STABILIZATION OF SOIL IN WATER LOGGED AREAS USING BAMBOO ASH

BY

OSEGHALE PRECIOUS ESELE

ENG2006237

DEPARTMENT OF CIVIL ENGINEERING,

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN,

BENIN CITY.

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PLAGIARISM

This work **STABILIZATION OF SOIL IN WATERLOOGGED AREAS USING BAMBOO ASH** by OSEGHALE, Precious Esele with Number ENG2006237 of the department of Civil Engineering ,Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

CERTIFICATION

This is to clarify that this work was carried out by Oseghale Precious Esele, Matriculation Number ENG2006237, of the Department of Structural Engineering, Faculty of Engineering, University of Benin City, Edo State Nigeria.

SUPERVISOR

Engr. Emeka M. Okolie

Signature and Date:______________________________

CO- SUPERVISOR

Name: Engr. (Mrs.) Gloria E. Evbaru-Okhuaihesuyi

Signature and Date:______________________________

HEAD OF DEPARTMENT:

Name:………………………………………………

Signature and Date:______________________________

DEDICATION

This project work is dedicated to God Almighty who made it possible that I passed through the school and full of wisdom. May his name be praised forever, Amen.

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I wish to express my profound gratitude and thanks to Almighty God for his grace and wisdom throughout my days in the University. I also want to specially thank my supervisor, Engr. E.M. Okolie and my co- supervisor Engr. G.E. Evbaru-Okhuaihesuyi for their guidance and also corrections, my HOD, and all the teaching and non-teaching staff of the department of Civil Engineering, University of Benin, who in one way or the order have impacted knowledge in my life.

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ABSTRACT

Water-logged soils are a persistent challenge in geotechnical engineering, especially in tropical regions where high rainfall and poor drainage lead to saturated ground conditions. These soils typically exhibit low shear strength, high compressibility, and poor loadbearing capacity, making them unsuitable for construction without prior treatment. In this study, bamboo ash especially bamboo leaf ash (BLA) was assessed for its ability in improving soil strength, reducing permeability, and enhancing durability.

Soil samples were collected from water-logged areas and classified using standard geotechnical tests. These soils fell under the category of high-plasticity clays or silts, which are prone to swelling, shrinkage, and settlement. Bamboo leaves were collected from a local source market. The bamboo ash was mixed with soil in varying proportions 2%, 4%, 6%, 8%, and 10% by weight. The mixture was thoroughly blended and compacted using standard procedures.

Test that were carried out include; Atterberg Limits test to assess changes in plasticity and consistency; Compaction; tests to determine optimum moisture content (OMC) and maximum dry density (MDD); California Bearing Ratio (CBR) to evaluate load-bearing capacity. The results showed that bamboo ash significantly increases shear strength, especially at an optimal content of around 4% to 6%, The plasticity index decreases, indicating better dimensional stability and reduced swelling/shrinkage behavior; CBR values improved, making the soil more suitable for subgrade and foundation applications.

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ACRONMYS

(OMC) - Optimal Moisture Content

(MDD) - Maximum Dry Density

(CBR) - California Bearing Ratio

(UCS), - Unconfined Compressive Strength

(PI) - Plasticity index

(PL) - plastic limit

(LL) - Liquid limit

(WSA) - Water stable aggregrate

CHAPTER ONE

INTRODUCTION

1.1 Background study

Early builders understood that soil needed to be strengthened to maintain roads, buildings, and agricultural land. As a result, they developed a number of methods that served as the basis for contemporary soil engineering. Early civilizations used several methods to fortify soil for the construction of infrastructure, demonstrating the thousands of years that soil stabilization has existed. The development of soil stabilization throughout history include:

Mesopotamian and Egyptian Techniques: Builders in Mesopotamia and Egypt used a mixture of clay, straw, and animal dung to reinforce soil for construction, especially in adobe bricks (McCarthy, 2007). The Egyptians used mud and clay mixed with organic materials to stabilize riverbanks along the Nile, preventing erosion and improving structural integrity (Xanthakos, Abramson, & Bruce, 1994)

Roman Innovations: By using lime and volcanic ash (pozzolana) to make early concrete, the Romans were pioneers in soil stabilization and greatly increased the longevity of roads (Schanz, 2012). In order to improve stability and longevity, their renowned roads were built using layers of gravel and compacted earth that were joined with cement based on lime (McDowell & Bolton, 2000).

Chinese Techniques: The Great Wall of China incorporated tamped earth (rammed earth) techniques where soil was compacted in layers using wooden frames (Bowles, 1996). This method improved soil cohesion and longevity, allowing structures to withstand environmental forces such as erosion and seismic activity (Holtz, Kovacs, & Sheahan, 2011).

Modern Times**:** Science Meets Soil: From the 1960s onward, things really took off. With natural resources getting scarce, engineers had to get creative. They developed new ways to treat soil using cement, which is frequently utilized for infrastructure projects nowadays, was inspired by concrete based on pozzolan (Schanz, 2012). lime, fly ash, and even synthetic materials like geotextiles.

Soil stabilization is vital in geotechnical engineering, especially in regions susceptible to erosion and waterlogging. It is crucial for developing infrastructure and promoting environmental sustainability, particularly in areas where soil integrity is at risk due to erosion and water saturation. Such locations experience diminished load-bearing capacity, heightened vulnerability to erosion, and substantial damage to roads, buildings, and farming lands (Shahibu Joshua 2021).

Conventional methods of soil stabilization typically employ cement, lime, and other chemical additives; however, concerns over environmental impact and cost have prompted researchers to investigate alternative materials. Standard stabilizers like cement and lime have been extensively utilized to enhance soil quality. Nonetheless, their production is associated with environmental harm due to high carbon emissions and depletion of natural resources. As global sustainability gains importance, there is a growing interest in ecofriendly substitutes that deliver effective stabilization while reducing environmental repercussions. Bamboo ash, which results from burning bamboo, is gaining attention as a possible soil stabilizer thanks to its high silica content and pozzolanic properties (Norbaya Sidek, 2018). Bamboo itself is a rapidly renewable resource that is plentiful in various regions worldwide. When transformed into ash, it contains chemical compounds that interact with soil minerals, improving cohesion, compressive strength, and the capacity to resist erosion and water saturation.

Numerous studies indicate that bamboo ash enhances soil workability, decreases permeability, and boosts load-bearing capacity when it is appropriately mixed with soil. It has the potential to either replace or complement traditional stabilizers, providing a costeffective and sustainable option for soil enhancement in infrastructure (Aswathy Krishna 2022). This research examines the viability and effectiveness of using bamboo ash as a soil stabilizer, focusing on its effects on different soil characteristics and its appropriateness for environments susceptible to erosion and waterlogging.

1.2 Statement of Problem

Erosion and waterlogging negatively impact infrastructure, land stability, and agricultural productivity. Roads constructed on unstable soil tend to develop cracks, settlements, and potholes, increasing maintenance costs and reducing longevity. Similarly, waterlogged soil lacks sufficient strength, leading to structural failures and reduced land usability.

Existing soil stabilization techniques often require expensive materials that contribute to environmental degradation through resource depletion and carbon emissions. The challenge lies in identifying a sustainable, cost-effective alternative capable of reinforcing soil without adverse ecological consequences. Bamboo ash, an abundant and natural pozzolanic material, has shown potential in improving soil properties, but research is needed to understand its effectiveness across various soil types and environmental conditions.

1.3 Aim & Objectives

The aim of this work is to investigate the potential of bamboo ash as a sustainable soil stabilizer in erosion-prone and waterlogged areas in Benin City, Edo State, Nigeria.

The objectives are to:

I. Evaluate the index properties, and strength characteristic of the soil samples

II. Determine the amount of bamboo ash powder required for optimum improvement of the soil properties

1.4 Scope of study

This study will focus essentially on investigating the strength of soil in areas that are vulnerable to erosion and flooding using bamboo ash. The study will employ laboratory testing to determine the effects of bamboo ash on soil stabilization. Compaction testing will be used to determine the ideal moisture content and maximum dry density of the soil; the California Bearing Ratio (CBR) will be used to assess the strength and load-bearing capacity of the soil, especially for road construction and pavement design; atterberg limit (liquid and plastic limit) test, and the triaxial test will be used to determine the shear strength of the soil. Soil samples will be taken at varying depths, ranging from 0.5 to 1m and 1.5 to 2m, and varying amounts of bamboo ash in a step increasing from 2% to 10% will be added to the soil samples. Also, assess the environmental sustainability and economic feasibility of adopting bamboo ash in geotechnical engineering applications.

1.5 Justification of study

Research on substitute materials has been prompted by the demand for economical and environmentally friendly soil stabilizing solutions. The following advantages of bamboo ash make its investigation in geotechnical applications warranted:

I. Environmental Benefits: Bamboo has no ecological impact and is a renewable resource. By using bamboo ash, waste is decreased and sustainability is encouraged.

II. Cost-Effectiveness: Because bamboo is readily available locally, its ash may be less expensive than conventional stabilizers, which would save building expenses.

III. Enhancement of Soil Performance: Silica and other pozzolanic chemicals found in bamboo ash react with soil minerals to increase durability, strength, and stability.

IV. Preventing Erosion and Waterlogging: Stabilized soil's increased load-bearing capacity and decreased permeability can help stop erosion and damage from water.

V. Erosion and Waterlogging Prevention: Stabilized soil can help prevent erosion and water damage due to its enhanced load-bearing capacity and decreased permeability.

CHAPTER TWO

LITERATURE REVIEW

This chapter review the use of bamboo ash as a stabilizing agent for waterlogged soil. soil stabilization is a vital engineering solution that strengthens weak or problematic soils using mechanical, chemical, biological, and advanced methods. It enhances soil performance, supports safer construction, mitigates erosion, and promotes sustainability especially in waterlogged areas. By improving soil behavior and reducing environmental impact, stabilization lays the foundation for more durable, resilient infrastructure. Bamboo ash is rich in pozzolanic properties such as silica which enhances the strength of soil.

2.1 soil stabilization

Soil stabilization is the modification of the soil's engineering properties through mechanical, chemical, or biological means. This process increases the soil's strength, durability, and load-bearing capacity. Soil stabilization is crucial for geotechnical applications because it improves soil performance by limiting settlement, decreasing permeability, and boosting shear strength. In clayey soils that are prone to waterlogging, stabilizing the soil is essential for lowering water retention. By improving drainage qualities and guaranteeing improved soil behavior in damp conditions, this improvement emphasizes the environmental importance of stabilization, which involves integrating waste materials like bamboo ash into stabilization processes to lessen dependency on traditional cement-based techniques.

Stabilization is frequently employed in foundation engineering, erosion management, and road building, where weak or unstable soil can result in long-term structural collapse (Keaton, 2018). Different strategies are employed to achieve desired changes, and the method and soil qualities determine how effective soil stabilization is. Stabilization ensures that soil maintains its structural soundness for a variety of engineering purposes by modifying its plasticity, workability, and compaction characteristics.

Koerner (2012) explains how the wider use of soil stabilization affects land reclamation, agriculture, and erosion control in addition to infrastructure. Engineers can improve environmental sustainability, optimize construction costs, and increase soil resilience by employing sustainable stabilization techniques, all of which contribute to safer and more resilient built environments.

2.2 Importance of soil stabilization

I. Improves Load-Bearing Capacity: It makes weak soil strong enough to support heavy structures like buildings, roads, and bridges

II. Reduces Soil Erosion: Especially in areas prone to wind or water erosion, stabilization helps keep soil in place.

III. Prevents Foundation Problems: Stabilized soil means fewer cracks, shifts, or sinking in foundations over time.

IV. Boosts Durability: Roads and pavements built on stabilized soil last longer and need fewer repairs.

V. Enhances Water Resistance: Treated soil absorbs less water, reducing the risk of swelling, shrinking, or becoming muddy.

VI. Increases Safety: Stabilized ground reduces the chances of landslides, collapses, or uneven surfaces.

VII. Supports Sustainable Construction: It allows builders to improve local soil instead of hauling in new materials, which helps conserve natural resources.

VIII. Allows for Construction on Problematic Soils: Even soils with high clay or silt content, which are usually poor for building, can be made usable with stabilization techniques.

IX. Improves Workability of Soil: Stabilized soil is easier to grade, compact, and shape, which speeds up construction and reduces manual labor.

2.3 Method of soil stabilization

I. Mechanical stabilization

One method of improving soil is mechanical stabilization, which modifies the physical characteristics of soil without the use of chemical additives. Engineers improve loadbearing capacity, decrease settlement, and boost erosion resistance by altering soil structure through compaction or blending with stabilizing additives. This technique is frequently applied in foundation reinforcement, embankment stability, and road construction

II. Chemical stabilization

This is a method of improving soil that involves adding stabilizing substances to change the soil's chemical and physical characteristics. These chemicals make the soil more suited for building by increasing its strength, decreasing its flexibility, controlling moisture fluctuations, and improving its durability. This technique is frequently applied in erosion prevention, foundation reinforcement, and roads. Wang et al. (2019) report that cementtreated soils exhibit a 300% increase in compressive strength.

III. Biological stabilization

This is a sustainable method of improving soil that uses organic materials, bacteria, and vegetation to strengthen the soil and stop erosion. Because it uses biological interactions to strengthen soil structure rather than mechanical or chemical stabilization, this approach is an environmentally beneficial option for geotechnical applications. Thomas (2022) highlights that native vegetation improves slope stability while enhancing soil moisture retention.

IV. **Polymer-based stabilization**

This uses synthetic polymers to increase the strength, cohesiveness, and durability of the soil. By creating strong molecular interactions between soil particles, polymer-based stabilization improves structural integrity and erosion resistance, in contrast to conventional techniques that depend on mechanical compaction or chemical additives. O'Brien & Patel (2021) describe polymer stabilization as an effective technique for dust control and erosion prevention.

V. **Electrochemical stabilization**

This uses controlled electrical currents and chemical reactions to change the properties of the soil, increasing its strength, decreasing its moisture content, and improving its stability. It is beneficial for difficult soil conditions like expansive clays, soft sediments, and unstable slopes. Kim & Zhou (2020) found that electrochemical treatment significantly strengthens expansive clay soils.

2.4 Challenges associated with erosion-prone and waterlogged soils.

I. Foundation Instability: Structures built on waterlogged or dissolved soils are at risk of uneven settlement or total disappointment. The ground loses its capacity to support loads, which can lead to tilting buildings, split establishments, and collapsed roadways.

II. Difficult Site Preparation: These soils require serious foundations; some time recently, development can indeed start. Meaning additional unearthing, soil substitution, or stabilization strategies like chemical additives or geotextiles adding time and fetched to ventures.

III. Limited Bearing Capacity: Waterlogged soils, particularly clays and sediments, have exceptionally poor load-bearing quality. Engineers must compensate with profound establishments, soil fortification, or ground change strategies to bolster structures securely.

IV. Construction Delays and Equipment Limitations: Overwhelming apparatus can sink or get stuck in delicate, soaked soils. Development plans frequently need to be balanced amid stormy seasons or in flood-prone regions, particularly in tropical climates.

V. Drainage and Waterproofing Demands: Abundance dampness increases the risk of hydrostatic pressure on holding dividers and cellars, requiring well-designed waste frameworks and waterproofing arrangements to secure auxiliary stability.

VI. Soil erosion undermining structures; In erosion-prone zones, streaming water can continuously expel soil around establishments, pipelines, or street edges, causing long-term upkeep issues or indeed disastrous disappointments on the off chance that unaddressed.

VII. Increased Maintenance Costs: Indeed, after development, structures built on such soils frequently require continuous review, waste upkeep, and repairs due to subsidence, splitting, or water damage.

VIII. Environmental Impact Considerations: When engineers attempt to illuminate these issues with conventional methods—like bringing in rock or utilizing cement there can be critical natural and financial costs. Usually, more economical materials, like bamboo ash or fly ash, are being investigated.

2.5 Bamboo Ash

Because of genetic variances and environmental adaptations, different species of bamboo have different mineral contents. Certain species have higher silica, calcium, or potassium content by nature, which has an immediate effect on the ash's pozzolanic activity and appropriateness for use in building. Furthermore, the arrangement of vascular bundles and fiber density in bamboo's anatomical structure influences how well minerals are maintained during combustion; the mineral content varies among species (Velasco, 2021). Bamboo's chemical composition is greatly influenced by its exposure to the environment, climate, and soil composition. Rusch et al (2023). Because it tends to absorb more nutrients, bamboo growing in mineral-rich soils has higher levels of beneficial oxides in its ash. The rate of nutrient absorption and the total development of biomass are also influenced by climate variables like temperature, humidity, and rainfall. For example, due to differences in soil acidity and organic matter concentration, bamboo grown in tropical locations may have a different chemical profile than bamboo grown in temperate zones. The ultimate composition of bamboo's ash is greatly influenced by the temperature at which it is burned. The efficiency of ash in cementitious applications may be diminished by organic residues left behind by lower combustion temperatures. (2018), Azeez and Orege. On the other hand, greater temperatures promote full combustion, which raises the concentration of oxides like calcium and silica. The ash's crystallinity, which affects its reactivity when combined with other materials, is similarly influenced by the thermal degradation process.

2.5.1 Chemical composition of bamboo ash

I. Silica Dioxide (SiO_2): A significant portion of bamboo ash is silica, which improves its pozzolanic qualities. Because of this, it can be used to stabilize soil and cement, increasing their strength and durability. Velasco (2021).

II. Calcium Oxide (CaO): This substance helps maintain structural integrity by adding binding qualities to bamboo ash when combined with cement or lime. (Rusch and others, 2023).

III. Iron oxide (FeO_3) and aluminum oxide (AlO_3): These oxides increase the mechanical strength of mixes made from bamboo ash and increase their resistance to environmental stresses. Orege and Azeez (2018).

IV. Magnesium Oxide (MgO): Plays a function in enhancing workability and setting time when bamboo ash is utilized in construction applications. Velasco (2021)

V. Potassium Oxide (K_2O) and Sodium Oxide (Na_2O): These alkali chemicals influence the reactivity of bamboo ash in cementitious applications, changing its hydration process. In 2023, Rusch et al.

VI. Carbon Content: The amount of carbon that bamboo ash has can affect its thermal characteristics and how it burns. Orege and Azeez (2018).

VII. Lignin and Cellulose Residues: The ash's ability to interact with other materials is impacted by certain organic components that are still present. Velasco (2021).

VIII. Trace Elements: Phosphorus (P), sulfur (S), and manganese (Mn) are trace elements that may be present in bamboo, depending on the species and combustion conditions. Rusch et al (2023).

2.5.2 Pozzolanic properties and their role in soil stabilization

According to Al-Kalili et al. (2022), pozzolanic compounds are essential for stabilizing soil since they increase strength, durability, and resilience to environmental influences. These minerals, which include volcanic ash, fly ash, and rice husk ash, include silica and alumina that, when combined with calcium hydroxide and water, create cementitious compounds (Makusa, 2016). By strengthening soil cohesiveness and decreasing permeability, this reaction increases the soil's resistance to erosion and structural collapse

(Al-Taie, 2022).

Pozzolanic materials aid in stabilizing soils by reducing problems such as expansive soils, which experience large volume changes as a result of moisture variations (Makusa, 2016). Engineers can improve soil qualities by adding pozzolanic additives, which will increase load-bearing capacity and decrease shrink-swell behavior (Al-Kalili et al., 2022). Additionally, by reusing industrial and agricultural waste, these materials help to minimize their negative effects on the environment (Al-Taie, 2022). The pozzolanic reaction occurs in three main stages:

I. Dissolution: The silica and alumina in the materials dissolve in water to form reactive compounds

II. Hydration: These compounds react with calcium hydroxide to form calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH)

III. Strength Development: The newly formed hydrates bind soil particles together, increasing load-bearing capacity and decreasing shrink-swell behavior.

2.5.3 Effects of Bamboo Ash on Soil Properties

I. Strength Enhancement

Bamboo ash is rich in silica and other pozzolanic compounds. When mixed with soil especially clayey or lateritic types it reacts with calcium (from lime or cement, if added) to form cementitious gels like calcium silicate hydrate (C-S-H). These gels bind soil particles together, significantly improving the unconfined compressive Strength (UCS), California Bearing Ratio (CBR) and Shear strength. The CBR test measures the loadbearing capacity of soil, which is crucial for road construction and foundation stability. Research has shown that incorporating bamboo ash into lime-stabilized lateritic soil significantly increases CBR values, making the soil more suitable for supporting heavy loads, For instance, studies conducted in Nigeria demonstrated that unsoaked CBR values increased from 4% to 11%, 2% to 10%, and 2% to 11% when bamboo leaf ash was added to lime-stabilized soil. shear strength determines how well soil resists deformation under stress, which is essential for construction stability. Bamboo ash contributes to higher shear strength by improving soil cohesion and internal friction (Nnochiri et al., 2023). Experimental results indicate that shear strength values increased substantially, with figures rising from 42.16 kN/m² to 398.96 kN/m², 42.96 kN/m² to 146.84 kN/m², and 197.48 kN/m² to 365.90 kN/m² when bamboo ash was incorporated into lime-stabilized soil.

II. Reduction in Plasticity

High-plasticity soils like black cotton soil tend to swell when wet and shrink when dry, causing cracks and instability, the addition of bamboo ash lowers the liquid limit and plasticity index, making the soil less susceptible to deformation under moisture variations. Research has shown that bamboo ash alters the Atterberg limits of soil, reducing its plasticity and improving its workability in construction applications (Nnochiri et al., 2023). This effect is particularly beneficial for clayey soils, which tend to expand and contract with moisture changes (Ismanti & Yasufuku, 2017).

III. Permeability and Drainage Enhancement

Bamboo ash helps reduce water retention in soil, improving its permeability and drainage characteristics. Studies indicate that bamboo ash increases the porosity of soil, allowing better water movement and reducing excess moisture buildup (Nnochiri et al., 2023). This property is advantageous for road construction, foundation stability, and agricultural applications where proper drainage is essential (Verma et al., 2017).

IV. Optimal Moisture Content (OMC) and Dry Density Improvement

Bamboo ash influences the moisture content required for effective soil compaction. Studies have shown that the addition of bamboo ash reduces the OMC, making the soil easier to compact with less water (Ameen et al., 2021). This effect is particularly beneficial in construction projects where excessive moisture can lead to instability (Shaibu et al., 2021). The incorporation of bamboo ash enhances the maximum dry density (MDD) of soil, improving its load-bearing capacity. Research indicates that MDD values increased significantly when bamboo ash was mixed with lime, reaching 1766 kg/m³ at 3% lime and 6% bamboo leaf ash, 1818 kg/m³ at 3% lime and 8% bamboo leaf ash, and 1866 kg/m³ at 3% lime and 2% bamboo leaf ash (Ameen et al., 2021). This improvement makes bamboo ash a viable stabilizing agent for lateritic soils used in road construction and foundation work (Bello et al., 2014).

V. Environmental and Economic Advantages

Bamboo is a fast-growing, renewable resource. Using its ash reduces waste and avoids the environmental costs of cement or lime production. In regions where bamboo is abundant, its ash is a low-cost alternative to traditional stabilizers. It also turns agricultural waste into a valuable engineering material, supporting circular economy goals.

VI. Improved Durability and Long-Term Performance

Soils treated with bamboo ash show better resistance to: Wet-dry cycles, Freeze-thaw conditions, Chemical attack (in some cases).

2.6 Field application of soil stabilization.

I. Road Construction

Soil stabilization is widely used in road construction to improve the strength and durability of subgrade materials. Techniques such as lime stabilization, cement stabilization, and mechanical stabilization enhance soil properties, making roads more resilient to traffic loads and environmental conditions. Stabilized soil provides a strong foundation, reducing maintenance costs and increasing longevity. (Archibong et al., 2020 | Makusa, 2016)

II. **Embankments and Slopes**

Stabilization methods reinforce embankments and slopes, preventing erosion and landslides. Geosynthetics, chemical stabilizers, and mechanical compaction techniques improve soil cohesion and stability, ensuring embankments remain structurally sound over time. In regions prone to landslides or excessive soil movement, stabilization techniques help maintain slope integrity, reducing the risk of structural failure. (Makusa, 2016 | Cunningham, 2024)

III. **Building and Infrastructure Foundations**

Soils that are weak or pliable might jeopardize the stability of infrastructure and buildings. By improving the qualities of the soil, soil stabilization methods like chemical stabilization, grouting, and deep mixing provide a strong base for building projects.

Stabilized soil increases a structure's overall durability, improves its load-bearing capacity, and inhibits excessive settlement. This is particularly significant in places with high groundwater levels or soft clay soils. (Cunningham, 2024; Archibong et al., 2020)

IV. **Control of Erosion**

By strengthening soil cohesiveness and lowering water infiltration, soil stabilization is a useful technique for minimizing erosion. Techniques such as vegetation reinforcement, geotextiles, and chemical stabilizers protect soil from erosion in agricultural and environmental applications. Stabilized soil is perfect for protecting slopes, riverbanks, and coastal areas because it prevents sediment loss, increases water retention, and decreases surface runoff. (Cunningham, 2024; Archibong et al., 2020)

V. **Waste Containment and Landfills**

In landfill construction, soil stabilization is utilized to increase soil impermeability and stop leachate contamination. By acting as a barrier, stabilized soil lowers the environmental dangers related to trash disposal. By preventing dangerous substances from leaking into groundwater, the procedure safeguards both public health and ecosystems. Furthermore, stabilization methods contribute to landfill sites' increased structural integrity by halting subsidence and guaranteeing stability over the long run. (Makusa, 2016; Archibong et al., 2020)

2.7 Performance evaluation in waterlogged areas and flood-prone regions.

I. Moisture Resistance and Permeability Bamboo ash-treated soils show reduced permeability due to the formation of cementitious compounds, which help seal soil pores and limit water absorption. This makes the soil more water-resistant, which is particularly beneficial in waterlogged and flood-prone regions (Norbaya Sidek, 2018).

II. Improved Load-Bearing Capacity Even in saturated conditions, bamboo ash enhances strength indicators like California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). This improvement is attributed to its pozzolanic properties and is valuable in supporting roads and infrastructure in high-moisture environments (Aswathy Krishna, 2022).

III. Resistance to Chemical Attack Bamboo ash has demonstrated resilience in environments where floodwaters may carry dissolved sulfates or chlorides. This resistance makes it suitable for long-term durability in chemically aggressive soils (Schanz, 2012).

IV. Durability Under Cyclic Wetting and Drying In areas that experience alternating flooding and drying, bamboo ash-treated soils maintain structural integrity better than untreated soil, showing less cracking and deformation (Holtz, Kovacs, & Sheahan, 2011).

V. Environmental and Economic Suitability Using bamboo ash offers a sustainable and affordable alternative to conventional stabilizers, particularly in rural or flood-prone areas where access to cement or lime might be limited. Its local availability reduces transportation costs and supports eco-friendly construction (Shahibu Joshua, 2021).

2.8 Sustainability benefits (carbon footprint reduction, waste utilization).

I. carbon footprint reduction

One of the greatest natural concerns in development is the overwhelming dependence on cement and lime, both of which are carbon-intensive to create. Cement fabricating alone contributes generally 5–7% of worldwide CO_2 emissions due to the high-temperature ovens and fossil fuels included (Olofintuyi et al.,)

2016). By mostly supplanting cement or lime with bamboo ash a byproduct of burning bamboo you essentially cut down on these emissions. For illustration, considers have shown that substituting 15% of cement with bamboo leaf ash can diminish CO_2 emissions by over 50 kg per ton of cement delivered (Olofintuyi et al., 2016). That's a significant drop, particularly when scaled over huge foundation ventures. Additionally, bamboo itself may be a carbon sink. It retains more CO_2 amid its fast development cycle than numerous other plants. As a result, it recovers rapidly without replanting, it offers a renewable source of biomass with negligible environmental impact (Tripathi et al., 2024).

II. Waste Utilization and Circular Economy

Bamboo ash is ordinarily a waste product from household cooking, agricultural burning, or bamboo preparation businesses. Rather than disposing of it into landfills or permitting it to contaminate the discuss, this ash can be repurposed as an important development fabric.

This approach underpins the standards of a circular economy—where waste isn't fair minimized but changed into something valuable. By utilizing bamboo ash in soil stabilization, we decrease landfill weight; Lower request for virgin crude materials, Energize nearby sourcing and reuse of biomass waste

III. Vitality Productivity

Creating bamboo ash requires less vitality than fabricating cement or lime. Whereas cement generation can expend over 3,000 MJ per ton, bamboo ash can be created with as little as 34 MJ per 10 kg of ash remains (Olofintuyi et al., 2016). That's a gigantic vitality saving, paticularly in locales with constrained access to mechanical control sources. One of the greatest natural concerns in development is the overwhelming dependence on cement and lime, both of which are carbon-intensive to create. Cement fabricating alone contributes generally 5–7% of worldwide CO_2 emissions due to the high-temperature ovens.

2.9 Potential for large-scale adoption in developing regions.

I. Abundant Local Availability In many developing countries especially across SubSaharan Africa, Southeast Asia, and parts of Latin America bamboo grows naturally or can be cultivated easily. Its fast growth rate and adaptability to degraded or marginal lands make it a reliable, renewable source of biomass (Olajuyigbe & Oluwatayo, 2017; Partey et al., 2017).

II. Low-Cost and Accessible Production Unlike cement or lime, which require industrial processing and transportation, bamboo ash can be produced locally using simple combustion methods. This makes it especially attractive in rural areas where access to industrial stabilizers is limited or unaffordable (Addo-Danso, 2018).

III. Community Empowerment and Livelihood Support Bamboo-based agroforestry and ash production can create jobs in farming, processing, and construction. In Nigeria, for example, farmers have shown willingness to adopt bamboo agroforestry if given proper training and policy support (Olajuyigbe & Oluwatayo, 2017). This opens up opportunities for income generation and rural development.

IV. Environmental Sustainability Using bamboo ash supports waste utilization and reduces reliance on carbon-intensive materials like cement. It also encourages bamboo cultivation, which contributes to carbon sequestration, erosion control, and land restoration (Partey et al., 2017).

V. Policy and Research Momentum Governments and research institutions in countries like Ghana, Nigeria, and Ethiopia are increasingly recognizing bamboo's potential. With proper incentives, training, and infrastructure, bamboo ash could

be scaled up as part of national strategies for sustainable construction and climate resilience (Addo-Danso, 2018; Partey et al., 2017).

2.10 Impact on local economies and waste management strategies.

I. Job Creation and Livelihoods: The collection, processing, and application of bamboo ash can create employment opportunities in rural communities. From bamboo farming and harvesting to ash production and soil treatment, the entire value chain supports small-scale enterprises and local labor markets (Olajuyigbe & Oluwatayo, 2017).

II. Support for Local Industries By encouraging the use of bamboo-based products, communities can stimulate demand for bamboo cultivation, which in turn supports agroforestry, furniture making, and construction sectors. This diversification strengthens local economies and reduces dependence on imported materials (Partey et al., 2017).

III. Cost Savings in Infrastructure Projects: Replacing cement or lime with bamboo ash in road construction or erosion control projects can significantly reduce material costs. These savings can be redirected toward other community development initiatives, such as schools, clinics, or water systems (Addo-Danso, 2018).

IV. Utilization of Agricultural Waste Bamboo ash is typically a byproduct of burning bamboo leaves or stems materials that would otherwise be discarded or openly burned. Repurposing this ash reduces environmental pollution and turns waste into a valuable resource (Rodier et al., 2019).

V. Reduction in Landfill Pressure: By diverting bamboo waste from landfills and using it in construction or soil stabilization, communities can extend the lifespan of waste disposal sites and reduce the need for costly landfill expansion.

VI. Promotion of Circular Economy Practices: Bamboo ash supports a circular economy model by closing the loop between agriculture and construction. Waste from one sector becomes input for another, promoting sustainability and resource efficiency (Carvalho & Velasco, 2021).

2.11 Review of past work on soil stabilization of soil in waterlogged areas using bamboo ash

Vivek Kakadiya, Pushpendra Mishra, Prachi Joshi, and Dhiren Paghdar: (2019) investigated on Soil Stabilization Using Geosynthetic Material (Bamboo Fibres)

This research investigates the effectiveness of bamboo fibres as a natural geosynthetic material in stabilizing black cotton soil, a problematic expansive soil found widely across India. The primary focus lies in evaluating how bamboo fiber additions affect strength characteristics, compaction behavior, and durability of soil when used as a road subgrade material. The use of bamboo fibres as a substitute for artificial geosynthetics promotes sustainability, leveraging waste from bamboo-based industries.

A range of standardized tests CBR (California Bearing Ratio), Unconfined Compression Test, and Standard Proctor Test was employed to evaluate soil performance. The study found that incorporating 0.75% bamboo fibre by weight led to the most substantial improvements in soil properties, including: CBR value increase from 1.82% to 5.41%, Maximum Dry Density (MDD) increase and Optimal Moisture Content (OMC) decrease, Notable enhancement in shear strength under unconfined conditions.

The effectiveness of bamboo fibres peaked at 0.75% dosage; beyond that, performance gains were limited or declined, using bamboo fibres can reduce pavement layer thickness, potentially lowering overall construction costs. Bamboo's physical properties (e.g., pH, texture, fineness) were catalogued, showing suitability for soil blending.

L. Rodier, K. Bilba, C. Onésippe, and MA Aresene (2016) Studied on the Pozzolanic Activity of Bamboo Stem Ashes for Use as Partial Replacement of Cement

This research explores the potential of bamboo stem ash (BA) as a pozzolanic material a substance that, when combined with calcium hydroxide, contributes to the strength and durability of cementitious materials. The study evaluates BA through multiple testing methods, including Chapelle testing, saturated lime methods, thermogravimetric analysis (TGA), and strength activity index (SAI), comparing its performance to that of sugarcane bagasse ash (SCBA) and natural pozzolan (NP).

Methodology: The use of four separate methods to evaluate pozzolanic activity (chemical, thermal, mechanical, and structural) offers a robust and multifaceted assessment.

BA showed high silica content (69%), amorphous structure, and a Chapelle index similar to SCBA. BA performed better than natural pozzolan (NP) in both lime fixation and strength development, particularly when used in binary or ternary mixes. The research confirmed that fine grinding and particle fineness greatly influence pozzolanic reactivity. Using BA in cement could reduce both cost and carbon footprint without compromising structural performance.

Comparative Analysis of Increasing CBR Value of Soil with Adding Bamboo Leaf Ash, published in Teknika: Jurnal Sains dan Teknologi (2021):

The research investigates the effectiveness of bamboo leaf ash (BLA) in enhancing the California Bearing Ratio (CBR) of low-strength soils. The study doesn't just evaluate one method it contrasts ordinary and furnace combustion of bamboo leaves, offering a clearer picture of how combustion temperature affects the pozzolanic quality of ash. By combining physical soil property tests, unsoaked CBR evaluations. The research emphasizes silica content’s role in enhancing strength and identifies furnace combustion (800–1000°C) as producing higher-silica ash that greatly improves soil performance.

The optimum CBR value for ordinary-combustion BLA was 13.1% at 10% BLA. For furnace-combusted BLA, the CBR value soared to 34.99% and 38.21% at just 6% BLA, a significant leap in load-bearing capacity. Although there was a minor reduction in plasticity index (PI), especially with furnace ash, the changes were not considered sufficient for meeting PI criteria in high-standard subgrade materials.

Influence of Compactive Efforts on Lateritic Soil Stabilized with Bamboo Leaf Ash by Osinubi and Bello (2015)

The study directly addresses the challenges of lateritic soil common in tropical regions and presents field-friendly recommendations for lightly trafficked roads. The laboratory-based research examines how varying compactive efforts impact the geotechnical behavior of lateritic soil when stabilized with bamboo leaf ash (BLA). The researchers utilized four compactive energies Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH) to evaluate changes in soil strength, density, and moisture-related properties. The research highlights the sweet spot for BLA content, particularly noting 6% as a consistently optimal amount for improving key soil properties.

With increasing compaction energy, maximum dry density (MDD) of natural soil ranged from 1.67 to 1.95 Mg/m^3. Stabilization slightly reduced MDD common when pozzolanic additives replace denser soil particles. Stabilized soils showed a noticeable increase in optimum moisture content (OMC), consistent with the high water demand of pozzolanic reactions. The plasticity index dropped from 16% to 10%, indicating better workability.
More significantly, CBR values of soaked samples rose up to 25%, especially at 6% BLA and with higher compactive efforts. The study supports was compaction with 6% BLA for

stabilizing subgrade layers of lightly loaded roads, emphasizing the benefits of timedependent strength gain from pozzolanic activity.

Compressive Strength and Durability of Bamboo Leaf Ash Concrete by G. Dhinakaran and Gangava Hari Chandana:

This study explores the feasibility of using bamboo leaf ash (BLA) as a partial replacement for cement in concrete. The researchers aimed to assess its impact on compressive strength, pozzolanic activity, porosity, and factors critical to concrete durability. Concrete mix designed for a target strength of 20 MPa using a mix ratio of 1:1.44:3.19. Tests Performed Included compressive strength tests (7 and 28 days), XRF and XRD analysis, pozzolanic activity using ASTM C311, absorptivity (ASTM C1585), and porosity measurements.

BLA is rich in SiO_2 (80.27%) and has an amorphous structure, classifying it as a Class N natural pozzolan. Concrete with 15% BLA showed optimal performance, with only a 10% strength reduction at 28 days considered acceptable. 10–15% BLA reduced porosity and absorptivity, suggesting enhanced resistance to water ingress and thus better durability. BLA offers potential savings of up to 15% in cement costs while promoting sustainable construction.

This research shows that bamboo leaf ash, when used up to 15%, can enhance concrete's environmental profile without severely compromising strength or durability.

Potential of Bamboo Stem Ash as Supplementary Cementitious Material in Concrete Production by Ikeagwuani et al., (2019)

This study investigates the use of Bamboo Stem Ash (BSA) as a partial replacement for Ordinary Portland Cement (OPC) in both concrete and mortar. The motivation is rooted in sustainability—reducing cement usage to lower CO_2 emissions and repurposing agricultural waste. OPC was partially replaced with BSA at 5%, 10%, 15%, 20%, 25%, and 30%. Concrete has 1:2:4 mix with water/cement ratio of 0.6 and Mortar 1:3 mix with water/binder ratio of 0.5 with 7, 14, 21, and 28 days Curing Periods

Slump test, compressive strength, sieve analysis, specific gravity, moisture content, and setting time was done

Slump values decreased with higher BSA content, indicating reduced workability. However, 10–15% BSA mixes maintained acceptable consistency Strength, 10% BSA replacement yielded 22.88 N/mm² at 28 days, just 6.9% lower than the control (24.58 N/mm²). Mortar showed slower strength gain and significantly lower compressive strength compared to control, even after 28 days. BSA demonstrated potential as a pozzolanic material, especially at lower replacement levels.

Empirical Study on Effect of Bamboo Leaf Ash in Concrete by A. A. Umoh and A. O. Ujene, published in Journal of Engineering and Technology (Vol. 5, No. 2, 2014):

This research investigates the mechanical and durability performance of concrete when Portland cement is partially replaced with Bamboo Leaf Ash (BLA) at 5–20% by weight. It evaluates compressive strength, tensile splitting strength, and water absorption over a curing period of up to 90 days.

Mix Ratio of 1:2:4 (cement: sand: granite) with water-cementitious ratio based on a slump of 10–30 mm. Bamboo leaves were burned, then calcined at 500°C, ground, and sieved.0%, 5%, 10%, 15%, and 20% BLA were replaced. Compressive strength, tensile splitting strength, and water absorption at 7, 14, 28, and 90 days were the test conducted 10% of BLA achieved 75% of the reference strength at 28 days, meeting ASTM C618 standards for pozzolanic materials. Strength decreased with higher BLA content beyond 10%. All BLA mixes achieved ≥75% of the reference strength at 28 and 90 days. Strong correlation with compressive strength ($R^2 = 0.790$). 10% BLA mix had the lowest water absorption, indicating improved impermeability. All BLA mixes absorbed less water than the control, suggesting reduced porosity.

Soil Aggregates as Indicator of Soil Health in Waterlogged Sodic Soil” by Sharif Ahamad et al (2012)

This research investigates how soil aggregation patterns specifically water stable aggregates (WSA)—can serve as indicators of soil health in waterlogged sodic soils. It compares aggregate distribution and stability under waterlogged and non-waterlogged conditions across different soil pH levels and depths. 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm were the depths studied

The 0–15 cm layer had the highest WSA (45.16%), which decreased with depth. In waterlogged soils, macro aggregates increased with pH at the surface (from 9.9% at pH 8.5 to 20.3% at pH 9.5). In non-waterlogged soils, macro aggregates decreased with increasing pH. Soils with lower pH (8.5) generally had better aggregation and stability.

The study confirms that soil aggregation especially macro aggregates and WSA is a reliable indicator of soil health in sodic environments. Waterlogging and high pH negatively affect soil structure, particularly in deeper layers. Managing pH and improving organic matter content are key to sustaining soil health in such conditions.

CHAPTER THREE

METHODOLOGY

This chapter covers how the study was carried out, starting with the selection of floodprone areas in Benin City, Textile Mill Road, based on visible signs of erosion and feedback from local residents. Soil samples was taken from these sites at about one meter deep using simple tools like hand augers and shovels, then carefully stored and sent to the University of Benin's engineering lab for analysis. There, the samples went through a series of tests,\ including Atterberg limits, CBR, compaction, and grain size distribution to better understand the soil's behavior and how it might be improved using bamboo leaf ash as a stabilizing material. The results will be in chapter four, where the effects of bamboo ash on soil behaviour will be analyzed and discussed.

3.1 Study Area

Waterlogged areas within Benin City, Edo State, Location as Textile Mill Road was selected based on its history of seasonal flooding, poor drainage, and visible erosion features.

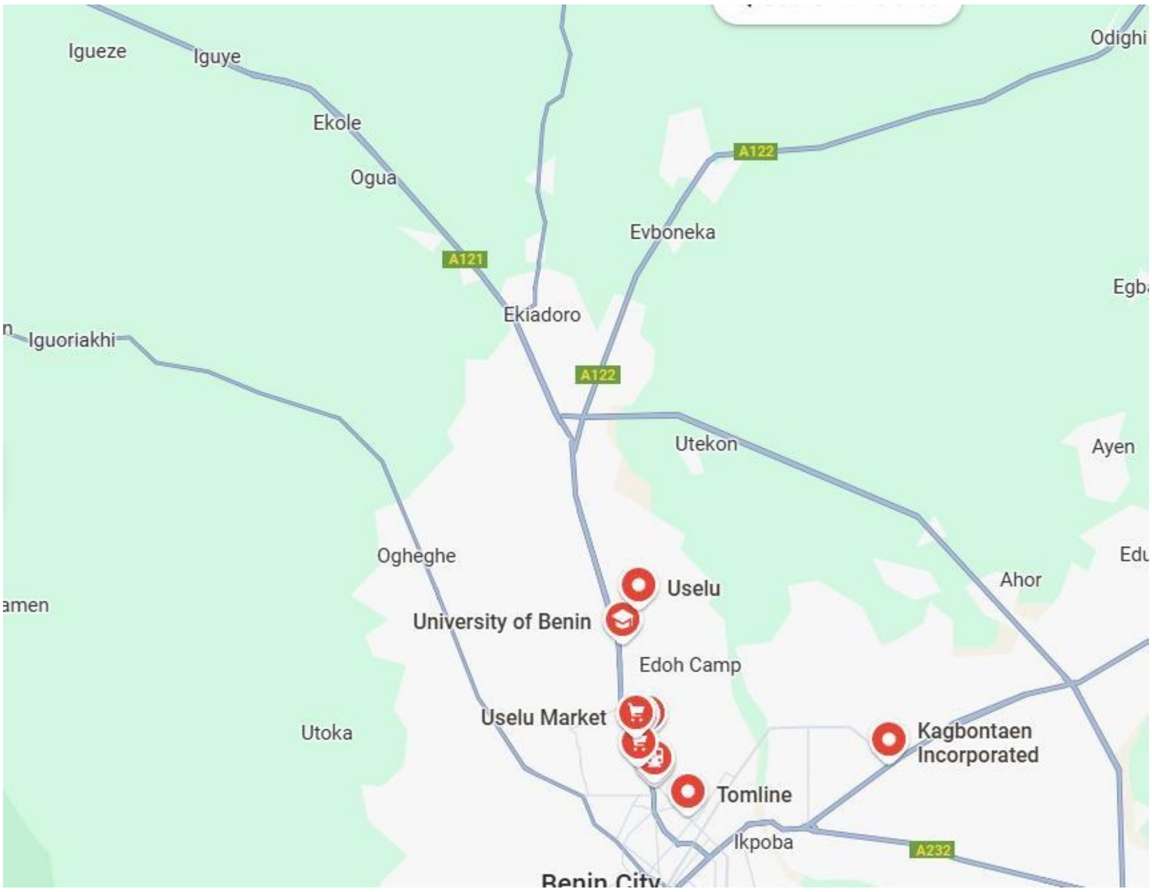

Figure 3.1: Site location

To validate the desk-based findings, field visits and community consultations were conducted. Local residents, farmers, provided valuable insights into areas regularly affected by erosion and flooding. This ensured accurate identification of representative sites for sampling and testing.

3.2 Sample Collection Procedure

A hand auger and a was used for sample extraction, particularly for deeper profiles. Tools was thoroughly cleaned between each sampling point to prevent cross-contamination. Collected samples will be placed in airtight, labeled appropriately.

Samples was collected at two depths: 1m, For each location, a minimum of three replicate samples were taken to improve accuracy and account for natural variability in soil characteristics. All samples were stored in cool, dry containers and promptly transported to the laboratory for testing. In addition to sample collection, field characteristics were recorded to support laboratory findings. Observations included:

a) Soil color, noted using the Munsell Soil Color Chart
b) Soil texture, assessed by hand to estimate proportions of sand, silt, and clay
c) Water saturation signs, such as mottling or pooling
d) Vegetation cover and land use, to understand the interaction between human activity and soil condition
e) Visible erosion indicators, including gullies, surface rills, and sediment buildup.

3.3 MATERIALS AND METHODS

3.3.1 MATERIALS

a) Soil Sample: Lateritic or clayey soil commonly found in water-logged areas, which are Collected from a depth of 1.0 meters in a water-logged site.
b) Bamboo Leaf Ash (BLA)
c) Water: Clean potable water used for mixing and compaction.
d) Hand auger o (for 0–60 cm depth)
e) Spade or shovel (for surface sampling or clearing vegetation)
f) Trowel or scoop (for transferring soil into containers)
g) Clean, labeled polyethylene or zip-lock bags

3.3.2 METHODS

All test such as California Bearing Ratio (CBR), atterberg limit (liquid and plastic limit), Atterberg, Unconfined Compressive Strength (UCS), Grain size distribution Compaction test was carried out at University Of Benin A Civil/Structural Engineering Laboratory located inside the school campus.

3.3.2.1 Laboratory Testing

3.3.2.1.1 Atterberg Limits

The Atterberg Limits test is conducted to determine the consistency and plasticity characteristics of fine-grained soils. These limits namely the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) are essential for classifying soils and predicting their behavior under varying moisture conditions. The results are particularly useful in assessing the suitability of soils for construction and stabilization purpose

Test Procedures

Liquid Limit (LL) The liquid limit is defined as the minimum water content at which soil changes from a plastic to a liquid state. The test is performed using the Casagrande apparatus. A soil paste is prepared and placed into the brass cup of the device. A standard grooving tool is used to cut a groove through the center of the soil. The cup is then repeatedly dropped from a height of 10 mm at a rate of two drops per second. The number of blows required to close the groove over a distance of 13 mm is recorded. This process is repeated for multiple moisture contents, and a flow curve is plotted. The liquid limit corresponds to the water content at which the groove closes at exactly 25 blows.

Plastic Limit (PL) The plastic limit is the lowest water content at which soil remains plastic and can be rolled into threads without crumbling. A portion of the soil is rolled by hand on a glass plate into threads approximately 3 mm in diameter. If the threads begin to crumble at this diameter, the water content is determined. The test is repeated several times, and the average moisture content at which crumbling occurs is recorded as the plastic limit.

Plasticity Index (PI) The plasticity index is calculated as the numerical difference between the liquid limit and the plastic limit: $\mathbf{PI = LL - PL}$ This value represents the range of moisture content over which the soil remains plastic. A higher PI indicates a more plastic and potentially problematic soil, while a PI of zero suggests non-plastic behavior.

Apparatus

a) Casagrande Liquid Limit Device – A mechanical device with a brass cup and cam mechanism used to determine the liquid limit by repeatedly dropping the cup from a fixed height.
b) Grooving Tool – A standard tool (either ASTM or Casagrande type) used to cut a groove in the soil paste placed in the liquid limit cup.
c) Glass Plate or Rolling Surface – A smooth, non-porous surface used for rolling soil threads during the plastic limit test.
d) Evaporating Dishes or Mixing Bowls – Used to mix soil with water to desired consistency.
e) Spatula – For mixing and transferring soil paste.
f) Balance (0.01 g sensitivity) – To weigh soil samples and containers accurately.
g) Moisture Containers (Aluminum or Tin **Cans)** – For determining water content of soil samples.
h) Drying Oven (105–110°C) – Used to dry soil samples for moisture content determination.
i) Sieve No. 40 (425 µm) – To separate fine-grained soil fraction for testing.

3.3.2.1.2 Moisture Content

The natural moisture content test is conducted to determine the amount of water present in a soil sample as it exists in the field. This parameter is essential in geotechnical engineering, as it influences soil strength, compaction behavior, and classification. It also provides insight into the soil's consistency and suitability for stabilization.

Test Procedure

A representative soil sample was collected and immediately sealed to prevent moisture loss. The sample was then weighed to determine its wet mass. After weighing, the sample was placed in a thermostatically controlled oven and dried at a temperature of 105–110°C for a period of 24 hours, or until a constant weight was achieved. Once dried, the sample was removed from the oven, allowed to cool in a desiccator to avoid moisture absorption from the air, and then reweighed to determine its dry mass.

Apparatus

I. Weighing Balance
II. Drying Oven
III. Moisture Containers
IV. Desiccator
V. Tongs or Heat-Resistant Gloves
VI. Spatula or Scoop
VII. Labeling Materials

3.3.2.1.3 Standard Proctor Compaction Test

The Standard Proctor Compaction Test is conducted to determine the relationship between the moisture content and the dry density of a soil sample. This relationship is critical in geotechnical engineering, as it helps identify the Optimum Moisture Content (OMC) at which a soil can be compacted to achieve its Maximum Dry Density (MDD). These parameters are essential for designing and constructing stable earthworks, road subgrades, and foundations.

Test Procedure

A representative soil sample was first air-dried and sieved through a 4.75 mm (No. 4) sieve to remove coarse particles. Approximately 3–4 kg of the prepared soil was used for each compaction trial.

The test was performed using a cylindrical metal mold with a volume of 944 cm^3 and a detachable collar. The mold was filled in three equal layers. Each layer was compacted using a standard Proctor rammer weighing 2.5 kg, dropped from a height of 30.5 cm. A total of 25 evenly distributed blows were applied to each layer to ensure uniform compaction.

After compaction, the collar was removed, and the excess soil was trimmed flush with the top of the mold using a straightedge. The mold and compacted soil were weighed to determine the bulk (wet) density. A representative sample was then taken from the compacted soil and oven-dried at 105–110°C for 24 hours to determine its moisture content.

This process was repeated for several trials, each with incrementally increased moisture content (typically in 2–3% steps). For each trial, the dry density was calculated using the formula:

The results were plotted on a graph with dry density on the vertical axis and moisture content on the horizontal axis. The peak of the resulting compaction curve indicated the Maximum Dry Density (MDD), and the corresponding moisture content was recorded as the Optimum Moisture Content (OMC).

Apparatus

a) Cylindrical metal mold (usually 1000 cm^3 volume) with detachable base plate and extension collar
b) Standard Proctor rammer (2.5 kg mass, 30.5 cm drop height)
c) Balance (sensitivity of 0.01 g)
d) Oven (maintained at 105–110°C)
e) Straightedge (steel)
f) Moisture content containers
g) Graduated cylinder (for water measurement
h) Mixing tools (spatula, trowel, or spoon)
i) Tray or pan (for soil preparation)
j) Sieve No. 4 (4.75 mm)

3.3.2.1.4 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test is a penetration test used to evaluate the loadbearing capacity of subgrade soils and base materials for road and pavement design. It provides a relative measure of the strength of the soil by comparing it to a standard crushed stone material. The CBR value is expressed as a percentage and is critical in determining the thickness of pavement layers.

The test was conducted in accordance with standard procedures (e.g., ASTM D1883 or IS: 2720 Part 16). A representative soil sample was first compacted into a cylindrical CBR mold (150 mm diameter, 175 mm height) in three layers using a standard Proctor compaction method. Each layer was compacted with 56 blows from a 2.5 kg rammer dropped from a height of 30.5 cm to achieve the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

After compaction, the surface was leveled, and a surcharge weight (typically 4.5 kg) was placed on top to simulate the weight of overlying pavement layers. For soaked CBR tests, the specimen was submerged in water for 96 hours (4 days) to simulate worst-case field conditions. Swelling was monitored using a dial gauge, and the percentage swell was recorded.

Following soaking, the mold was placed under a loading frame equipped with a penetration piston of 50 mm diameter. The piston was driven into the soil at a constant rate of 1.25 mm/min. The load required to achieve penetrations of 2.5 mm and 5.0 mm was recorded using a proving ring or load cell.

The CBR value was calculated using the formula:

CBR (%) = (PT/PS) X 100

Where the standard loads are:

1370 kg for 2.5 mm penetration

2055 kg for 5.0 mm penetration

3.3.2.1.5 particle Size Distribution

The grain size distribution test is conducted to determine the proportions of different particle sizes within a soil sample. This classification helps in understanding the soil's drainage characteristics, compaction behavior, and suitability for construction purposes. The results are typically used to classify the soil according to systems such as the Unified Soil Classification System (USCS) or AASHTO.

Test Procedure

The test was carried out using the sieve analysis method, which is suitable for soils with particle sizes ranging from coarse gravel to fine sand (typically particles larger than 75 µm). The procedure followed is as outlined below:

First, the soil sample was oven-dried at a temperature of 105–110°C for a minimum of 24 hours to remove all moisture. Once dried, the sample was allowed to cool and then weighed to determine the total dry mass.

A stack of standard sieves was arranged in descending order of mesh size, typically starting from 4.75 mm down to 75 µm. The sieves were securely placed on a mechanical sieve shaker, with a pan at the bottom to collect the finest particles.

The dried soil sample was poured into the top sieve, and the entire stack was shaken mechanically for 10 –15 minutes to ensure thorough separation of particles by size. After shaking, each sieve was carefully removed, and the mass of soil retained on each sieve was recorded.

The percentage of soil retained on each sieve was calculated by dividing the mass retained by the total sample mass and multiplying by 100. The cumulative percentage retained was then determined, and the percentage passing through each sieve was obtained by subtracting the cumulative retained from 100%.

Finally, the results were plotted on a semi-logarithmic graph to produce a grain size distribution curve. This curve was used to determine key parameters such as the effective size (D_{10}), uniformity coefficient (C_u), and coefficient of curvature (C_c), which are essential for soil classification and engineering analysis.

Apparatus

a) Set of Standard Sieves

b) Balance (0.01 g sensitivity)

c) Oven (105–110°C)

d) Weighing Dishes or Trays

e) Brush and Spatula

f) Mortar and Pestle (optional)

g) Sieve Pan and Lid The pan

CHAPTER FOUR

RESULT AND ANALYSIS OF RESULTS

This chapter shows the results of the laboratory tests conducted to evaluate the effect of bamboo ash on soil stabilization. parameters such as Atterberg limits, compaction, and California bearing ratio (CBR) were analyzed. Results from treated and untreated samples are compared to assess performance improvements (using percentages ranging from 2 – 10).

4.1 Specific Gravity Analysis Result

The Specific gravity test was conducted on the soil sample, and the result is presented in table 4.1 and the laboratory sheet is shown in the appendix.

Table 4.1: Specific gravity test was conducted

S/N	SAMPLE ID	GS
1.	Soil Sample	2.26

The specific gravity of the soil sample was obtained from the formula

$$Gs = \frac{w_2 - w_1}{W}$$ Equation 4.1

where :

GS = weight of soil sample

W= weight of water displaced by soil.

w_1 = Weight of bottle

w_2 = Weight of bottle + soil

From the result, the specific gravity obtained for the soil sample is 2.26, which implies a soil unsuitable for road construction. According (Amadi, 2010), GS of soils suitable for road construction are within the range of 2.5 and 3.4 for laterite

4.2 Particle Size Distribution Test Result

Sieve analysis result for some selected sieve sizes (2.0mm, 0.425 mm and 0.075 mm) are is shown in Table 4.2 whereas the full laboratory sheet is presented in the appendix.

Table 4.2: Sieve Analysis Test Result

S/N	SAMPLE ID	% PASSING SIEVE SIZES		
		2.0mm	0.425mm	0.075mm
1	SOIL	98.2	85.5	37.8

From table 4.1, the percentage passing through 0.075mm or no.200 sieve is 37% which implies that the sample falls have significant clay or silt content. The particle size distribution is shown in figure 4.1.

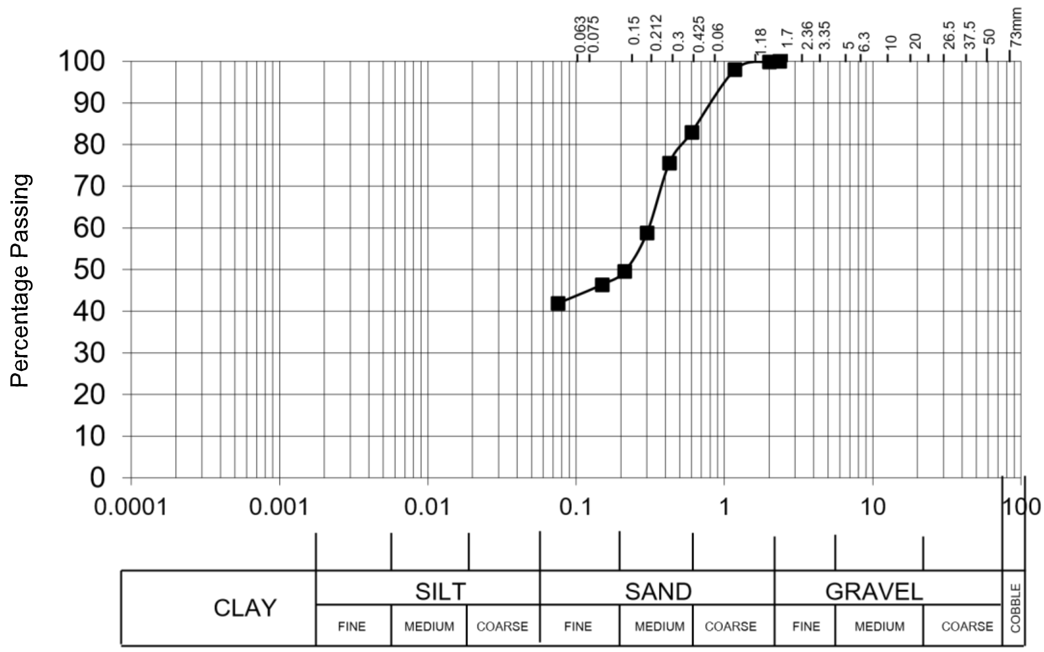

Figure 4.1: Sieve Analysis Graph Show the Particle Sizes of the Soil

The curve shows a smooth transition from fine to coarse sand.

4.3 ATTEBERT LIMIT TEST

The Atterberg limits test result (Liquid limit (LL), plastic limit (PL) and the plasticity index (PI))is shown in table 4.3 and the laboratory sheet is shown in the appendix.

Table 4.3: Atterberg Limit Test Result

S/N	SAMPLE ID	LL	PL	PI	QUALIFYING TERMS
1	0%	31.25	19.69	11.56	CL,
2	2%	28.36	21.52	6.87	CL
3	4%	28.24	19.63	8.61	CL
4	6%	31.58	18.99	12.28	CL
5	8%	31.58	19.69	11.89	CL

6	10%	34.83	23.90	10.93	CL

From the result, the liquid limit of the soil samples ranges from 28.36 to 34.83%, the plastic limit range from to 23.90% And the PI ranges from 6.87 to 12.28% . according to the British System (BS 5930. 1999) plasticity chart they are qualified as low clay soils (CL).

4.4 Compaction Test Result

The compaction test result are presented in table 4.4 and in the appendix.

Table 4.4 Compaction Test Result

BAMBOO ASH	0%	2%	4%	6%	8%	10%
MOISTURE CONTENT **(%)**	13.0	1.65	14.55	13.45	14.07	10.10
DRY DENSITY (g/cm^3)	1.75	1.73	1.48	1.70	1.59	1.55

From the test carried out, an increase in the proportion of bamboo ash and (0%, 2%, 4%, 6%, 8%, 10%) increased the optimum moisture content and decreased the maximum dry density.

At 0% ash, the soil has a high dry density (1.75 g/cm^3) and moderate moisture (13.0%), indicating good natural compaction. At 6% ash, dry density is nearly as high (1.70 g/cm^3) with similar moisture content (13.45%), suggesting effective stabilization. Beyond 6%, dry density decreases, and moisture content fluctuates, indicating diminishing returns in compaction efficiency.

This pattern is typical, according to Akinwumi, I. I., & Eberemu, A. O. (2016)

adding stabilizers like bamboo ash improves compaction up to a point, after which excess ash can reduce density due to increased voids or poor particle bonding. Optimal bamboo ash content appears to be around 6%, balancing moisture and density effectively.

4.5 California Bearing Ratio (CBR) Result

The California Bearing Ratio (CBR) Result was conducted on the soil sample and the stabilizing agent (bamboo ash) and result is presented in table 4.5 and the laboratory sheet is shown in the appendix.

Table 4.5: California Bearing Ratio (CBR) Result

S/N	SAMPLE ID	UNSOACKED		SOACKED	
		2.5mm	5.0mm	2.5mm	5.0mm
1	0%	6.659	6.72	4.56	7.20
2	2%	9.00	10.72	6.54	7.88
3	4%	6.41	7.37	4.80	5.48
4	6%	7.27	8.02	5.54	6.30
5	8%	7.5	8.3	6.78	7.77
6	10%	7.59	8.5	7.27	7.8

The 2% sample shows the highest CBR values in both unsoaked conditions (10.72mm) and soaked conditions (7.88mm), suggesting optimal improvement at this level.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This research examined the effectiveness of bamboo ash as a stabilizing agent for waterlogged and erosion-prone soils in Benin City, Edo State. The study achieved its stated objectives, which were to (i) evaluate the index and strength properties of the natural and stabilized soils, and (ii) determine the optimum bamboo ash content required to improve soil performance.

From the experimental results obtained through laboratory testing in accordance with AASHTO**,** ASTM standards, the conclusions were drawn. Based on the Atterberg Limits**,** specific gravity**,** and grain size distribution**,** the natural soil was classified as a low plastic clay (CL) under the Unified Soil Classification System (USCS) and as an A-6 soil under the AASHTO classification system. Such soils are known for low bearing strength and poor drainage capacity, typical of waterlogged subgrade materials.

The addition of bamboo ash reduced the plasticity index (PI) of the soil from 11.56% to about 6.87% at 2–4% ash content, indicating improved workability and reduced swelling potential. This implies that bamboo ash effectively decreased the plastic behavior of the soil, making it more stable under moisture variations.

The Optimum Moisture Content (OMC) increased while the Maximum Dry Density (MDD) decreased slightly with increasing bamboo ash content. The trend shows that the ash, being lightweight and porous, absorbs more water during compaction but enhances bonding between soil particles. The optimal performance was observed at 6% bamboo ash content**,** where the soil achieved a balance between strength and density.

The CBR values improved with the inclusion of bamboo ash. The unsoaked CBR increased from 6.72% (natural soil) **to** 10.72% at 2% bamboo ash, while the soaked CBR improved from 7.20% to 7.88% at the same percentage. This shows that bamboo ash significantly enhances load-bearing capacity and strength, even under soaked conditions.

The findings indicate that the optimum range for bamboo ash addition lies between 2% and 6%**,** where the best improvements in soil strength and consistency were achieved without reducing density excessively.

5.2 RECOMMENDATIONS

Bamboo ash should be adopted as **a** stabilizing additive for low-bearing and waterlogged soils**,** particularly in subgrade layers of low-traffic or rural roads. The recommended optimum range **is** 4–6% by weight of dry soil.

Field compaction and testing should strictly follow AASHTO T99 (Standard Proctor Test)**,** AASHTO T193 (CBR Test)**,** and specifications to ensure uniformity, density, and longterm stability.

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APPENDIX

APPENDIX A

Table A-1 Specific Gravity Readings

S/N	**LOCATION**	**DEPTH (m)**	**BN**	**B+W**	**B+S+W**	**B+S**	**B**	**Ad. W**	**WWAS**	**WS**	**WOWDS**	**Gs**	**AGs**
1			S6	74.58	95.36	58.13	20.37	54.21	37.28	37..94	16.93	2.24	2.26
			NE	76.70	95.60	55.49	21.82	54.88	40.11	33.67	14.77	2.28	

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

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

B+S = Wt. of Bottle + Soil W2

B = Wt. of Bottle W1

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

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

WS = Wt. of Soil (W2-W1)

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

GS = Specific Gravity (W2-W1)/W

Table A-2 Sieve Analysis

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2 ½				
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	0.8	99.2	99.2
10	2	1.0	98.2	98.2

14	1.18	2.5	95.7	95.7
25	0.6	0.2	95.5	95.5
36	0.425	10.0	85.5	85.5
52	0.3	12.5	73	73
72	0.212	13.6	59.4	59.4
100	0.15	11.1	48.3	48.3
200	0.075	10.5	37.8	37.8

Table A-3 Atterberg limit test

BAMBOO ASH	PLASTIC LIMIT	LIQUID LIMIT	PLASISISTY INDEX
0%	19.69	31.25	11.56
2%	22.49	28.36	5.87
4%	19.63	28.24	8.61
6%	18.99	31.588	12.28
8%	19.69	31.588	11.89
10%	23.90	34.83	10.93

Table A – 4 Compaction Test

BAMBOO ASH	0%	2%	4%	6%	8%	10%
MOISTURE CONTENT	13.0	1.65	14.55	13.45	14.07	10.10
DRY DENSITY	**1.75**	**15.73**	**1.48**	**1.70**	**1.59**	**1.55**

Table A-5 CBR RESULTS

FOR 0%

	UNSOAKED		**SOAKED**	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	6.659	6.383	5.426	7.201
TOP	6.659	7.038	3.700	7.201

2% FOR BAMBOO ASH

	UNSOAKED		**SOAKED**	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	9.126	10.802	6.659	7.856
TOP	8.879	10.638	6.413	7.856

OF 4% OF BAMBOO ASH

	UNSOAKED		**SOAKED**	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	6.659	7.529	5.179	6.056
TOP	6.166	7.201	4.439	4.910

6% of Bamboo ash

	UNSOAKED		**SOAKED**	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	7.646	8.183	5.919	6.547
TOP	6.906	7.856	5.179	6.056

8% OF BAMBOO ASH

	UNSOAKED		**SOAKED**	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	7.892	8.674	6.906	7.856
TOP	7.153	8.019	6.659	7.692

OF BAMBOO ASH

	UNSOAKED		**SOAKED**	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	7.892	8.674	7.892	8.674
TOP	7.399	8.183	6.659	7.038

APPENDIX B

Figure B- 1 Seive Analysis Graph

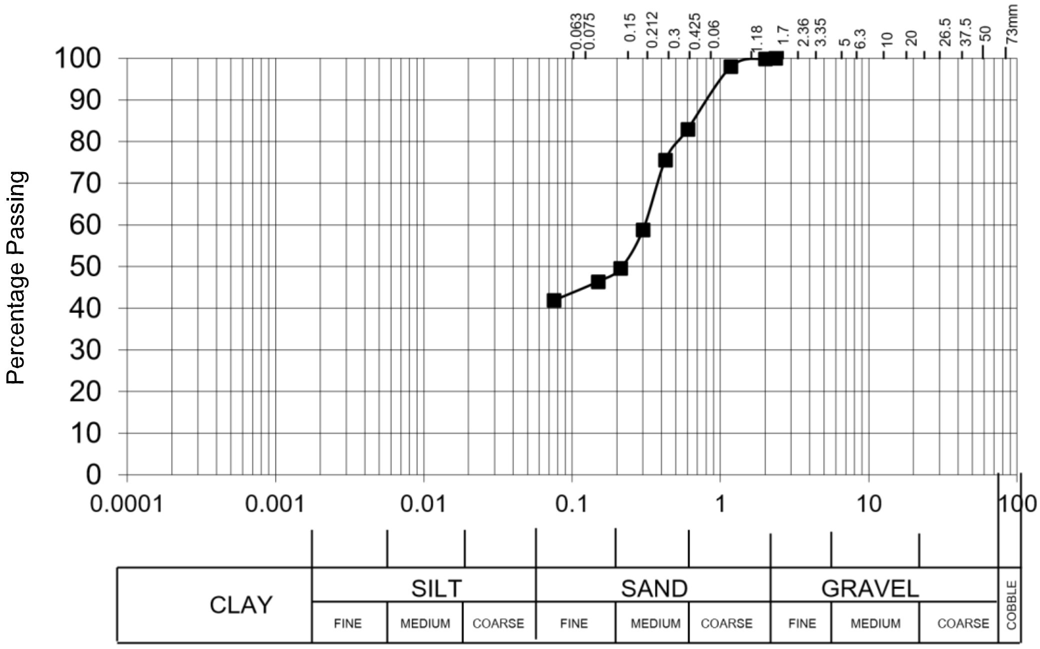
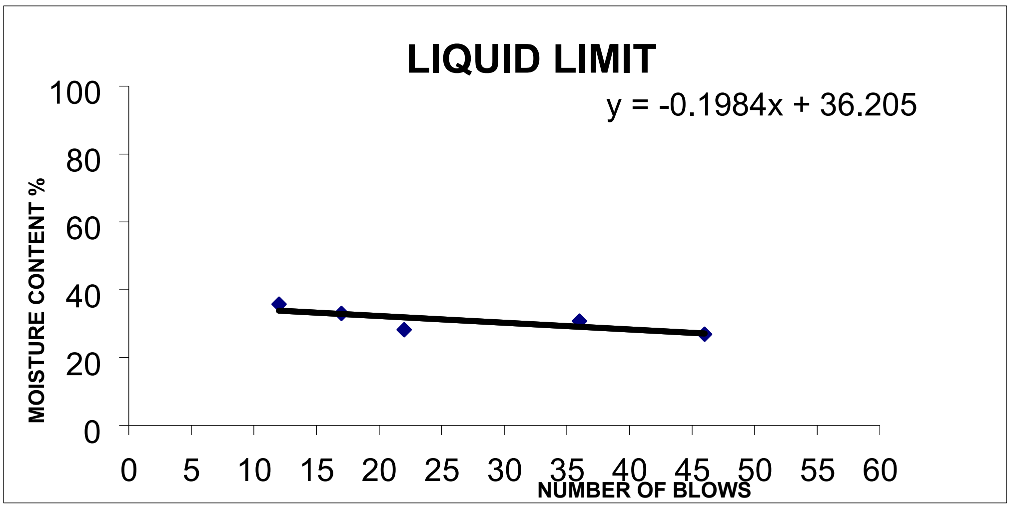
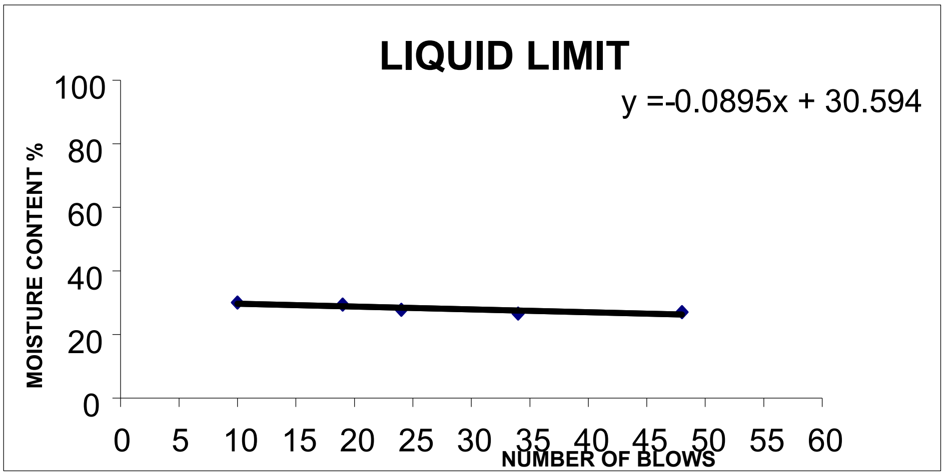


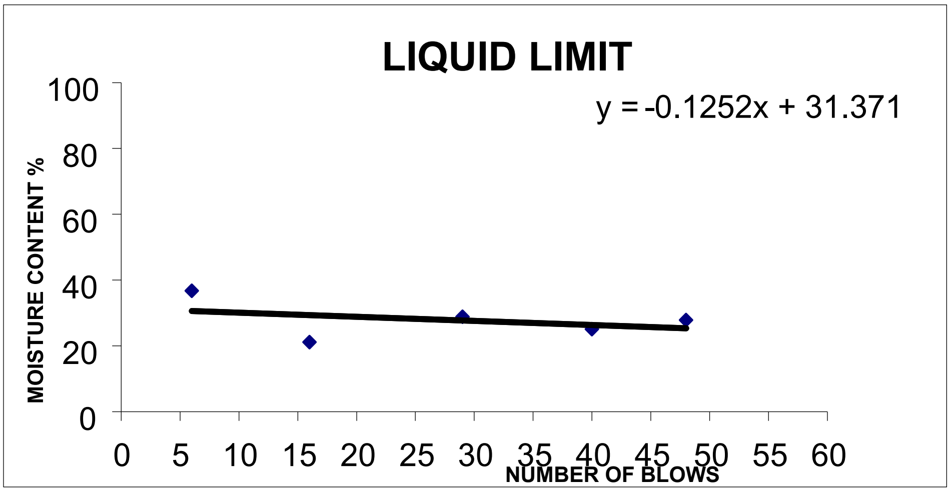
Figure B-2 Graph of altterberg Limit Test.



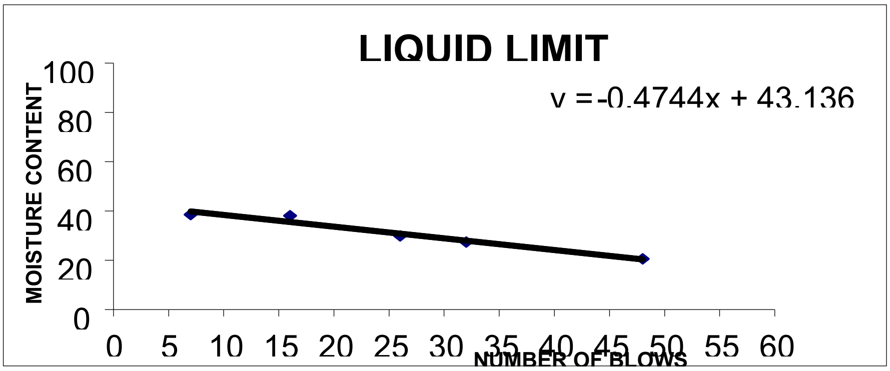
0% PERCENT



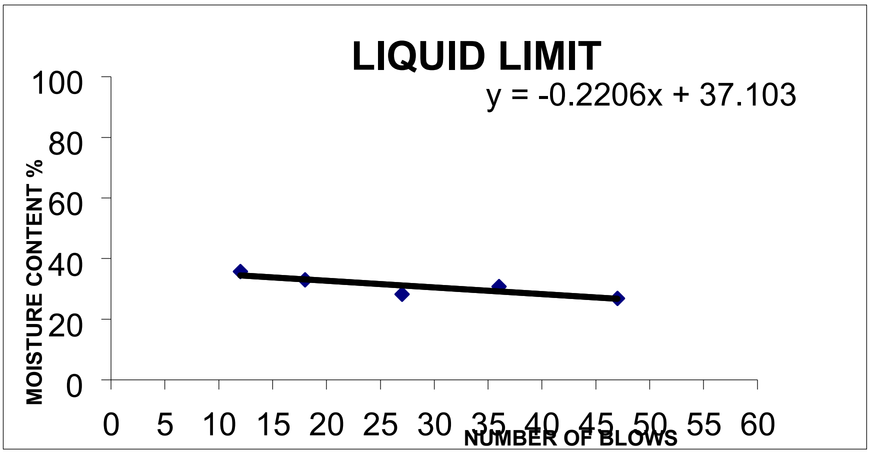
2 PERCENT



4 PERCENT

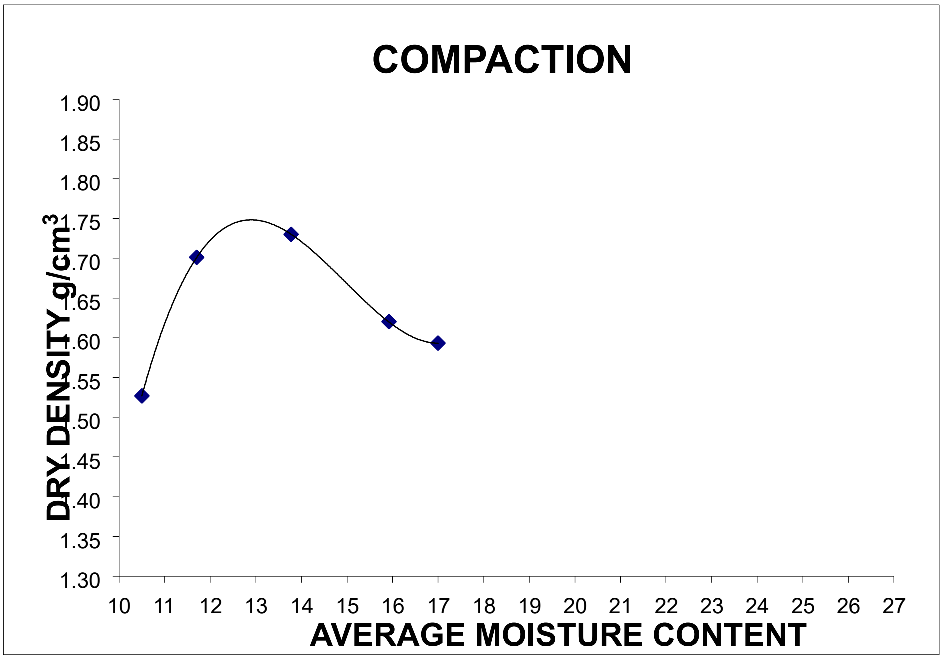


6 PERCENT

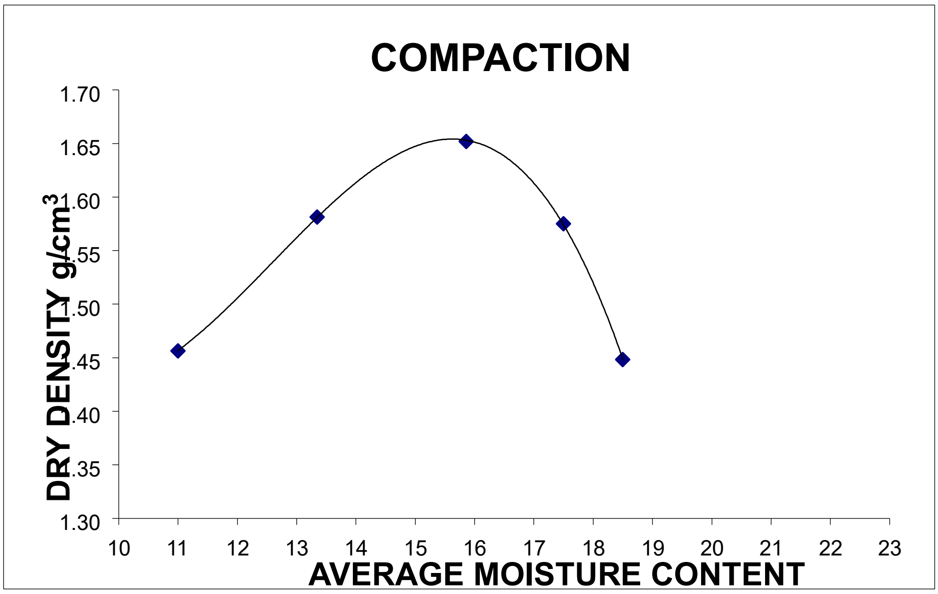


8 PERCENT

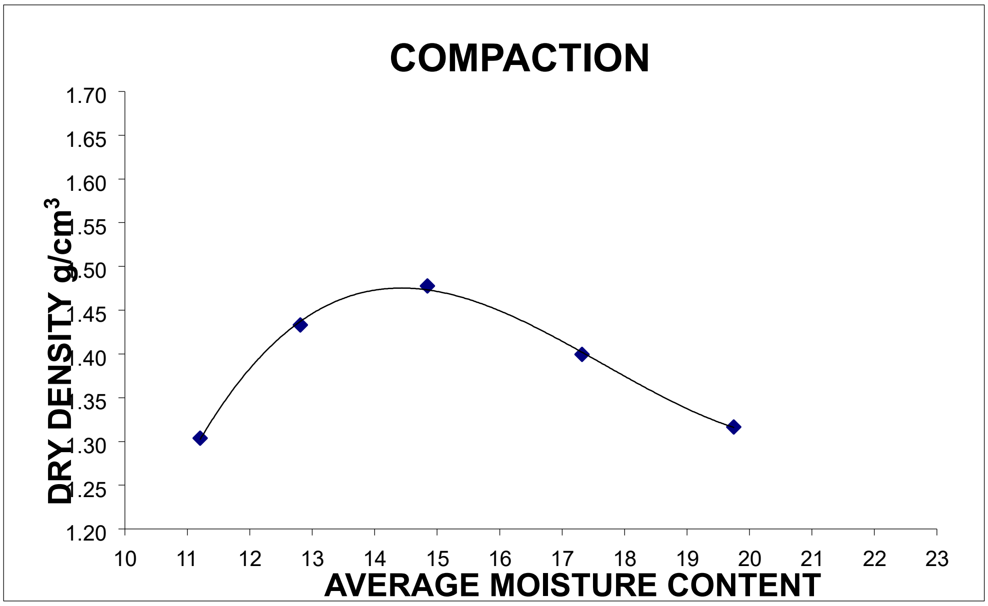
Figure B- 3 Compaction Graphs



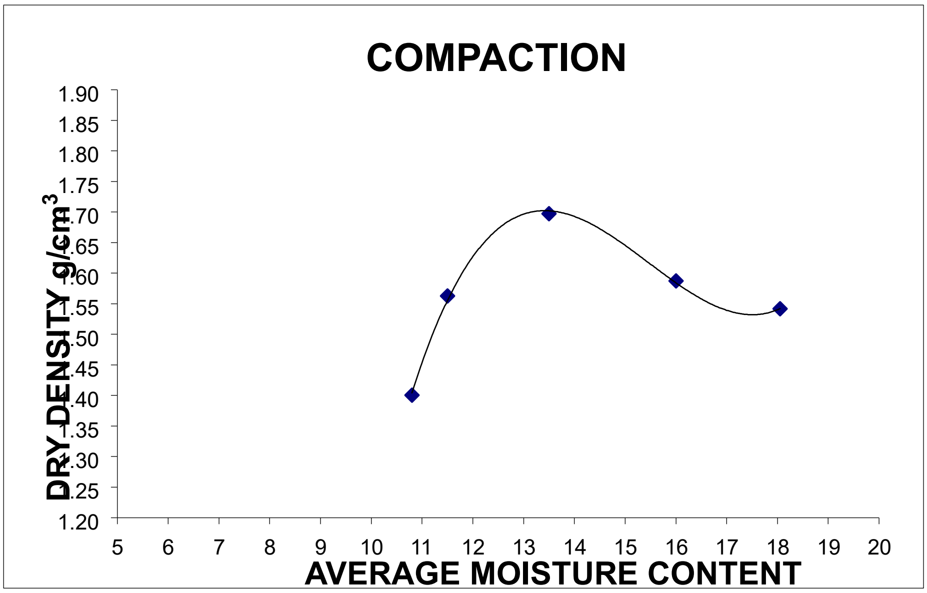
GRAPH 0 PERCENT



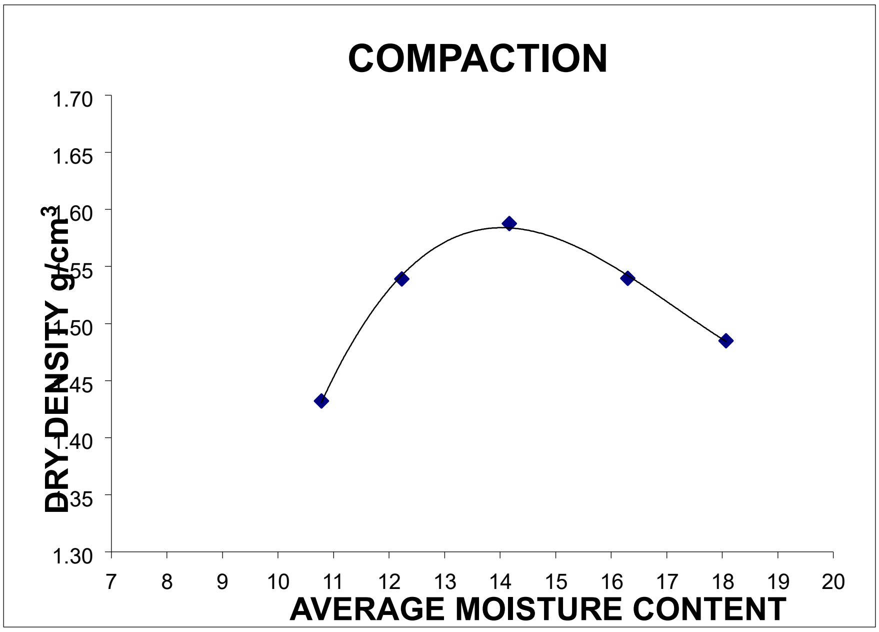
GRAPH FOR 2 PERCENT



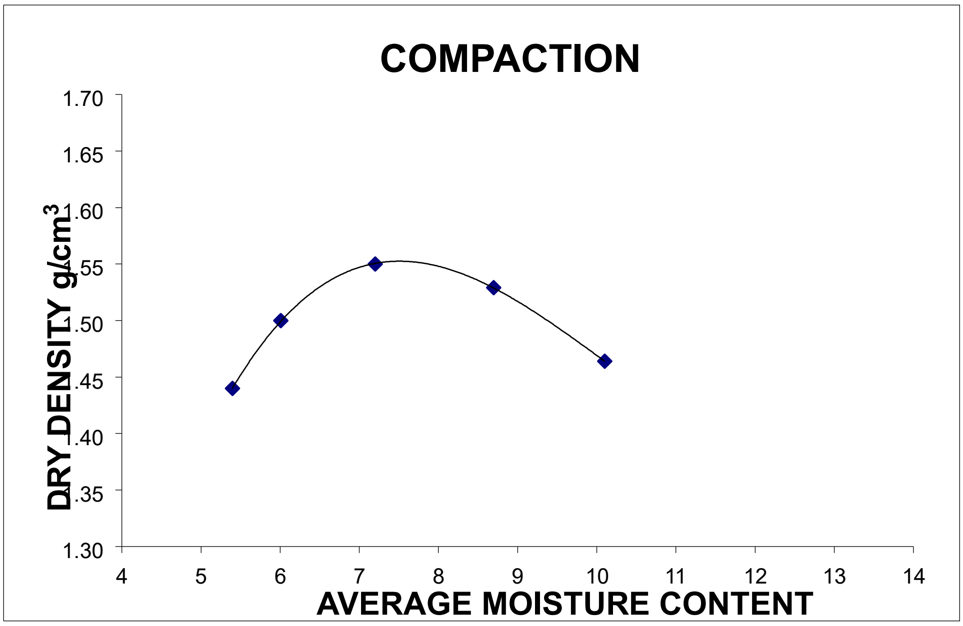
GRAPH 4 PERCENT



GRAPH FOR 6 PERCENT

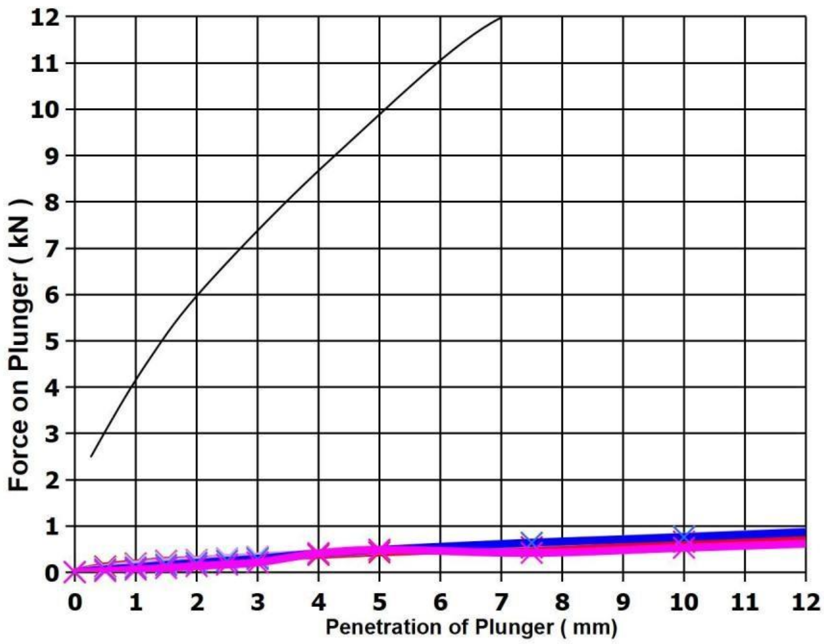


GRAPH FOR 8 PERCENT

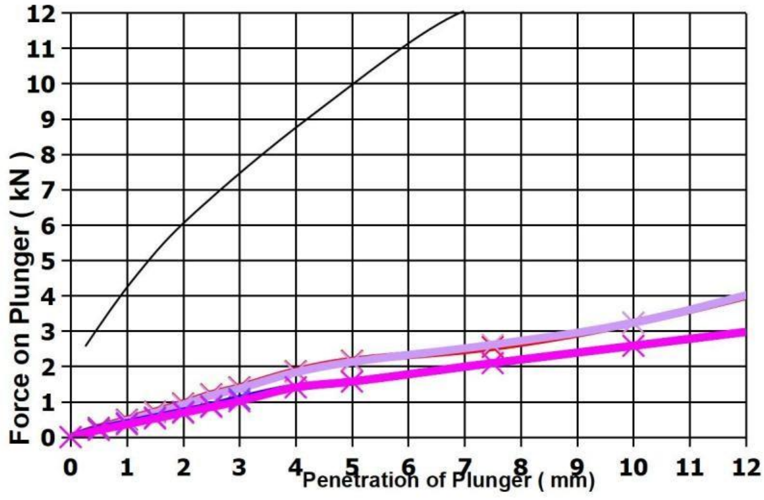


GRAPH FOR 10 PERCENT

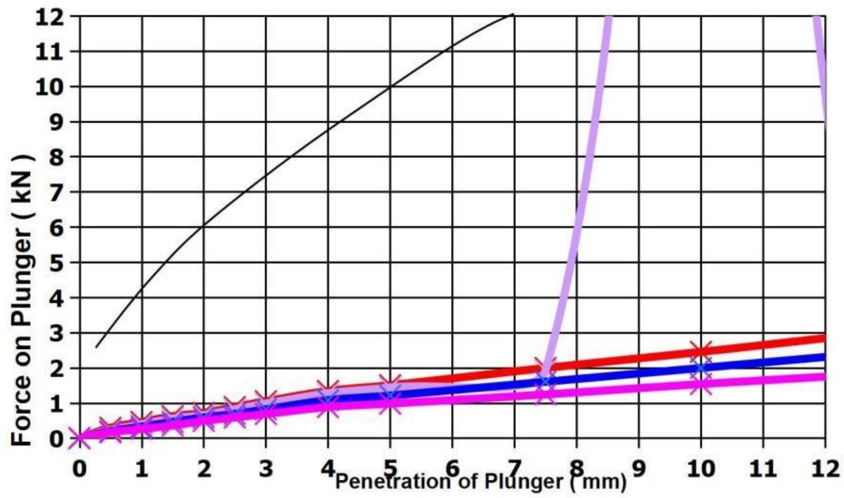
Figure B- 4 Califonial bearing ratio graph of bamboo ash



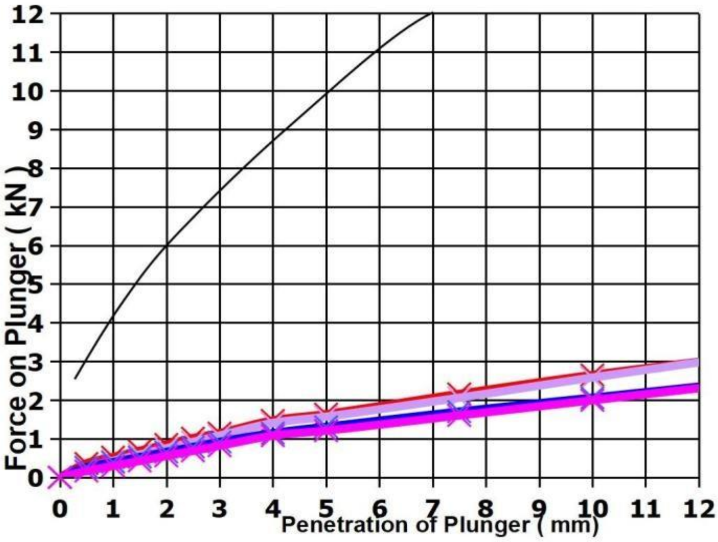
Graph of 0%



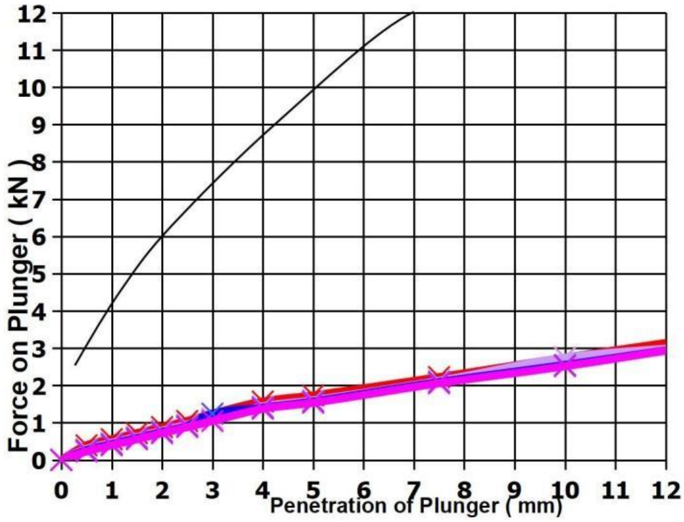
Graph of 2%



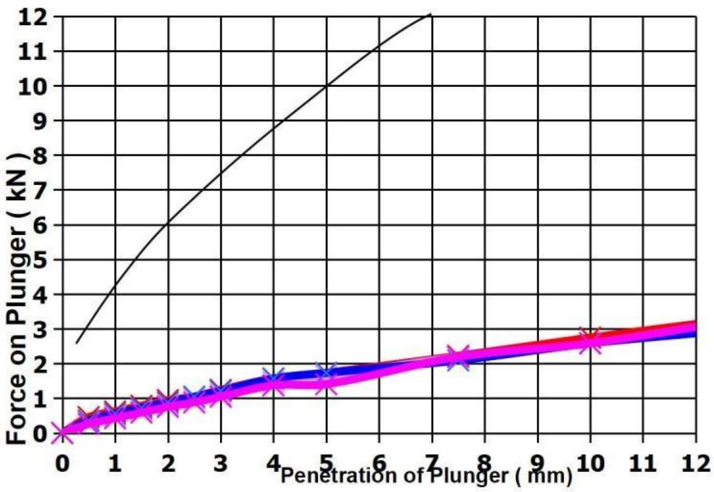
Graph of 4%



Graph for 6%



Graph of 8%



Graph of 10%

APPENDIX C

Plate C-1 : Burning of bamboo ash

Plate C- 2: Specific gravity test been carried out

Plate C- 3: Various kinds of sieves used in sieve analysis

Plate C- 4: Researcher carrying out Atterberg limit test

PlateC- 5: Researcher carrying out Compaction test