ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS FOR SUBGRADE CONSTRUCTION

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ABSTRACT

Sandy soils are characterized by their low bearing capacity and high permeability and are very prone to erosion. In geotechnical and construction applications, these soils present considerable challenges. Many stabilization techniques use energy-intensive substances like lime and cement, which present problems for the environment and the economy. This research investigate the feasibility of using cement kiln dust (CKD), an industrial by-product produced during the cement manufacturing process, as a sustainable alternative for stabilizing sandy soils. Because CKD is high in calcium oxide and silica, it has potential pozzolanic properties that may improve soil cohesiveness and mechanical performance while resolving disposal-related waste management issues. This study assesses the geotechnical characteristics of CKD-stabilized sandy soils through laboratory tests, including the Proctor test, Unconfined Compressive Strength (UCS), California Bearing Ratio test, and permeability test. To find the ideal percentage for maximizing strength and durability, various percentages of cement kiln dust, ranging from 5% to 20%, were combined with sandy soil samples. After a 7-day curing period, the results showed a 45% improvement in UCS and a 58.5% improvement in CBR values, indicating that the optimum percentage of cement kiln dust to be added was 15%. Furthermore, the permeability significantly dropped by 93%, indicating improved soil. According to the MoWT general specifications for Road and Bridge Works 2005, the soil's PI, CBR swell and linear shrinkage were all determined to be within allowable limits.

DECLARATION

I declare that this research proposal is the result of my own efforts, free of plagiarism, and has never been presented to any other institution for any academic research except at this University.

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APPROVAL

This research report by BAMANISA KABAGAMBE Rachel has been under my supervision and submitted to the Department of Engineering, Design and Technology as partial fulfillment for award of Bachelor of Science in Civil and Environmental Engineering.

Academic Supervisor: Mr. ZZIGWA MARVIN

SIGNATURE…………………………………… DATE…………………………………

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ABBREVIATIONS

MDD: Maximum dry density

OMC: optimum moisture content

L L: Liquid limit

PL: plastic limit

PI: plasticity index

CBR: California bearing ratio

MoWT: Ministry of Work and Transport

AASTHO: American Society of State Highway and Transport Official

ASTM: American society for testing and materials

BS: British Standard

CKD: Cement Kiln Dust

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

As a developing nation, Uganda's infrastructure is emerging very fast, especially in road development. The roads play an essential role in the growth of trade locally as well as with surrounding areas, and to facilitate the expansion of the public as well as business sectors (Foster & Ranganathan, 2021). But the state of roads, especially in East Africa, that can be attributed to a deficiency of proper geotechnical investigation and the use of subquality materials during construction usually renders such infrastructure ineffective.

The condition of subgrade essentially influences the performance of pavements on roads. To keep the pavement system maintained and guaranteed to have a long life, a properly designed subgrade is required (Khodary et al., 2020). Therefore, one must evaluate the engineering properties of the soil, including its bearing capacity, before construction to see if it is appropriate for use to support structural loads.

In construction, cohesiveless soils, such as sandy soils, pose significant challenges. These soils are of low bearing capacity and shear strength due to their poor grading and non-plasticity. They are prone to fines migration, which could lead to stability problems. Differential settlement under loading will be more probable in sandy soils due to their inherent heterogeneity in strength and compressibility. Though the replacement of such soils with imported materials is one way of improving geotechnical conditions, it is usually expensive and time-consuming (Mohamed et al., 2023).

Sandy soil comes from breakdown of rocks due to weathering process. We talk about weathering when there is break down of rocks into smaller particles that can be taken by water or wind. When these particles accumulate with time, they lead to the formation of sandy soils(Vakili et al., 2023).

Sandy soil is classified by its sand particles quantity, generally made of more than 75% sand, while the remaining composition is made of a blending of silt and clay.

This specific soil type causes challenges for construction industries because of its low high drainage, low water absorption, low bearing capacity, high settlement potential, and increased vulnerability to erosion. Consequently, this results in a naturally unstable ecosystem. This make this soil type not suitable for construction work(S. Wang et al., 2023).

Stabilizing sandy soils might be the better way to increase its bearing capacity. Different stabilizers and methods have been used to modify the physical characteristics of these types of soils and make them more practical for construction purposes(S. Wang et al., 2023).

The main objective of stabilizing sandy soil is to improve its performance in the construction industry by increasing its bearing capacity and decrease its permeability, increase its cohesion properties and decrease its excessive settlement when subjected to a load. There are many techniques of stabilizing sandy soil mechanically and chemically and one of them the use of cement kiln dust as stabilizer (Abdila et al., 2022).

Cement kiln dust (CKD) is a Portland cement by-product generated during the cement production process. It is estimated that CKD constitutes approximately 15–20% of the total cement output, resulting in the generation of hundreds of millions of metric tons in alignment with the annual global cement production figures. However, not all components of CKD are suitable for recycling within the cement manufacturing process due to their elevated levels of alkalis, sulphate, and chloride, which can lead to excessive concentrations in the final product (Kunal et al., 2012). Research findings indicate that CKD possesses both physical and chemical characteristics that render it useful in various applications, including soil stabilization, concrete mixtures, chemical treatment, and the production of ceramics and bricks, as well as mine backfill(Al-Bakri et al., 2022).

1.2 PROBLEM STATEMENT

Sandy soils, distinguished by their coarse particle sizes, minimal cohesion, and high permeability, frequently present considerable difficulties in construction and engineering endeavors. The soils are susceptible to instability, resulting in issues like excessive settlement, erosion, and diminished load-bearing capacity. Because of their low natural stability, roads built on sandy soils are prone to surface erosion and ultimate failure, particularly in areas with significant rainfall(S. Wang et al., 2023).

Paicho Road, a 23.7km road located in Gulu District, faces many difficulties, especially during the rainy season, because of the presence of ferruginous and sandy soils, which have a low bearing capacity and a high susceptibility to erosion. A lot of water seeps in and settles on the road after heavy rains. The underlying clayey sand (SC) is composed of loosely packed particles that are easily dislodged, causing deformation under heavy loads and rendering the roads impassable, according to a 2022 Onen study. This study aims to assess the potential use of cement kiln dust (CKD) to stabilise and improve the performance of these sandy soils.

1.3 MAIN OBJECTIVE

To assess the use of cement kiln dust in sandy soil stabilization

1.3.1 SPECIFIC OBJECTIVES

1. To determine engineering properties of neat sandy soil.
2. To determine chemical properties of cement kiln dust.
3. To determine the engineering properties of sandy soil stabilized with varying percentages of cement kiln dust and polypropylene fiber.

1.3.2 RESEARCH QUESTIONS

1. What are the engineering properties of the neat sandy soil to be stabilized?
2. What are the chemical properties of cement kiln dust?
3. What are the engineering properties of sandy soils when stabilized with different percentages of cement kiln dust?

1.4 JUSTIFICATION

Cement Kiln Dust (CKD) is a byproduct produced during the cement production process, characterised for its high levels of free lime (CaO), silica (SiO2), and alumina (Al2O3). When CKD is mixed with water, it generates calcium oxide (CaO) and different alkalis, which then interact with moisture to form calcium hydroxide ($Ca(OH)_2$). The subsequent rise in calcium ions in the pore water promotes pozzolanic reactions, where the silica and alumina present in CKD engage with calcium hydroxide and the sandy soil. This interaction results in the formation of Calcium Silicate Hydrates (C-S-H), which are essential for binding soil particles, thus improving the shear strength and load-bearing capacity of the sandy soil.(Rimal et al., 2019). It is also a cost-effective way to achieve high-strength soils and other construction materials by reducing the construction cost; it is environmentally friendly product and provides excellent chemical resistance too many common solvents. This alteration successfully decreases permeability, thus minimizing the risks linked to erosion and excessive(Benziane et al., 2019).The use of CKD for stabilizing sandy soil also promotes environmental sustainability by reusing an industrial byproduct often discarded in landfills. This method provides a more economical substitute for conventional stabilizers like cement or lime.

1.5 GEOGRAPHICAL SCOPE

This study is centered on sandy soils from Paicho road in Gulu District in Northern Uganda as shown in Figure 1 map, with latitude 2.9000° N, and longitude 32.4500° E.

Figure 1: showing the Paicho Road map

CHAPTER TWO: LITERATURE REVIEW

2.1 THEORETICAL LITERATURE REVIEW

2.1.1 Soil

Soil is described as a collection of mineral grains that are either loosely bonded or only lightly bound, formed through the weathering of rocks. The gaps among these particles hold both water and air. Soils can exist in different conditions: dry, partially moist, or completely saturated. In dry condition, the spaces are filled with air; in fully saturated state, they are filled with water; and in partially saturated state, the spaces hold a combination of air and water. The condition of soil differs considerably in various geographical regions. Soils that lack plasticity because they have no clay minerals are categorized as cohesive less soil(Anthony et al., 2023).

2.1.2 Sandy soil

Sandy soil is described as frictional or cohesionless soil because its particles lack adhesion. These soils exhibit reduced shear strength and bearing capacity, have poor water retention, display no plasticity, and show minimal or no shear strain among particles. Traditional stabilization methods for sandy soil, such as utilizing fly ash, bitumen, and lime cement, generally require prolonged curing durations. As a result, the use of polymers for stabilizing sandy soils has grown in popularity in modern practices, since they do not need extended curing periods and are chemically stable. The application of polymers for soil improvement is not limited to sandy soils; it has also been successfully utilized in clay soils to enhance several physical characteristics, including boosting shear strength and bearing capacity, decreasing settlement, minimizing swelling, and tackling problems related to weak soils(J.-P. Wang et al., 2020).

Settlement in sandy soils is known to happen quickly because of their effective drainage capabilities. The degree of this settlement is significantly affected by the structural properties of the soil. In the scenario of dense sandy soils, the resulting deformation is slight; however, as the sand's density reduces, the deformation typically rises. If the density of saturated sand drops below a critical level under certain stresses, the load will shift to the pore water and cause liquefaction, which could lead to the collapse of the soil structure(Luat et al., 2020).

In saturated cohesionless soils or when water is added to the soil, vibrations can also result in liquefaction. After the excess pore water pressure decreases, the soil densifies(Soleimani et al., 2018). The PI of Sandy soil lays within A-1 to A-3 as shown in table 1.

Table 1: ASSHTO Classification of Sandy Soil

Properties	Values
Percentages passing No.200	Max 15%
Liquid limit LL	0
Plasticity index PI	Max 6%
Classification	A-1a, A-1b, A-3

Source: ASSHTO system of soil classification

2.2 CEMENT KILN DUST (CKD)

Cement kiln dust (CKD), a byproduct of Portland cement production, is usually disposed of in landfills. This substance has a fine, powdery texture similar to Portland cement. CKD poses several challenges, such as possible health hazards, storage issues, and environmental contamination. The increasing demand for cement around the world has resulted in a noticeable buildup of kiln dust at cement manufacturing facilities. This fine dust is a major environmental hazard and is challenging to eliminate. Research is being done all over the world to find economical ways to use cement kiln dust in a range of applications, including agriculture, pavement construction, soil stabilization, waste material stabilization, cement manufacturing, and the production of cement-based products(Ahmed et al., 2023).

2.2.1. How is CKD generated?

The method entails burning raw materials in a rotary kiln to produce clinker. Around 2.6 to 2.8 tons of raw materials are needed to produce one ton of cement. Between 5% and 10% of these finely milled substances will become airborne and remain suspended as dust within the gases. Usually, for each ton of clinker created, a typical kiln releases approximately 0.06 to 0.07 tons of cement kiln dust(CKD)(Sreekrishnavilasam & Santagata, 2006).

2.2.3. Environmental problem related to the use of CKD

CKD has been observed to significantly impact both flora and fauna within the ecosystem. The recorded impacts include stunted development in plants and animals, diminished chlorophyll levels in vegetation, obstructed stomata on leaves, changed cellular metabolism in both plants and animals, respiratory illnesses in animals, blood issues, various cancers, and vision problems, among additional concerns (Al-Bakri et al., 2022).

Moreover, dust emissions primarily take place during different stages of the cement production process, including raw mills, the kiln system, the clinker cooler, and cement mills. Typically, these processes involve the passage of heated exhaust gases or air through crushed materials, resulting in a mixture of gas and particles (Mater, 2019). The characteristics of the produced particulates are closely tied to the source substances, such as raw materials, clinker, or cement. These emissions present significant health hazards to humans and deteriorate the quality of the air. Acid precipitation, climate change, ozone depletion, loss of biodiversity, and reduced agricultural output are a few examples of the local and global environmental effects of these emissions(Uliasz-Bocheńczyk & Deja, 2024).

2.2.4. Justificatin for the reuse of cement kiln dust (CKD) for soil stabilization

Rimal et al. investigated the use of CKD to treat 2 types of natural soils across multiple curing times. Numerous laboratory tests were completed to look at changed in unconfined compressive strength in specimens where the soil tested was treated with CKD to varying concentrations. Research was done on soils in both dry and submerged stage states (wet), and specimens were tested both with and without CKD. The research found that the addition of CKD added considerable unconfined compressive strength to the natural soil (El-aziz & Abo-hashema, 2018).

Additionally, researchers, in their research of the mechanistic action of CKD in clay, found that CKD had properties similar to concrete, which was demonstrated by the formation of hydration products and the subsequent decrease in void space. As a result, the plasticity index decreased and the strength increased over time. Using the ASTM D4546 procedure, the swelling potential of the clay reduced significantly from above 7% to 0.4% with 25% CKD. Likewise, the swell potential had decreased from about 9.0% to 2.5% during a CBR test (Alaneme et al., 2022).

Optical examination of voids in the CKD-stabilized clay samples indicated that void space decreased as CKD concentration increased. When untreated, the clay soil had voids of approximately 7% but the samples treated with 25% CKD had voids that ranged from only 1% to 2.3% (Rimal et al., 2019). This reduction in empty spaces may explain the strength increase that was observed. Interestingly, this reduction seems to be more impacted by the level of CKD, or depth of treatment, than by the treatment duration or timing in relation to when it was placed. This reduction in voids may come from many valid interactions occurring simultaneously, such as the new products being formed from hydration and associated products filling the void spaces, and the CKD particles reshaping the clay and stabilized mass. Further characterization of the various conditions of the clay samples treated with CKD is warranted (Ranjkesh Adarmanabadi et al., 2022).

2.3. PROCESS OF STABILIZATION

Soil stabilization involves changing or retaining one or more properties of soil to improve the engineering properties and functionality of soil. For instance, improving the shear strength of soil and modifying its shrink-swell characteristics can those properties overall increase the ability of subgrades to support loads for pavements and foundations (Reiterman et al., 2022). There are numerous methods available to accomplish soil stabilization. The methods to stabilizing soil can be generally broken down into two groups: mechanical stabilization and chemical stabilization. Mechanical stabilization methods include compaction and fibrous or other non-biodegradable reinforcements typically made of geomaterials to improve strength. Chemical stabilization improves the behaviors of clay soils using chemicals and emulsions as binders and water repellents.

2.3.1. Mechanical Stabilization

To create a material that exhibits the requisite soil properties, various soil gradations are blended further and mechanically stabilized in an effort. This process improves the soil's stability and load-bearing ability by mechanically separating and blending the natural soil with a stabilizing agent to form a homogenous mixture (Chatterjee et al., 2006). Furthermore, mechanical stabilization will increase the specified engineering properties by compacting the soil aggregate particles and producing a dense soil mass. To assist in the compaction process, finer aggregates or materials can be introduced to create a uniform, well-graded, and dense soil-aggregate mixture. Careful consideration should be exercised when selecting construction techniques based on the gradation of soil or soil-aggregate/materials. If it improves the engineering properties of the soil, geotextiles may be incorporated (Maalekian et al., 2007).

2.3.2. Chemical Stabilization

The procedure of improving soil properties encompasses the use of various chemicals, such as cement, lime, and fly ash, which aid in improving properties, such as plasticity and swelling index, etc. This stabilization process improves workability in the compaction process, reduces the impact of swelling and shrinkage, reduces dust emissions, and increases the strength and stiffness of the soil. The plasticity index of the soil serves as a critical factor in determining the appropriate stabilizer. For example, when dealing with soil that has a plasticity index exceeding 10% and more than 25% passing through a sieve of 200, lime is typically the preferred stabilizer (Haak & Indraratne, 2023). Conversely, for cohesive soils, cement may be utilized. Additionally, the strength requirements post-stabilization will be influenced by the specifications of the pavement.

2.3.3. Lime as chemical stabilizer

Lime serves as a chemical stabilizer in soil treatment, with various types employed, including hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, and dolomite lime. Typically, the amount of lime utilized for soil stabilization ranges from 5% to 10%. The process of lime modification enhances soil strength through cation exchange capacity(Pushpakumara & Mendis, 2022).

Lime stabilization can also involve a pozzolanic reaction, where pozzolanic materials interact with lime in the presence of water, resulting in the formation of cementitious compounds. This reaction can occur with either quick lime or hydrated lime (Ca(OH)2).

Sherwood's research highlights the reduction in plasticity achieved initially through cation exchange, wherein sodium and hydrogen cations are substituted by calcium ions, which have a lower affinity for water in clay minerals. However, the use of lime as a soil stabilizer has its constraints. As noted by Morse et al. (2007), there is a significant likelihood that the interaction between calcium ions and black humic acid produced from lime leads to the formation of insoluble calcium hemic acid. The breakdown of organic materials can impede the polymerization of silicates, thereby obstructing the formation of cementitious compounds.

Lime can effectively serve to permanently stabilize fine-grained soils for use as a subgrade layer in pavement systems. The reaction between silica and alumina released from the soil and calcium from lime results in the creation of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH), both of which are cementation products akin to those generated in Portland cement. This method strengthens layers of lime-stabilized soil to convert the sandy, granular soil into a rigid, relatively impermeable layer that can support considerable weight (Malkanthi et al., 2020).

2.3.4. Cement as a stabilizer

When cement is mixed with water, hydration occurs, which produces excess calcium hydroxide (Ca (OH)2) and other cementing agents such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). During the soil cement stabilization process, the bonding of soil particles provides substantial compressive strength. This process is initiated by the hydration of cement particles, which form interlocking crystals. As the cement hydrates, soil-cement ultimately sets into a durable material. The stabilization process reduces the soil void ratio as the cement fills the voids between the soil particles when unexpected compaction is taking place. Introducing water enables the cement to solidify making the soil heavier. Hardening cement also increases the shear strength, and bearing capacity of the soil. Cement reduces the liquid limit making clay-rich soils easier to work with (Santos et al., 2020).

Nonetheless, there are drawbacks of using cement as a stabilizer. Heave and disintegration may occur when an addition is a calcium-based additive, such as cement, when used with soils that contain sulfates, compromising the soil strength. Sulfates may come from the natural composition of the soil or from groundwater (Radwan et al., 2021).

2.3.5. Bituminous stabilization

The application of bituminous stabilization is defined as the precise incorporation of a specified amount of bituminous material with existing soil or aggregate to develop a stable base or surface layer. In addition to increasing the cohesion stability of soil and load support capability of soil, bitumen increases its resistance to water intrusion. Bituminous stabilization can be conducted with asphalt emulsions, asphalt cement, or asphalt cutback (Venkatesh, 2017).

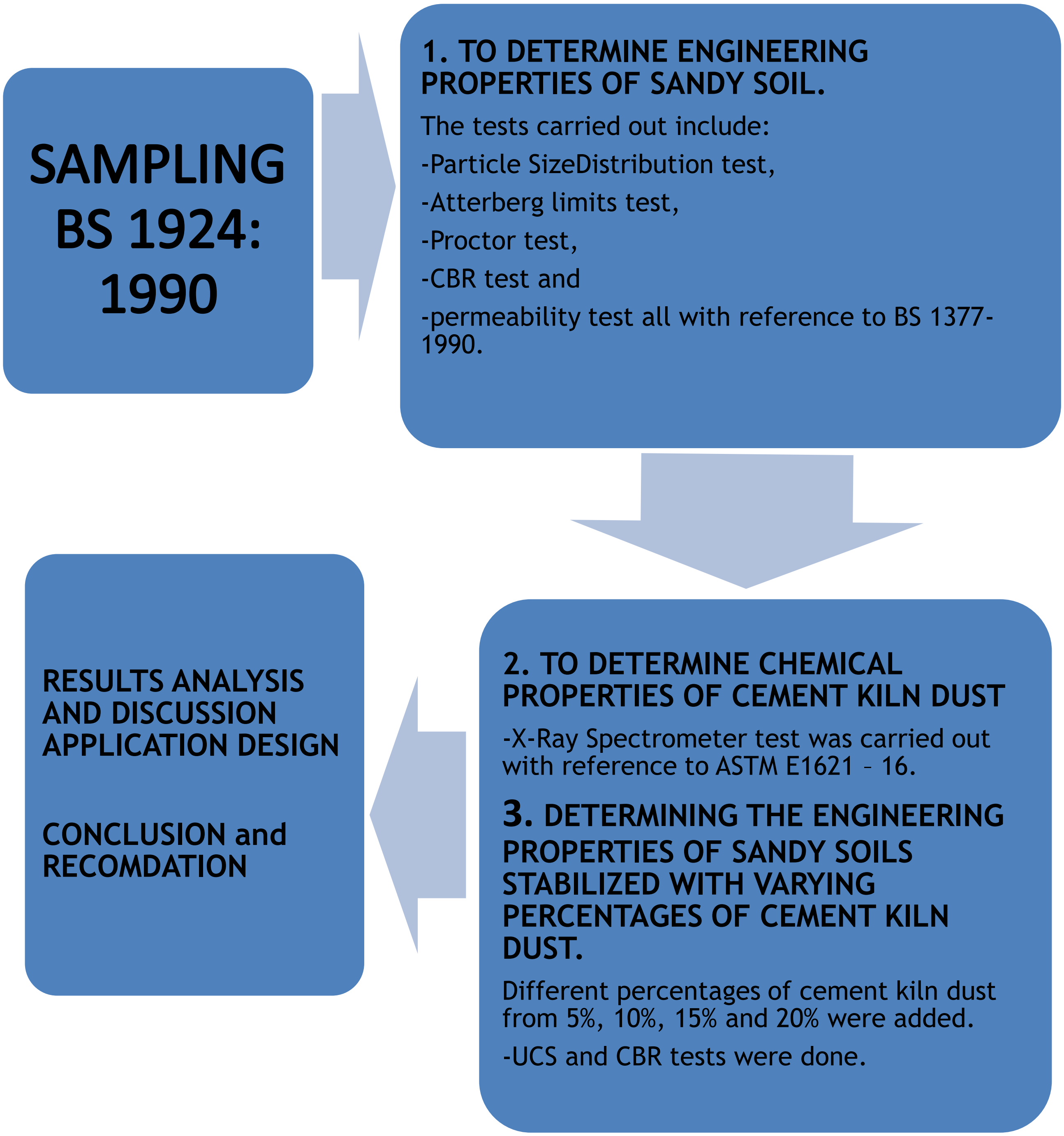
Scientists indicate that the best type of bitumen for stabilizing soil is impacted by the type of soil being treated, the technique that is employed to build the soil, and the existing weather conditions. Bituminous materials act as a waterproofing agent by stabilizing the soil by binding its particles together or protecting it from the adverse effects of water. The types of soils that usually yield the best results have a plasticity index of less than 18% and a liquid limit of less than 40% (Gautam & Jaysawal, 2008).

CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

This part outlines, in detail, laboratory testing and procedures, material acquisition, sampling, and data analysis, which were employed in this work. The protocol and details of its administration are included in the methodology (Hibbett, 2024).

Standard laboratory tests and standard laboratory processes were employed for data collection on materials. The following procedure was used to generate the study:


SAMPLING BS 1924: 1990
1. TO DETERMINE ENGINEERING PROPERTIES OF SANDY SOIL.
The tests carried out include:
-Particle SizeDistribution test,
-Atterberg limits test,
-Proctor test,
-CBR test and
-permeability test all with reference to BS 1377-1990.
2. TO DETERMINE CHEMICAL PROPERTIES OF CEMENT KILN DUST
-X-Ray Spectrometer test was carried out with reference to ASTM E1621 – 16.
3. DETERMINING THE ENGINEERING PROPERTIES OF SANDY SOILS STABILIZED WITH VARYING PERCENTAGES OF CEMENT KILN DUST.
Different percentages of cement kiln dust from 5%, 10%, 15% and 20% were added.
-UCS and CBR tests were done.
RESULTS ANALYSIS AND DISCUSSION APPLICATION DESIGN
CONCLUSION and RECOMDATION

3.2 TEST PLAN

The table below, table 2, shows the plan of various tests with the proportions used to mix them.

Table 2: Test plan of various tests with the proportions used to mix them.

Mix ID	CKD (%)	Weight of Sample (kg)	Weight of CKD (Kg)	Tests to Perform
1	0	80	0	Atterberg limits, Proctor test, Particle Size Distribution, CBR test, Permeability test
2	5	80	4	Atterberg limits, Proctor test, Particle Size Distribution, CBR test, Permeability test
3	10	80	8	Atterberg limits, Proctor test, Particle Size Distribution, CBR test, Permeability test
4	15	80	12	Atterberg limits, Proctor test, Particle Size Distribution, CBR test, Permeability test
5	20	80	16	Atterberg limits, Proctor test, Particle Size Distribution, CBR test, Permeability test

3.3 MATERIALS AND METHODS

3.3.1 Materials

1. Sandy Soil

The soil was collected from a borrow pit along the Paicho Road at two different locations at a depth of 1m in a disturbed state using a shovel and hoe. This borrow pit was the source of the material used in the road. The total weight of the collected soil samples was about 350 kg. It was transported for testing in 5 sealed bags.

On arrival at the laboratory the material was placed on large trays and to air dry to bring the soil at constant moisture content so that soil tests could be carried out on the dried sample.

2. Cement Kiln Dust

Cement kiln dust was obtained from Simba Cement Plant, Tororo. The use of pre-calciner kiln dust is recommended as it contains more SiO_2, Al_2O_3, free lime and is concentrated in volatile alkaline substances, giving better stabilizing properties.

3.2.2 Methods

1. To determine engineering properties of the neat soil.

1.1. 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 as shown in Figure 2. 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

Figure 2: Particle Size Distribution

1.2 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 done to obtain the plasticity index of the neat soil.

Equipment

- Cone penetrometer
- 0.045mm Sieve
- Drying oven
- Liquid limit (LL)

A sample of 200g of the air-dried sample that had passed the 0.0425mm sieve was obtained and was prepared in accordance with the standard. The cone penetrometer test process is shown in figure 3.

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

Figure 3: Cone Penetrometer

1.3 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.

1.4 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 as shown in Figure 4.

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 4.5kg 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 at maximum.

Figure 4: Proctor Test

1.5 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 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 as shown in Figure 5.

Figure 5: CBR Test

1.6 Permeability test

A sandy soil sample containing some ratios of Cement Kin Dust and polypropylene fiber is placed in a permeameter. Water will flow across the sample in controlled conditions and the flow rate will be measured. Then, Darcy's law will be applied to determine the permeability (k). This test examines how the CKD alters the water seepage properties of the stabilized soil. To verify the suitability of stabilized soils in drainage and erosion applications, the permeability will be analyzed (Giriprasad & Niranjan, 2021).

Equipment

Permeameter cell

Two discs of wire gauge diameters equal to the inner diameter of the cell body

A vertical adjustable tank

A discharge with an overflow valve to maintain the level

A set of transparent manometer tubes

Digital weighing scale

2. To determine chemical composition of the cement kiln dust

2.1. XRF TEST

It was done to determine the chemical composition of the Cement Kiln dust. 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 as shown in Figure 6. The sample then emitted florescent x- rays where each element reacted by releasing a specific fluorescent print. An X-ray analyzer then captured these signals and they were analyzed to determine the chemical composition of the sample.

Figure 6: XRF Test

3. To evaluate the engineering properties of sandy soil stabilized with varying proportions of cement kiln dust.

3.1. Unconfined Compressive Strength TMH1: method A14:1986

The Unconfined Compression Test is a strength test carried out in the lab. It shows the maximum axial force that a soil sample can withstand under zero confinement.

Figure 7 is showing the preparation for the sample to be soaked for 4 days. When carrying out the UCS test, plates on which the sample is to be tested are cleaned and then subjected to a continuous load at 0.5 MPa/s until 1.0 MPa/s until the sample was seen to fail.

The values of the normal force and resultant shear stress were noted and recorded.

Figure 7: Uncofined Compressive Strength

3.2. Permeability Test in accordance with BS 1377-5:1990.

A sandy soil sample, incorporating different ratios of Cement Kin Dust and polypropylene fiber, is placed within a permeameter. Water is allowed to flow through the sample under controlled conditions, and the flow rate is recorded. Next, Darcy's law is applied to find the permeability (k).

This test looks at how CKD affects the stabilized soil's water seepage properties. Verifying the efficacy of stabilized soil in drainage and erosion control applications requires analyzing permeability changes (a-Te et al., 2020).

3.3. California Bearing Ratio (CBR) according to BS 1377-4: 1990

The CBR test evaluates the strength of sandy soils stabilized with various concentrations of CKD and polypropylene fiber for use in road construction and other cases involving heavy loads. After obtaining a compacted sample of the stabilized soil, the sample is placed in a water bath. After placing a cylindrical plunger into the sample, the amount of resistance the sample provides is measured. The CBR value is calculated as the ratio of the measured pressure to the standard bearing pressure (Baghbani et al., 2023).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. INTRODUCTION

In this chapter, we summarize and review the findings from a substantial number of laboratory experiments and studies carried out on both stable and unstable soil samples. These tests consist of, for strength, the California bearing ratio and proctor compaction tests; for durability, the Unconstrained Compressive Strength (UCS) test; and for soil classification, the Atterberg tests and sieve analysis. The findings were compared to the standard values provided by AASHTO and to the 2005 existing specification for roads and bridges as published by the Ministry of Works and Transport.

4.2. NEAT SANDY SOILS

Soil samples were analyzed at Stirling laboratory located in Mbalal, Mukono having been collected from Paicho Road, Gulu. The tests carried out include particle size distribution, Atterberg test, compaction test, and CBR test. The properties or summary of the neat sandy soils analyzed are shown in the table 3 below.

Table 3: Neat sandy Soil Summary

Test	Result	General Specifications for Roads and Bridge works (MoW&T)
Plasticity Index	7.2%	Maximum 25
Maximum Dry Density	2.008g/cm^3	-
Optimum Moisture Content	10.2%	-
AASHTO classification	A-2-4 material	-
USCS	SC	-
CBR	9.9%	Minimum 15
CBR swell	0.75%	Maximum 1.5
UCS	0 MPa	Minimum 0.5 MPa
Permeability	7.3 x10^{-5}m/s	-

4.3. ENGINEERING PROPERTIES OF THE NEAT SANDY SOIL

4.3.1 Particle Size Distribution

According to the particle size distribution graph, 22% of the particles pass through sieve No. 200, 55% pass through sieve No. 40, and 80% pass through sieve No. 10. The Plasticity Index is 7.1%, the Liquid Limit is 21.3%, and the Plastic Limit is 14.2%. AASHTO classification yields an A-2-4 material, which is a well-graded sand, since the percentage passing sieve No. 200=22%<35% suggests that the material is granular. Applying the USCS (Unified Soil Classification System).

According to the Unified Soil Classification System (USCS), the material is classified as coarse-grained soil because over half of it was retained on the 75μm sieve. The soil was classified as a SC, which is a sandy soil that contains some clay.

4.3.2 Atterberg limits

The liquid limit is the maximum moisture content at which soil will flow under its own weight. It is the quantity of moisture in the soil at the point where it changes from a liquid to a plastic state. The liquid limit of the sample was found to be 21.3%. This implies that sandy soils will flow more easily when water is added than clay soils, which expand before flowing (James, 1990).

The plastic limit is the moisture content at which soil can be rolled into a 3 mm thread without breaking. When soil changes from a plastic to a semi-solid state, it contains this amount of moisture. The plastic limit of the soil was found to be 14.2% and hence the plasticity index was found to be 7.1%.

The soil's capacity to absorb water is described by the plasticity index. It is derived from the difference between the plastic and liquid limits. The more the soil's PI increases, the more its volume changes as a result of variations in moisture content, and vice versa. It is implied that the sandy soil will not undergo volume changes when exposed to moisture conditions because the obtained.

PI is a relatively low value. According to the MoWT General specifications for Roads and Bridge Works, the sample's PI of 7.1% falls within the acceptable ranges for a G15 material. The low PI can be attributed to the low percentage of fines in the sample which indicates that the soil has a very low percentage of clay and silt and mostly sand which significantly reduces its Plasticity Index.

4.3.3 Proctor test

The Proctor test was used to determine the optimum moisture content for compaction as well as the maximum dry density of a given soil for a given compaction effort. Because the dry soil particles are not in contact with one another, the earth becomes rigid and splits when it is compacted, resulting in gaps. A thin layer forms around each soil particle when water is added to low-moisture soil during compaction. This layer acts as a lubricant, pulling the particles closer together and raising the soil's density. Because it allows the soil particles to move freely during compaction, adding water to soil that has a low moisture content leads to low void ratios. As such, as the volume of air in the sample decreases and the dry density of the soil reaches its maximum. The moisture content at this point is the optimum moisture content (Shivaprakash & Sridharan, 2021).

The dry density decreases when water is added in excess of the ideal moisture content. This is because the water fills the voids and forces the soil particles apart, decreasing the dry density of the soil, rather than serving as a lubricant.

The soil's OMC was 10.2% and its maximum dry density was 2.008g/cm3. This indicated that the optimal compaction level for this soil is 10.2% moisture content.

4.3.4 California Bearing Ratio CBR

CBR is used to measure soil strength. It is determined by calculating a soil sample's resistance to penetration. According to the MoWT General specifications for road and bridge construction from 2005, the soil did not meet the requirements for G15 subgrade material. The sample's CBR was 10, even though the standards call for the material to have a CBR of 15. Therefore, this soil must be stabilised before the subgrade can be built (Othman & Abdelwahab, 2023).

Additionally, the CBR swell was determined to be 0.75, falling within the general specifications set by the Ministry of Works and Transportation's maximum 1.5 limit for G15 material. This suggests that the rate of soil swell is within reasonable bounds.

Significant amount of fines in the soil weakens it by causing volumetric changes in response to variations in moisture content. The loose particle sizes of sandy soils may be the cause of this low CBR value. The soil's non-plastic nature makes it difficult for the particles to bind together to create a more robust soil matrix (Sorsa, 2022).

Since the soil's tidy qualities make it unsuitable for use as G15 subgrade material, stabilization of the material is required to raise the CBR in accordance with the MoWT General specifications for road and bridge construction 2005.

4.3.5 Permeability test

The permeability of the neat sandy soil was determined using the falling head method and the results tabulated in the table 4 below.

Table 4: Neat Sandy Soil Permeability Result

Test No.	H_1 (m)	H_2 (m)	T(s)	Inflow volume(m^3)	Outflow volume (m^3)	Hydraulic Conductivity, K (m/s)
1	0.132	0.005	25.88	1.27×10^{-5}	1.08×10^{-5}	1.52×10^{-4}
2	0.245	0.132	19.32	1.13×10^{-5}	4.63×10^{-5}	3.85×10^{-5}
3	0.345	0.245	14.28	1.00×10^{-5}	1.04×10^{-5}	2.88×10^{-5}
			Average			7.3×10^{-5}

The value of coefficient of permeability, k was obtained as 7.3 x10-5m/s which accounts for the high rate of infiltration of water through the sandy soil thereby causing erosion.

4.4 CHEMICAL COMPOSITION OF CEMENT KILN DUST

The chemical composition of cement kiln dust depends on a number of factors, such as the raw material composition, combustion conditions, kiln operation, and process parameters (Sorsa, 2022).

The table lists the various chemical components of the cement kiln dust that were subjected to XRF analysis.

Table 5: Neat Soil Chemical Composition

Parameter	Units	Result
Calcium Oxide	% m/m	50.52
Silicon dioxide	% m/m	27.77
Aluminium Oxide	% m/m	15.13
Potassium Oxide	% m/m	0.76
Manganese (II) Oxide	% m/m	0.26
Iron (II) Oxide	% m/m	5.33
Chloride	% m/m	0.23

The primary oxides found in the sample were aluminium oxide, silicon dioxide, and calcium oxide. The formation of calcium silicate hydrate gel (tobermorite) depends on these oxides.

For the CKD and water mixture to form a CSH gel, the calcium to silica molar ratio must be between 1.6 and 2.5 (citation). The corresponding molar masses of silicon dioxide and calcium oxide were divided by the percentages of CaO and SiO2 to determine the moles of each, as shown below.

Moles of Cao=$\frac{50.52}{56} = 0.90$

Moles SiO_2=$\frac{27.77}{60} = 0.46$

C/S ratio=$\frac{0.90}{0.46} = 1.97$

Since the calcium to silica molar ratio of 1.97 was determined to be within the required limits, the calcium silicate hydrate gel will form when the CKD is exposed to moisture conditions. This gel will produce a more stable soil matrix by tying the loose, sandy soil particles together.

4.5 STABILIZED SANDY SOIL

4.5.1 Engineering properties of sandy soils stabilized with varying percentages of cement kiln dust

PLASTIC INDEX VARIATION

The observed PI of 8.7 indicated in Figure 8 shows that the clean sandy soil contains fines like silt and clay. The PI then gradually drops with the addition of cement kiln dust, reaching a value of 7.3 following a 20% addition. The interaction between CKD and the sandy clay minerals explains the slight drop in Plasticity index values observed. In addition to filling the voids left by the coarser sand grains, the fine particles that comprise cement kiln dust alter the soil's gradation and lessen reactions that resemble clay. Moreover, the cementitious and pozzolanic processes caused by

CKD bind the soil particles, reducing the range of moisture that the soil can still be worked.

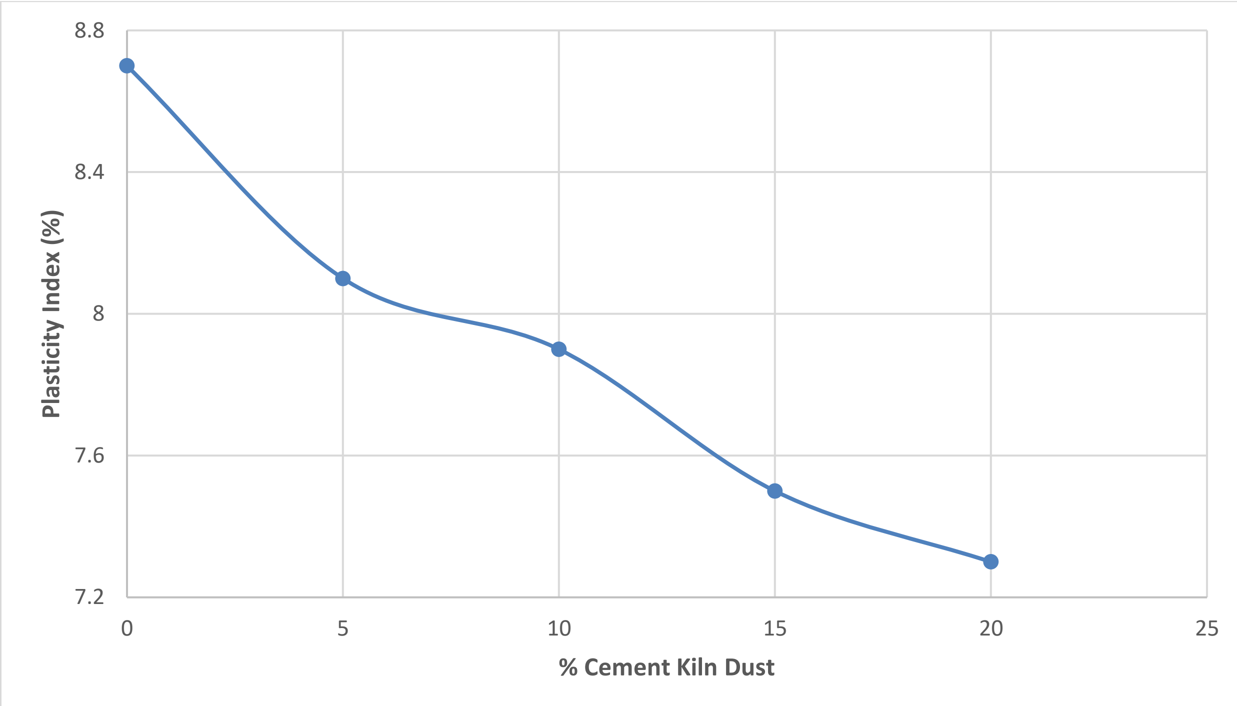


Figure 8: Plastic Index Result Variation Graph

4.5.2 Effect of cement kiln dust on proctor values on the compaction characteristics

The MDD gradually rises from 2.008g/cm3 to 2.032g/cm3 when cement kiln dust is added at a rate of 5 to 15% as it is shown in Figure 9. This is because the CKD particles efficiently fill in the voids left by the sand grains, enhancing particle packing and increasing the soil's density. However, when the CKD content increases to 20%, the ideal particle interlock is broken, resulting in a drop in the MDD to 1.993g/cm3. According to Atraa et al. (2015), this is because the soil particles were cemented together at higher cement kiln dust content levels, which led to the formation of a continuous structure with stronger connections made possible by secondary reactions and hydration products. The density is greatly reduced as a result of the soil particles becoming stuck together and having little mobility. Excessive CKD causes a less dense matrix and more interparticle spaces by introducing more fines. Furthermore, the formation of calcium silicate hydrates, which increase volume but do not increase overall density, resulted in a slight decrease in the MDD.

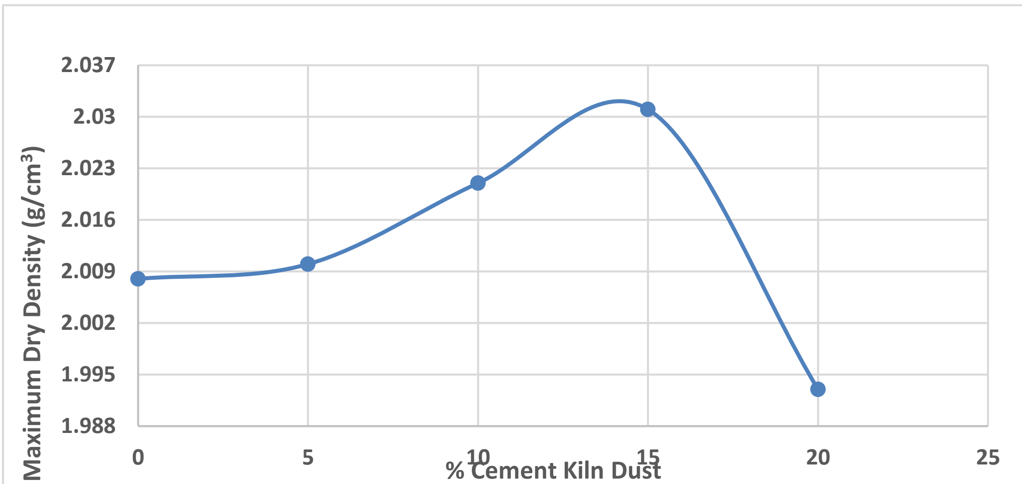


Figure 9: MDD Variation Result Graph

4.5.3 Effect of cement kiln dust on the optimum moisture content

The optimum moisture content is impacted when CKD is used in place of clay minerals That absorbs water. The OMC gradually decreases from 5 to 15% CKD addition, from 10.2% to 8.4% as shown in Figure 10. The soil requires less water for compaction because CKD increases particle lubrication and decreases the mixture's overall water affinity (Athraa et al, 2015). The increased surface area and reactivity of the additional fines, however, increase the water demand because more water is needed to support both the pozzolanic reactions and effective particle lubrication, which raises the ideal moisture content. As a result, the OMC dramatically increases to 10.3% at 20%

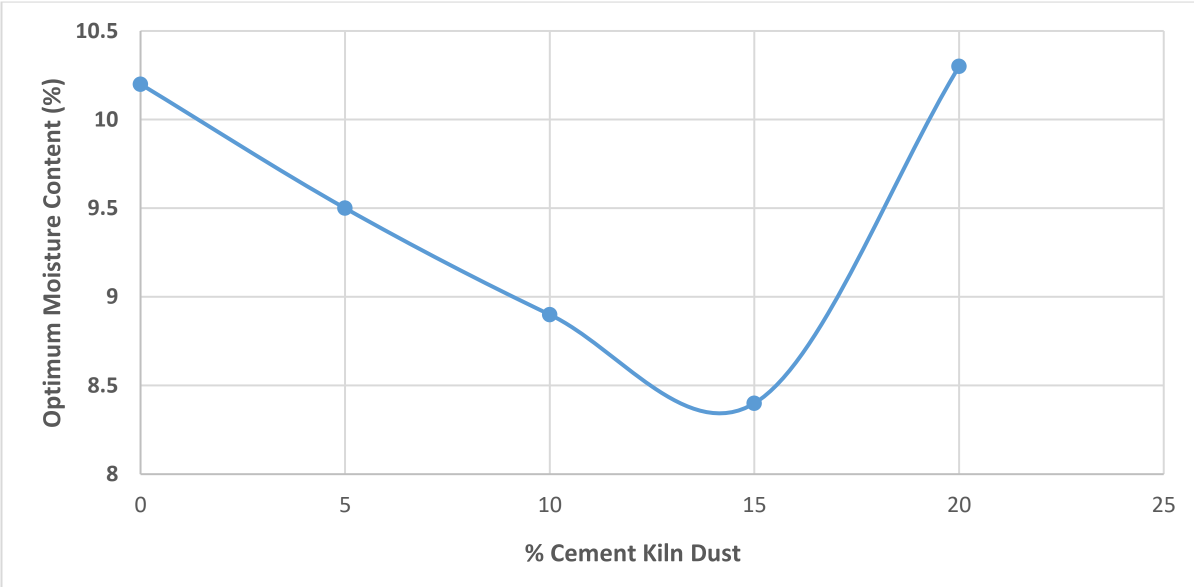


Figure 10: OMC Result Variation

4.5.4 Effect of cement kiln dust on CBR

The CBR values gradually increased as the CKD content increased with the addition of cement kiln dust. The recorded CBR was 16% at 15%, which was higher than the minimum of 15 required by MoWT. CBR has improved as a result of improved particle bonding and densification brought about by the addition of CKD. By effectively cementing the sand particles together, CKD improves pozzolanic processes that produce C-S-H gels as it is shown in Figure 11. This bonding significantly increases the soil's rigidity and load-bearing capacity (Alhassani et al, 2021). The reduction of voids to an optimal CKD content further improves particle interlock and load distribution.

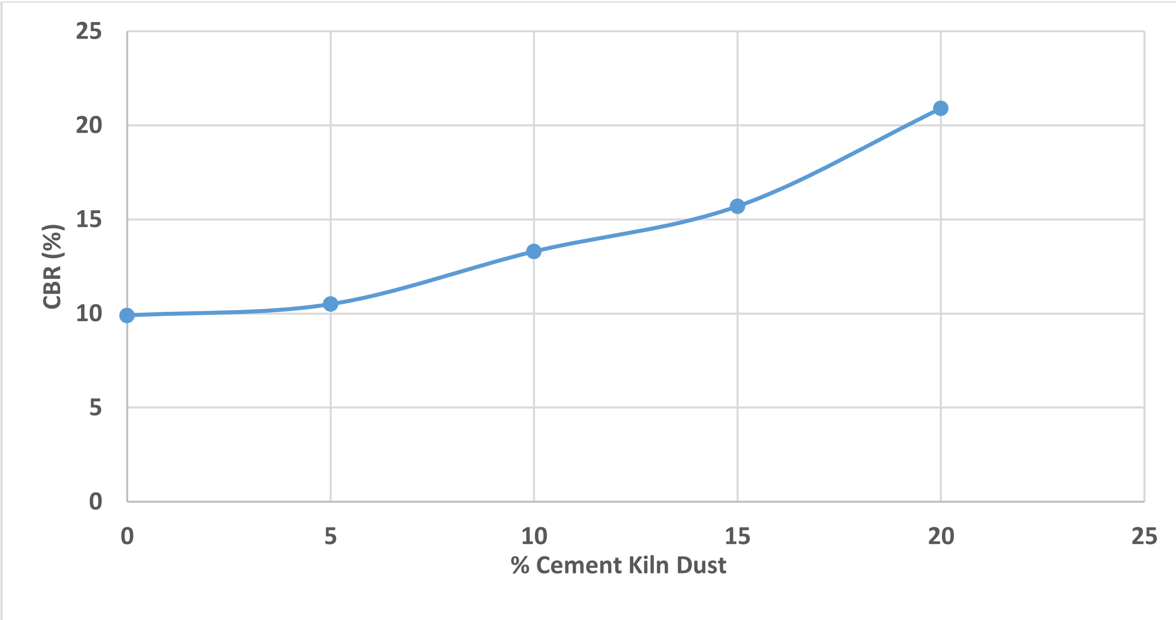


Figure 11: CBR Result Variation graph

4.5.5 Effect of cement kiln dust on UCS

The results showed a 45% increase in Unconfined Compressive Strength after 15% cement kiln dust was added. For CKD levels between 0 and 10%, rapid strength increases are observed when CKD combines with natural moisture to form a cementitious matrix that significantly enhances interparticle bonding as shown in Figure 12. The rate of strength development slows down between 15 and 20% when excess CKD is present, preventing further compressive strength improvement due to reactive site saturation and the introduction of microstructural weakness, such as brittleness, to the stabilized soil matrix (Amadi, 2022).

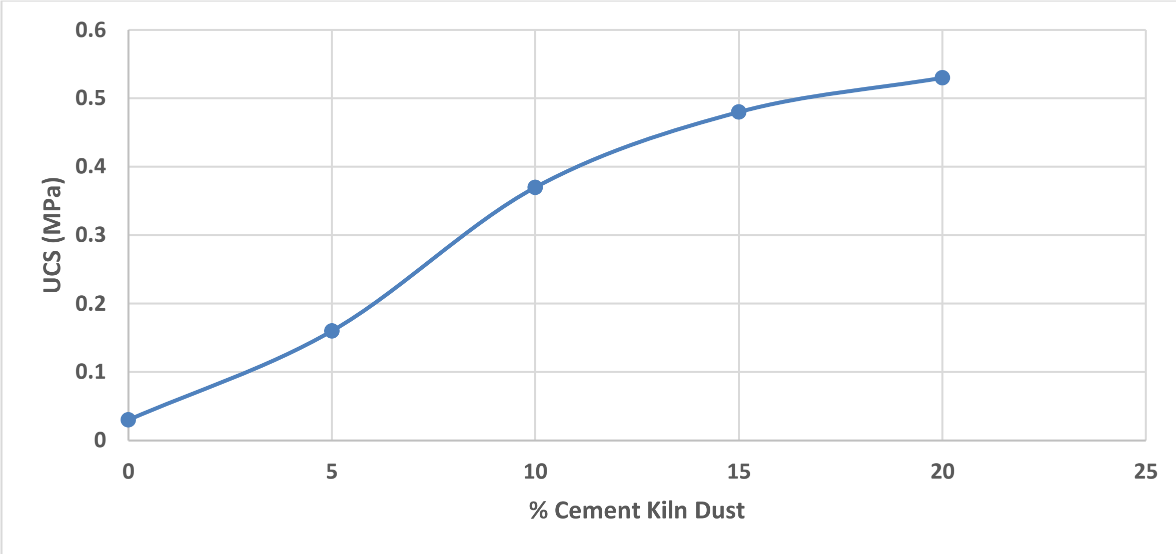


Figure 12: UCS Result Variation Graph

4.5.6 Effect of cement kiln dust on permeability

The permeability of the sandy soil decreased significantly from 7.3 x10-5 m/s to 8.8 x10-7 m/s at 15% CKD addition as shown in Figure 13. This happens because the fine particles of cement kiln dust fill in the gaps between the larger sand particles, reducing the overall porosity and the size of the water-permeable pores. Chemical reactions that bind the sand particles together to create a more cohesive and dense matrix are made possible by the cementitious properties of the dust. This binding effect further restricts their connection by making it harder for water to move through the pore spaces.

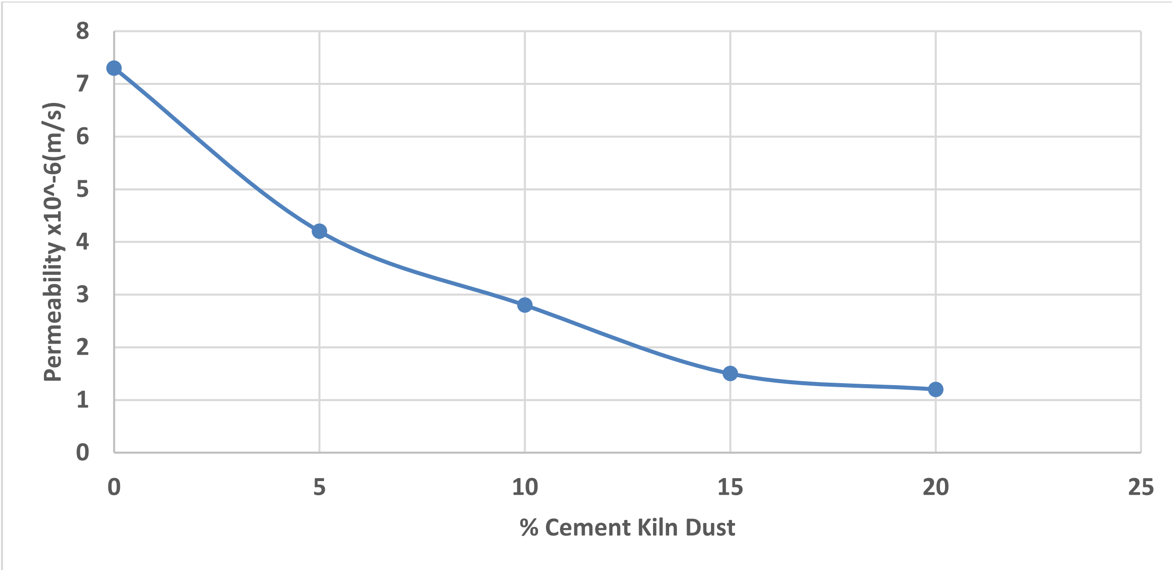


Figure 13: Permeability Variation Result Graph

4.6 Research Design

Table 6: Research Design Summary

Parameter	**Sandy soil with 15% CKD**	**General Specifications for Roads and Bridge works (MoW&T)**
Plasticity Index	7.5%	Maximum 25
Maximum Dry Density	2.032g/cm^3	-
Optimum Moisture Content	8.4%	-
AASHTO classification	A-2-5 material	-
USCS	SW	-
CBR	16%	Minimum 15
CBR swell	0.48%	Maximum 1.5
UCS	0.48 MPa	Minimum 0.5 MPa
Permeability	8.8 x10^{-7}m/s	-

4.7 FIELD-SCALE TRIAL

Test Area = 100m x 7m= 700m2

Stabilization depth = 300mm

Soil Bulk Density = 2.211g/cm3 (2211kg/m3)

Optimum CKD dosage = 15% by weight of soil

Optimum Moisture Content = 8.4%

Volume of Soil = Area x Depth

= 700 x 0.3

= 210m3

Dry Weight of soil = Volume x Soil Density

= 210 x 2211

= 464,310 kg =464.31 tons

CKD required=Dry Weight of Soil x %CKD

= 464,310 x 15/100

= 70,000kg (70 tons)

Water Required = Dry Weight of soil x OMC/100

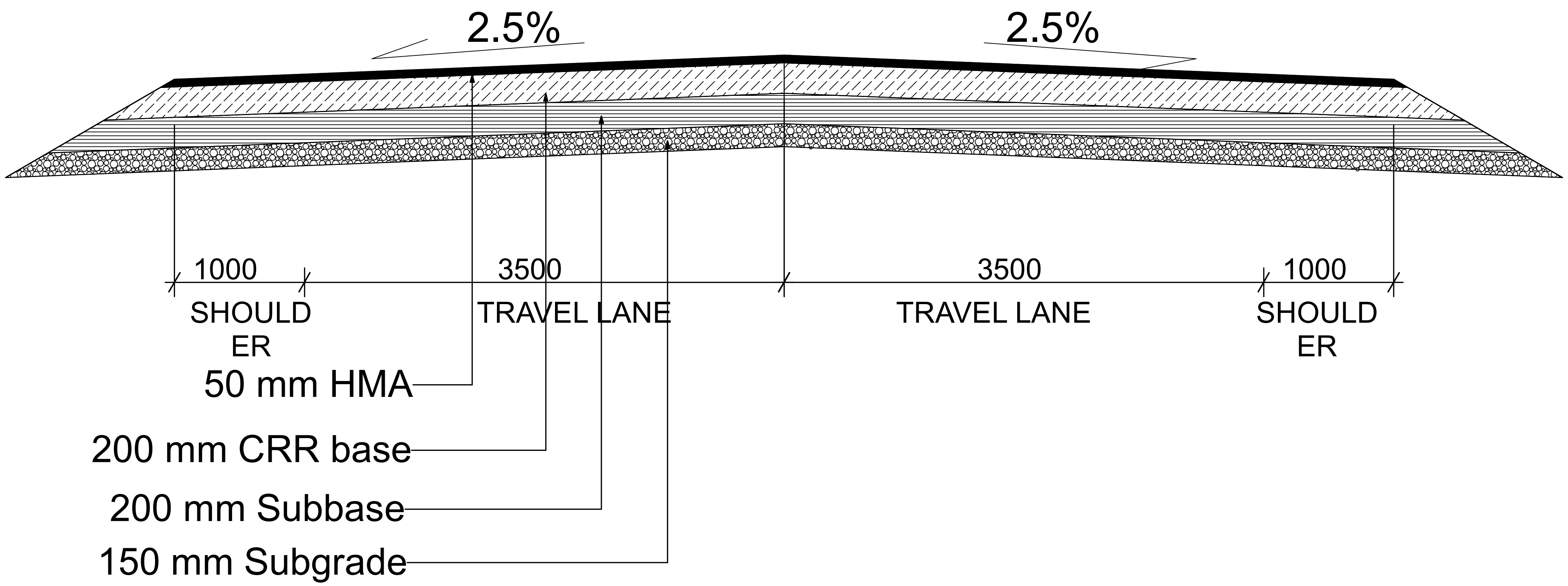
= 464,310 x 8.4/100

= 40,000 kg (40m3 or 40,000 litres)

Mixing method: Mechanical mixing using a grader

Compaction method: Vibratory roller

Curing and Strength: 7-28 days of curing before testing CBR and UCS



PAVEMENT LAYER DETAILS		
PAVEMENT LAYER TYPE	**Thickness**	**Material and Level of Compaction**
Surfacing	50 mm	50 mm Hot Mix Continuously Graded Asphalt (AC 20)
Base	200 mm	200 mm CRR (Coarse type) (min 102% of BS-Heavy Compaction according to BS 1377: Part 4)
Sub-base	200mm	200 mm G45 Gravel (min 98% of BS-Heavy Compaction according to BS 1377: Part 4)
Subgrade	150 mm	150 mm G15 Sandy soil stabilized with 15% cement kiln dust (min 95% of BS-Heavy Compaction according to BS 1377: Part 4)

PROJECT TITLE
ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS FOR SUBGADE CONTSRUCTION

Drawing Name
TYPICAL ROAD CROSS-SECTION

NAME
KABAGAMBE RACHEL

Drawing Scale
1:50 A3

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The neat soil did not meet the requirements for G15 subgrade material according to the Ministry of Works General specifications for Roads and Bridge works 2005 and therefore needed to be stabilized for this purpose.

It was found that the sandy soil sample collected from Paicho road was a clayey sand and a had a PI of 8.7% which lies below the required PI as given by the specifications that states a maximum of 25% for G15 material according to the General specifications for Roads and Bridges. The CBR of the neat soil was 10% which lies below the required CBR In the same specifications that is a minimum of 15%. The soil's properties were below the required standards for G15 due to the loosely bound sand particles in the soil. Therefore, the soil required stabilization to improve the strength parameters to be able to meet the required specifications for a G15 subgrade material.

The strength parameters of the sandy soil stabilized with cement kiln dust varying from 5%, 10%, 15% and 20% were seen to increase registering a 58.5% increase in CBR, a 45% increase in UCS and an overall reduction in permeability of 98.79% at 15% addition of cement kiln dust which was the optimum percentage of cement kiln dust.

At this dosage, several critical parameters indicate an optimal balance between improved mechanical strength and favorable compaction characteristics. For instance, the Maximum Dry Density reaches its peak at 15% CKD, suggesting that the finer CKD particles are effectively filling the voids between the coarser sand grains to enhance particle packing. Simultaneously, the Optimum Moisture Content as at its lowest at this level implying that less water is needed for proper compaction. Although the CBR and UCS values continue to increase with higher CKD content, the observed decrease in MDD and the rebound in OMC at 20% indicate that excessive CKD may lead to a less stable matrix due to the formation of additional fines and microstructural irregularities. Therefore, while higher percentages of CKD can further enhance strength, they may also compromise the soil's overall density and workability.

5.2 RECOMMENDATIONS

More tests should be conducted on cement kiln dust with supplementary silica sources like fly ash, and activators like gypsum for the maximum calcium to silica ratio, which would improve gel stability hence producing a stronger stable soil matrix.

More work should also be done on the implementation of ductile reinforcements to give the stabilized soil resiliency or at least inhibit crack occurrence and propagation, thus increasing the ductility of the stabilized soil matrix and reducing its brittleness. To furnish a better picture of the long term performance properties and durability of the stabilized soil, the research could easily be expanded to include a microstructural analysis of the stabilized matrix (with cement kiln dust) in the future.

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APPENDIX

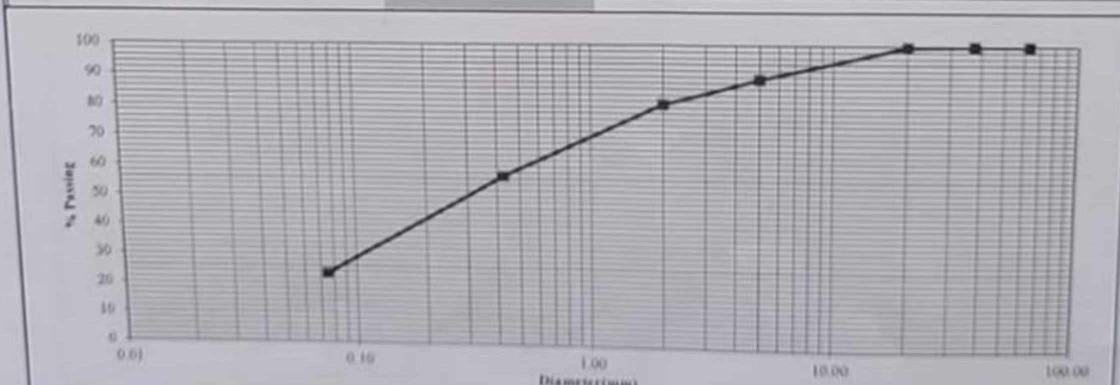
INSTITUTION	STUDENTS NAMES	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

PROJECT : ASSESSING THE USE OF CEMENT KILN DUST AND POLYPROPYLENE FIBER TO STABILIZE SANDY SOILS

PARTICLE SIZE DISTRIBUTION (BS 1377 - 2 - 90)

Test Reference No.:		Lab. Refernece No.:		
Location :(km)	FROM PAICHO ROAD	Dry wt. of sample before washing: (g)		4914.7
Depth: (m)		Dry wt. of sample after washing: (g)		3800.7
Material description:	SANDY SOIL	Date Sampled:	Date Tested:	Technician
		20/Jan/2025	27/Jan/2025	Lab team

Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Grading Limits (G60 & 80)	
63.0	0.0	0	100	100	100
37.5	0.0	0.0	100	80	100
20.0	17.4	0.4	100	60	95
5.0	513.9	10.5	89	30	65
2.00	403.7	8.2	81	20	50
0.425	1186.1	24.1	57	10	30
0.075	1640.4	33.4	23	5	15
Total fines	1153.2	23.5			
Bottom Pan	39.2				
Extracted fines	1114.0				
Total sample	4914.7				
Grading Modulus		1.39			



STIRLING CIVIL ENGINEERING
FOR TESTING LAB
17 FEB 20..
Lab Technician
Materials Engineer
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	REACHEL AND HENRY	Stirling

PROJECT:	ASSESSING THE USE OF CEMENT KILN DUST AND POLYPROPYLENE FIBER TO STABILIZE SANDY SOILS

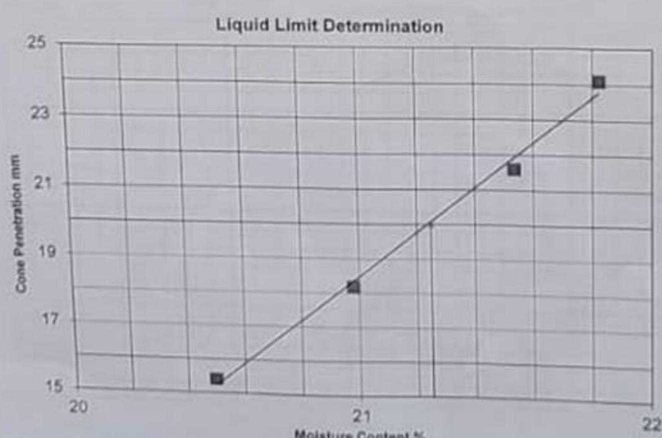
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Material description:	0		Technician:	Lab Team
mix	FROM PAICHO ROAD		Sample Date	12/Jan/2025
Test method	BS 1377: Part 2, 1990:4.3/4.4		Test Date	28/Jan/2025
LAYER	0			
Depth:	0			

PLASTIC LIMIT	Test No.	P4	13		Average
Mass of wet soil + container (g)		45.65	38.52		42.085
Mass of dry soil + container (g)		42.85	36.49		39.67
Mass of container (g)		22.64	22.48		22.56
Mass of moisture (g)		2.8	2.0		2.415
Mass of dry soil (g)		20.21	14.01		17.11
Moisture content %		13.9	14.5		14.2
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.4	18.2	21.6	24.1
penetration (mm)		15.4	18.2	21.6	24.1
AVERAGE		15.4	18.2	21.6	24.1
Container No.		PI6OO	6E	PI33	ME
Mass of wet soil + container (g)		55.19	47.88	56.16	53.10
Mass of dry soil + container (g)		47.01	40.82	47.47	44.84
Mass of container (g)		7.10	7.17	7.12	6.99
Mass of moisture (g)		8.18	7.06	8.69	8.26
Mass of dry soil (g)		39.91	33.65	40.35	37.85
Moisture content (%)		20.5	21.0	21.5	21.8
AVERAGE		20.5	21.0	21.5	21.8



Liquid limit (%)	21.3
Plastic limit (%)	14.2
Plasticity Index (%)	7.1
Linear shrinkage	
Trough No.	R
Trough length (cm)	14.0
Specimen length (cm)	13.6
L.shringage =	0.4
% L.shrinkage =	3.2

Remarks

STIRLING CIVIL ENGINEERING LTD

TESTING LAB

Materials Engineer

P. O. BOX 796, KAMPALA (U)

Lab Technician

STUDENTS

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ECT:	ASSESSING THE USE OF CEMENT KILN DUST AND POLYPROPYLENE FIBER TO STABILIZE SANDY SOILS			
Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
ATION	FROM PAICHO ROAD	20/Jan/25	27/Jan/25	Lab team
rial description:	SANDY SOIL	Natural moisture (%) :	11.0	

TEST DATA

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

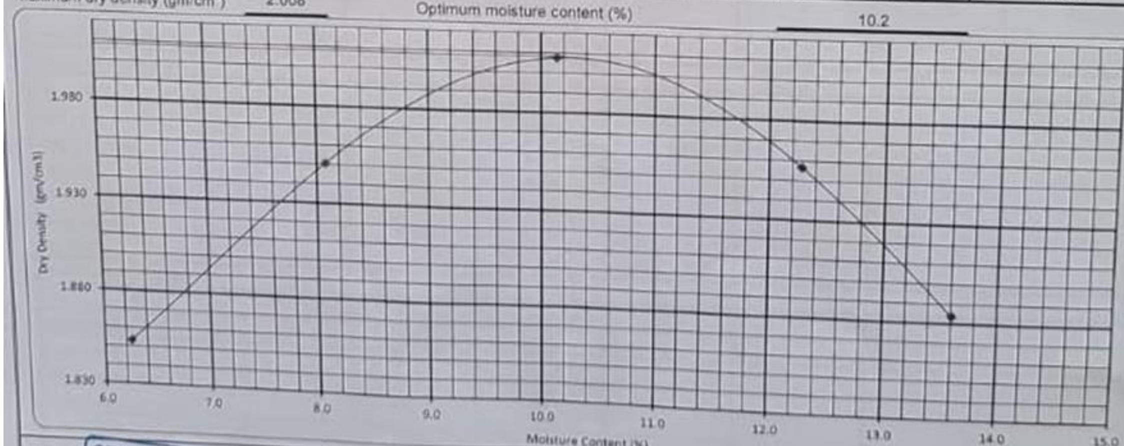
MOISTURE CONTENT DATA

t No.		1	2	3	4	5
No.		A	A	A	A	A
ter Added	cm^3	150	210	270	330	390
ss of Compacted soil + mould	gm	6,246	6,385	6,488	6,474	6,417
ss of Mould	gm	4,277	4,277	4,277	4,277	4,277
ss of Compacted soil	gm	1969	2108	2211	2197	2140
lume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
t density of soil	g/cm^3	1.969	2.108	2.211	2.197	2.140

DATA FOR PROCTOR CURVE

ntainer No.		UMT	2I	BAR	Z6T	BKX
ass of wet soil + Container	gm	2,109.0	2,097.0	2,737.0	2,025.0	2,420.0
ass of dry soil + container	gm	2,032.0	2,000.0	2,559.0	1,892.0	2,226.0
ass of container	gm	800.0	799.0	803.0	809.0	800.0
lass of water added	gm	77	97	178	133	194
lass of dry soil	gm	1232	1201	1756	1083	1426
loisture content	%	6.3	8.1	10.1	12.3	13.6
ry density	g/cm^3	1.853	1.950	2.008	1.957	1.884

Maximum dry density (gm/cm^3) 2.008 Optimum moisture content (%) 10.2



Remarks: STIRLING CIVIL ENGINEERING LTD
FOR TESTING LAB
07 FEB 2025
P.O. BOX 796, KAMPALA (U)

Lab Technician

Materials Engineer

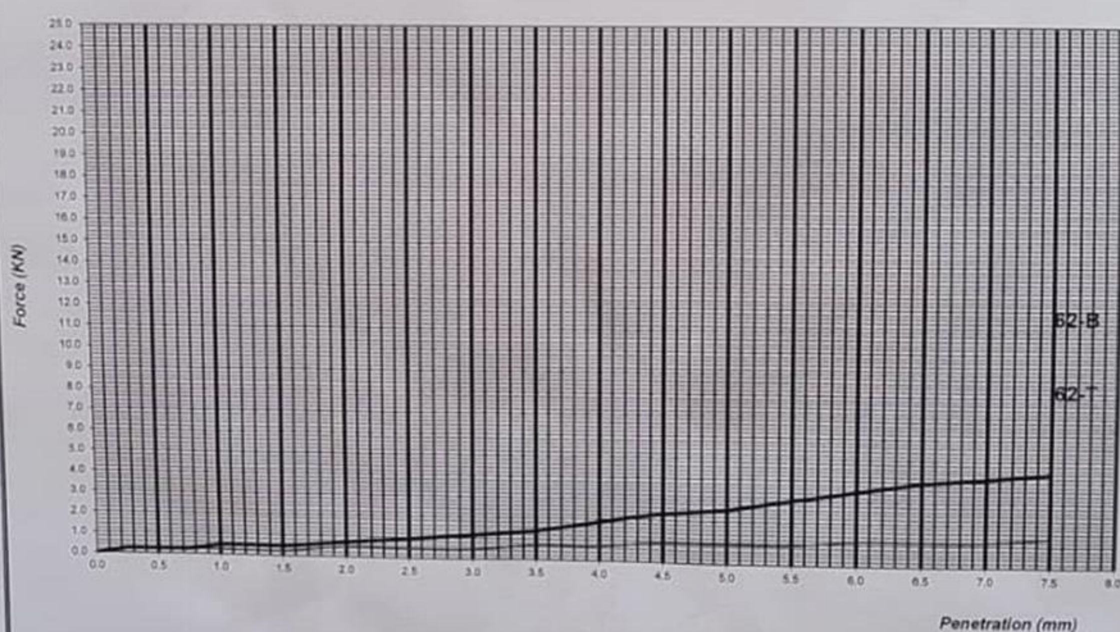
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST AND POLYPROPYLENE FIBER TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:		Testing Date :	28/Jan/25
Depth:		Technician	: Lab team
Sample Description:	SANDY SOIL		

PENETRATION vs FORCE CURVE



	62 blows			
	Force		CBR	
	Bottom	Top	Bottom	Top
2.5 mm Penetration	0.9	0.5	7	3
5.0 mm Penetration	2.5	0.9	13	5
Average	1.7	0.7	9.9	4.1
Retained CBR	9.9			

Observations

CBR= 9.9

For the Lab

Lab. Technician

Materials Engineer

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

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST AND POLYPROPYLENE FIBER TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:	FROM PAICHO ROAD	Casting date :	24/Jan/25
		Testing Date :	28/Jan/25
		Technician :	Lab team
Sample Description	SANDY SOIL	**Volume of Mould used (m^3)**	**2305**

Natural moisture of air dried sample			Volume of water added	
Tin No.	LDD		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	1671		MDD (Mg/m^3)	2.008
Tin + oven dry soil sample (g)	1651		N.M.C (%)	1.6
Tin (g)	419		OMC (%)	10.2
Dry soil sample	1232		Added OMC (%)	8.6
Water (g)	20		Calculated dry wt of soil (g)	5902.6
N.M.C (%)	1.6		Water added (g)	506
Average (%)	1.6		**Water added (mL)**	**506**

Number of blows		62													
Number of layer		5													
Water Content Determination		Before Soaking		After Soaking											
Tare No		BI	-	DJ	-										
Mass of wet sample + Tare	g	680	-	2440	-										
Mass of dry sample + Tare	g	620	-	2241	-										
Mass of Tare	g	65	-	546	-										
Mass of water	g	60	-	199	-										
Mass of dry sample	g	555	-	1695	-										
Water content	%	10.8	-	11.7	-										
Average water Content	%	10.8		11.7											
Density determination															
Mould No		RH													
Mass of mould + soil	g	10290		10336											
Mass of mould	g	5313		5313											
Mass of soil	g	4977		5023											
Volume of the mould	cm3	2305		2305											
Moist density	g/cm3	2.159		2.179											
Dry density	g/cm3	1.949		1.950											
Swell Determination															
Date		Hour		D.Gauge Reding											
Initial reading		96 hrs		9.34											
Final reading				10.29											
Height of the specimen				127											
Height of swell				0.95											
		Swelling(%)		**0.75**											

Observations

STIRLING CIVIL ENGINEERING LTD
07 FEB 2025
For the Lab
P. O. BOX 796, KAMPALA (U)

Lab. Technician	*Materials Engineer*		

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST AND POLYPROPYLENE FIBER TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	20/Jan/25
Location:		Penetration Date	28/Jan/25
Depth :		Technician	:: Lab team
Sample Description :	SANDY SOIL		

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

Speed : mm/min.		Top		Bottom	
Penetration of the plunger (mm)	Time (s)	Reading $*10^3$mm	Force (KN)	Reading $*10^3$mm	Force (KN)
0	0	0	0.0	0	0.0
0.25	12	1	0.2	1	0.2
0.5	24	1	0.2	1	0.2
0.75	35	1	0.2	1	0.2
1	47	1	0.2	2	0.5
1.5	71	1	0.2	2	0.5
2	94	2	0.5	3	0.7
2.5	118	2	0.5	4	0.9
3	142	2	0.5	5	1.2
3.5	165	3	0.7	6	1.4
4	189	3	0.7	8	1.8
4.5	213	4	0.9	10	2.3
5	236	4	0.9	11	2.5
5.5	260	4	0.9	13	3.0
6	283	5	1.2	15	3.5
6.5	307	5	1.2	17	3.9
7	331	5	1.2	18	4.2
7.5	354	6	1.4	19	4.4

Observations

STIRLING CIVIL ENGINEERING LTD For the Contractor

Lab. Technician 07 FEB 2025

P. O. BOX 796, KAMPALA (U)

TERZAGHI'S
Soils & Materials Lab

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Document No.: TZG/LFHP/TF-12	
Revision No.	: 00
Revision Date	: 1st/02/2022
Approved by	: MD

SOIL HYDRAULIC CONDUCTIVITY BY FALLING HEAD METHOD

Project:	Assessing the use of cement kiln dust to stablise sandy soils		
Client:	Student		
Location/Chainage:	Paicho road - Gulu district	**Offset(m):**	NA
Test Pit/Borehole No.:	TP 1	**Sampling Date:**	16-Jan-25
Depth (m):	1	**Testing Date:**	5-Feb-25
Sample Description	Gravelly sand	**Technician:**	Fred

Test Information

Reference Method:	ASTM D5856 - 95 (Method B)	**Initial Bulk Density (Kg/m^3)**	1859.5
Mass of Ring + Specimen (Kg)	0.7197	**Specific gravity, G_s**	2.61
Mass of Ring (Kg)	0.2736	**MC before test, w (%)**	3.4
Mass of Test Specimen, M (Kg)	0.4461	**Initial Dry Density, ρ_{di} (Kg/m^3)**	1798.8
Length of Specimen (m)	0.0589	**Specimen Porosity, n**	0.3108
Specimen Diameter (m)	0.072	**Volume of pores, V_p (m^3)**	7.457E-05
Area of Specimen, A (m^2)	0.004073	**Influent cross section area, a (m^2)**	0.00010001
Volume of Specimen, V (m^3)	0.000240		

Permeation

Test No.	h_1 (m)	h_2(m)	t (s)	Inflow volume (m^3)	Out flow volume (m^3)	outflow/ in flow ratio	Hydraulic Conductivity, K (m/s)	Temp °c	Correction factor, R_T	Corrected Hydraulic Conductivity, K_{20}
1	0.132	0.005	25.88	1.27E-05	1.08E-05	0.85	1.83E-04	28.5	0.832	1.52E-04
2	0.245	0.132	19.32	1.13E-05	1.05E-05	0.93	4.63E-05	28	0.832	3.85E-05
3	0.345	0.245	14.28	1.00E-05	1.04E-05	1.04	3.47E-05	28	0.832	2.88E-05
									Average	7.3E-05

After Test

MC after test, w (%)	15.2	**Final Dry Density, ρ_{df} (Kg/m^3)**	1491.31
Oven Dried Mass, M_s (Kg)	0.3578	**Pore Volumes of inflow, N_{PV}**	0.456
Final Degree of Saturation, S	59		

Formulas Used:

$$V = \frac{\pi D^2 L}{4} \qquad \rho_{di} = \frac{M}{(1+w)V} \qquad n = 1 - \frac{\rho_{di}}{G_s \rho_w} \qquad V_p = nV \qquad S = \frac{w}{\frac{\rho_w}{\rho_{df}} - \frac{1}{G_s}} \times 100 \qquad N_{PV} = \frac{Q_{in}}{V_p} \qquad k = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right)$$

Checked by

Laboratory Engineer

Aproved by

Technical Manager

TERZAGHI'S SOILS & MATERIALS LAB LTD
07 FEB 2025
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Page 1 of 1

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL AND BAGONZA HENRY	Stirling

PROJECT:	ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

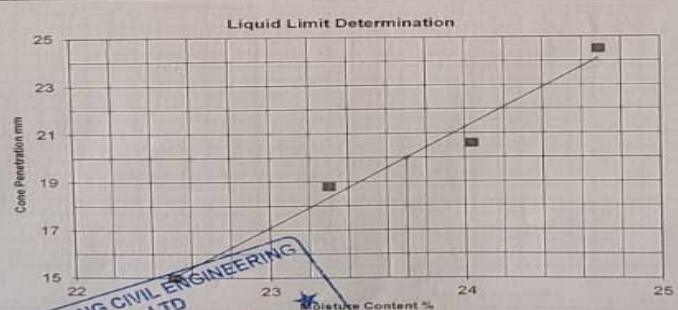
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Material description:	SANDY SOIL WITH 5% CKD	Technician:	Lab Team
mix	FROM PAICHO ROAD	Sample Date	12/Jan/2025
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	28/Jan/2025
LAYER	0		
Depth:	0		

PLASTIC LIMIT	Test No.	44	SO		Average
Mass of wet soil + container (g)		35.6	34.12		34.86
Mass of dry soil + container (g)		33.57	32.55		33.06
Mass of container (g)		21.22	22.91		22.065
Mass of moisture (g)		2.03	1.6		1.8
Mass of dry soil (g)		12.35	9.64		10.995
Moisture content %		16.4	16.3		16.4
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.0	18.8	20.6	24.5
penetration (mm)		15.0	18.8	20.6	24.5
AVERAGE		15.0	18.8	20.6	24.5
Container No.		FORD	PX	PI43	PI8
Mass of wet soil + container (g)		56.74	59.86	62.07	48.57
Mass of dry soil + container (g)		47.61	49.84	51.42	40.29
Mass of container (g)		7.05	6.84	7.11	6.75
Mass of moisture (g)		9.13	10.02	10.65	8.28
Mass of dry soil (g)		40.56	43	44.31	33.54
Moisture content (%)		22.5	23.3	24.0	24.7
AVERAGE		22.5	23.3	24.0	24.7



Liquid limit (%)	23.7
Plastic limit (%)	15.7
Plasticity Index (%)	8.0
Linear shrinkage	
Trough No.	3
Trough length (cm)	14.0
Specimen length (cm)	13.1
L.shringage =	0.9
% L.shrinkage =	6.4

Remarks:

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

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

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

PROJECT:	ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
LOCATION	FROM PAICHO ROAD	20/Jan/25	1/Mar/25	Lab team
Material description:	SANDY SOIL STABILISED WITH 5% CEMENT KILN DUST	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

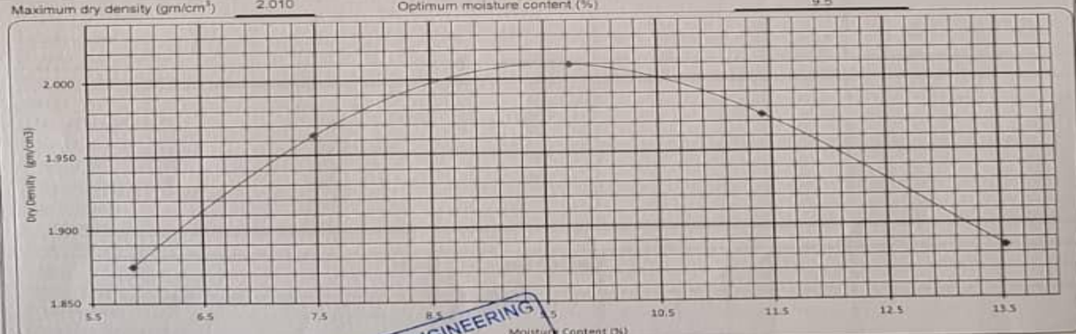
MOISTURE CONTENT DATA

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	5,190	5,315	5,410	5,405	5,345
Mass of Mould	gm	3,205	3,205	3,205	3,205	3,205
Mass of Compacted soil	gm	1985	2110	2205	2200	2140
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.985	2.110	2.205	2.200	2.140

DATA FOR PROCTOR CURVE

Container No.		UCU	CR7	UMI	YY	Y2Y
Mass of wet soil + Container	gm	2,595.0	2,365.0	2,210.0	2,590.0	2,615.0
Mass of dry soil + container	gm	2,496.0	2,254.0	2,085.0	2,405.0	2,401.0
Mass of container	gm	810.0	770.0	800.0	785.0	820.0
Mass of water added	gm	99	111	125	185	214
Mass of dry soil	gm	1686	1484	1285	1620	1581
Moisture content	%	5.9	7.5	9.7	11.4	13.5
Dry density	g/cm^3	1.875	1.963	2.010	1.975	1.885

Maximum dry density (gm/cm^3) 2.010 Optimum moisture content (%) 9.5



Remarks:

FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD
MAR 2025
Materials Engineer
P.O. BOX 798, KAMPALA (U)

Lab Technician

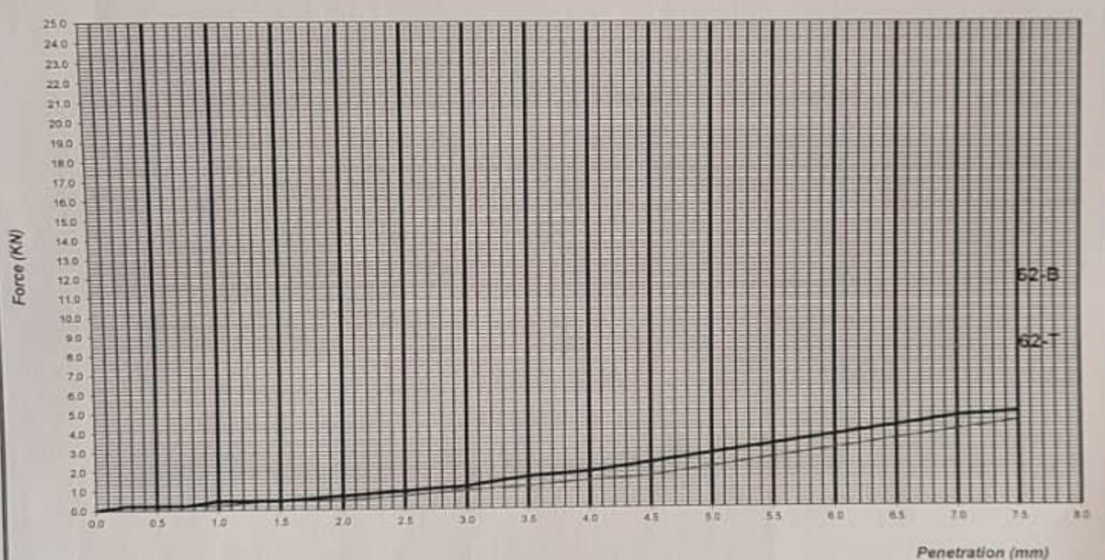
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSIGNG THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:		Testing Date :	9/Mar/25
Depth:		Technician	: Lab team
Sample Description:	SANDY SOIL STABILISED WITH 5% CEMENT KILN DUST		

PENETRATION vs FORCE CURVE



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	0.9	0.7	[illegible]	[illegible]								
5.0 mm Penetration	2.8	[illegible]	14	10								
Average	[illegible]	[illegible]	10.5	7.8								
Retained CBR	10.5											

Observations	CBR = 10.5	
For the Lab		
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	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:	FROM PAICHO ROAD	Casting date :	2/Mar/25
		Testing Date :	9/Mar/25
Sample Description:	SANDY SOIL STABILISED WITH 5% CEMENT KILN DUST	Technician :	Lab team
		Volume of Mould used (m^3)	2305

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	MJR		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2735		MDD (Mg/m^3)	2.021
Tin + oven dry soil sample (g)	2723		N.M.C (%)	0.6
Tin (g)	790		OMC (%)	8.6
Dry soil sample	1933		Added OMC (%)	8.0
Water (g)	12		Calculated dry wt of soil (g)	5962.8
N.M.C (%)	0.6		Water added (g)	476
Average (%)	0.6		**Water added (mL)**	476

Number of blows		62			
Number of layer		5			
Water Content Determination		Before Soaking		After Soaking	
Tare No		ZION	-	BA	-
Mass of wet sample + Tare	g	1305	-	1670	-
Mass of dry sample + Tare	g	1232	-	1562	-
Mass of Tare	g	441	-	768	-
Mass of water	g	73	-	108	-
Mass of dry sample	g	791	-	794	-
Water content	%	9.2	-	13.6	-
Average water Content	%	9.2		13.6	
Density determination					
Mould No		K			
Mass of mould + soil	g	11925		12159	
Mass of mould	g	6571		6571	
Mass of soil	g	5354		5588	
Volume of the mould	cm3	2305		2305	
Moist density	g/cm3	2.323		2.424	
Dry density	g/cm3	2.127		2.134	
Swell Determination					
Date		Hour		D.Gauge Reding	
Initial reading		96 hrs		12.5	
Final reading				13.14	
Height of the specimen				127	
Height of swell				0.64	
		Swelling (%)		0.50	
Observations					

For the Lab.		
Lab. Technician	*Materials Engineer*	

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 790, KAMPALA (U)
2? MAR 2025

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	20/Jan/25
Location:		Penetration Date	9/Mar/25
Depth :		Technician	:: Lab team
Sample Description :	: SANDY SOIL STABILISED WITH 5% CEMENT KILN DUST		

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

Speed : ....mm/min.		Top		Bottom	
Penetration of the plunger (mm)	Time (s)	Reading $*10^3$mm	Force (KN)	Reading $*10^3$mm	Force (KN)
0	0	0	0.0	0	0.0
0.25	12	1	0.2	1	0.2
0.5	24	1	0.2	1	0.2
0.75	35	1	0.2	1	0.2
1	47	1	0.2	2	0.5
1.5	71	2	0.5	2	0.5
2	94	2	0.5	3	0.7
2.5	118	3	0.7	4	0.9
3	142	4	0.9	5	1.2
3.5	165	5	1.2	7	1.6
4	189	6	1.4	8	1.8
4.5	213	7	1.6	10	2.3
5	236	9	2.1	12	2.8
5.5	260	11	2.5	14	3.2
6	283	13	3.0	16	3.7
6.5	307	15	3.5	18	4.2
7	331	17	[illegible]	20	4.6
7.5	354	[illegible]	[illegible]	[illegible]	4.9

Observations

	For the Contractor
Lab. Technician	Materials Engineer

STIRLING CIVIL ENGINEERING LTD
21 MAR 2025
KAMPALA (U)

TERZAGHI'S
Soils & Materials Lab

Block 109, Plot No. 225, Kireka, Namugongo Road.
P. O. Box 860003, Kireka, Kampala - Uganda
Tel.: +256200900287, +256709013553
Email: info@terzaghislab.com,
Website: www.terzaghislab.com

SOIL HYDRAULIC CONDUCTIVITY BY FALLING HEAD METHOD

Project:	Assessing the use of cement kiln dust to stabilize sandy soils		
Client:	Kabagambe Rachel and Bagonza Henry		
Location/Chainage:	Paicho road – Gulu district	**Offset (m)**	
Test Pit/Borehole No.:	TP 1	**Sampling Date:**	7/3/2025
Depth (m):	1	**Testing date:**	9/3/2025
Sample Description	Sandy soil with 5% Cement Kiln Dust	**Technician:**	NS

Test Information

Reference Method:	ASTM D5856-95 (Method B)	Initial Bulk Density (Kg/m³)	1859.5
Mass of Ring + Specimen (Kg)	0.7197	Specific gravity, Gs	2.61
Mass of Ring (Kg)	0.2736	MC before test, w (%)	3.4
Mass of Test Specimen, M (Kg)	0.4461	Initial Dry Density, ρ_{di} (Kg/m³)	1798.8
Length of Specimen (m)	0.0589	Specimen Porosity, *n*	0.3108
Specimen Diameter (m)	0.072	Volume of pores, V_p (m³)	7.45E-05
Area of Specimen, A (m²)	0.004073	Influent cross section area, a (m²)	0.00010001
Volume of Specimen, V (m³)	0.000240		

Permeation

Test No.	H_1 (m)	H_2(m)	T (s)	Inflow volume (m³)	Outflow volume (m³)	Outflow/ inflow ratio	Hydraulic Conductivity, K (m/s)	Temp °c	Correction factor, R_T	Corrected Hydraulic Conductivity, K_{20}
1	0.183	0.005	25.88	1.27E-05	1.08E-05	0.85	1.23E-04	28.5	0.832	1.91E-05
2	0.394	0.132	19.32	1.13E-05	1-05E-05	0.93	4.57E-05	28	0.832	3.11E-06
3	0.872	0.245	14.28	1.00E-05	1.04E-05	1.04	3.03E-05	28	0.832	2.02E-06
										9.4E-06

After Test

MC after test, w (%)	17.6	Final Dry Density, ρ_{df} (Kg/m³)	1522.31
Oven Dried Mass, M_s (Kg)	0.542	Pore Volumes of inflow, N_{PV}	0.548
Final Degree of Saturation, S	32		

Formulas Used:

$$V = \frac{\pi D^2 L}{4} \quad \rho di = \frac{M}{(1+w)V} \quad n = 1 - \frac{\rho di}{Gs\rho w} \quad Vp = nV \quad S = \frac{w}{\left(\frac{\rho w}{\rho df}\right)\left(\frac{1}{Gs}\right)} \times 100 \quad Npv = \frac{Qin}{Vp} \quad k = \frac{aL}{At}\ln\left(\frac{h1}{h2}\right)$$

Prepared by:

Laboratory Technician

Approved by:

Technical Manager

TERZAGHI'S SOILS & MATERIALS LAB LTD
21 MAR 2025
P.O. Box 860003, Kampala
info@terzaghislab.com
Block 109, Plot 225, Kireka

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL AND BAGONZA HENRY	Stirling

PROJECT:	ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

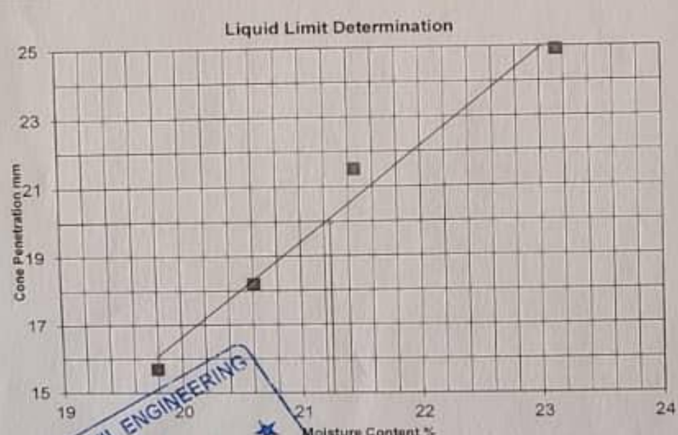
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Material description:	SANDY SOIL WITH 10% CKD	Technician:	Lab Team
mix	FROM PAICHO ROAD	Sample Date	12/Jan/2025
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	28/Jan/2025
LAYER	0		
Depth:			

PLASTIC LIMIT	Test No.	OG	BA		Average
Mass of wet soil + container (g)		35.43	37.31		36.37
Mass of dry soil + container (g)		33.47	35.4		34.435
Mass of container (g)		21.38	23.12		22.25
Mass of moisture (g)		1.96	1.9		1.935
Mass of dry soil (g)		12.09	12.28		12.185
Moisture content %		16.2	15.6		15.9
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.7	18.2	21.5	24.9
penetration (mm)		15.7	18.2	21.5	24.9
AVERAGE		15.7	18.2	21.5	24.9
Container No.		PI38	PI52	PIVPN	BI5
Mass of wet soil + container (g)		51.63	54.42	55.05	69.14
Mass of dry soil + container (g)		44.28	46.35	46.56	57.46
Mass of container (g)		7.14	7.19	6.98	6.98
Mass of moisture (g)		7.35	8.07	8.49	11.68
Mass of dry soil (g)		37.14	39.16	39.58	50.48
Moisture content (%)		19.8	20.6	21.5	23.1
AVERAGE		19.8	20.6	21.5	23.1



Liquid limit (%)	21.3
Plastic limit (%)	13.4
Plasticity Index (%)	7.9
Linear shrinkage	
Trough No.	K
Trough length (cm)	14.0
Specimen length (cm)	13.5
L.shringage =	0.5
% L.shrinkage =	3.6

Remarks:

TESTING LAB		STUDENTS
Materials Engineer Lab Technician		

STIRLING CIVIL ENGINEERING LTD P.O. BOX 4628, KAMPALA (U)

INSTITUTION	STUDENTS NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

PROJECT:	ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS			
Test Reference No.	Lab. Reference No.	Date Sampled	Date Tested	Technician
LOCATION	FROM PAICHO ROAD	20/Jan/25	1/Mar/25	Lab team
Material description:	SANDY SOIL STABILISED WITH 10% CEMENT KILN DUST	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

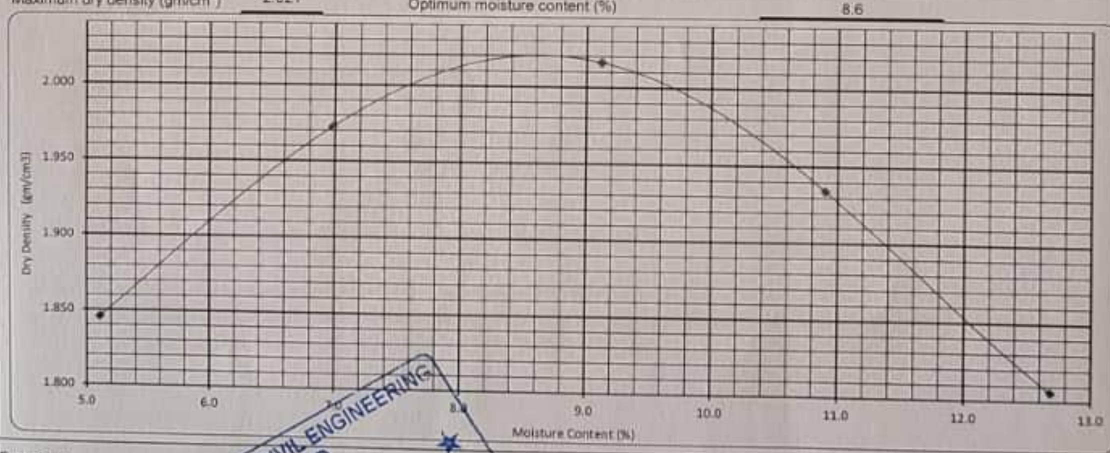
MOISTURE CONTENT DATA

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	6,210	6,380	6,470	6,415	6,305
Mass of Mould	gm	4,270	4,270	4,270	4,270	4,270
Mass of Compacted soil	gm	1940	2110	2200	2145	2035
Volume of mould	cm^3	1,000	1,000	1,000	1,000	1,000
Wet density of soil	g/cm^3	1.940	2.110	2.200	2.145	2.035

DATA FOR PROCTOR CURVE

Container No.		KT	Z6T	RWE	NMT	NBN
Mass of wet soil + Container	gm	2,580.0	2,445.0	2,705.0	2,255.0	2,480.0
Mass of dry soil + container	gm	2,493.0	2,338.0	2,547.0	2,109.0	2,290.0
Mass of container	gm	790.0	805.0	815.0	770.0	792.0
Mass of water added	gm	87	107	158	146	190
Mass of dry soil	gm	1703	1533	1732	1339	1498
Moisture content	%	5.1	7.0	9.1	10.9	12.7
Dry density	g/cm^3	1.846	1.972	2.016	1.934	1.806

Maximum dry density (gm/cm^3) 2.021 Optimum moisture content (%) 8.6



Remarks:

STIRLING CIVIL ENGINEERING LTD

TESTING LAB

Lab Technician

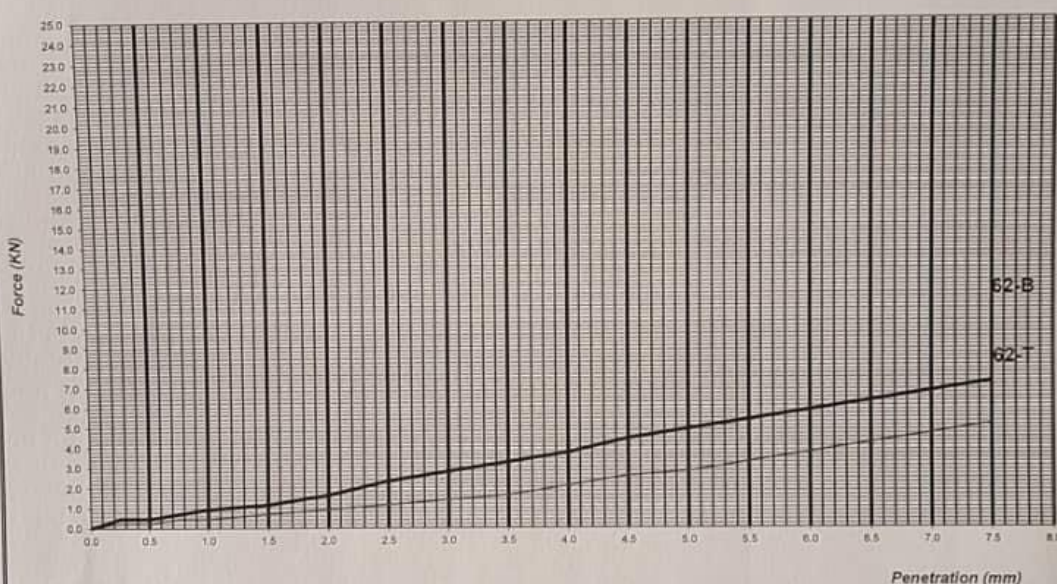
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:		Testing Date :	9/Mar/25
Depth:		Technician	: Lab team
Sample Description:	SANDY SOIL STABILISED WITH 10% CEMENT KILN DUST		

PENETRATION vs FORCE CURVE



	62 blows											
	Force		CBR									
	Bottom	Top	Bottom	Top								
2.5 mm Penetration	2.3	1.2	17	9								
5.0 mm Penetration	4.9	2.8	24	14								
Average	3.6	2.0	[illegible]	11.3								
Retained CBR	13.3											

Observations CBR= 13.3

For the Lab

Lab. Technician Materials Engineer

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date	20/Jan/25
Location:		Penetration Date	9/Mar/25
Depth :		Technician	: Lab team
Sample Description :	SANDY SOIL STABILISED WITH 10% CEMENT KILN DUST		

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

Speed : ....mm/min.		Top		Bottom	
Penetration of the plunger (mm)	Time (s)	Reading $*10^3$mm	Force (KN)	Reading $*10^3$mm	Force (KN)
0	0	0	0.0	0	0.0
0.25	12	1	0.2	2	0.5
0.5	24	1	0.2	2	0.5
0.75	35	2	0.5	3	0.7
1	47	2	0.5	4	0.9
1.5	71	3	0.7	5	1.2
2	94	4	0.9	7	1.6
2.5	118	5	1.2	10	2.3
3	142	6	1.4	12	2.8
3.5	165	7	1.6	14	3.2
4	189	9	2.1	16	3.7
4.5	213	11	2.5	19	4.4
5	236	12	2.8	21	4.9
5.5	260	14	3.2	23	5.3
6	283	16	3.7	25	5.8
6.5	307	18	4.2	27	6.2
7	331	20	[illegible]	29	6.7
7.5	354	[illegible]	5.1	31	7.2

Observations

STIRLING CIVIL ENGINEERING LTD

For the Contractor.

Lab. Technician

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS 1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:	FROM PAICHO ROAD	Casting date :	2/Mar/25
		Testing Date :	9/Mar/25
Sample Description:	SANDY SOIL STABILISED WITH 10% CEMENT KILN DUST	Technician :	Lab team
		Volume of Mould used (m^3)	**2305**

Natural moisture of air dried sample			**Volume of water added**	
Tin No.	FDC		Mass of air dried soil (g)	6000
Tin + air dried soil sample (g)	2365		MDD (Mg/m^3)	2.010
Tin + oven dry soil sample (g)	2354		N.M.C (%)	0.7
Tin (g)	805		OMC (%)	9.5
Dry soil sample	1549		Added OMC (%)	8.8
Water (g)	11		Calculated dry wt of soil (g)	5957.4
N.M.C (%)	0.7		Water added (g)	**524**
Average (%)	0.7		**Water added (mL)**	**524**

Number of blows		62								
Number of layer		5								
Water Content Determination		Before Soaking		After Soaking						
Tare No		DAD	-	KT	-					
Mass of wet sample + Tare	g	679	-	1471	-					
Mass of dry sample + Tare	g	631	-	1396	-					
Mass of Tare	g	118	-	794	-					
Mass of water	g	48	-	75	-					
Mass of dry sample	g	513	-	602	-					
Water content	%	9.4	-	12.5	-					
Average water Content	%	9.4		12.5						
Density determination										
Mould No		5								
Mass of mould + soil	g	12195		12361						
Mass of mould	g	6846		6846						
Mass of soil	g	5349		5515						
Volume of the mould	cm3	2305		2305						
Moist density	g/cm3	2.321		2.393						
Dry density	g/cm3	2.122		2.128						
Swell Determination										
Date		Hour		D.Gauge Reding						
Initial reading		96 hrs		9.2						
Final reading				9.62						
Height of the specimen				127						
Height of swell				0.42						
		Swelling(%)		0.33						

Observations

For the Lab

Lab. Technician

STIRLING CIVIL ENGINEERING LTD
MAR 2025
P.O. BOX 248 KAMPALA (U)
Materials Engineer

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL AND BAGONZA HENRY	Stirling

PROJECT: ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

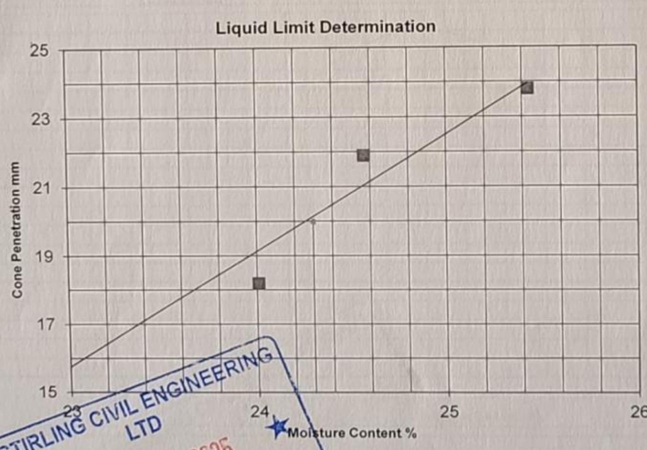
ATTERBERG LIMITS

Liquid limit (cone penotrometer) and plastic limit

Material description:	SANDY SOIL STABILISED WITH 15% C	Technician:	Lab Team
mix	FROM PAICHO ROAD	Sample Date	12/Jan/2025
Test method	BS 1377: Part 2, 1990:4.3/4.4	Test Date	28/Jan/2025
LAYER	SANDY SOIL STABILISED WITH 15% CEMENT KILN DUST		
Depth:	0		

PLASTIC LIMIT	Test No.	OG	DT		Average
Mass of wet soil + container (g)		31.31	29.32		30.315
Mass of dry soil + container (g)		29.88	28.37		29.125
Mass of container (g)		21.4	22.75		22.075
Mass of moisture (g)		1.43	0.9		1.19
Mass of dry soil (g)		8.48	5.62		7.05
Moisture content %		16.9	16.9		16.9
AVERAGE					

LIQUID LIMIT	Test No	1	2	3	4
Initial gauge reading (mm)		0	0	0	0
Final gauge reading (mm)		15.9	18.2	21.9	23.8
penetration (mm)		15.9	18.2	21.9	23.8
AVERAGE		15.9	18.2	21.9	23.8
Container No.		PI57	KO	PI53	PI8II
Mass of wet soil + container (g)		60.49	64.74	67.49	67.63
Mass of dry soil + container (g)		50.47	53.54	55.86	55.39
Mass of container (g)		6.85	6.89	8.52	7.26
Mass of moisture (g)		10.02	11.2	11.63	12.24
Mass of dry soil (g)		43.62	46.65	47.34	48.13
Moisture content (%)		23.0	24.0	24.6	25.4
AVERAGE		23.0	24.0	24.6	25.4



Liquid limit (%)	24.3
Plastic limit (%)	16.9
Plasticity Index (%)	7.4
Linear shrinkage	
Trough No.	I
Trough length (cm)	14.0
Specimen length (cm)	12.9
L.shringage =	1.1
% L.shrinkage =	7.9

Remarks:

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 56, KAMPALA (U)
2 MAR 2025

TESTING LAB		STUDENTS
Materials Engineer		
Lab Technician		

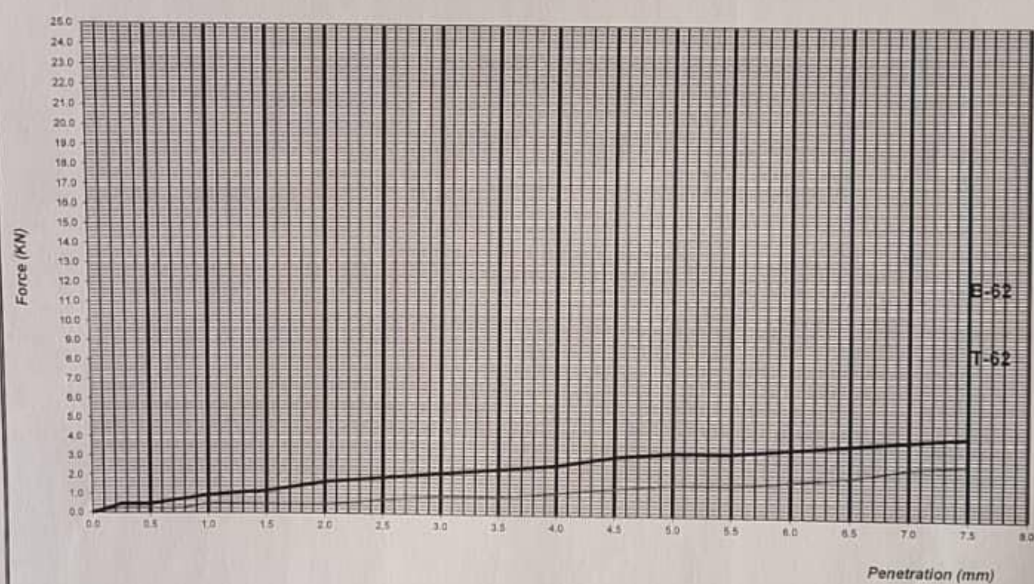
Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No.:	Sampling Date :	20/Jan/25
Location:		Testing Date :	7/Mar/25
Depth:		Technician	: Lab team
Sample Description:	SANDY SOIL STABILISED WITH 15% CEMENT KILN DUST		

PENETRATION vs FORCE CURVE



	62 blows			
	Force		CBR	
	Bottom	Top	Bottom	Top
2.5 mm Penetration	1.8	0.7	14	5
5.0 mm Penetration	3.2	1.6	[illegible]	8
Average	2.5	[illegible]	15.1	6.7
Retained CBR	15.1			
Observations	CBR= 15.1			
For the Lab				
Lab. Technician				

STIRLING CIVIL ENGINEERING LTD
2 MAR 2025
Materials Engineer
P.O. BOX 296, KAMPALA (U)

Institution	Students Names	Testing Lab
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KABAGAMBE RACHEL & BAGONZA HENRY	Stirling

ASSESSING THE USE OF CEMENT KILN DUST TO STABILIZE SANDY SOILS

CALIFORNIA BEARING RATIO TEST (BS1377 Part 4)

Test sample reference :	Laboratory Reference No. :	Sampling Date	20/Jan/25
Location:		Penetration Date	7/Mar/25
Depth :		Technician	: : Lab team
Sample Description :	SANDY SOIL STABILISED WITH 15% CEMENT KILN DUST		

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

Speed : .... mm/min.		Top		Bottom	
Penetration of the plunger (mm)	Time (s)	Reading $*10^3$mm	Force (KN)	Reading $*10^3$mm	Force (KN)
0	0	0	0.0	0	0.0
0.25	12	1	0.2	2	0.5
0.5	24	1	0.2	2	0.5
0.75	35	1	0.2	3	0.7
1	47	2	0.5	4	0.9
1.5	71	2	0.5	5	1.2
2	94	2	0.5	7	1.6
2.5	118	3	0.7	8	1.8
3	142	4	0.9	9	2.1
3.5	165	4	0.9	10	2.3
4	189	5	1.2	11	2.5
4.5	213	6	1.4	13	3.0
5	236	7	1.6	14	3.2
5.5	260	7	1.6	14	3.2
6	283	8	1.8	15	3.5
6.5	307	9	2.1	16	[illegible]
7	331	11	2.5	[illegible]	3.9
7.5	354	12	[illegible]	[illegible]	[illegible]

Observations

For the Contractor	
Lab. Technician	Materials Engineer

STIRLING CIVIL ENGINEERING LTD
2 MAR 2025
P.O. BOX 795, KAMPALA (U)

TERZAGHI'S
Soils & Materials Lab

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SOIL HYDRAULIC CONDUCTIVITY BY FALLING HEAD METHOD

Project:	Assessing the use of cement kiln dust to stabilize sandy soils		
Client:	Kabagambe Rachel and Bagonza Henry		
Location/Chainage:	Paicho road – Gulu district	**Offset (m)**	
Test Pit/Borehole No.:	TP 1	**Sampling Date:**	7/3/2025
Depth (m):	1	**Testing date:**	9/3/2025
Sample Description	Sandy soil with 15% Cement Kiln Dust	**Technician:**	NS

Test Information			
Reference Method:	ASTM D5856-95 (Method B)	Initial Bulk Density (Kg/m³)	1859.5
Mass of Ring + Specimen (Kg)	0.7197	Specific gravity, Gs	2.61
Mass of Ring (Kg)	0.2736	MC before test, w (%)	3.4
Mass of Test Specimen, M (Kg)	0.4461	Initial Dry Density, ρ_{di} (Kg/m³)	1798.8
Length of Specimen (m)	0.0589	Specimen Porosity, *n*	0.4634
Specimen Diameter (m)	0.072	Volume of pores, V_p (m³)	9.32E-06
Area of Specimen, A (m²)	0.005638	Influent cross section area, a (m²)	0.00010001
Volume of Specimen, V (m³)	0.000353		

Permeation										
Test No.	H_1 (m)	H_2(m)	T (s)	Inflow volume (m³)	Outflow volume (m³)	Outflow/ inflow ratio	Hydraulic Conductivity, K (m/s)	Temp °c	Correction factor, R_T	Corrected Hydraulic Conductivity, K_{20}
1	0.834	0.005	25.88	1.27E-05	1.08E-05	0.85	2.34E-04	28.5	0.832	7.04E-06
2	0.745	0.132	19.32	1.13E-05	1-05E-05	0.93	9.80E-05	28	0.832	9.48E-07
3	0.254	0.245	14.28	1.00E-05	1.04E-05	1.04	8.61E-05	28	0.832	8.53E-07
										8.8E-07

After Test			
MC after test, w (%)	17.4	Final Dry Density, ρ_{df} (Kg/m³)	1672.98
Oven Dried Mass, M_S (Kg)	0.5271	Pore Volumes of inflow, N_{PV}	0.362
Final Degree of Saturation, S	66		

Formulas Used:

$$V = \frac{\pi D^2 L}{4} \quad \rho di = \frac{M}{(1+w)V} \quad n = 1 - \frac{\rho di}{Gs\rho w} \quad Vp = nV \quad S = \frac{w}{\left(\frac{\rho w}{\rho df}\right)\left(\frac{1}{Gs}\right)} \times 100 \quad Npv = \frac{Qin}{Vp} \quad k = \frac{aL}{At}\ln\left(\frac{h1}{h2}\right)$$

Prepared by:

Laboratory Technician

Approved by:

Technical Manager

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21 MAR 2025
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Project:	Assessing the use of cement kiln dust to stabilize sandy soils		
Client:	Kabagambe Rachel and Bagonza Henry		
Location/Chainage:	Paicho road – Gulu district	**Offset (m)**	
Test Pit/Borehole No.:	TP 1	**Sampling Date:**	7/3/2025
Depth (m):	1	**Testing date:**	9/3/2025
Sample Description	Sandy soil with 20% Cement Kiln Dust	**Technician:**	NS

Test Information

Reference Method:	ASTM D5856-95 (Method B)	Initial Bulk Density (Kg/m^3)	1859.5
Mass of Ring + Specimen (Kg)	0.7197	Specific gravity, Gs	2.61
Mass of Ring (Kg)	0.2736	MC before test, w (%)	3.4
Mass of Test Specimen, M (Kg)	0.4593	Initial Dry Density, ρ_{di} (Kg/m^3)	1798.8
Length of Specimen (m)	0.0723	Specimen Porosity, *n*	0.2763
Specimen Diameter (m)	0.075	Volume of pores, V_p (m^3)	7.76E-06
Area of Specimen, A (m^2)	0.005044	Influent cross section area, a (m^2)	0.00010001
Volume of Specimen, V (m^3)	0.000327		

Permeation

Test No.	H_1 (m)	H_2(m)	T (s)	Inflow volume (m^3)	Outflow volume (m^3)	Outflow/ inflow ratio	Hydraulic Conductivity, K (m/s)	Temp °c	Correction factor, R_T	Corrected Hydraulic Conductivity, K_{20}
1	0.334	0.005	25.88	1.27E-05	1.08E-05	0.85	2.34E-04	28.5	0.832	8.99E-06
2	0.887	0.132	19.32	1.13E-05	1-05E-05	0.93	9.80E-05	28	0.832	3.22E-07
3	0.385	0.245	14.28	1.00E-05	1.04E-05	1.04	8.61E-05	28	0.832	5.83E-07
										4.3E-07

After Test

MC after test, w (%)	15.6	Final Dry Density, ρ_{df} (Kg/m^3)	1410.83
Oven Dried Mass, M_s (Kg)	0.4620	Pore Volumes of inflow, N_{PV}	0.398
Final Degree of Saturation, S	54		

Formulas Used:

$$V = \frac{\pi D^2 L}{4} \quad \rho di = \frac{M}{(1+w)V} \quad n = 1 - \frac{\rho di}{Gs\rho w} \quad Vp = nV \quad S = \frac{w}{\left(\frac{\rho w}{\rho df}\right)\left(\frac{1}{Gs}\right)} \times 100 \quad Npv = \frac{Qin}{Vp} \quad k = \frac{aL}{At}\ln\left(\frac{h1}{h2}\right)$$

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