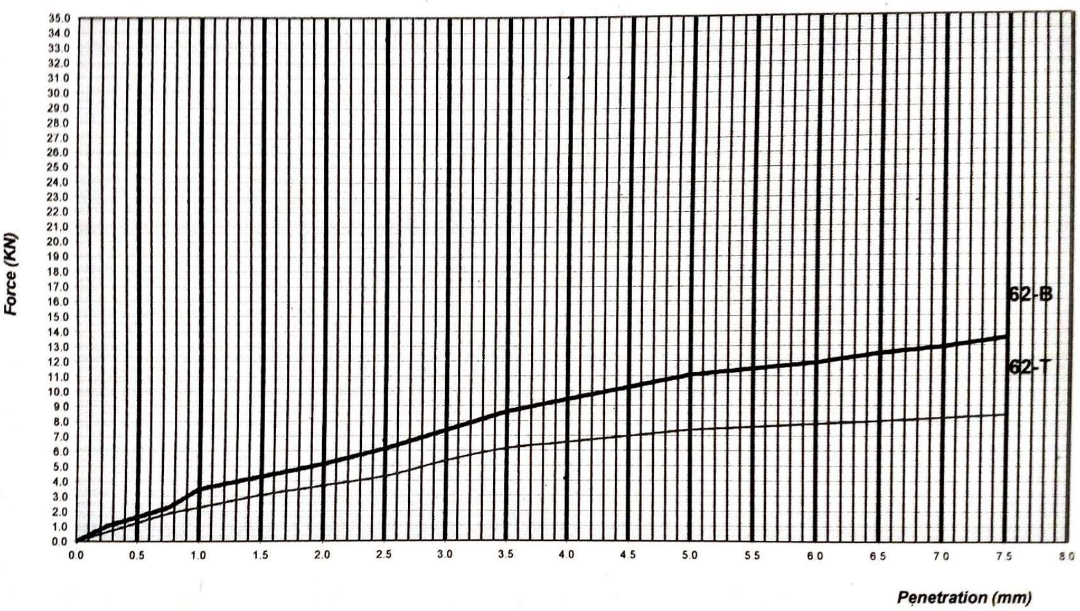
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date : 9/Dec/23
Location		Testing Date : 10/Feb/24
Depth		Technician : Lab team
Sample Description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 2% METAKAOLINE	

PENETRATION vs FORCE CURVE



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	6.2	4.3	46	33								
5.0 mm Penetration	11.1	7.4	56	37								
Average	8.6	5.8	51.0	34.8								
Retained CBR	51.0											
Observations	CBR= 51.0											

For the Lab			
Lab. Technician	Materials Engineer		

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 706, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 3% CEMENT & 4% METAKAOLIN

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 COMPACTION	62	AVERAGE
3% CEMENT & 4% METAKAOLIN	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN	12/9/2023	100	100	89	53	44	30	20	2.06	42.4	29.2	13.2	6.4	2.071	12.2	57	0.30	0.30
			100	100	89	57	47	30	18	2.06	42.3	29.3	13.0	6.4	-	-	- - -	-	
			100	**100**	**89.42**	**55.36**	**45.45**	**29.75**	**18.93**	**2.06**	**42.4**	**29.2**	**13.1**	**6.4**	**2.071**	**12.2**	**57**	**0.30**	**0.30**
	AVERAGE		100	100	89	55	45	30	19	2.059	42.4	29.3	13.1	6.4	2.071	12.2	57	0.30	0.30

FOR LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 3% CEMENT & 4% METAKAOLIN

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 COMPACTION	62	AVERAGE
3% CEMENT & 4% METAKAOLIN	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN	12/9/2023	100	100	89	53	44	30	20	2.06	42.4	29.2	13.2	6.4	2.071	12.2	57	0.30	0.30
			100	100	89	57	47	30	18	2.06	42.3	29.3	13.0	6.4	-	-	- - -	-	
			100	**100**	**89.42**	**55.36**	**45.45**	**29.75**	**18.93**	**2.06**	**42.4**	**29.2**	**13.1**	**6.4**	**2.071**	**12.2**	**57**	**0.30**	**0.30**
	AVERAGE		100	100	89	55	45	30	19	2.059	42.4	29.3	13.1	6.4	2.071	12.2	57	0.30	0.30

FOR LAB

Lab Technician

Materials Engineer

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

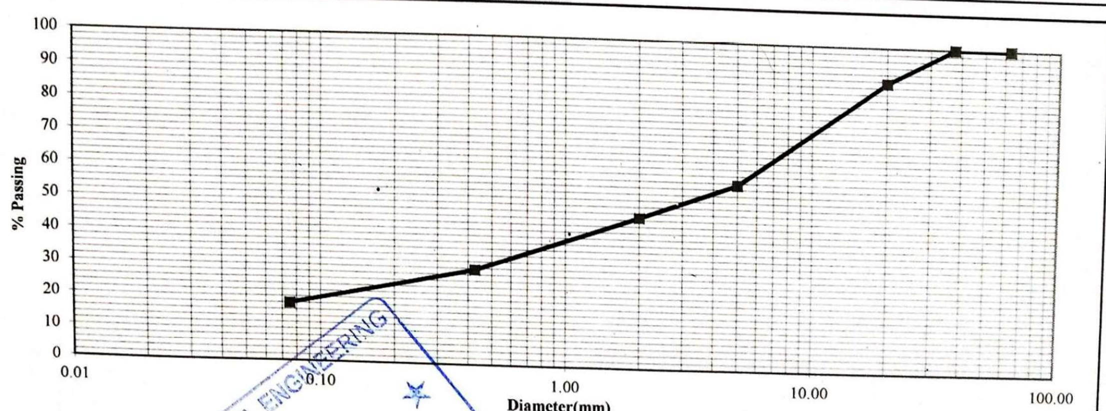
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	3% CEMENT & 4% METAKAOLIN	Dry wt. of sample before washing: (g)		4729.8
Depth: (m)		Dry wt. of sample after washing: (g)		3883.8
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0			
37.5	0.0	0.0	**100**	100	100
20.0	502.6	10.6	**100**	80	100
5.0	1515.8	32.0	**89**	60	95
2.00	502.6	10.6	**57**	30	65
0.425	811.4	17.2	**47**	20	50
0.075	546.3	11.6	**30**	10	30
Total fines	851.1	18.0	**18**	5	15
Bottom Pan	5.1				
Extracted fines	846.0				
Total sample	4729.8				
Grading Modulus		**2.06**			



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	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	**PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS**

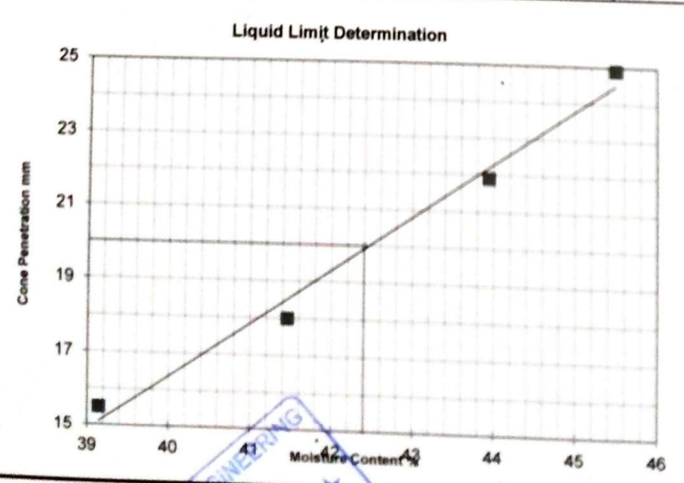
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT & 4% METAKAOLIN	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2: 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN		

PLASTIC LIMIT	Test No	RAD	I3		Average
Mass of wet soil + container (g)		36.17	33.18		34.675
Mass of dry soil + container (g)		32.95	30.77		31.86
Mass of container (g)		21.96	22.47		22.215
Mass of moisture (g)		3.22	2.4		2.815
Mass of dry soil (g)		10.99	8.3		9.645
Moisture content %		29.3	29.0		29.2
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.5	18	21.9	24.9
penetration (mm)		15.5	18.0	21.9	24.9
AVERAGE		15.5	18.0	21.9	24.9
Container No		A15	P153	A5	A43
Mass of wet soil + container (g)		57.62	56.62	63.39	62.38
Mass of dry soil + container (g)		43.36	42.55	46.13	45.05
Mass of container (g)		6.93	8.61	6.85	6.96
Mass of moisture (g)		14.26	14.07	17.26	17.33
Mass of dry soil (g)		36.43	33.94	39.28	38.09
Moisture content (%)		39.1	41.5	43.9	45.5
AVERAGE		39.1	41.5	43.9	45.5



Liquid limit (%)	42.4
Plastic limit (%)	29.2
Plasticity Index (%)	13.2
Linear shrinkage	
Trough No	R
Trough length (cm)	14.0
Specimen length (cm)	13.1
L.shringage =	0.9
% L.shrinkage =	6.4

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

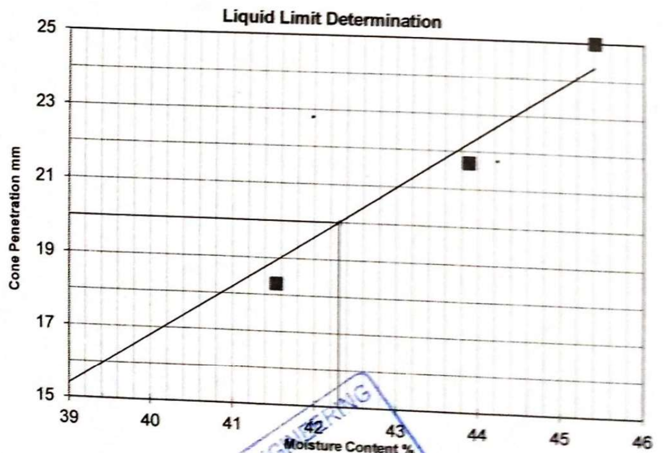
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT & 4% METAKAOLIN	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN		

PLASTIC LIMIT	Test No.	J	4		Average
Mass of wet soil + container (g)		29.65	32.46		31.055
Mass of dry soil + container (g)		27.36	29.77		28.565
Mass of container (g)		19.56	20.55		20.055
Mass of moisture (g)		2.29	2.7		2.49
Mass of dry soil (g)		7.8	9.22		8.51
Moisture content %		29.4	29.2		29.3
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.9	18.3	21.7	25.0
penetration (mm)		15.9	18.3	21.7	25.0
AVERAGE		15.9	18.3	21.7	25.0
Container No.		A6	AX	A4	AO
Mass of wet soil + container (g)		54.20	59.06	55.86	59.53
Mass of dry soil + container (g)		40.91	43.78	40.90	43.10
Mass of container (g)		6.83	6.99	6.81	6.92
Mass of moisture (g)		13.29	15.28	14.96	16.43
Mass of dry soil (g)		34.08	36.79	34.09	36.18
Moisture content (%)		39.0	41.5	43.9	45.4
AVERAGE		39.0	41.5	43.9	45.4



Liquid limit (%)	42.3
Plastic limit (%)	29.3
Plasticity Index (%)	13.0
Linear shrinkage	
Trough No	R
Trough length (cm)	14.0
Specimen length (cm)	13.1
L.shringage =	0.9
% L.shrinkage =	6.4

Remarks:

TESTING LAB

Materials Engineer.

Lab Technician

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
Mix	3% CEMENT & 4% METAKAOLIN	9/Dec/23	24/Jan/24	Lab team
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN	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

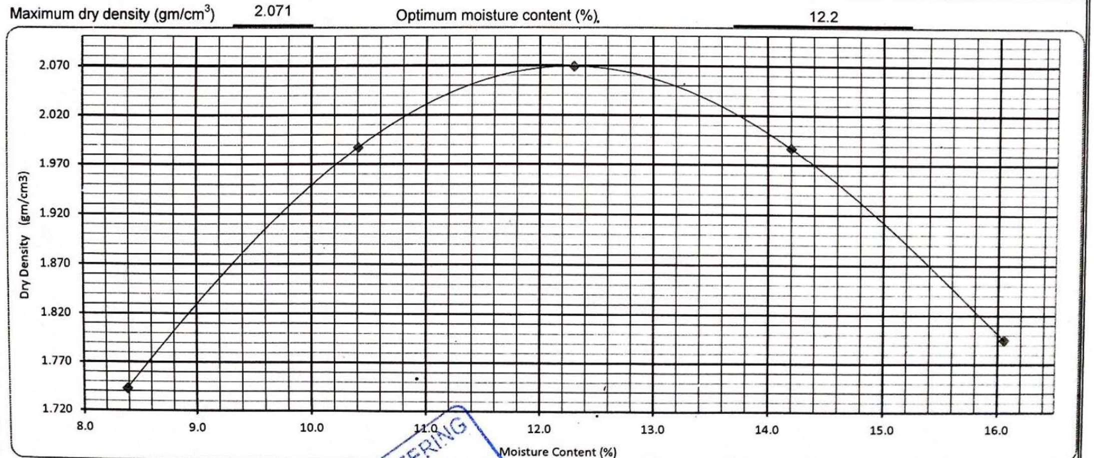
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	180	280	380	480	580
Mass of Compacted soil + mould	gm	5,108	5,413	5,543	5,488	5,302
Mass of Mould	gm	3,219	3,219	3,219	3,219	3,219
Mass of Compacted soil	gm	1889	2194	2324	2269	2083
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.889	2.194	2.324	2.269	2.083

DATA FOR PROCTOR CURVE

Container No.		KT	UPC	MJR	CML	CR7
Mass of wet soil + Container	gm	2,375.0	2,251.0	2,196.0	2,282.0	2,346.0
Mass of dry soil + container	gm	2,253.0	2,115.0	2,042.0	2,093.0	2,128.0
Mass of container	gm	798.0	808.0	790.0	762.0	770.0
Mass of water added	gm	122	136	154	189	218
Mass of dry soil	gm	1455	1307	1252	1331	1358
Moisture content	%	8.4	10.4	12.3	14.2	16.1
Dry density	g/cm^3	1.743	1.987	2.069	1.987	1.795

Maximum dry density (gm/cm^3) 2.071 Optimum moisture content (%) 12.2



Remarks:

FOR TESTING LAB

Lab Technician Materials Engineer

STIRLING CIVIL ENGINEERING LTD P.O. BOX 793, K...

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference	Laboratory Reference No.:	Sampling Date :	9/Dec/23
Location	3% CEMENT & 4% METAKAOLIN	Casting date :	27/Jan/24
		Testing Date :	10/Feb/24
Sample Description	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN	Technician :	: Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No	BA		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2546		MDD (Mg/m^3)	2.071
Tin + oven dry soil sample (g)	2510		N.M.C (%)	2.1
Tin (g)	768		OMC (%)	12.2
Dry soil sample	1742		Added OMC (%)	10.1
Water (g)	36		Calculated dry wt of soil (g)	5876.0
N.M.C (%)	2.1		Water added (g)	**596**
Average (%)	2.1		**Water added (mL)**	**596**

Number of blows		62							
Number of layer		5							
Water Content Determination		Before Soaking		After Soaking					
Tare No		YY	-	BBC	-				
Mass of wet sample + Tare	g	1835	-	2103	-				
Mass of dry sample + Tare	g	1710	-	1965	-				
Mass of Tare	g	783	-	809	-				
Mass of water	g	125	-	138	-				
Mass of dry sample	g	927	-	1156	-				
Water content	%	13.5	-	11.9	-				
Average water Content	%	13.5		11.9					
Density determination									
Mould No		OMS							
Mass of mould + soil	g	10728		10647					
Mass of mould	g	5465		5465					
Mass of soil	g	5263		5182					
Volume of the mould	cm3	2305		2305					
Moist density	g/cm3	2.283		2.248					
Dry density	g/cm3	2.012		2.008					
Swell Determination									
Date		Hour		D.Gauge Reding					
Initial reading		96 hrs		12.89					
Final reading				13.27					
Height of the specimen				127					
Height of swell				0.38					
		Swelling(%)		**0.30**					

Observations

For the Lab

Lab. Technician	*Materials Engineer*		

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
		Penetration Date	10/Feb/24
Location:		Technician	: : Lab team
Depth :			
Sample Description :	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	OMS		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2052	0.2052	0.2052

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**	1	0.2	2	0.4
0.5	**24**	2	0.4	4	0.8
0.75	**35**	4	0.8	7	1.4
1	**47**	5	1.0	10	2.1
1.5	**71**	9	1.8	16	3.3
2	**94**	14	2.9	24	4.9
2.5	**118**	19	3.9	33	6.8
3	**142**	24	4.9	39	8.0
3.5	**165**	28	5.7	45	9.2
4	**189**	32	6.6	52	10.7
4.5	**213**	35	7.2	57	11.7
5	**236**	37	7.6	62	12.7
5.5	**260**	40	8.2	66	13.5
6	**283**	42	8.6	69	14.2
6.5	**307**	45	9.2	73	15.0
7	**331**	47	9.6	77	15.8
7.5	**354**	50	10.3	80	16.4

Observations

For the Contractor

Lab. Technician | Materials Engineer

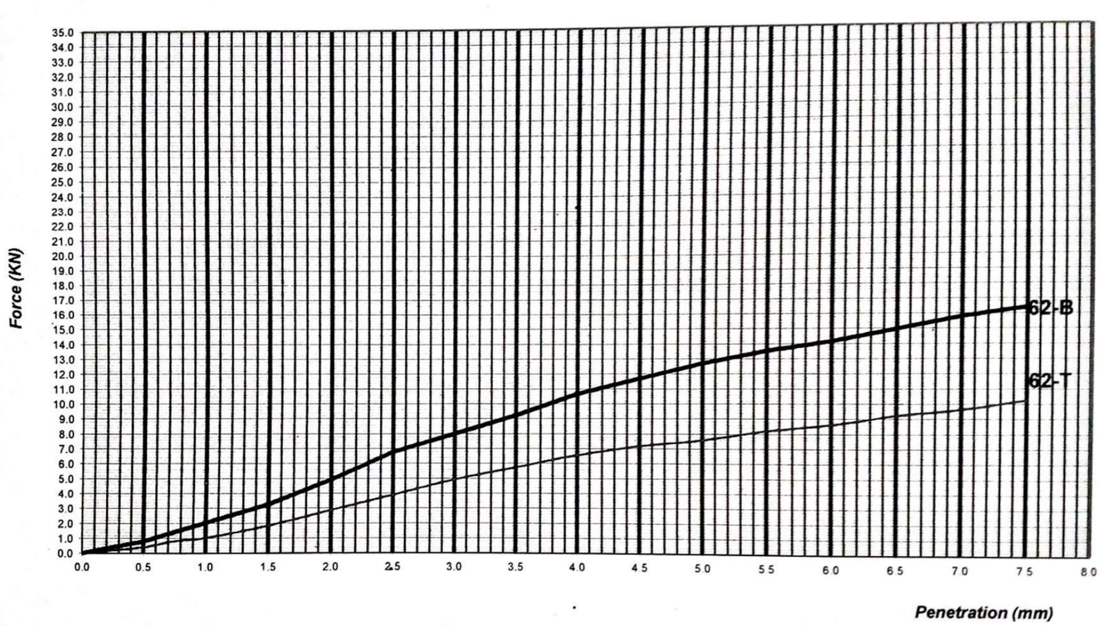
STIRLING CIVIL ENGINEERING LTD P. O. BOX 705, KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date : 9/Dec/23
Location:		Testing Date : 10/Feb/24
Depth:		Technician : Lab team
Sample Description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 4% METAKAOLIN	



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	6.8	3.9	51	29								
5.0 mm Penetration	12.7	7.6	64	38								
Average	9.7	5.7	57.4	33.7								
Retained CBR	57.4											
Observations	CBR= 57.4											

For the Lab

Lab. Technician | *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD. P.O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 3% CEMENT & 6% METAKAOLIN

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	30 BLOWS 95% COMPACTION	62	AVERAGE
3% CEMENT & 6% METAKAOLIN	LATERIC . GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN	12/9/2023	100	97	79	48	40	26	18	2.16	42.8	28.4	14.4	7.1	2.033	12.3	50	0.63	0.63
			100	97	83	50	42·	27	18	2.13	43.0	28.7	14.2	· 7.1	-	-	- - -	-	
			100	**96.94**	**80.93**	**48.86**	**40.62**	**26.72**	**18.21**	**2.14**	**42.9**	**28.6**	**14.3**	**7.1**	**2.033**	**12.3**	**50**	**0.63**	**0.63**
	AVERAGE		100	97	81	49	41	27	18	2.145	42.9	28.7	14.3	7.1	2.033	12.3	50	0.63	0.63

FOR LAB

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 793, KAMPALA (U)

Lab Technician

Materials Engineer

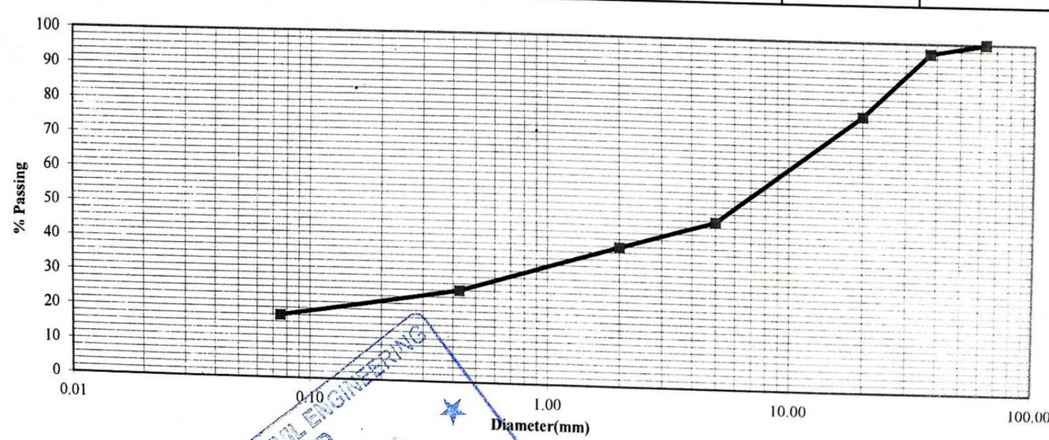
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	3% CEMENT & 6% METAKAOLIN	Dry wt. of sample before washing: (g)		5410.2
Depth: (m)		Dry wt. of sample after washing: (g)		4442.0
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	151.7	2.8	**97**	80	100
20.0	986.7	18.2	**79**	60	95
5.0	1693.8	31.3	**48**	30	65
2.00	433.6	8.0	**40**	20	50
0.425	733.1	13.6	**26**	10	30
0.075	440.4	8.1	**18**	5	15
Total fines	970.9	17.9			
Bottom Pan	2.7				
Extracted fines	968.2				
Total sample	5410.2				
Grading Modulus		**2.16**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD P. O. BOX 706, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

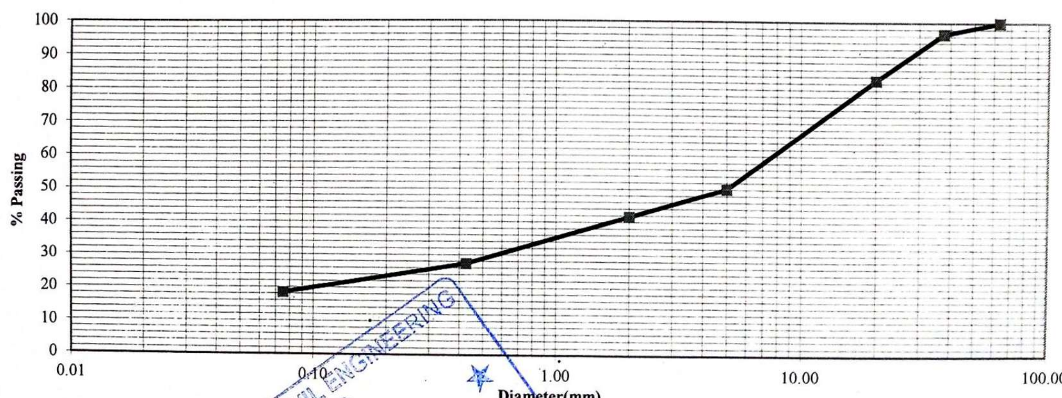
PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:	
Location :(km)	3% CEMENT & 6% METAKAOLIN	Dry wt. of sample before washing: (g)	4861.2
Depth: (m)		Dry wt. of sample after washing: (g)	3965.5

Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	**100**	100	100
37.5	161.2	3.3	**97**	80	100
20.0	670.3	13.8	**83**	60	95
5.0	1596.1	32.8	**50**	30	65
2.00	411.5	8.5	**42**	20	50
0.425	692.4	14.2	**27**	10	30
0.075	431.5	8.9	**18**	5	15
Total fines	898.2	18.5			
Bottom Pan	2.5				
Extracted fines	895.7				
Total sample	4861.2				
Grading Modulus		**2.13**			



FOR TESTING LAB

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

Lab Technician *Materials Engineer*

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

ATTERBERG LIMITS

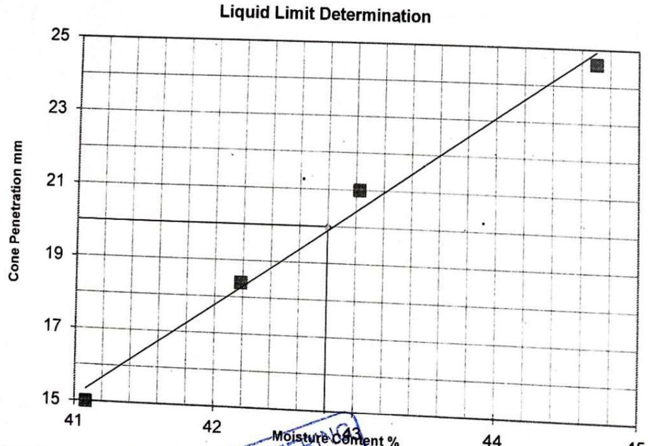
Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT & 6% METAKAOLIN	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN		

PLASTIC LIMIT	Test No.	JL	PL		Average
Mass of wet soil + container (g)		39.3	36.31		37.805
Mass of dry soil + container (g)		35.59	33.28		34.435
Mass of container (g)		22.54	22.61		22.575
Mass of moisture (g)		3.71	3.0		3.37
Mass of dry soil (g)		13.05	10.67		11.86
Moisture content %		28.4	28.4		28.4
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.0	18.4	21	24.6
penetration (mm)		15.0	18.4	21.0	24.6
AVERAGE		15.0	18.4	21.0	24.6
Container No.		A3	PI84	PI8	P135
Mass of wet soil + container (g)		53.18	49.24	45.84	59.68
Mass of dry soil + container (g)		39.73	36.72	34.06	44.11
Mass of container (g)		6.99	7.04	6.68	9.28
Mass of moisture (g)		13.45	12.52	11.78	15.57
Mass of dry soil (g)		32.74	29.68	27.38	34.83
Moisture content (%)		41.1	42.2	43.0	44.7
AVERAGE		41.1	42.2	43.0	44.7

Liquid Limit Determination



Liquid limit (%)	42.8
Plastic limit (%)	28.4
Plasticity Index (%)	14.4
Linear shrinkage	
Trough No.	I
Trough length (cm)	14.0
Specimen length (cm)	13.0
L.shringage =	1.0
% L.shrinkage =	7.1

Remarks:

TESTING LAB

Materials Engineer.

Lab Technician

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

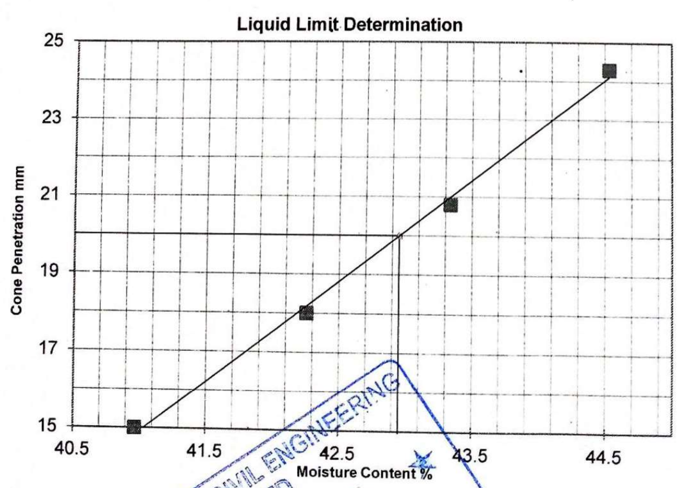
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT & 6% METAKAOLIN	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN		

PLASTIC LIMIT	Test No.	P4	DT		Average
Mass of wet soil + container (g)		38.52	35.01		36.765
Mass of dry soil + container (g)		34.99	32.23		33.61
Mass of container (g)		22.78	22.5		22.64
Mass of moisture (g)		3.53	2.8		3.155
Mass of dry soil (g)		12.21	9.73		10.97
Moisture content %		28.9	28.6		28.7
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.0	18	20.8	24.3
penetration (mm)		15.0	18.0	20.8	24.3
AVERAGE		15.0	18.0	20.8	24.3
Container No.		P128	PI26	PIVPN	FORD
Mass of wet soil + container (g)		50.96	45.11	41.11	45.14
Mass of dry soil + container (g)		38.17	33.79	30.77	33.33
Mass of container (g)		6.95	7.00	6.91	6.81
Mass of moisture (g)		12.79	11.32	10.34	11.81
Mass of dry soil (g)		31.22	26.79	23.86	26.52
Moisture content (%)		41.0	42.3	43.3	44.5
AVERAGE		41.0	42.3	43.3	44.5



Liquid limit (%)	43.0
Plastic limit (%)	28.7
Plasticity Index (%)	14.2
Linear shrinkage	
Trough No.	I
Trough length (cm)	14.0
Specimen length (cm)	13.0
L.shringage =	1.0
% L.shrinkage =	7.1

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
Mix	3% CEMENT & 6% METAKAOLIN.	9/Dec/23	24/Jan/24	Lab team
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN	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

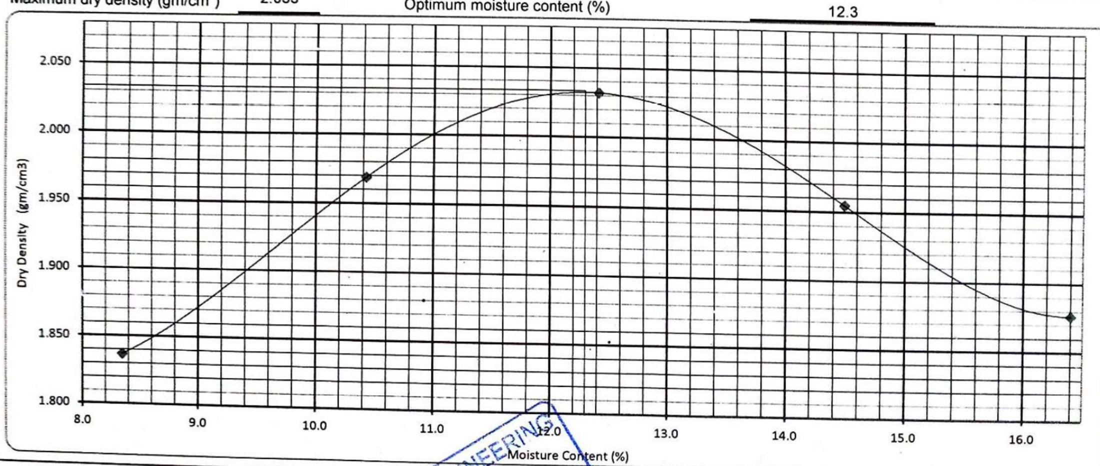
MOISTURE CONTENT DATA

Test No		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	160	220	280	340	400
Mass of Compacted soil + mould	gm	5,209	5,393	5,503	5,457	5,403
Mass of Mould	gm	3,219	3,219	3,219	3,219	3,219
Mass of Compacted soil	gm	1990	2174	2284	2238	2184
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.990	2.174	2.284	2.238	2.184

DATA FOR PROCTOR CURVE

Container No.		MANU	NM	MU	YY	YMC
Mass of wet soil + Container	gm	2,275.0	1,634.0	2,266.0	2,444.0	2,093.0
Mass of dry soil + container	gm	2,142.0	1,531.0	2,104.0	2,234.0	1,857.0
Mass of container	gm	548.0	543.0	799.0	785.0	418.0
Mass of water added	gm	133	103	162	210	236
Mass of dry soil	gm	1594	988	1305	1449	1439
Moisture content	%	8.3	10.4	12.4	14.5	16.4
Dry density	g/cm^3	1.837	1.969	2.032	1.955	1.876

Maximum dry density (gm/cm^3) 2.033 Optimum moisture content (%) 12.3



Remarks:

FOR TESTING LAB

Lab Technician	Materials Engineer		

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location	3% CEMENT & 6% METAKAOLIN	Casting date :	13/Dec/23
		Testing Date	20/Dec/23
Sample Description	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN	Technician	Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			Volume of water added	
Tin No	Y6Y		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2589		MDD (Mg/m^3)	2.033
Tin + oven dry soil sample (g)	2539		N.M.C (%)	2.9
Tin (g)	819		OMC (%)	12.3
Dry soil sample	1720		Added OMC (%)	9.4
Water (g)	50		Calculated dry wt of soil (g)	5825.6
N.M.C (%)	2.9		Water added (g)	**548**
Average (%)	2.9		**Water added (mL)**	**548**

Number of blows		62			
Number of layer		5			
Water Content Determination		Before Soaking		After Soaking	
Tare No		NBM	-	CR7	-
Mass of wet sample + Tare	g	1729	-	2279	-
Mass of dry sample + Tare	g	1622	-	2112	-
Mass of Tare	g	790	-	770	-
Mass of water	g	107	-	167	-
Mass of dry sample	g	832	-	1342	-
Water content	%	12.9	-	12.4	-
Average water Content	%	12.9		12.4	
Density determination					
Mould No		AZ			
Mass of mould + soil	g	10790		10768	
Mass of mould	g	5521		5521	
Mass of soil	g	5269		5247	
Volume of the mould	cm3	2305		2305	
Moist density	g/cm3	2.286		2.276	
Dry density	g/cm3	2.025		2.024	
Swell Determination					
Date		Hour		D.Gauge Reding	
Initial reading		96 hrs		9.6	
Final reading				10.4	
Height of the specimen				127	
Height of swell				0.8	
		Swelling(%)		**0.63**	

Observations

For the Lab

Lab. Technician | *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD P.O. BOX 798, KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:		Penetration Date	20/Dec/23
Depth :		Technician	: Lab team
Sample Description :	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN		

Number of blows per layer	62		
Number of layers	5	5	5
Mould No	AZ		
Capacity of the Proving Ring (KN)	50	50	50
Proving Ring Constant (KN/div.)	0.2052	0.2052	0.2052

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**	1	0.2	3	0.6
0.5	**24**	3	0.6	10	2.1
0.75	**35**	5	1.0	12	2.5
1	**47**	9	1.8	14	2.9
1.5	**71**	11	2.3	20	4.1
2	**94**	19	3.9	25	5.1
2.5	**118**	24	4.9	32	6.6
3	**142**	28	5.7	37	7.6
3.5	**165**	31	6.4	41	8.4
4	**189**	34	7.0	45	9.2
4.5	**213**	36	7.4	49	10.1
5	**236**	38	7.8	50	10.3
5.5	**260**	41	8.4	53	10.9
6	**283**	44	9.0	56	11.5
6.5	**307**	46	9.4	58	11.9
7	**331**	48	9.8	60	12.3
7.5	**354**	51	10.5	62	12.7

Observations

For the Contractor

Lab. Technician	*Materials Engineer*	

STIRLING CIVIL ENGINEERING LTD P.O. BOX 796, K...

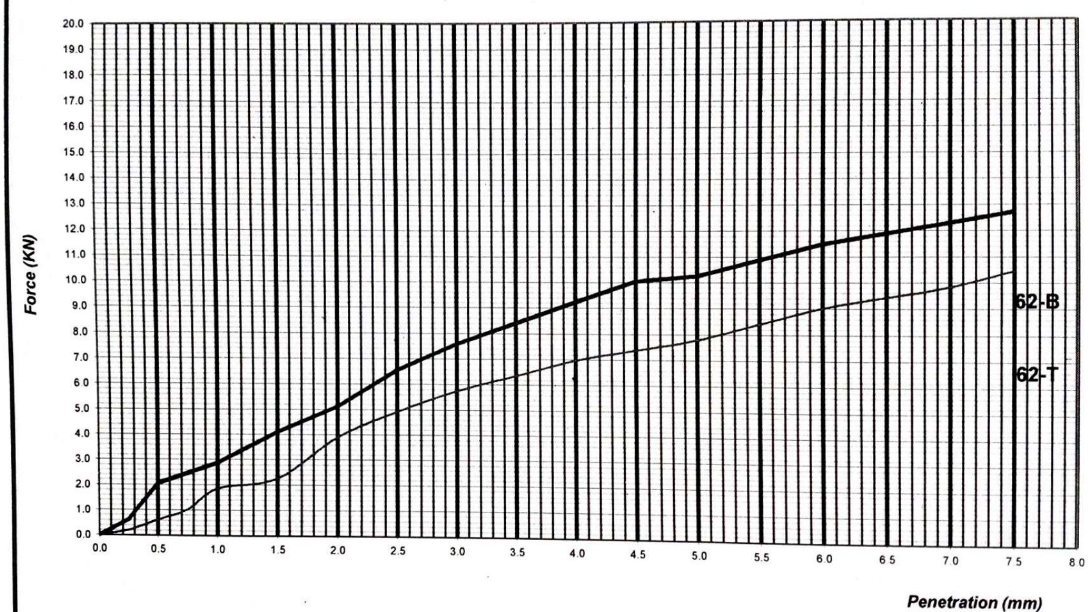
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date : 9/Dec/23
Location:		Testing Date : 20/Dec/23
Depth:		Technician : Lab team
Sample Description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 6% METAKAOLIN	

PENETRATION vs FORCE CURVE



	62 blows										
	Force		CBR								
	Bottom	Top	Bottom	Top							
2.5 mm Penetration	6.6	4.9	50	37							
5.0 mm Penetration	10.3	7.8	51	39							
Average	8.4	6.4	50.5	38.1							
Retained CBR	50.5										
Observations	CBR= 50.5										
For the Lab											
Lab. Technician	*Materials Engineer*										

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 796, KAMPALA

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT: PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

SUMMARY OF TEST RESULTS FOR LATERATIC GRAVEL 3% CEMENT & 8% METAKAOLIN

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
3% CEMENT & 8% METAKAOLIN	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN	12/9/2023	100	100	98	74	56	38	26	1.80	41.8	25.7	16.1	8.2	2.022	13.4	45			0.75	0.75
			100	100	100	66	51	38	31	1.80	41.7	25.4	16.3	8.2	-	-	-	-	-	-	
			100	**100**	**98.69**	**70.26**	**53.58**	**37.98**	**28.59**	**1.80**	**41.8**	**25.6**	**16.2**	**8.2**	**2.022**	**13.4**	**45**			**0.75**	**0.75**
	AVERAGE		100	100	99	70	54	38	29	1.799	41.8	25.4	16.2	8.2	2.022	13.4	45			0.75	0.75

FOR LAB

Lab Technician

Materials Engineer

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

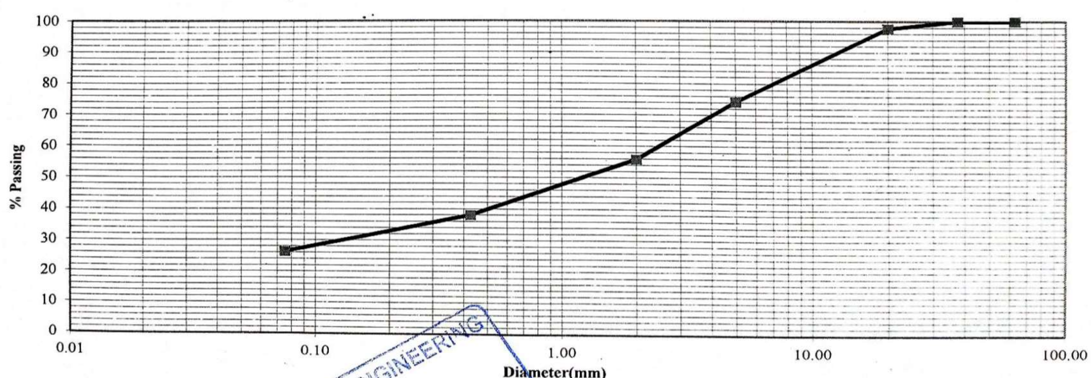
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	3% CEMENT & 8% METAKAOLIN	Dry wt. of sample before washing: (g)		5024.7
Depth: (m)		Dry wt. of sample after washing: (g)		3717.3
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	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	117.3	2.3	**98**	60	95
5.0	1178.6	23.5	**74**	30	65
2.00	924.4	18.4	**56**	20	50
0.425	892.5	17.8	**38**	10	30
0.075	588.6	11.7	**26**	5	15
Total fines	1323.3	26.3			
Bottom Pan	15.9				
Extracted fines	1307.4				
Total sample	5024.7				
Grading Modulus		**1.80**			



FOR TESTING LAB

Lab Technician

Materials Engineer

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

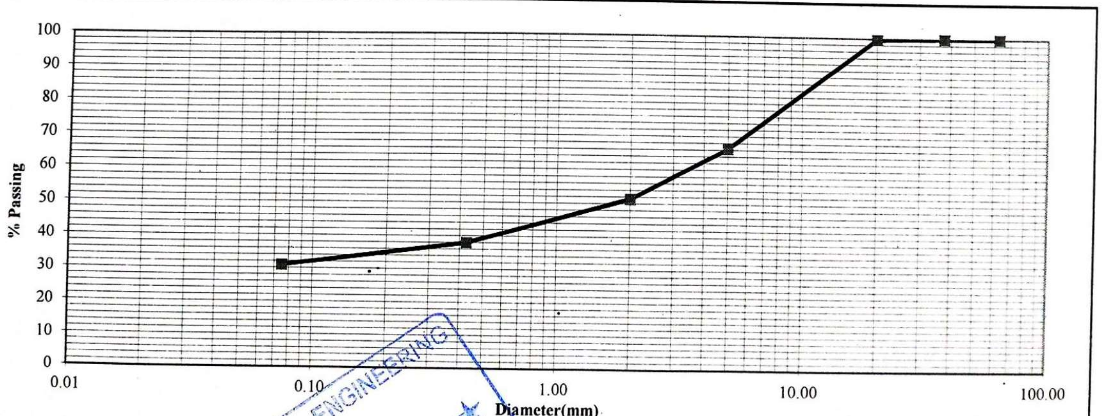
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT : PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	3% CEMENT & 8% METAKAOLIN	Dry wt. of sample before washing: (g)		4956.2
Depth: (m)		Dry wt. of sample after washing: (g)		3448.2
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN	Date Sampled:	Date Tested:	Technician
		9/Dec/2023	24/Jan/2024	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	14.5	0.3	**100**	60	95
5.0	1655.2	33.4	**66**	30	65
2.00	742.1	15.0	**51**	20	50
0.425	665.1	13.4	**38**	10	30
0.075	350.8	7.1	**31**	5	15
Total fines	1528.5	30.8			
Bottom Pan	20.5				
Extracted fines	1508.0				
Total sample	4956.2				
Grading Modulus		**1.80**			



FOR TESTING LAB

Lab Technician *Materials Engineer*

STIRLING CIVIL ENGINEERING LTD P.O. BOX 7??, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	**PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS**

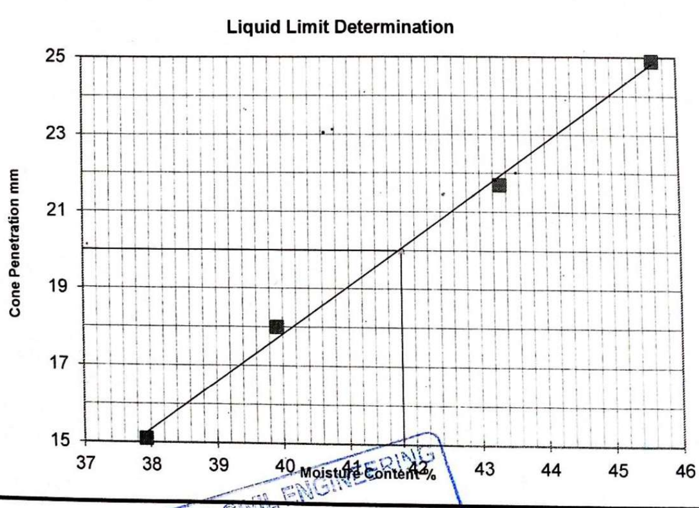
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT & 8% METAKAOLIN	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN		

PLASTIC LIMIT	Test No.	4Z	D		Average
Mass of wet soil + container (g)		40.65	39.05		39.85
Mass of dry soil + container (g)		36.64	35.11		35.875
Mass of container (g)		21.04	19.8		20.42
Mass of moisture (g)		4.01	3.9		3.975
Mass of dry soil (g)		15.6	15.31		15.455
Moisture content %		25.7	25.7		25.7
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.1	18	21.7	24.9
penetration (mm)		15.1	18.0	21.7	24.9
AVERAGE		15.1	18.0	21.7	24.9
Container No.		P152	P112	P182	P12H
Mass of wet soil + container (g)		68.27	62.51	70.18	68.47
Mass of dry soil + container (g)		51.46	46.65	51.13	50.67
Mass of container (g)		7.14	6.91	7.14	11.67
Mass of moisture (g)		16.81	15.86	19.05	17.8
Mass of dry soil (g)		44.32	39.74	43.99	39
Moisture content (%)		37.9	39.9	43.3	45.6
AVERAGE		37.9	39.9	43.3	45.6



Liquid limit (%)	41.8
Plastic limit (%)	25.7
Plasticity Index (%)	16.1
Linear shrinkage	
Trough No.	2
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.2
% L.shrinkage =	8.2

Remarks:

TESTING LAB

Materials Engineer

Lab Technician

STIRLING CIVIL ENGINEERING LTD P. O. BOX 795, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	**PARTIAL.REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS**

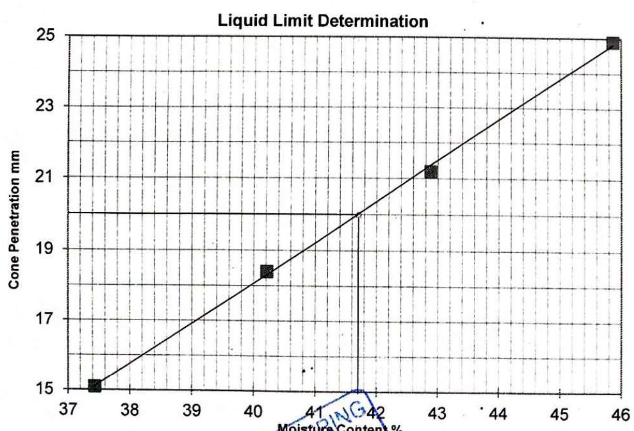
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Test Reference No.:	Lab. Reference No.:	Technician:	Lab Team
Location	3% CEMENT & 8% METAKAOLIN	Sample Date	9/Dec/2023
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	13/Feb/2024
LAYER	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN		

PLASTIC LIMIT	Test No.	I8	TI		Average
Mass of wet soil + container (g)		42.79	38.96		40.875
Mass of dry soil + container (g)		38.02	35		36.51
Mass of container (g)		19.32	19.38		19.35
Mass of moisture (g)		4.77	4.0		4.365
Mass of dry soil (g)		18.7	15.62		17.16
Moisture content %		25.5	25.4		25.4
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.1	18.4	21.2	24.9
penetration (mm)		15.1	18.4	21.2	24.9
AVERAGE		15.1	18.4	21.2	24.9
Container No.		4B	AX	PIB6	A6
Mass of wet soil + container (g)		65.98	62.93	76.49	65.70
Mass of dry soil + container (g)		49.84	46.91	55.67	47.22
Mass of container (g)		6.72	7.07	7.12	6.93
Mass of moisture (g)		16.14	16.02	20.82	18.48
Mass of dry soil (g)		43.12	39.84	48.55	40.29
Moisture content (%)		37.4	40.2	42.9	45.9
AVERAGE		37.4	40.2	42.9	45.9



Liquid limit (%)	41.7
Plastic limit (%)	25.4
Plasticity Index (%)	16.3
Linear shrinkage	
Trough No.	2
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.2
% L.shrinkage =	8.2

Remarks:

TESTING LAB

Materials Engineer.

Lab Technician

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PROJECT:	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
Mix	3% CEMENT & 8% METAKAOLIN	9/Dec/23	24/Jan/24	Lab team
Material description:	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN	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

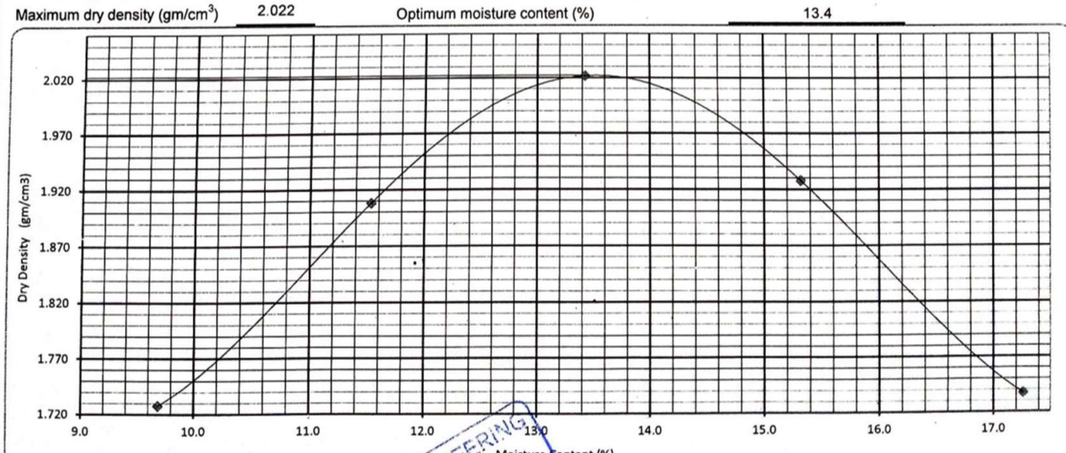
MOISTURE CONTENT DATA

Test No.		1	2	3	4	5
Tin No.		A	A	A	A	A
Water Added	cm^3	180	280	380	480	580
Mass of Compacted soil + mould	gm	5,960	6,193	6,358	6,288	6,102
Mass of Mould	gm	4,065	4,065	4,065	4,065	4,065
Mass of Compacted soil	gm	1895	2128	2293	2223	2037
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.895	2.128	2.293	2.223	2.037

DATA FOR PROCTOR CURVE

Container No.		HED	FDC	KT	BOJ	BA
Mass of wet soil + Container	gm	2,869.0	3,015.0	2,735.0	2,795.0	2,645.0
Mass of dry soil + container	gm	2,685.0	2,786.0	2,506.0	2,530.0	2,369.0
Mass of container	gm	785.0	800.0	800.0	800.0	770.0
Mass of water added	gm	184	229	229	265	276
Mass of dry soil	gm	1900	1986	1706	1730	1599
Moisture content	%	9.7	11.5	13.4	15.3	17.3
Dry density	g/cm^3	1.728	1.908	2.022	1.928	1.737

Maximum dry density (gm/cm^3) 2.022 Optimum moisture content (%) 13.4



Remarks:

FOR TESTING LAB

Lab Technician	Materials Engineer		

STIRLING CIVIL ENGINEERING LTD P.O. BOX 7..., KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location	3% CEMENT & 8% METAKAOLIN	Casting date :	28/Jan/24
		Testing Date	11/Feb/24
Sample Description	LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN	Technician :	Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			Volume of water added	
Tin No.	NMT		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	3280		MDD (Mg/m^3)	2.022
Tin + oven dry soil sample (g)	3195		N.M.C (%)	3.5
Tin (g)	765		OMC (%)	13.4
Dry soil sample	2430		Added OMC (%)	9.9
Water (g)	85		Calculated dry wt of soil (g)	5790.1
N.M.C (%)	3.5		Water added (g)	574
Average (%)	3.5		**Water added (mL)**	**574**

Number of blows		62							
Number of layer		5							
Water Content Determination		Before Soaking		After Soaking					
Tare No		Z6T	-	NMT	-				
Mass of wet sample + Tare	g	3005	-	2661	-				
Mass of dry sample + Tare	g	2750	-	2390	-				
Mass of Tare	g	815	-	769	-				
Mass of water	g	255	-	271	-				
Mass of dry sample	g	1935	-	1621	-				
Water content	%	13.2	-	16.7	-				
Average water Content	%	13.2		16.7					
Density determination									
Mould No		21							
Mass of mould + soil	g	12595		12780					
Mass of mould	g	7365		7365					
Mass of soil	g	5230		5415					
Volume of the mould	cm3	2305		2305					
Moist density	g/cm3	2.269		2.349					
Dry density	g/cm3	2.005		2.013					
Swell Determination									
Date		Hour		D.Gauge Reding					
Initial reading		96 hrs		20.14					
Final reading				21.09					
Height of the specimen				127					
Height of swell				0.95					
		Swelling(%)		**0.75**					

Observations

For the Lab

Lab. Technician	Materials Engineer		

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference	Laboratory Reference No.:	Sampling Date	9/Dec/23
Location:		Penetration Date	11/Feb/24
Depth :		Technician	: : Lab team
Sample Description :	: LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN		

Number of blows per layer		62					
Number of layers		5				5	5
Mould No		2I					
Capacity of the Proving Ring (KN)		50				50	50
Proving Ring Constant (KN/div.)		0.2052				0.2052	0.2052
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**	4	0.8	2	0.4		
0.5	**24**	6	1.2	5	1.0		
0.75	**35**	8	1.6	8	1.6		
1	**47**	13	2.7	13	2.7		
1.5	**71**	19	3.9	16	3.3		
2	**94**	24	4.9	21	4.3		
2.5	**118**	28	5.7	26	5.3		
3	**142**	34	7.0	31	6.4		
3.5	**165**	37	7.6	35	7.2		
4	**189**	40	8.2	40	8.2		
4.5	**213**	42	8.6	45	9.2		
5	**236**	44	9.0	49	10.1		
5.5	**260**	46	9.4	52	10.7		
6	**283**	48	9.8	57	11.7		
6.5	**307**	50	10.3	60	12.3		
7	**331**	52	10.7	64	13.1		
7.5	**354**	53	10.9	67	13.7		

Observations

	For the Contractor		
Lab. Technician	Materials Engineer		

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AGABA JOEL & KAKOOZA PAUL	Stirling

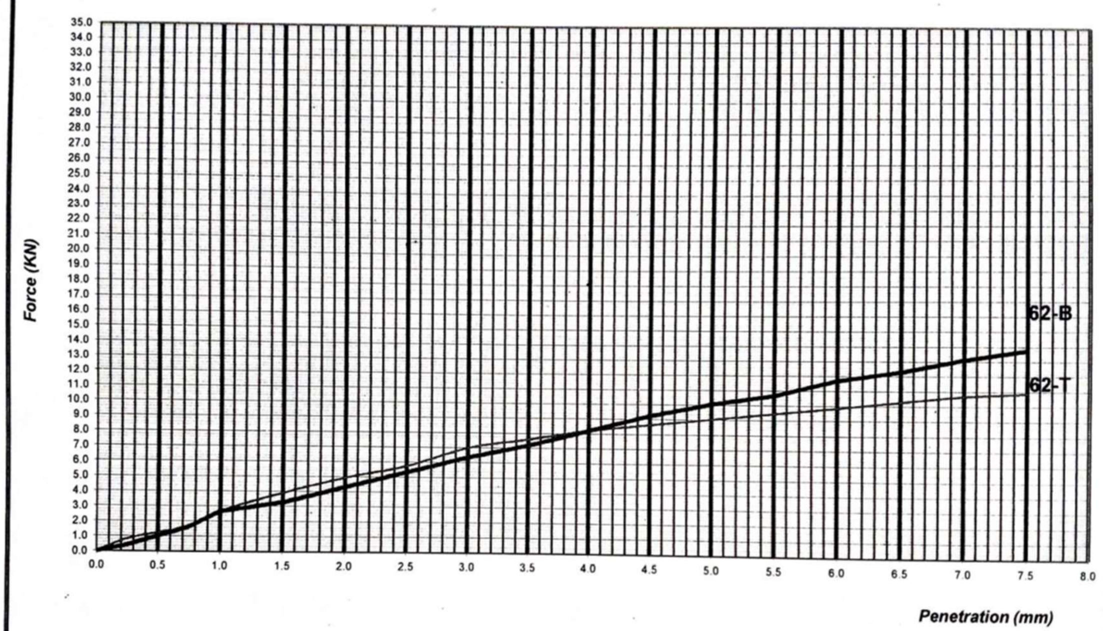
PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date : 9/Dec/23
Location:		Testing Date : 11/Feb/24
Depth:		Technician : Lab team

Sample Description: LATERIC GRAVEL STABILISED WITH 3% CEMENT & 8% METAKAOLIN

PENETRATION vs FORCE CURVE



	62 blows			
	Force		CBR	
	Bottom	Top	Bottom	Top
2.5 mm Penetration	5.3	5.7	40	43
5.0 mm Penetration	10.1	9.0	50	45
Average	7.7	7.4	45.3	44.3
Retained CBR	45.3			
Observations	CBR= 45.3			

For the Lab

Lab. Technician Materials Engineer

STIRLING CIVIL ENGINEERING P. O. BOX 703, KAMPALA

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR

(BS 1924 PART 2 1)

STABILISED WITH 5% METAKAOLINE ONLY

M/c of air dried sample				M/c After Mixing			
Tin No		NBM		Stabliser	5% METKAOLINE ONLY		
Tin + Wet soil	gm	1713		Content	5.0		
Tin + Dry Soil	gm	1693		Tin No.	BA		
Tin	gm	797		Tin + Wet Soil	2,395.0		
Water	gm	20.0		Tin + Dry Soil	2,215.0		
Dry Soil	gm	896.0		Tin	768.0		
M/c	%	2.2		Water	180.0		
Av. M/c	%	2.2		Dry Soil	1,447.0		
				M/c	12.4		

(a)MDD	2.152	kg/m3	(b)Air Dry M/c	2.2	%
(c)WD	2.174	kg/m3	(e)M/c to add	7.9	%
(d)OMC	10.1	%	(F) volume	2.305	

Date prepared 27/Jan/24 Date immerse 3/Feb/24 Date tested 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	5,010.0		
(j) Wt of air dried soil	6,000		
Air dry M/c	2.2		
(k) soil dry wt (100j/100+b)	5,869.0		
Stabliser	5% METKAOLINE ONLY		
(m)Stablisers content %	5.0		
(n) Stabliser to add k x(m/100)	293.4		
Water Addition((j+n)x(d-b))/(100+b)	484.3		
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% METKAOLINE ONLY	5% METKAOLINE ONLY	
Content %	5.0	5.0	
Mould g	A	B	
Wet Soil g	5,553.4	5,486.0	
Compaction M/c %	12.4	12.4	
Dry density kg/m3	2.143	2.117	
%Compaction	99.6	98.4	
FORCE	2.1	2.5	
UCS	0.113	0.135	0.12

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

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	THE PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR

(BS 1924 PART 2 1)

STABILISED WITH 5% METAKAOLINE ONLY

M/c of air dried sample				M/c After Mixing			
Tin No	NBM			Stabliser	5% METKAOLINE ONLY		
Tin + Wet soil gm	1713			Content	5.0		
Tin + Dry Soil gm	1693			Tin No.	BA		
Tin gm	797			Tin + Wet Soil	2,395.0		
Water gm	20.0			Tin + Dry Soil	2,215.0		
Dry Soil gm	896.0			Tin	768.0		
M/c %	2.2			Water	180.0		
Av. M/c %	2.2			Dry Soil	1,447.0		
				M/c	12.4		

(a)MDD	2.152	kg/m3	(b)Air Dry M/c	2.2	%
(c)WD	2.174	kg/m3	(e)M/c to add	7.9	%
(d)OMC	10.1	%	(F) volume	2.305	

Date prepared 27/Jan/24 Date immerse 3/Feb/24 Date tested 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	5,010.0		
(j) Wt of air dried soil	6,000		
Air dry M/c	2.2		
(k) soil dry wt (100j/100+b)	5,869.0		
Stabliser	5% METKAOLINE ONLY		
(m)Stablisers content %	5.0		
(n) Stabliser to add k x(m/100)	293.4		
Water Addition((j+n)x(d-b))/(100+b)	484.3		
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% METKAOLINE ONLY	5% METKAOLINE ONLY	
Content %	5.0	5.0	
Mould g	A	B	
Wet Soil g	5,553.4	5,486.0	
Compaction M/c %	12.4	12.4	
Dry density kg/m3	2.143	2.117	
%Compaction	99.6	98.4	
FORCE	2.1	2.5	
UCS	0.113	0.135	0.12

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

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR

(BS 1924 PART 2 1)

3% CEMENT & 4% METAKAOLINE

M/c of air dried sample		
Tin No.	ZION	
Tin + Wet soil gm	2240	
Tin + Dry Soil gm	2212	
Tin gm	436	
Water gm	28.0	
Dry Soil gm	1,776.0	
M/c %	1.6	
Av. M/c %	1.6	

M/c After Mixing			
Stabliser	2% CEMENT & 3% METAKAOLIN		
Content	2 0		
Tin No.	Y6Y		
Tin + Wet Soil	2,141.0		
Tin + Dry Soil	1,984.0		
Tin	820.0		
Water	157.0		
Dry Soil	1,164.0		
M/c	13.5		

(a)MDD 2.138 kg/m3
(c)WD 2,587 kg/m3
(d)OMC 12.1 %

(b)Air Dry M/c 1.6 %
(e)M/c to add 10.5 %
(F) volume 2.305

Date prepared 27/Jan/24 Date immerse 3/Feb/24 Date tested 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	5,963.0		
(j) Wt of air dried soil	6,000		
Air dry M/c	1.6		
(k) soil dry wt (100j/100+b)	5,906.9		
Stabliser	2% CEMENT & 3% METAKAOLIN		
(m)Stablisers content %	2.0		
(n) Stabliser to add k x(m/100)	118.1		
Water Addition((j+n)x(d-b))/(100+b)	633.8		
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	2% CEMENT & 3% METAKAOLIN	2% CEMENT & 3% METAKAOLIN	
Content %	2.0	2.0	
Mould g	A	B	
Wet Soil g	5,293.0	5,199.0	
Compaction M/c %	13.5	13.5	
Dry density kg/m3	2.023	1.987	
%Compaction	94.6	93.0	
FORCE	26.5	25.1	
UCS (F/A)	1.452	1.379	1.42

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

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR

(BS 1924 PART 2 1)

3% CEMENT & 2% METAKAOLIN

M/c of air dried sample

Tin No.	BA	
Tin + Wet soil gm	2546	
Tin + Dry Soil gm	2510	
Tin gm	768	
Water gm	36.0	
Dry Soil gm	1,742.0	
M/c %	**2.1**	
Av. M/c %	**2.1**	

M/c After Mixing

Stabliser	3% CEMENT & 2% METAKAOLIN		
Content	3.0		
Tin No.	YY		
Tin + Wet Soil	1,835.0		
Tin + Dry Soil	1,710.0		
Tin	783.0		
Water	**125.0**		
Dry Soil	**927.0**		
M/c	**13.5**		

(a)MDD 2.071 kg/m3 **(b)Air Dry M/c** 2.1 %

(c)WD 2,527 kg/m3 **(e)M/c to add** 10.1 %

(d)OMC 12.2 % **(F) volume** 2.305

Date prepared 27/Jan/24 **Date immerse** 3/Feb/24 **Date tested** 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	5,823.9		
(j) Wt of air dried soil	6,000		
Air dry M/c	2.1		
(k) soil dry wt (100j/100+b)	5,878.5		
Stabliser	3% CEMENT & 2% METAKAOLIN		
(m)Stablisers content %	3.0		
(n) Stabliser to add k x(m/100)	176.4		
Water Addition((j+n)x(d-b))/(100+b)	613.2		
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	3% CEMENT & 2% METAKAOLIN	3% CEMENT & 2% METAKAOLIN	
Content %	3.0	3.0	
Mould g	A	B	
Wet Soil g	5,476.0	5,452.0	
Compaction M/c %	13.5	13.5	
Dry density kg/m3	2,093	2.084	
%Compaction	101.1	100.6	
FORCE	19.1	18.1	
UCS	1.047	0.990	1.02

STIRLING CIVIL ENGINEERING LTD P.O. BOX 733, KA...

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR

(BS 1924 PART 2 1)

3% CEMENT ONLY

M/c of air dried sample		
Tin No	K26	
Tin + Wet soil gm	3125	
Tin + Dry Soil gm	3026	
Tin gm	805	
Water gm	99.0	
Dry Soil gm	2,221.0	
M/c %	**4.5**	
Av. M/c %	**4.5**	

M/c After Mixing			
Stabliser	3% CEMENT ONLY		
Content	3.0		
Tin No.	HOY		
Tin + Wet Soil	1,965.0		
Tin + Dry Soil	1,833.0		
Tin	758.0		
Water	**132.0**		
Dry Soil	**1,075.0**		
M/c	**12.3**		

(a)MDD 2.097 kg/m3 — **(b)Air Dry M/c** 4.5 %

(c)WD 2,579 kg/m3 — **(e)M/c to add** 7.8 %

(d)OMC 12.3 % — **(F) volume** 2.305

Date prepared 27/Jan/24 **Date immerse** 3/Feb/24 **Date tested** 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	5,945.3		
(j) Wt of air dried soil	6,000		
Air dry M/c	4.5		
(k) soil dry wt (100j/100+b)	5,744.0		
Stabliser	3% CEMENT ONLY		
(m)Stablisers content %	3.0		
(n) Stabliser to add k x(m/100)	172.3		
Water Addition((j+n)x(d-b))/(100+b)	463.4		
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	3% CEMENT ONLY	3% CEMENT ONLY	
Content %	3.0	3.0	
Mould g	A	B	
Wet Soil g	5,563.0	5,601.0	
Compaction M/c %	12.3	12.3	
Dry density kg/m3	2.150	2.164	
%Compaction	102.5	103.2	
FORCE	12.1	12.5	
UCS	0.664	0.687	**0.68**

STIRLING CIVIL ENGINEERING LTD P. O. BOX 700, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR
(BS 1924 PART 2 1)

3% CEMENT & 6% METAKAOLIN

M/c of air dried sample

Tin No.	NMT	
Tin + Wet soil gm	3280	
Tin + Dry Soil gm	3195	
Tin gm	765	
Water gm	85.0	
Dry Soil gm	2,430.0	
M/c %	3.5	
Av. M/c %	3.5	

M/c After Mixing

Stabliser	3% CEMENT & 6% METAKAOLIN		
Content	3.0		
Tin No.	TED		
Tin + Wet Soil	2,635.0		
Tin + Dry Soil	2,415.0		
Tin	805.0		
Water	220.0		
Dry Soil	1,610.0		
M/c	13.7		

(a)MDD 2.022 kg/m3
(c)WD 2,709 kg/m3
(d)OMC 13.4 %

(b)Air Dry M/c 3.5 %
(e)M/c to add 9.9 %
(F) volume 2.305

Date prepared 27/Jan/24 Date immerse 3/Feb/24 Date tested 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	6,245.4		
(j) Wt of air dried soil	6,000		
Air dry M/c	3.5		
(k) soil dry wt (100j/100+b)	5,797.2		
Stabliser	3% CEMENT & 6% METAKAOLIN		
(m)Stablisers content %	3.0		
(n) Stabliser to add k x(m/100)	173.9		
Water Addition((j+n)x(d-b))/(100+b)	590.7		
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	3% CEMENT & 6% METAKAOLIN	3% CEMENT & 6% METAKAOLIN	
Content %	3.0	3.0	
Mould g	A	B	
Wet Soil g	5,896.0	5,785.0	
Compaction M/c %	13.7	13.7	
Dry density kg/m3	2.250	2.208	
%Compaction	111.3	109.2	
FORCE	24.4	23.6	
UCS	1.339	1.294	1.32

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

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	AGABA JOEL & KAKOOZA PAUL	Stirling
PROJECT	PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN THE STABILISATION OF LATERITE SOILS	

STABLISED CBR

(BS 1924 PART 2 1)

3% CEMENT & 8% METAKAOLINE

M/c of air dried sample		
Tin No	Y6Y	
Tin + Wet soil gm	2589	
Tin + Dry Soil gm	2539	
Tin gm	819	
Water gm	50.0	
Dry Soil gm	1,720.0	
M/c %	**2.9**	
Av. M/c %	**2.9**	

M/c After Mixing			
Stabliser	3% CEMENT & 8% METAKAOLINE		
Content	4.0		
Tin No	NBM		
Tin + Wet Soil	1,729.0		
Tin + Dry Soil	1,622.0		
Tin	790.0		
Water	**107.0**		
Dry Soil	**832.0**		
M/c	**12.9**		

(a)MDD 2.033 kg/m3 — **(b)Air Dry M/c** 2.9 %

(c)WD 2.501 kg/m3 — **(e)M/c to add** 9.4 %

(d)OMC 12.3 % — **(F) volume** 2,305

Date prepared 27/Jan/24 **Date immerse** 3/Feb/24 **Date tested** 10/Feb/24

Mould No.			
Factor(f)	2.305		
(h)Wet Soil to fill mould c x f x %comp	5,763.9		
(j) Wt of air dried soil	6,000		
Air dry M/c	2.9		
(k) soil dry wt (100j/100+b)	5,830.5		
Stabliser	3% CEMENT & 8% METAKAOLINE		
(m)Stablisers content %	4.0		
(n) Stabliser to add k x(m/100)	233.2		
Water Addition((j+n)x(d-b))/(100+b)	568.9		
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	3% CEMENT & 8% METAKAOLINE	3% CEMENT & 8% METAKAOLINE	
Content %	4.0	4.0	
Mould g	A	B	
Wet Soil g	5,389.0	5,392.0	
Compaction M/c %	12.9	12.9	
Dry density kg/m3	2.072	2.073	
%Compaction	101.9	102.0	
FORCE	9.2	8.2	
UCS	0.506	0.450	**0.48**

STIRLING CIVIL ENGINEERING LTD P.O. BOX 798, KAMPALA (U)