THE EFFECT OF COMPACTIVE EFFORT ON THE ENGINEERING PROPERTIES OF LATERITE SOIL IN BENIN CITY, NIGERIA

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THE DEPARTMENT OF CIVIL ENGINEERING,

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JULY, 2025

AN UNDERGRADUATE PROJECT

ON

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PROJECT WORK SUBITTED TO THE DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

IN LINE WITH THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng) DEGREE.

JULY, 2025

CERTIFICATION

This is to certify that this research work was carried out by OMOAREGBA EMMANUEL BENJAMIN, Matriculation Number **ENG2006235** of the Department of Structural Engineering, Faculty of Engineering, University of Benin, in partial fulfilment for the award of Bachelor 0f Engineering (B.Eng) in Civil Engineering.

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DEDICATION

This work is dedicated to my loving family, whose unwavering support and encouragement have been my pillars of strength throughout this journey.

ACKNOWLEDGEMENT

My sincere gratitude to the almighty God for his guidance and favor throughout my undergraduate days in the university studying as a civil engineer, it could not have been a reality if not for the heavenly father's involvement

My heartfelt gratitude goes to my project supervisor Engr. Prof. N. Kayode-Ojo and Engr. Janet O. Odemerho whose advice, guardians, criticism and encouragement has led to the success of this project; I so much appreciate her positive impact on me such as skill documentation, ability to observe in depth studying and time management

Special thanks goes to the Head of the Department, Engr. Prof. Mrs. N. Ihimekpen and project coordinator Engr. E. Oria Usifo. I want to appreciate all civil lectures Engr N. K. Oghoyafedo, Engr Prof O.C. Izinyon, Engr Prof. S.O. Qsuji, Engr U. Ogbonna, Engr Prof: J.O. Okovido, Engr (Mrs), G.E. Evbaru-Okhuahesuyi, Engr Prof. S.D. Iyeke, Engr. Prof. R.I. Umasabor, Engr. Prof. R.O. Qgirigbo, Engr. Dr. (Mrs) A. Rawlings, Dr. (Mrs) L.O. Bobor, Engr Dr. A. Agbonaye, Engr. Dr. S. Okonofua, Engr Dr. R. Ilaboya, Engr U. Ukeme, Engr P.N Ogbeifun, Engr O. Oriakhi, Engr. B. Omosefe, Mr. O. Osasu, For their positive support and assistance in the process of my undergraduate degree in this great department of Civil Engineering

Also, my profound and unreserved gratitude goes to my parents Mr. Lucky Omoaregba and Mrs. Gina Omoaregba for their relentless efforts, love, care and financial support towards my career.

TABLE OF CONTENTS

COVER PAGE……..… ii
CERTIFICATION iii
DEDICATION……..…….iv
ACKNOWLEDGEMENT..... v
TABLE OF CONTENTS vi
LIST OF FIGURES ixx
LIST OF TABLES x
LIST OF ABBREVIATIONS……xi
LIST OF EQUATIONS……xii
ABSTRACT xiii
CHAPTER ONE 1
INTRODUCTION 1
1.1 Background of the Study 1
1.2 Statement of Problem 1
1.3 Aims and Objectives 2
1.4 Scope of Study 3
1.5 Justification of Study..... 4
CHAPTER TWO 5
LITERATURE REVIEW..... 5
2.1 Role of Moisture Content in Soil Compaction..... 5
2.2 Principles of Soil Compaction 5
2.3 Engineering Properties of Laterite Soil 6
2.3.1 Plasticity……7
2.3.2 Strength……7
2.3.3. Permeability……7
2.3.4 Compressibility……8
2.3.5 California Bearing Ratio (CBR)……8
2.3.5.1 Principle of the CBR Test……..9
2.3.5.2 Applications and Limitations……9
2.4 Factors Affecting Compaction..... 10
2.4.1 Soil Type and Properties……..……..10
2.4.2 Method of Compaction.……10
2.5 Compactive Effort and its Influence on Soil Properties 11

2.5.1 Compaction Tests Explained……..12
2.6 Empirical Review 14
2.7 Research Gap 17
CHAPTER THREE 18
METHODOLOGY 18
3.1 The Study Area 18
3.2 Sample Collection and Preparation 19
3.2.1 Sample Collection……19
3.3 Preliminary Soil Characterization 20
3.3.1 Particle Size Distribution (Sieve Analysis)……...20
3.3.2 Atterberg Limits…….21
3.4 Compaction Tests 21
3.4.1 Standard Proctor Compaction Test (Light Compaction)…….22
3.4.2 Modified Proctor Compaction Test (Heavy Compaction)…….…….…22
3.4.3 West African Standard Compaction Efforts…….…22
3.5 Engineering Property Tests at Varying Compactive Efforts 22
3.5.1 California Bearing Ratio (CBR) Test……..23
CHAPTER FOUR 23
RESULTS AND DISCUSSION…….24
4.1 Preliminary Soil Characterization 23
4.1.1 Particle Size Distribution…….24
4.1.1.1 Blocks of Flat Gully Site…….24
4.1.2 Atterberg Limits and Specific Gravity 29
4.1.3 Moisture Content 31
4.1.3.1 BS Code……..32
4.1.3.2 ASTM Code……32
4.1.4 Specific Gravity…….33
4.1.4.1 ASTM Code……33
4.1.4.2 BS Code……..33
4.1.4.3 Specific Gravity of Gully Site……33
4.2 Compaction Test Result 33
4.2.1 Standard Proctor Test 33
4.2.2 Modified Proctor Test 35
4.2.3 West-African Standard Proctor Test 37
4.3 California Bearing Ratio (CBR) Results……41
4.4 Discussion of Results……..43
CHAPTER FIVE 46

CONCLUSION AND RECOMMENDATION……..47
5.1 Conclusion 46
5.2 Recommendations 47
REFERENCES 49
APPENDIX 53

LIST OF FIGURES

Fig. 3.1: Location Map Showing Oluku in Edo State South South Nigeria (Fega et al.)

Fig. 3.2: A Set of Sieves for the Sieve Analysis Test (Fega et al.)

Fig. 4.1: Particle Size Distribution Curve for Gully Site at 1m

Fig. 4.2: Particle Size Distribution Curve for Gully Site at 2m

Fig. 4.3: Particle Size Distribution Curve for Gully Site at 3m

Fig. 4.4: Particle Size Distribution Curve for Oluku at 1m

Fig. 4.5: Particle Size Distribution Curve for Oluku at 2m

Fig. 4.6: Particle Size Distribution Curve for Oluku at 3m

Fig. 4.7: Liquid Limit Flow Curve for Gully Site

Fig. 4.8: Liquid Limit Flow Curve for Oluku Site

Fig. 4.9: Standard Proctor Compaction Curve

Fig. 4.10: Modified Proctor Compaction Curve

Fig. 4.11: West African Standard Compaction Curve

Fig. 4.12: Unsoaked CBR Comparison at Different Compactive Efforts

Fig. 4.13: Soaked CBR Comparison at Different Compactive Efforts

LIST OF TABLES

Table 4.1: Particle Size Distribution Analysis of Gully Site Soil Sample at 1m Depth

Table 4.2: Particle Size Distribution Analysis of Gully Site Soil Sample at 2m Depth

Table 4.3: Particle Size Distribution Analysis of Gully Site Soil Sample at 3m Depth

Table 4.4: Particle Size Distribution Analysis of Oluku Soil Sample at 1m Depth

Table 4.5: Particle Size Distribution Analysis of Oluku Soil Sample at 2m Depth

Table 4.6: Particle Size Distribution Analysis of Oluku Soil Sample at 3m Depth

Table 4.7.1: Liquid Limit Test Results for Gully Site Soil Sample

Table 4.7.2: Plastic Limit Test Results for Gully Site Soil Sample

Table 4.8.1: Liquid Limit Test Results for Oluku Soil Sample

Table 4.8.2: Plastic Limit Test Results for Oluku Soil Sample

Table 4.9.1: Natural Moisture Content for Gully Site Soil Sample (1m Depth)

Table 4.9.2: Natural Moisture Content for Gully Site Soil Sample (1.5m Depth)

Table 4.9.3: Natural Moisture Content for Gully Site Soil Sample (2m Depth)

Table 4.10.1: Specific Gravity Test Results for Gully Site Soil Sample (1m Depth)

Table 4.10.2: Specific Gravity Test Results for Gully Site Soil Sample (1.5m Depth)

Table 4.10.3: Specific Gravity Test Results for Gully Site Soil Sample (2m Depth)

Table 4.11: Standard Proctor Compaction Results (Gully Site)

Table 4.12: Modified Proctor Compaction Results (Gully Site)

Table 4.13: West African Standard Compaction Results (Gully Site)

Table 4.14: Unsoaked CBR Results for Gully Site

Table 4.15: Soaked CBR Results for Gully Site

LIST OF ABBREVIATIONS

AASHTO: American Association of State Highway and Transportation Officials

CBR: California Bearing Ratio

CPT: Cone Penetration Test

CSA: Canadian Standards Association

GRS: Geosynthetic Reinforced Soil

IS: Indian Standard

MDD: Maximum Dry Density

MMA: Maximum Moisture Absorption

OMC: Optimum Moisture Content

PI: Plasticity Index

UCS: Unconfined Compressive Strength

USCS: Unified Soil Classification System

WAS: West African Standard

LIST OF EQUATIONS

Eqn. 2.1: California Bearing Ratio (CBR)

ABSTRACT

The lateritic soils show a great variation in their properties as per their geological parent, weathering and mineralogical structure resulting in natural variation even in the relatively small geographical regions. Such variability presents serious difficulties to the engineers in determining their behaviour as well as designing the necessary compaction specifications. This study was intended to examine the impacts of different compactive efforts on lateritic soil engineering properties and to see how best they can be utilized in a civil work activity, using Oluku Borrow Pit and Blocks of Flats Gully Site in Benin City as the case study.

Two samples of bulk laterite soil samples were collected at the two sites, dried in the air, ground and sent to the lab. The preliminary index tests such as particle size distribution, Atterberg limits, natural moisture content and specific gravity were conducted in order to classify the soils. Standard Proctor, West African Standard (WAS) and Modified Proctor methodology were used to conduct compaction tests to measure the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). To determine the strength properties of the compacted soils, California Bearing Ratio (CBR) tests were later conducted in the soaked and unsovid states.

The findings indicated that the maximum dry densities and the optimum moisture contents of both soils were increased by the increase in the compactive effort. Using the West African Standard compactive effort, optimum moisture content in the form of the West African Standard was a maximum of 10 per cent, with a maximum of 2.08 Mg/m3 dry density. The Oluku Borrow Pit soil, which had a lower content of fines (about 4.95-5.53% less the 0.075 mm sieve at shallow depths), presented a better performance with unsoaked CBR ranging between 28% at the shallow depths of compaction under the Modified Proctor compaction, whereas the soaked CBR was between 4-6%. Conversely, the Gully Site soil, which contains more fines (30 to 44 percent passing 0.075 mm sieve) registered lower unsoaked values of CBR of 2 to 4 percent and soaked values below 1 percent, which means that it is highly sensitive to moisture. This paper hence arrives at the conclusion that compactive effort is a crucial factor when improving the engineering qualities of lateritic soils, but, soil composition is a controlling aspect. Oluku laterite can be used under grade under the condition that they are compacted and drained and the Gully Site soil has to be stabilized first before it can be used in structural pavement layers.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Soils form the fundamental building blocks of almost all civil engineering constructions, serving as foundational support for structures, embankments, and pavements. Among the diverse soil types, lateritic soils hold particular significance, especially in tropical and subtropical regions, due to their widespread occurrence and distinctive engineering characteristics (Oyelami *et al*., 2023). Laterites are products of intense weathering of parent rocks under hot and humid climatic conditions, leading to the accumulation of hydrated oxides of iron and aluminium, and often possessing a reddish-brown coloration (Bello *et al*., 2022). Their unique mineralogical composition and formation processes impart properties that differ significantly from temperate zone soils, affecting their behaviour under various engineering loads and environmental conditions.

Compaction is a critical ground improvement technique in geotechnical engineering, aiming to increase the density of soil by reducing its air voids, thereby enhancing its engineering properties such as strength, stiffness, and stability, while simultaneously reducing compressibility and permeability (Adeyeye and Ajagbe, 2021). The effectiveness of compaction is quantified by the 'compactive effort,' which refers to the mechanical energy imparted to the soil mass during the compaction process. This effort directly influences the attained maximum dry density (MDD) and the corresponding optimum moisture content (OMC) at which this density is achieved. For lateritic soils, understanding the optimal compactive effort is paramount for ensuring the long-term performance and stability of civil engineering structures. Sub-optimal compaction can lead to excessive settlements, reduced bearing capacity, and premature pavement failures, while over-compaction can be uneconomical and potentially cause particle crushing (Olajide and Adewole, 2024). This research endeavors to comprehensively investigate how variations in compactive effort systematically influence the fundamental engineering properties of laterite soil, providing critical data for design and construction in laterite-rich regions.

1.2 Statement of Problem

Despite the extensive use of lateritic soils in various construction projects across tropical

and sub-tropical zones, their engineering behaviour, particularly their response to varying compactive efforts, remains a subject requiring continuous and detailed investigation. Lateritic soils exhibit a wide range of properties depending on their geological origin, degree of weathering, and mineralogical composition, leading to inherent variability even within relatively small geographical areas (Nwafor *et al.*, 2023). This variability poses significant challenges for engineers in predicting their behaviour and designing appropriate compaction specifications. Current compaction practices often rely on generalized empirical relationships or standard specifications that may not fully capture the nuanced response of specific laterite types to different compactive energies.

The problem lies in the potential for either under-compaction or over-compaction, both of which can lead to adverse engineering consequences. Under-compaction results in low density, high void ratios, increased compressibility, and reduced shear strength, culminating in excessive settlement and structural instability. Conversely, applying excessive compactive effort beyond the optimum can lead to particle breakdown, which might alter the soil's gradation and plasticity, potentially leading to increased water sensitivity or reduced long-term durability. Furthermore, over-compaction is an economically inefficient process (Abdulazeez and Obianyo, 2021). There is a paucity of comprehensive studies specifically detailing the quantitative relationship between a controlled range of compactive efforts and the consequential changes in key engineering parameters (such as shear strength, California Bearing Ratio, and permeability) for diverse lateritic soil types under controlled laboratory conditions. Without a clear understanding of this relationship, engineers risk either over-designing, leading to uneconomical projects, or under-designing, resulting in premature infrastructure failure.

1.3 Aims and Objectives

The aim of this study is to assess the effect of compactive effort on the engineering properties of Laterite soil in Benin City, Nigeria.

The specific objectives of this study are to:

1. Determine the preliminary engineering index properties of the selected laterite soil samples, including particle size distribution, Atterberg limits, and specific gravity.
2. Establish the relationship between compactive effort, maximum dry density (MDD), and optimum moisture content (OMC) for the laterite soil using both standard and

modified Proctor compaction methods.

3. Evaluate the influence of different compactive efforts on the unconfined compressive strength (UCS) of the compacted laterite soil.

4. Assess the effect of varying compactive efforts on the California Bearing Ratio (CBR) of the laterite soil, crucial for pavement design.

5. Analyze and interpret the interrelationships among the studied engineering properties as a function of increasing compactive effort.

1.4 Scope of Study

This study is focused on a comprehensive laboratory investigation into the engineering behavior of a specific laterite soil sample, subjected to varying compactive efforts. The key objectives of this study include the following:

1. Soil Sampling and Reconnaissance Survey

The study begins with a reconnaissance survey and soil sampling from two locations in Benin City: Oluku Borrow Pit and Blocks of Flats Gully Site. These samples serve as the basis for subsequent laboratory tests.

2. Engineering Index Properties Characterization

Fundamental engineering index properties of the selected laterite soil samples were determined. Laboratory tests were conducted for particle size distribution (via sieve and hydrometer analysis), Atterberg limits (Liquid Limit, Plastic Limit, and Plasticity Index), and specific gravity. These tests are essential for classifying the soil and understanding its basic behavior.

3. Compactive Effort and Moisture-Density Relationships

The relationship between applied compactive effort, maximum dry density (MDD), and optimum moisture content (OMC) was investigated. This was achieved through the Standard Proctor and Modified Proctor compaction tests, representing distinct levels of compactive energy. These tests provide insight into how compaction energy affects the soil's density and moisture characteristics.

4. Unconfined Compressive Strength (UCS) Evaluation

The impact of varying compactive efforts on the unconfined compressive strength (UCS) of the compacted laterite soil was assessed. UCS specimens were prepared at their respective MDD and OMC to determine how different levels of compaction energy influence the strength of the soil.

5. California Bearing Ratio (CBR) Assessment

The study also evaluated the effect of compactive effort on the California Bearing Ratio (CBR) of the laterite soil. CBR tests were performed on compacted specimens prepared under both Standard Proctor and Modified Proctor conditions. This is crucial for understanding the soil's suitability for use in pavement design and subgrade applications.

6. Interrelationship Analysis of Engineering Properties

Finally, the interrelationships among the studied engineering properties; particle size, Atterberg limits, specific gravity, MDD, OMC, UCS, CBR, and permeability, were analyzed. The study focused on identifying trends and correlations to provide a holistic understanding of how increasing compactive effort influences the overall engineering performance of the laterite soil.

1.5 Justification of Study

Currently, engineering designs and construction specifications often rely on empirical data or generalized standards that may not fully account for the unique characteristics and variability of lateritic soils. This can lead to either conservative designs that are uneconomical or, more critically, inadequate designs that result in structural failures, excessive maintenance costs, and compromised safety. By systematically investigating the effects of varying compactive efforts on laterite soil properties, this study provided a more precise and evidence-based foundation for compaction specifications.

The findings will contribute to:

1. Providing engineers and contractors with specific data to select the most appropriate compactive effort for a given laterite soil and desired engineering performance, thereby minimizing material usage and energy consumption.
2. Informing design parameters for foundations, road pavements, and earthworks, leading to more stable and durable structures that are less prone to settlement, erosion, or failure.
3. Preventing over-compaction, which is energy-intensive and can lead to particle degradation, and avoiding under-compaction, which necessitates costly remedial works.
4. Generating specific data for lateritic soils in a local context, which can be invaluable given the geographical variability of these soils, thereby supporting region-specific design codes and construction guidelines (Mohammed and Bala, 2020).
5. Existing body of knowledge on lateritic soil mechanics, particularly concerning the nuanced interplay between compactive effort and key engineering properties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Role of Moisture Content in Soil Compaction

Moisture content plays a pivotal role in the compaction of soils, profoundly influencing the degree of densification achievable under a given compactive effort (Aigbovbiosa and Aigbovbiosa, 2021). The relationship between moisture content, dry density, and compactive effort is encapsulated by the Proctor compaction curve, which defines the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD). The OMC is the moisture content at which a soil can be compacted to its highest dry density for a specific compactive effort (Abiola *et al*., 2023). Below the OMC, the soil particles are too dry and stiff, and there is insufficient water to act as a lubricating agent, preventing the soil from achieving maximum densification. The friction between particles remains high, resisting rearrangement into a denser configuration.

As moisture content increases towards the OMC, water films around soil particles begin to reduce inter-particle friction, allowing for easier rearrangement and closer packing, leading to an increase in dry density (Okonkwo and Okoye, 2020). Water also fills the pores, facilitating the expulsion of air. However, beyond the OMC, the dry density starts to decrease despite increasing moisture content. At this stage, water begins to occupy the voids that would otherwise be filled by solid particles, leading to a saturation condition where further addition of water causes a displacement of soil solids rather than a reduction in air voids. The soil pores become primarily water-filled, and the soil effectively becomes a two-phase system (solids and water), which resists further compaction by the generation of pore water pressure. This excess pore water pressure counteracts the compactive effort, hindering the ability of particles to move closer together and thus reducing the achievable dry density (Sani and Abubakar, 2022). Therefore, achieving compaction at or near the OMC is crucial for optimizing the engineering properties of compacted soil.

2.2 Principles of Soil Compaction

Soil compaction is a mechanical process involving the application of external energy to a soil mass to reduce its void ratio, primarily by expelling air from the voids, thereby increasing its dry density (Egwuonwu and Ugwuele, 2023). This process is distinct from consolidation, which involves the expulsion of water over a longer period. The

fundamental principles of compaction are rooted in the work of R.R. Proctor, who in the 1930s established the relationship between moisture content, compactive effort, and dry density. His tests, now standardized as the Standard Proctor Compaction Test, involve compacting soil in a mould using a standard hammer dropped from a specific height for a defined number of blows and layers, yielding a specific compactive energy (Ahmed *et al.,* 2024).

The compactive effort is the total energy imparted per unit volume of soil. Increasing the compactive effort generally leads to a higher maximum dry density (MDD) and a lower optimum moisture content (OMC) (Babalola and Olorunfemi, 2021). This is because greater energy input can overcome more inter-particle friction, allowing particles to pack more closely even with less lubricating water. The Modified Proctor Compaction Test, developed to simulate heavier compaction equipment used in the field, utilizes a heavier hammer and a greater drop height, thereby imparting significantly more compactive energy than the Standard Proctor test. This higher energy typically results in a higher MDD and a lower OMC for the same soil type compared to the Standard Proctor test (Aliyu *et al.,* 2023).

The effectiveness of compaction is crucial for enhancing various engineering properties. A well-compacted soil exhibits increased shear strength, reduced settlement under load, decreased permeability, and improved bearing capacity. These improvements are directly attributable to the denser packing of soil particles and the resulting reduction in void spaces (Igba *et al.,* 2020). Conversely, inadequately compacted soil remains loose, highly permeable, and susceptible to excessive settlement and deformation, leading to structural instability and premature failure of civil engineering infrastructure. Understanding these principles allows engineers to specify appropriate compaction methods and quality control measures to achieve desired engineering performance in the field.

2.3 Engineering Properties of Laterite Soil

Lateritic soils possess a unique suite of engineering properties that set them apart from temperate climate soils, largely due to their specific geological formation processes involving intense weathering and leaching (Musa *et al.,* 2023). Characteristically, laterites are residual soils rich in hydrated oxides of iron and aluminium, often presenting a reddish, yellowish, or brownish hue. Their engineering properties are highly variable, influenced by factors such as parent rock, drainage conditions, climate, and degree of laterization

(Olawole and Oyedepo, 2022).

Key engineering properties include:

2.3.1 Plasticity

Plasticity refers to the capacity of a soil to undergo deformation without cracking or changing volume significantly, and it is a fundamental property used to classify and predict soil behavior, particularly in fine-grained soils such as laterites. In geotechnical engineering, plasticity is quantified through Atterberg Limits, which include the Liquid Limit (LL), Plastic Limit (PL), and the derived Plasticity Index (PI = LL − PL). These parameters reflect the moisture content range over which a soil exhibits plastic behavior.

Lateritic soils often display a wide spectrum of plasticity characteristics, heavily influenced by their mineralogical composition, degree of weathering, and iron/aluminium oxide content (Olawole and Oyedepo, 2022; Musa *et al.*, 2023). Unlike temperate-region clays that derive plasticity primarily from silicate clay minerals such as kaolinite, montmorillonite, or illite, the plasticity of lateritic soils is significantly affected by sesquioxides hydrated oxides of iron and aluminium (e.g., goethite, gibbsite, hematite). These oxides bind soil particles and provide what is often termed "apparent cohesion," allowing the soil to behave plastically even with relatively low clay content (Okafor and Okoro, 2021).

The plasticity behavior of lateritic soils is therefore not solely dependent on true clay minerals but also on the degree of cementation and agglomeration induced by iron and aluminium oxides. This makes classification more complex, as two laterites with similar particle size distributions may exhibit different plastic behaviors depending on the presence or absence of oxide bonding. For instance, highly laterized soils with significant sesquioxide content may show low to moderate plasticity, but behave structurally like high-plasticity soils due to internal cementation.

2.3.2 Strength

The shear strength of lateritic soils, represented by parameters like cohesion and angle of internal friction, is generally good when compacted to optimum conditions. The presence of sesquioxides often contributes to improved strength and stability. Unconfined Compressive Strength (UCS) tests are commonly used to evaluate the cohesive strength of compacted laterites, which is vital for assessing their performance as subgrade or fill material (Adewoye *et al.*, 2024).

2.3.3 Permeability

Permeability is a measure of the ability of a soil to allow the passage of fluids, most commonly water, through its void spaces. It is a critical engineering property, particularly in applications involving drainage, seepage control, groundwater flow, and stability of embankments and foundations. In geotechnical engineering, permeability is quantified using the coefficient of permeability (k), typically expressed in units of cm/s or m/s. The value of k depends on the soil's texture, structure, degree of saturation, and the method of compaction.

Lateritic soils, due to their unique origin from intense tropical weathering and high oxide content, exhibit a wide range of permeability characteristics depending on their mineral composition, grain size distribution, and degree of laterization (Musa *et al.,* 2023; Olawole and Oyedepo, 2022). These soils often contain a mix of coarse particles and fine materials cemented by sesquioxides (iron and aluminium oxides), leading to a structure that may be porous in its natural state but can become significantly less permeable upon compaction.

When compacted, the permeability of lateritic soils typically decreases substantially. This is because the application of compactive effort reduces the void ratio by eliminating air spaces and tightening the arrangement of soil particles. The reduction in void continuity and pore connectivity impedes the movement of water through the soil mass (Salisu and Umar, 2020). The nature of this relationship is inversely proportional: as maximum dry density (MDD) increases with compactive effort, coefficient of permeability tends to decrease.

The reduction in permeability is particularly beneficial in engineering applications where water movement must be minimized, such as in earth dams, canal linings, sanitary landfills, pavement subgrades, and slope stability designs. In such cases, compacted lateritic soils serve as hydraulic barriers due to their low permeability. However, for applications requiring good drainage such as in sub-base layers of pavements; lateritic soils with moderate to high permeability are preferred, or may require blending with more granular materials to improve water flow characteristics.

2.3.4 Compressibility

Well-compacted lateritic soils tend to exhibit low compressibility due to their dense structure and particle interlocking. This property is crucial for minimizing settlement under static loads, ensuring the long-term stability of structures founded upon them (Obi *et al.,* 2023).

2.3.5 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) is a critical empirical parameter used to assess the load-bearing capacity of soils, especially for use in pavement subgrades, sub-bases, and base courses. Developed by the California Division of Highways, the CBR test provides a standardized measure of soil strength by evaluating its resistance to penetration by a plunger under controlled conditions. The test result is expressed as a percentage of the load-bearing capacity of a standard crushed stone material.

For lateritic soils which are extensively used in tropical and sub-tropical regions due to their abundance CBR is particularly relevant in evaluating their suitability for road construction and other shallow foundation applications. Laterites, when properly compacted, generally exhibit moderate to high CBR values, making them favourable materials for low-traffic and medium-traffic roadways (Ezeagu and Osadebe, 2021; Adeleke *et al.*, 2022).

2.3.5.1 Principle of the CBR Test

In the CBR test, a standard cylindrical plunger (50 mm diameter) is penetrated into a compacted soil specimen at a rate of 1.25 mm/min. The applied load is recorded at penetration depths of 2.5 mm and 5.0 mm. The CBR value is then calculated using the CBR equation which is as follows:

$$CBR = \left(\frac{Load\ on\ soil\ sample\ at\ a\ given\ penetration}{Standard\ load\ for\ crushed\ stone\ at\ same\ penetration}\right) \times 100$$

Eqn. 2.1: California Bearing Ratio (CBR)

For compacted soils, the higher of the two penetration readings (2.5 mm or 5.0 mm) is reported as the CBR value.

Lateritic soils, when compacted to Modified Proctor energy and tested under unsoaked conditions, often fall within or above the 10–30% CBR range, making them viable for rural and secondary roads, provided moisture ingress is controlled (Olajide and Adewole, 2024).

2.3.5.2 Applications and Limitations

While the CBR test is simple and widely adopted, it does have limitations. It does not directly measure shear strength, stiffness, or stress-strain behaviour, and its values can vary widely depending on compaction and soaking. Additionally, its empirical nature limits its application outside road engineering. Nonetheless, for comparative evaluation and

material selection especially in developing regions relying on local lateritic soils CBR remains indispensable.

2.4 Factors Affecting Compaction

The compaction characteristics of a soil, specifically its Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), are influenced by a complex interplay of several factors. Recognizing these factors is crucial for controlling and optimizing compaction efforts in the field and laboratory (Nwafor and Okoro, 2020).

2.4.1 Soil Type and Properties

1. Particle Size Distribution: Well-graded soils with a good distribution of particle sizes can generally achieve higher densities than uniformly graded or gap-graded soils because smaller particles can fill the voids between larger particles, leading to a denser packing (Ajide *et al.*, 2022).

2. Shape of Particles: Angular particles tend to offer more inter-particle friction, requiring greater compactive effort to achieve densification compared to rounded particles.

3. Specific Gravity: Soils with higher specific gravity values generally yield higher MDDs, assuming other factors are constant, as the solid particles themselves are denser.

4. Clay Mineralogy: The type and amount of clay minerals significantly influence the soil's water retention capacity and plastic behavior, directly affecting the OMC and the shape of the compaction curve (Oke *et al.*, 2023). Highly expansive clays, for example, have high OMCs.

5. Moisture Content: As discussed in Section 2.1, moisture content is perhaps the most critical factor. There is an optimum moisture content at which a given compactive effort achieves maximum dry density. Deviations from this optimum, either too dry or too wet, result in lower dry densities.

6. Compactive Effort: The amount of mechanical energy applied per unit volume of soil profoundly affects the compaction curve. Increased compactive effort leads to a higher MDD and a lower OMC (Oyelami *et al.*, 2023). This is due to the greater energy overcoming frictional resistance and enabling closer particle packing.

2.4.2 Method of Compaction

The type of compaction equipment used (e.g., rollers, vibrators, ramming) and the method of application (e.g., static, dynamic, kneading) influence the effectiveness of compaction. Different methods impart energy in different ways, which can have varying effects on soil structure and density (Bello *et al.*, 2022). Laboratory tests (Proctor tests) simulate the

effects of field compaction equipment.

1. Admixtures: The addition of stabilizing agents like cement, lime, fly ash, or chemical additives can alter the soil's compaction characteristics, often by modifying its plasticity, particle aggregation, or pore fluid properties (Abdulazeez and Obianyo, 2021). These can shift the OMC and MDD.

2. Layer Thickness: In field compaction, the thickness of soil layers being compacted affects the uniform distribution of compactive energy. Thinner layers are generally more effectively compacted than thicker ones for a given roller pass.

Understanding these factors is essential for effective quality control in earthwork construction, ensuring that specified densities and properties are consistently achieved.

2.5 Compactive Effort and its Influence on Soil Properties

Compactive effort, defined as the energy imparted to a soil mass per unit volume, is a primary determinant of the post-compaction engineering properties of soil (Olajide and Adewole, 2024). The most immediate effects of increasing compactive effort are on the maximum dry density (MDD) and optimum moisture content (OMC), which in turn, profoundly influence other critical engineering parameters.

As compactive effort increases, the MDD generally rises, while the OMC typically decreases (Abiola *et al.*, 2023). This inverse relationship is fundamental: higher energy allows for greater particle rearrangement and void reduction, requiring less water to lubricate the particles to achieve maximum densification. The increased dry density signifies a reduction in porosity and an increase in the number of solid-to-solid contacts within the soil matrix, which has direct implications for mechanical strength and hydraulic conductivity.

The influence on specific engineering properties includes:

1. Unconfined Compressive Strength (UCS): UCS is a direct measure of the cohesive strength of fine-grained soils. For lateritic soils, increasing compactive effort generally leads to a significant increase in UCS up to a certain point (Okonkwo and Okoye, 2020). Denser packing improves particle interlocking and strengthens the bonds between particles, leading to a higher resistance to compressive failure. However, beyond a certain optimal compactive effort, excessive energy might cause particle crushing, which could potentially reduce the UCS or lead to more brittle behavior.

2. California Bearing Ratio (CBR): The CBR is a critical parameter for pavement design, indicating the strength of subgrade and base course materials. Higher compactive efforts typically result in significantly improved CBR values for lateritic soils (Ezeagu and Osadebe, 2021). A denser soil mass is more resistant to penetration, signifying a greater bearing capacity and load-distributing capability. This directly translates to thinner and more economical pavement layers.

3. Permeability: Permeability, or hydraulic conductivity, measures the ease with which water flows through a soil. Increasing compactive effort generally leads to a reduction in permeability (Salisu and Umar, 2020). By reducing the void ratio and creating a more tortuous path for water flow through smaller, less interconnected pores, compaction significantly impedes water movement. This is particularly important for earth dams, canal linings, and landfill barriers where low permeability is desired to prevent seepage and contamination.

4. Compressibility: A higher compactive effort leads to a more rigid soil structure with reduced void spaces, consequently decreasing the compressibility of the soil (Obi *et al.*, 2023). This means the compacted soil will undergo less settlement under applied loads, enhancing the long-term stability and performance of overlying structures.

In summary, the applied compactive effort serves as a critical control parameter in geotechnical engineering. By optimizing this effort, engineers can tailor the properties of lateritic soils to meet specific design requirements, ensuring the durability, stability, and cost-effectiveness of civil engineering projects.

2.5.1 Compaction Tests Explained

1. Standard Proctor Compaction Test

The Standard Proctor Compaction Test is a laboratory procedure introduced by R.R. Proctor in 1933 to simulate the effects of light field compaction on soil. It is used to determine the relationship between the dry density of soil and its moisture content under a defined compactive effort. The test is standardized under ASTM D698 and BS 1377-4:1990.

Characteristics

1) Compactive energy: ~592 kJ/m³

2) Hammer weight: 2.5 kg
3) Drop height: 300 mm
4) Layers: 3
5) Blows per layer: 27
6) Results in moderate MDD and higher OMC
7) Suitable for silty and clayey soils (Abiola *et al.*, 2023; Babalola and Olorunfemi, 2021)

Application

1) Light civil works such as rural road subgrades and pedestrian paths
2) Projects involving manual or low-pressure compaction methods
3) Baseline testing for evaluating soil responsiveness to compaction (Adeyeye and Ajagbe, 2021)

2. Modified Proctor Compaction Test

The Modified Proctor Test was developed by the U.S. Army Corps of Engineers during World War II to simulate heavier compactive efforts common in airfields and highways. It is defined by ASTM D1557 and AASHTO T180 standards.

Characteristics

1) Compactive energy: ~2700 kJ/m³
2) Hammer weight: 4.5 kg
3) Drop height: 450 mm
4) Layers: 5
5) Blows per layer: 27
6) Produces higher MDD and lower OMC than Standard Proctor
7) Better simulates field compaction from heavy rollers (Aliyu *et al.*, 2023; Ahmed *et al.*, 2024).

Application

1) Highways, airport runways, railways, and heavy-duty pavements
2) Compaction control for embankments and foundations under high load
3) Ensures durability and minimizes post-construction settlement (Olajide and

Adewole, 2024; Igba *et al*., 2020)

3. West African Standard (WAS) Compaction Test

The West African Standard (WAS) Compaction Test is a regionally adapted procedure that applies an intermediate compactive effort to better represent field conditions common in West African construction projects. It is particularly used in countries like Nigeria, Ghana, and Cameroon.

Characteristics

1) Compactive energy: ~1230–1300 kJ/m³
2) Hammer weight: 4.5 kg
3) Drop height: 450 mm
4) Layers: 3
5) Blows per layer: 25
6) MDD and OMC values lie between those of Standard and Modified Proctor
7) More closely reflects local construction practices (Oyelami *et al.,* 2023; Adeleke *et al.,* 2022)

Application

1) Local roads, residential foundations, and rural embankments
2) Regionally relevant design of subgrades and fills
3) Commonly used by road agencies in Nigeria and other West African countries (Mohammed and Bala, 2020; Bello *et al.,* 2022)

2.6 Empirical Review

Numerous studies have explored the compaction characteristics and engineering properties of lateritic soils, reflecting their importance in tropical and subtropical regions. This section reviews selected contemporary research, highlighting their objectives, methodologies, and key findings.

In the year 2022, Adeleke *et al* wrote on the Influence of Compaction Characteristics on the Geotechnical Properties of Lateritic Soils for Road Construction in Southwestern Nigeria.

This research focuses on the compaction and geotechnical properties of lateritic soils from

three different locations in Southwestern Nigeria was studied, specifically for their suitability as road construction materials. Standard Proctor compaction tests were conducted to determine OMC and MDD. Subsequent tests, including UCS, CBR, and permeability, were performed on samples compacted at varying moisture contents and compactive efforts (Standard Proctor and a higher energy level). Results indicated that higher compactive efforts significantly improved UCS and CBR values, while reducing permeability. The study concluded that proper compaction at optimum moisture content is crucial for achieving desirable engineering properties, though significant variability existed between the soil samples from different locations.

In the year 2021, Eze and Okoro wrote on the Evaluation of the Strength and Permeability of Compacted Lateritic Soil Stabilized with Cement Kiln Dust

This research focused on enhancing the engineering properties of a problematic lateritic soil using cement kiln dust (CKD) as a stabilizer. The study conducted a series of Modified Proctor compaction tests to establish the maximum dry density and optimum moisture content of both untreated and CKD-treated lateritic soil. UCS and permeability tests were performed on compacted samples at various CKD contents. The findings revealed that CKD significantly increased the MDD and UCS, while notably decreasing the permeability of the lateritic soil, particularly at higher compactive efforts. The study recommended CKD as an effective stabilizer for lateritic subgrades, provided the compaction energy is adequate.

In the year 2023, Idowu and Bello wrote on the Response of Compacted Lateritic Soil to Cyclic Loading and its Implications for Pavement Performance

This study investigated the resilient modulus and accumulated plastic strain of compacted lateritic soil under repeated cyclic loading, aiming to understand its long-term performance in flexible pavements. Lateritic soil samples were compacted at both Standard and Modified Proctor energies and then subjected to triaxial cyclic loading tests. The results demonstrated that laterite compacted at higher energies (Modified Proctor) exhibited significantly higher resilient moduli and lower accumulated plastic strains compared to those compacted at Standard Proctor energy. This indicated improved stiffness and reduced permanent deformation potential. The research underscored the importance of adequate compactive effort in achieving durable pavement layers.

In the year 2020, Okoro and Obi wrote on the Characterization of Lateritic Soils in the Niger Delta Region of Nigeria for Engineering Applications

This paper provided a comprehensive geotechnical characterization of lateritic soils found

in the Niger Delta region of Nigeria. The study involved extensive laboratory testing, including particle size analysis, Atterberg limits, specific gravity, and compaction tests (Standard and Modified Proctor). It also evaluated the UCS and CBR of compacted samples. The research highlighted the diverse properties of laterites within the region, linking variations to geological origin. It emphasized that while many laterites show promising engineering properties, their response to compaction and moisture variation necessitates careful site-specific evaluation to ensure satisfactory performance in civil engineering projects.

In the year 2021, Okafor and Okoro wrote on Improving the Engineering Properties of Laterite Soil Using Sharp Sand: A Sustainable Stabilization Technique

This study investigated the use of sharp sand to stabilize laterite soil, aiming to improve its poor engineering properties for infrastructure development. The research involved subjecting samples with varying ratios of laterite to sharp sand to laboratory tests, including California Bearing Ratio (CBR) tests, compaction tests, and Atterberg limits. The results indicated that adding sharp sand to laterite increases its strength and reduces its flexibility, making it a sustainable stabilization technique for improving laterite soil's structural integrity by filling spaces between particles, which lessens compaction, cracking, and shrinking

In the year 2020, Okonkwo and Okoye wrote on the Effect of Compactive Effort on Compaction Characteristics of Lateritic Soil Stabilized With Terrasil

This research explored the impact of compactive effort on the compaction characteristics of laterite soil treated with varying percentages of Terrasil (2%, 4%, 6%, 8%, and 10% by dry weight of soil). The study used British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH) compaction energies. For natural soil, MDD values increased with higher compactive effort. For Terrasil-stabilized lateritic soil, an average increase in MDD with increasing energy level was observed, and BSH compactive effort at an optimal blend of 6% Terrasil was recommended for use as subgrade material

In the year 2022, Olawole and Oyedepo wrote on the Engineering Properties of Lateritic Soils around Dall Quarry in Sango Area, Iloror, Nigeria

This study evaluated the engineering properties of lateritic soils from the Dall Quarry area in Sango, Ilorin, Nigeria. The research highlighted that properties like particle size distribution, Atterberg limits, and compaction characteristics are crucial for determining the suitability of lateritic soils as construction materials. It concluded that based on their geotechnical properties, these compacted soil samples are suitable for use as sub-base

materials in road construction, as their CBR values fall within acceptable ranges

In the year 2024, Idowu and Bello wrote on the Effect of Multiple-Compaction on Laterite Soil: Geotechnical and Geo-Statistical Analysis:

This recent research explored the effects of repeated (cyclic) compaction on the geotechnical properties of laterite soils commonly used in highway construction. The study investigated changes in engineering properties and moisture-density characteristics across laterite soils derived from different geological sources. Key findings included the disintegration of larger soil grains into smaller particles under multiple compactions and an observed increase in the plasticity index after multiple compaction cycles across various soil types.

2.7 Research Gap

While the reviewed literature provides valuable insights into the compaction and engineering properties of lateritic soils, several research gaps persist that this current study aims to address:

Many previous studies focus on the impact of compaction on one or two engineering properties (e.g., strength or permeability). There is a need for a more comprehensive, integrated investigation that simultaneously assesses the influence of a systematic range of compactive efforts on multiple critical engineering properties (MDD, OMC, UCS, CBR, and permeability) using a single, well-characterized laterite soil sample. This integrated approach allows for a clearer understanding of the interdependencies and trade-offs. The current study aims to provide this holistic perspective.

The geographical and geological variability of lateritic soils means that findings from one region or a generic 'laterite' may not be directly applicable elsewhere. While some studies focus on regional laterites (e.g., Adeleke *et al.*, 2022; Okoro and Obi, 2020), this research focuses on a specific laterite soil type from a defined location in Oluku, offering detailed insights into its unique response to compaction. This reduces the ambiguity of generalizing from studies that might combine data from highly variable laterites.

While standard (Proctor) and modified (Proctor) compactive efforts are widely studied (e.g., Idowu and Bello, 2023), there is often a lack of detailed data on the effects of *intermediate* compactive efforts. This study intends to explore a continuum

of compactive efforts beyond just the standard and modified, providing a more granular understanding of how properties evolve with incremental increases in compaction energy. This can inform more precise compaction specifications in the field, optimizing energy input.

While some studies mention permeability (e.g., Eze and Okoro, 2021; Adeleke *et al.*, 2022), the specific quantitative relationship between systematically varied compactive efforts and the resulting permeability of lateritic soil is often not the primary focus or is presented as a secondary finding. This research places significant emphasis on this relationship, providing detailed data crucial for applications requiring control over water flow, such as hydraulic barriers or drainage layers.

In essence, this study differentiates itself by providing a comprehensive, multi-property analysis of a specific laterite soil's response to a systematic variation in compactive effort, moving beyond generalized observations to offer quantitative relationships that are directly applicable to engineering design and construction.

CHAPTER THREE

METHODOLOGY

3.1 The Study Area

The laterite soil samples for this investigation was obtained from Oluku burrow pit and Blocks of Flat Gully site as shown in (Fig 1.1) below. This region is characterized by a tropical savannah climate with distinct wet and dry seasons, contributing to intense weathering processes that favor laterite formation. Geologically, the area predominantly consists of Precambrian basement complex rocks, including gneisses, schists, and granites, which serve as parent materials for the development of lateritic soils (Oyelami *et al.*, 2023). The borrow pit selected is known to contain significant deposits of lateritic soil routinely used for various construction projects in the region, ensuring the sample is representative

of locally available materials. The precise coordinates of the sampling location will be recorded using a Global Positioning System (GPS) for future reference.

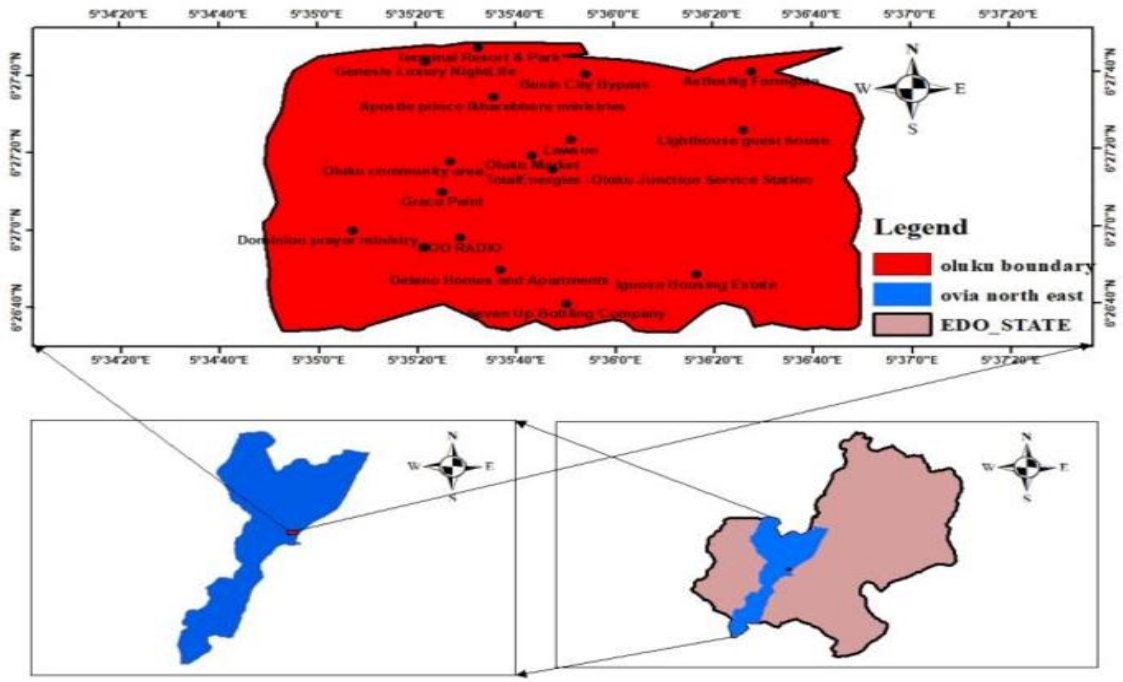


Fig 3.1 Location map showing Oluku in Edo State South South Nigeria (Fega *et al*.)

3.2 Sample Collection and Preparation

3.2.1 Sample Collection

A bulk sample of disturbed laterite soil, approximately 100 kg, was collected from both sites. The topsoil (vegetation and organic matter-rich layer) will be carefully removed to a depth of about 30 cm to ensure the collection of true lateritic material free from surface contaminants. The soil will be excavated manually using shovels and transferred into clean, clearly labelled, airtight bags to prevent moisture loss and contamination during transportation to the laboratory. Multiple sub-samples was taken from different points within the two designated area of the borrow pit to account for potential localized variability, and then thoroughly mixed to form a composite, representative sample.

3.2.2 Sample Preparation:

Upon arrival at the laboratory, the composite soil sample was air-dried to remove excess moisture. Following air-drying, visible foreign materials such as roots, leaves, gravel larger than 4.75 mm, and organic debris were carefully removed by hand. The air-dried soil were then pulverized using a rubber mallet to break down larger aggregates without

crushing individual soil particles, ensuring that the natural particle sizes are retained. The pulverized soil was then sieved through a 4.75 mm sieve (No. 4 sieve) to remove any remaining coarse aggregate and prepare it for various laboratory tests, in accordance with BS 1377-2:1990 (Methods of test for soils for civil engineering purposes – Classification tests). The portion passing the 4.75 mm sieve was used for all subsequent tests. The prepared sample will be stored in sealed containers to maintain its condition until testing.

3.3 Preliminary Soil Characterization

Prior to conducting compaction and engineering property tests, the laterite soil samples underwent a series of preliminary tests to characterize its basic index properties. These tests are essential for classifying the soil and understanding its inherent characteristics.

3.3.1 Particle Size Distribution (Sieve Analysis)

The particle size distribution was determined by combining sieve analysis for the coarser fractions and hydrometer analysis for the finer fractions (silt and clay), as per BS 1377-2:1990.

1. Sieve Analysis: A representative oven-dried sample was sieved through a nest of standard sieves (e.g., 4.75 mm, 2.00 mm, 0.850 mm, 0.425 mm, 0.250 mm, 0.150 mm, 0.075 mm) as shown in fig 1.2. The cumulative percentage passing each sieve was calculated and plotted on a semi-logarithmic graph to obtain the particle size distribution curve.

(Fig 3.2) A set of sieves for the sieve analyses test (Fega *et al*.)

3.3.2 Atterberg Limits

The Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) was determined using the Casagrande liquid limit device and rolling thread method, respectively, in accordance

with BS 1377-2:1990.

1. Liquid Limit (LL): The minimum moisture content at which a soil paste flows to close a groove of standard dimensions when the cup of the Casagrande device is dropped 25 times.

2. Plastic Limit (PL): The minimum moisture content at which a soil can be rolled into a thread 3 mm in diameter without crumbling.

3. Plasticity Index (PI): The numerical difference between the Liquid Limit and the Plastic Limit (PI = LL - PL) Eq (3.1), indicating the range of moisture content over which the soil behaves plastically.

3.3.3 Specific Gravity

The specific gravity (Gs) of the laterite soil particles was determined using the pycnometer method, adhering to BS 1377-2:1990. A known mass of oven-dried soil was placed in a pycnometer, and the volume of water displaced was measured. The specific gravity was calculated as the ratio of the mass of soil solids to the mass of an equal volume of water at a specified temperature. This parameter is crucial for calculating void ratio, porosity, and degree of saturation.

3.4 Compaction Tests

Compaction tests was carried out to establish the relationship between moisture content and dry density under varying compactive efforts. Both the Standard Proctor and Modified Proctor compaction tests, as specified by BS 1377-4:1990 (Methods of test for soils for civil engineering purposes – Compaction related tests), was performed.

3.4.1 Standard Proctor Compaction Test (Light Compaction)

A cylindrical mould of 1000 cm^3 capacity (105 mm internal diameter and 115 mm height) was used. A representative air-dried soil sample (approximately 3 kg) was mixed with a predetermined amount of distilled water to achieve an initial moisture content below the estimated OMC. The moist soil was compacted in three equal layers in the mould, with each layer receiving 27 blows from a 2.5 kg rammer falling freely from a height of 300 mm. After compaction, the collar was removed, and the excess soil trimmed flush with the top of the mould. The total mass of the mould plus compacted soil was determined. Small samples was taken from the compacted soil for moisture content determination by oven-drying. This procedure was repeated for at least five different moisture contents, gradually increasing the water content to cover a range that includes both dry and wet sides of the

OMC. For each trial, the wet density, dry density, and moisture content will be calculated. A compaction curve (dry density vs. moisture content) was plotted to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for this compactive effort.

3.4.2 Modified Proctor Compaction Test (Heavy Compaction)

The Modified Proctor test employs a higher compactive effort than the Standard Proctor test. The same 1000 cm^3 mould was used. The soil was compacted in five equal layers, with each layer receiving 27 blows from a heavier 4.5 kg rammer falling freely from a greater height of 450 mm. The procedure for mixing soil with water, compacting, trimming, weighing, and determining moisture content was identical to that described for the Standard Proctor test. A separate series of trials with increasing moisture contents was conducted to generate the Modified Proctor compaction curve and determine the MDD and OMC corresponding to this higher compactive effort.

3.4.3 West African Standard Compaction Efforts

To investigate the effect of intermediate compactive efforts, additional compaction curves was generated using a reduced number of blows or layers for the Modified Proctor test, or by varying the drop height of the rammer. For instance, an effort equivalent to 75% or 50% of the Modified Proctor energy could be used. This will involve systematically adjusting the energy input to obtain compaction curves corresponding to efforts between the Standard and Modified Proctor levels. For each targeted compactive effort, the MDD and OMC was determined.

3.5 Engineering Property Tests at Varying Compactive Efforts

To evaluate the impact of compactive efforts on the engineering properties of the laterite soil, samples was prepared at their respective Optimum Moisture Contents (OMC) corresponding to various compactive efforts (Standard Proctor, Modified Proctor, and chosen intermediate efforts). These compacted samples was subjected to California Bearing Ratio (CBR).

3.5.1 California Bearing Ratio (CBR) Test

CBR tests was conducted on compacted laterite soil samples to assess their subgrade strength for pavement design, in accordance with BS 1377-4:1990.

1. Sample Preparation: Laterite soil samples was compacted in a standard CBR mould (152 mm diameter) at their respective OMCs and corresponding MDDs for each chosen compactive effort (Standard, Modified, and intermediate). This involves compacting the

soil in layers using the specified rammer and blows. Three samples will be prepared for each compactive effort. Some samples were subjected to a 4-day soaking period to simulate worst-case saturation conditions, while others was tested immediately after compaction (unsoaked).

2. Test Procedure: The compacted sample in the mould was placed under a loading frame. A surcharge weight (to simulate pavement layers) was placed on the sample. A standard plunger (49.63 mm diameter) was seated on the soil surface, and load was applied at a constant rate of penetration (1.25 mm/minute). The loads corresponding to penetration depths of 2.5 mm and 5.0 mm was recorded.

3. Data Analysis: The CBR value was calculated as the ratio of the load sustained by the soil to the load sustained by a standard crushed rock material, expressed as a percentage. The higher of the two values (at 2.5 mm or 5.0 mm penetration) will typically be reported. The average CBR for the three replicates at each compactive effort (both soaked and unsoaked) was determined.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the laboratory test results for the laterite soil samples collected from the two designated sites: the Oluku Borrow Pit and the Blocks of Flat Gully Site. The results are presented for preliminary soil characterization, compaction tests, and subsequent engineering property tests conducted at varying compactive efforts (Standard Proctor, WAS, and Modified Proctor). The findings are then discussed to determine the engineering suitability of the two laterite sources.

4.1 Preliminary Soil Characterization

The initial index property tests were conducted to classify and determine the basic physical characteristics of the soil samples from both sites.

4.1.1 Particle Size Distribution

4.1.1.1 Blocks of Flat Gully Site

Table 4.1: Particle Size Distribution Analysis of Gully Site Soil Sample At 1m Depth

Sieve Size	Mass Retained	%Passing	%Finer
2.36	0.15	0.15	99.85
2.00	0.23	0.38	99.62
1.18	2.33	2.71	97.29
0.600	13.97	16.68	83.32
0.425	4.52	21.2	78.8
0.300	8.51	29.71	70.29
0.212	25.83	55.54	44.46
0.150	6.05	61.59	38.41
0.075	7.77	69.36	30.64

Fig. 4.1 Particle size Distribution Curve for Gully Site at 1m

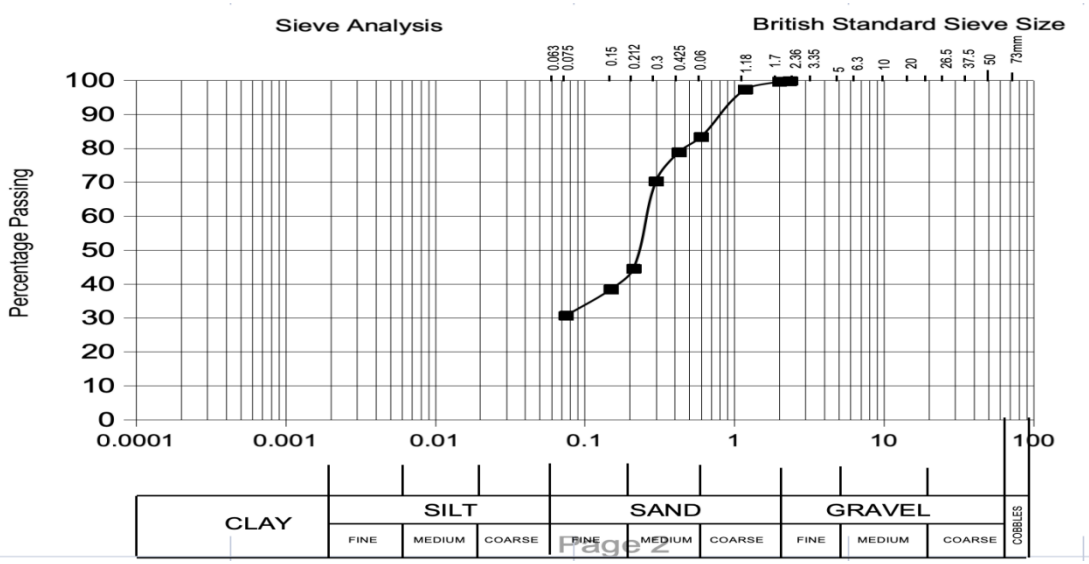
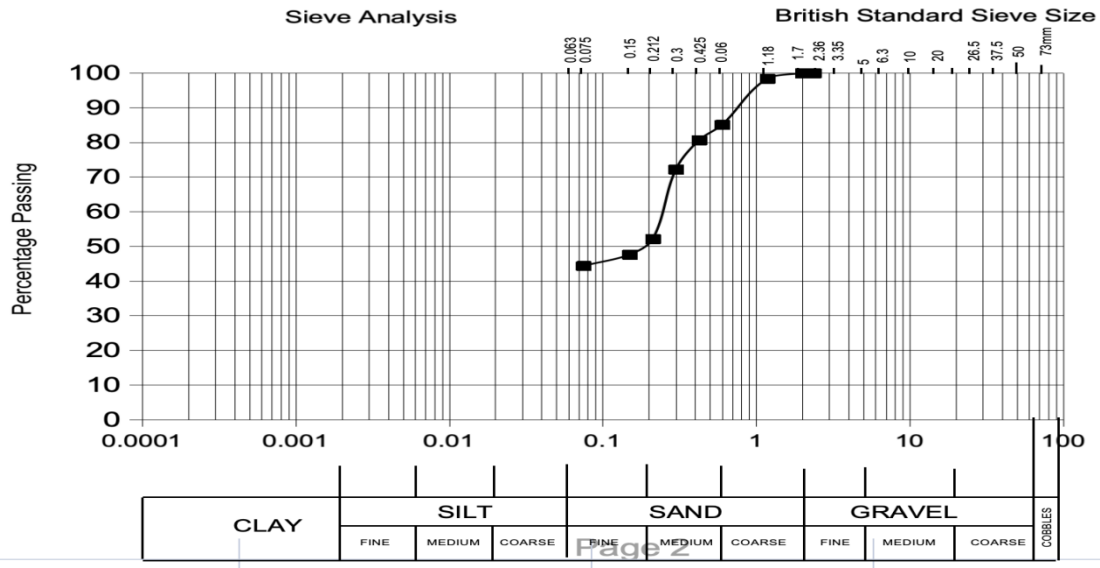


Table 4.2: Particle Size Distribution of Gully Site Soil at 2 m Depth

Sieve Size	Mass Retained	%Passing	%Finer
2.36	0.04	0.04	99.96
2.00	0.02	0.06	99.94
1.18	1.59	1.65	98.35
0.600	13.32	14.97	85.03
0.425	4.43	19.40	80.60
0.300	8.46	27.86	72.14
0.212	20.07	47.93	52.07
0.150	4.50	52.43	47.57
0.075	3.25	55.68	44.32

Fig. 4.2: Particle Size Distribution Curve for Gully Site at 2m



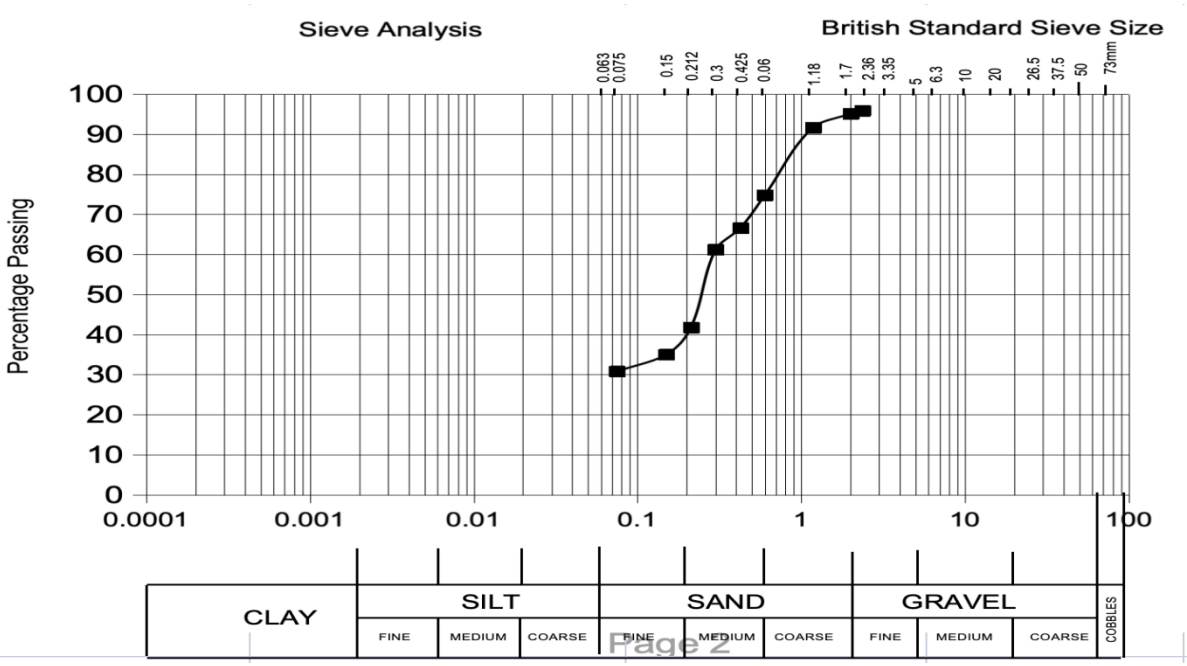
Page 2

Table 4.3: Particle Size Distribution Analysis of Gully Site Soil Sample at 3m depth

Sieve Size	Mass Retained	%Passing	%Finer
2.36	4.1	4.1	95.9
2.00	0.8	4.9	95.1
1.18	3.4	8.3	91.7
0.600	16.9	25.2	74.8
0.425	8.2	33.4	66.6
0.300	5.4	38.8	61.2
0.212	19.4	58.2	41.8

0.150	**6.8**	**65**	**35.0**
0.075	**4.2**	**69.2**	**30.8**

Fig. 4.3: Particle Size Distribution Curve for Gully Site at 3m



Page 2

4.1.1.2 Oluku Borrow Pit

Table 4.4: Particle Size Distribution of Oluku Soil at 1m Depth

Sieve Size	Mass Retained	%Passing	%Finer
2.36	**1.42**	**1.42**	**98.58**
2.00	**2.12**	**3.54**	**96.46**

1.18	**4.80**	**8.34**	**91.66**
0.600	**10.90**	**19.24**	**80.76**
0.425	**8.30**	**27.54**	**72.46**
0.300	**34.80**	**62.34**	**37.66**
0.212	**18.80**	**81.14**	**18.86**
0.150	**6.8**	**87.94**	**12.06**
0.075	**6.53**	**94.47**	**5.53**

Fig. 4.4: Particle Size Distribution Curve for Oluku at 1m

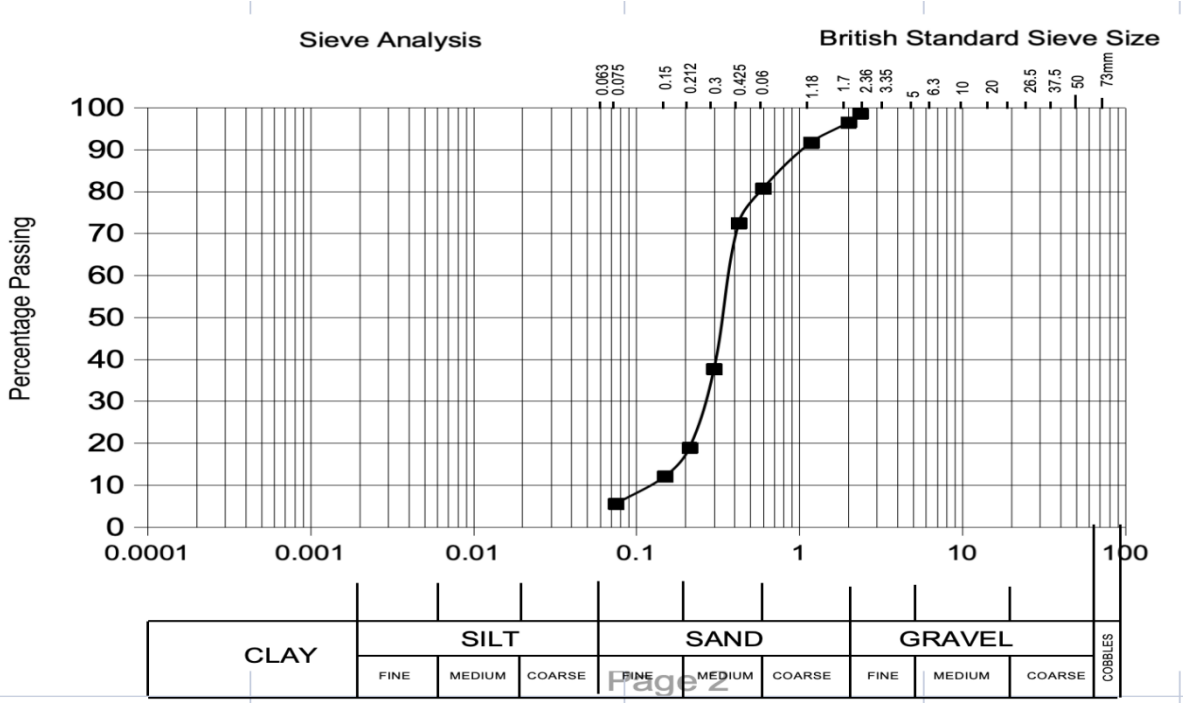


Table 4.5: Particle Size Distribution of Oluku Soil at 2m Depth

Sieve Size	Mass Retained	%Passing	%Finer
2.36	**1.85**	**1.85**	**98.15**
2.00	**3.0**	**4.85**	**95.15**

1.18	**4.10**	**8.95**	**91.05**
0.600	**9.98**	**18.93**	**81.07**
0.425	**8.0**	**26.93**	**73.07**
0.300	**34.30**	**61.23**	**38.77**
0.212	**18.27**	**79.5**	**20.5**
0.150	**7.08**	**86.58**	**13.42**
0.075	**8.47**	**95.05**	**4.95**

Fig. 4.5: Particle Size Distribution Curve for Oluku at 2m

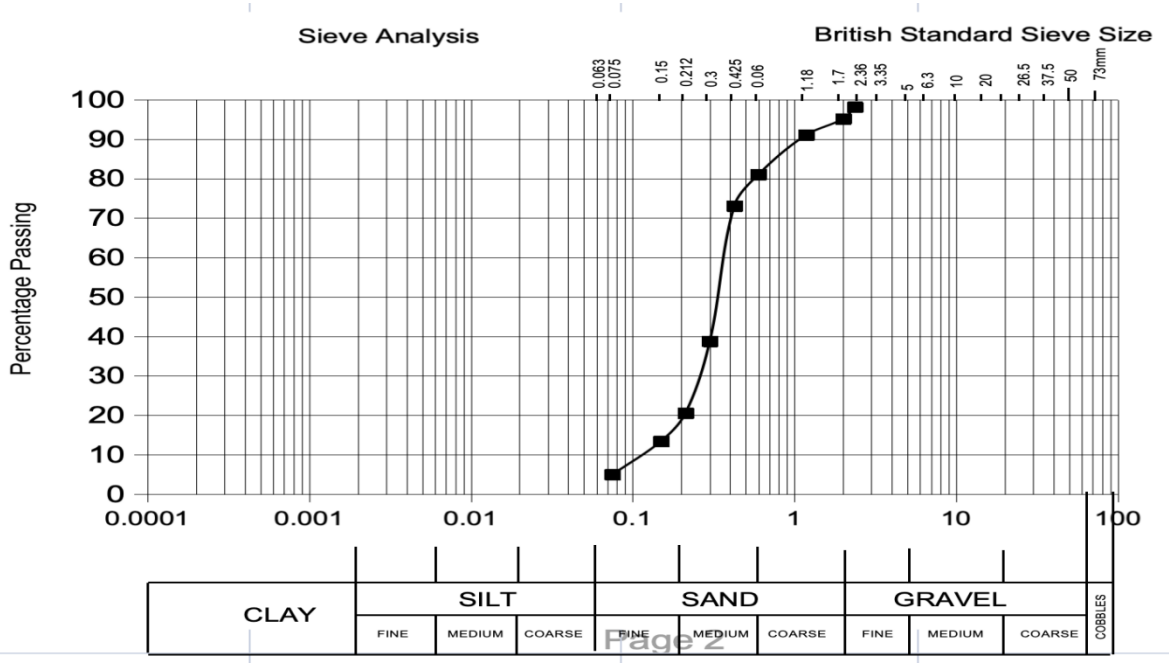
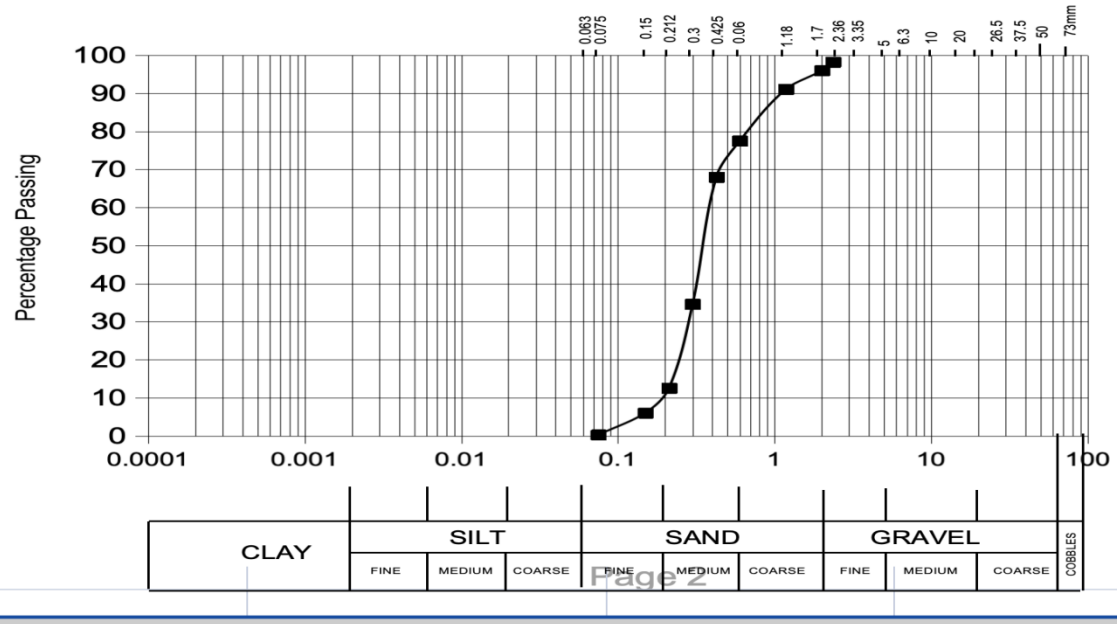


Table 4.6: Particle Size Distribution of Oluku Soil at 3 m Depth

Sieve Size	Mass Retained	%Passing	%Finer
2.36	**1.77**	**1.77**	**98.23**
2.00	**2.28**	**4.05**	**95.95**
1.18	**4.91**	**8.96**	**91.04**

0.600	**13.56**	**22.52**	**77.48**
0.425	**9.51**	**32.03**	**67.97**
0.300	**33.39**	**65.42**	**34.58**
0.212	**22.02**	**87.44**	**12.56**
0.150	**6.51**	**93.95**	**6.05**
0.075	**5.8**	**15.95**	**0.25**

Fig. 4.6: Particle Size Distribution Curve for Oluku at 3m



Both soils classify as A-2-6 (AASHTO: silty/clayey sand) and SC (USCS: clayey sand), but Site B's higher PI and fines suggest greater plasticity and swell risk. Site A's sandy dominance (93% sand, low fines per sieve) indicates better drainage; the abstract's 31–68% "passing" likely overestimates silty fines from fine sands. Site B exceeds FMW&H fines limit marginally, risking deformation in wet conditions.

4.1.2 Atterberg Limits and Specific Gravity

The Atterberg limits and specific gravity results are summarized below:

4.1.2.1 Atterberg Limits of Gully Site Soil

Table 4.7.1 Liquid Limit

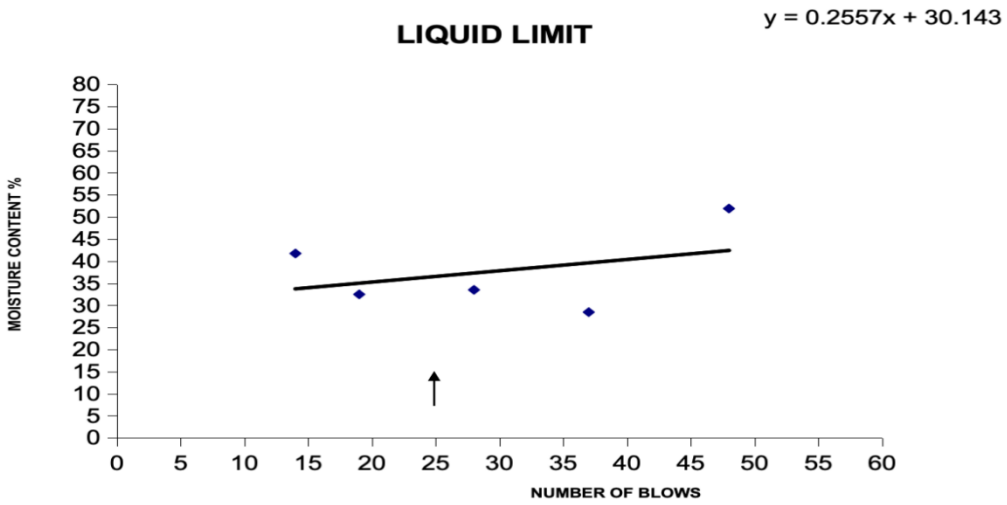
Blows	48	37	28	19	14

Can No.	VC	TQ	2C	YC	DG
Can Weight	32.40	29.29	24.41	24.21	31.57
Can +Wet	57.19	65.86	46.61	48.40	53.92
Can+Dry	48.72	57.76	41.04	42.47	47.34
Moisture content	51.90	28.45	33.49	32.48	41.72

Table 4.7.2 Plastic Limit

Can No.	JI8	A	FX
Can Weight	24.41	33.42	30.40
Can+Wet	29.52	40.66	53.80
Can+Dry	28.41	39.05	49.59

Fig. 4.7: Liquid Limit Flow Curve for Gully Site



4.1.2.2 Atterberg Limits of Oluku Soil

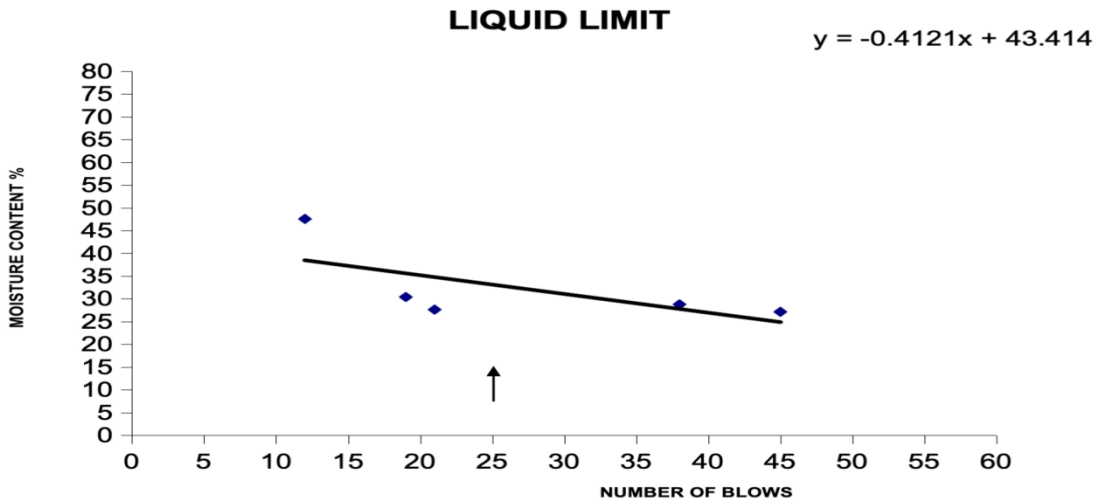
Table 4.8.1 Liquid Limit

Blows	45	38	21	19	12
Can No.	TQ	JES	BX4	Q9	MX
Can Weight	29.10	32.90	24.63	24.21	31.57
Can +Wet	56.33	66.83	48.20	49.40	48.73
Can+Dry	50.52	59.25	43.10	43.53	43.20
Moisture content	31.23	30.79	32.69	33.28	33.26

Table 4.8.2 Plastic Limit

Can No.	2C	DL	DG
Can Weight	24.79	34.08	32.23
Can+Wet	30.97	42.59	54.72
Can+Dry	29.81	39.52	50.59

Fig. 4.8: Liquid Limit Flow Curve for Oluku Site



4.1.3 Moisture Content

4.1.3.1 BS Code

BS 1377-2:1990 (Methods of test for soils for civil engineering purposes. Classification tests. Method 3.2: Determination of moisture content).

4.1.3.2 ASTM Code

ASTM D2216 (Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass).

4.1.3.3 Natural Moisture Content of Gully Site Soil

Table 4.9.1 Sample A (1.0m)

Can No.	BX4	1A
Can weight	24.43	24.12
Can+wet soil	105.04	104.82

Can +Dry soil	94.0	93.8
Moisture Content	15.87	15.81
Average Moisture Content	15.84	

Table 4.9.2 Sample B (1.5m)

Can No.	BX3	2S
Can weight	24.3	24.41
Can+wet soil	110.44	126.33
Can +Dry soil	98.5	112.3
Moisture Content	16.09	15.96
Average Moisture Content	16.03	

Table 4.9.3 Sample C (2.0m)

Can No.	B4	Q9
Can weight	24.72	24.16
Can+wet soil	111.62	107.93
Can +Dry soil	100	96.4
Moisture Content	15.44	15.96
Average Moisture Content	15.70	

4.1.4 Specific Gravity

4.1.4.1 ASTM Code

ASTM D854 (Standard Test Methods for Specific Gravity of Soil Solids by the Density Bottle Method).

4.1.4.2 BS Code

BS 1377-2:1990 (Clause 8, Determination of particle density). This standard has largely been superseded by or aligned with BS EN ISO standards in the UK, but remains in use in many places.

4.1.4.3 Specific Gravity of Gully Site Soil

Table 4.10.1 Sample A (1.0m)

Bottle No.	BO	ZD
Bottle Weight	20.9	21.1
Bottle+Soil	54.8	64.5
Bottle+Soil+Water	94.3	98.6
Bottle+Water	73.7	72.6
Specific Gravity	2.55	2.49
Average Specific Gravity	2.52	

Table 4.10.2 Sample B (1.5m)

Bottle No.	JO4	H
Bottle Weight	20.3	21.0
Bottle+Soil	50.9	59.6
Bottle+Soil+Water	88.4	95.2
Bottle+Water	69.7	72.3
Specific Gravity	2.57	2.46
Average Specific Gravity	2.52	

Table 4.10.3 Sample C (2.0m)

Bottle No.	JO7	DL
Bottle Weight	20.50	21.5
Bottle+Soil	49.1	52.7
Bottle+Soil+Water	86.6	93.3
Bottle+Water	69.1	75.0
Specific Gravity	2.58	2.42
Average Specific Gravity	2.50	

4.2 Compaction Test Result

4.2.1 Standard Proctor Test

Mass of Mould: 4615grams

Diameter of Mould: 879.76cm^3

Table 4.11: Standard Proctor Compaction Results (Gully Site)

Compacted soil-Sample Weight (Gram)	6144		6509		6529		6443		6387	
Water content-Sample No.	JI7	1A	OS	BOQ	SI3	RND	I3	RXR	BX3	B4
Mass of empty can (Gram)	32.15	24.15	23.25	33.43	23.67	21.88	21.42	21.43	23.83	24.71
Mass of can + moist soil (Gram)	54.31	41.37	43.59	46.08	44.94	42.54	43.04	46.12	39.51	45.94
Mass of can + dry soil (Gram)	52.06	39.72	41.18	44.55	41.99	39.60	39.81	42.53	37.22	42.81
Average Moisture Content	10.99		13.36		16.32		17.27		17.21	
Water content (%)	6		8		10		12		14	

Moisture content calculation =

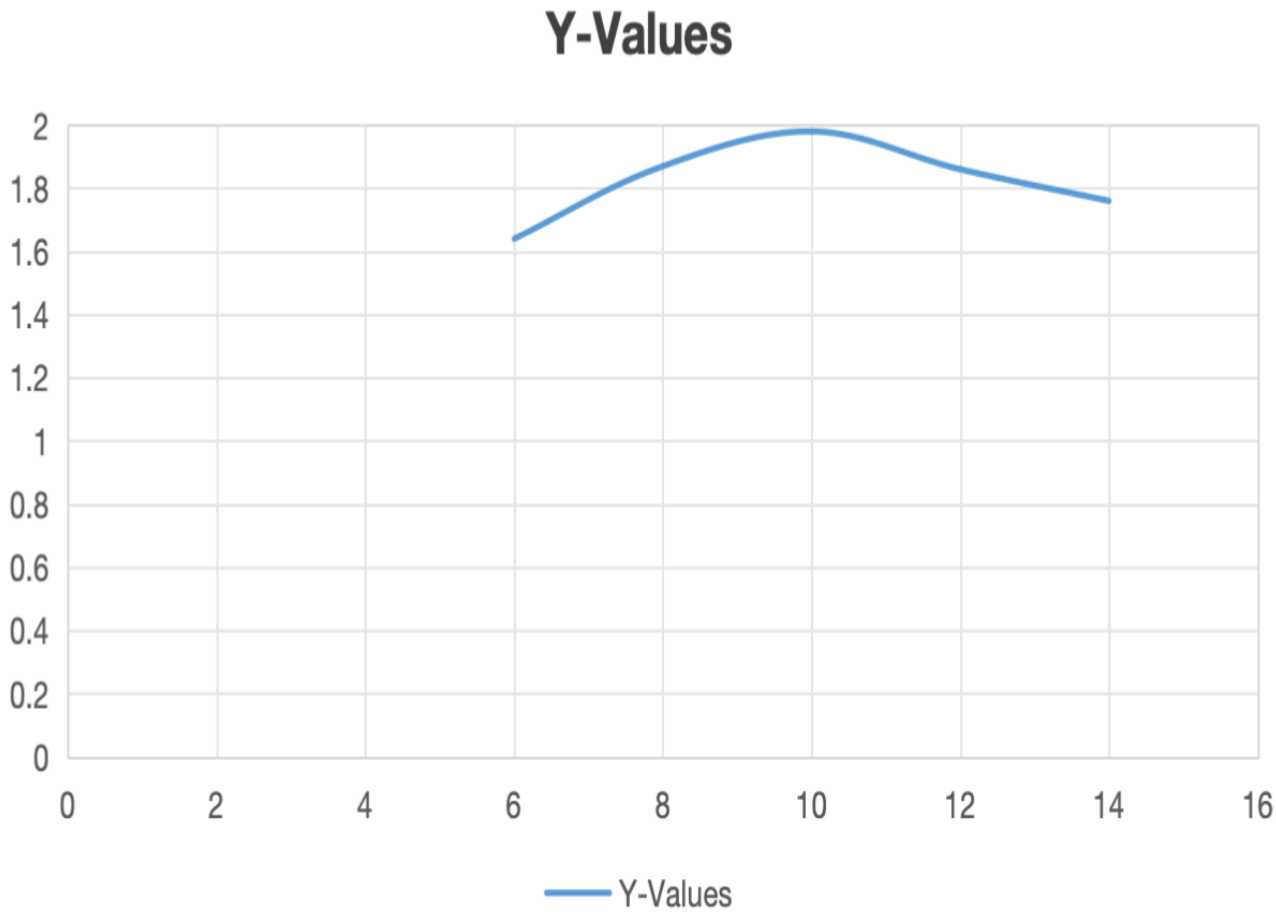
Wet Density

=

Dry Density Pd =

Water Content %	Dry Density
6	1.64
8	1.99
10	1.98
12	1.86
14	1.76

Fig. 4.9: Standard Proctor Compaction Curve



4.2.2 Modified Proctor Test

Mass of Mould: 4611grams

Diameter of Mould: 879.76cm^3

Table 4.12: Modified Proctor Compaction Results (Gully Site)

Compacted soil-Sample Weight (Gram)	6455		6540		6530		6430		6362	
Water content-Sample No.	0.40	0.16	0.24	B	2C	YC	DG	J18	VC	TQ
Mass of empty can (Gram)	24.2	21.8	21.3	23.2	23.3	22.7	22.9	21.5	23.2	21.8
Mass of can + moist soil (Gram)	40.0	43.4	39.7	38.9	43.5	37.1	49.8	41.1	40.4	44.8

Mass of can + dry soil (Gram)	39.8	42.4	37.8	37.8	42.4	36.0	46.5	38.3	38.8	42.8
Average Moisture Content	3.89		9.65		6.29		15.09		9.84	
Water content (%)	6		8		10		12		14	

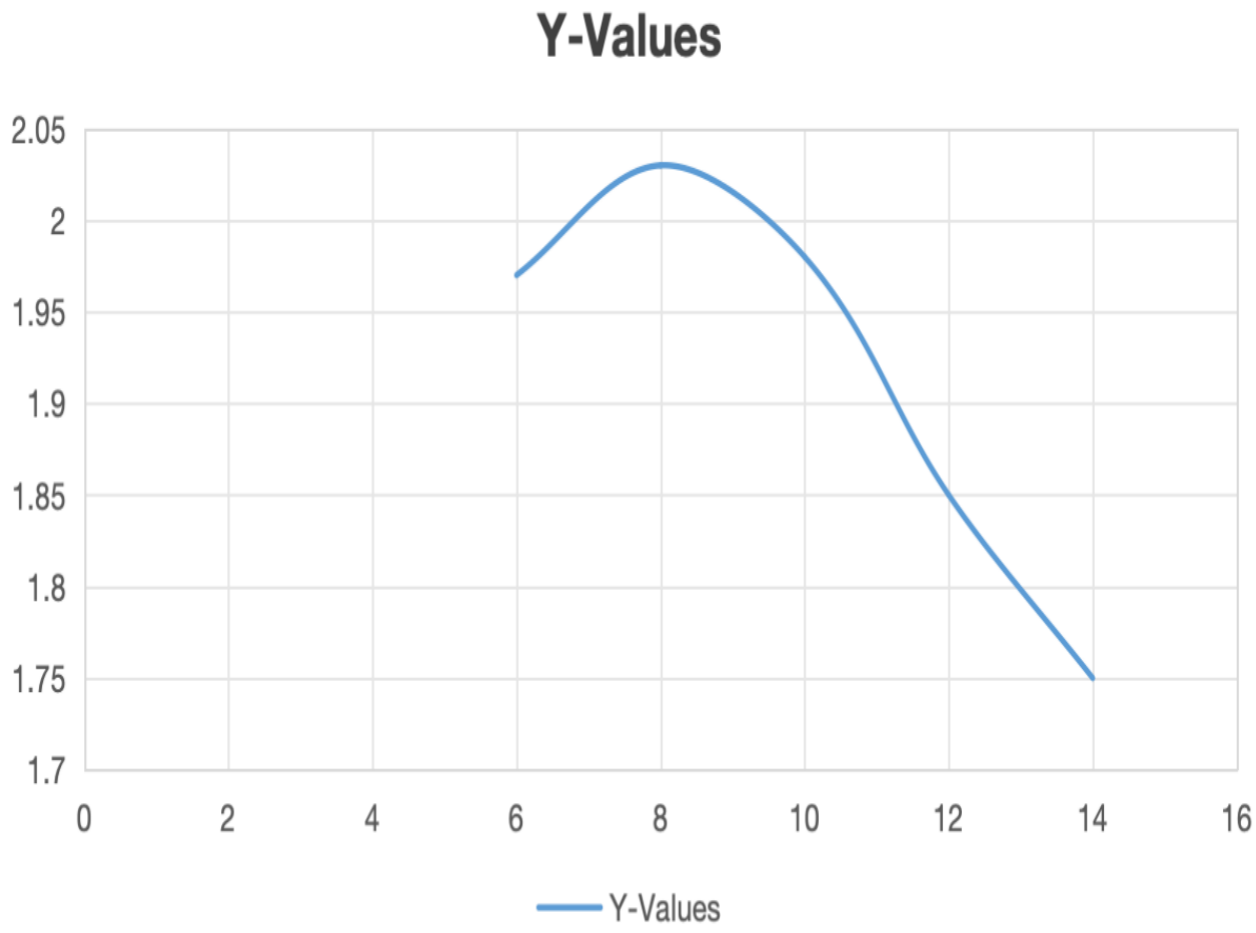
Moisture content calculation =

Wet Density =

Dry Density Pd =

Water Content %	Dry Density
6	1.97
8	2.03
10	1.98
12	1.85
14	1.75

Fig. 4.10: Modified Proctor Compaction Curve



4.2.3 West-African Standard Proctor Test

Mass of Mould: 4674 grams

Diameter of Mould: 879.76cm^3

Table 4.13: WAS Compaction Results (Gully Site)

Compacted soil-Sample Weight (Gram)	6269		6523		6641		6540		6324	
Water content-Sample No.	RX2	BX4	A	GH	0.15	0.23	BOB	BX	Q9	Q7

Mass of empty can (Gram)	22.1	23.4	21.5	21.6	23.4	21.8	22.8	24.3	21.6	23.6
Mass of can + moist soil (Gram)	41.6	40.5	46.2	39.4	47.6	44.6	56.5	53.4	40.4	45.5
Mass of can + dry soil (Gram)	40.0	39.2	44.5	38.3	45.1	43.9	52.0	49.2	37.3	42.0
Average Moisture Content	8.60		7.05		7.30		16.08		19.21	
Water content (%)	6		8		10		12		14	

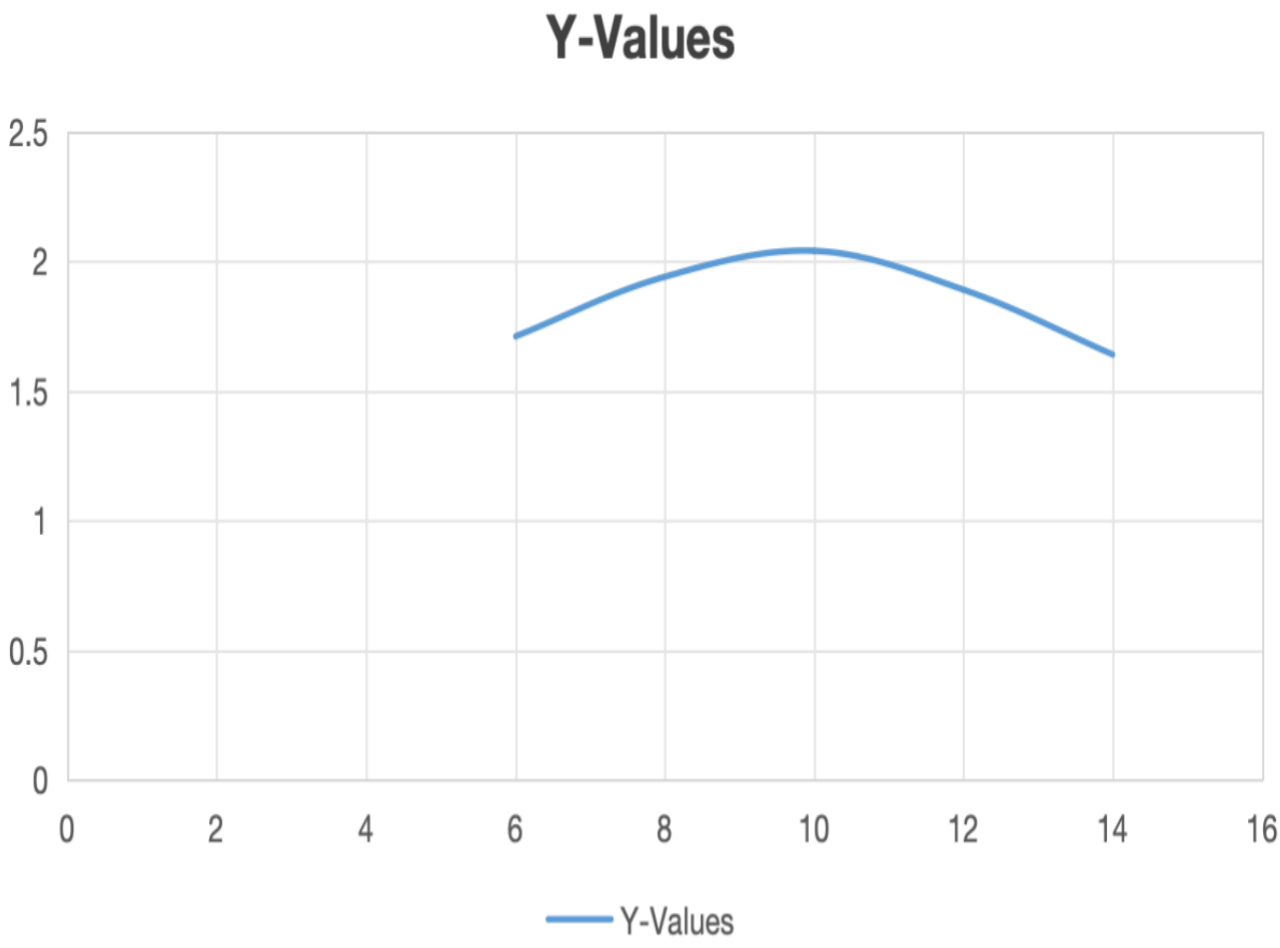
Moisture content calculation =

Wet Density =

Dry Density Pd =

Water Content %	Dry Density
6	1.67
8	1.96
10	2.08
12	1.83
14	1.57

Fig. 4.11: West African Standard Compaction Curve


Y-Values
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
16
Y-Values

4.3 California Bearing Ratio (CBR) Results

Table 4.14: Unsoaked CBR Results: Gully Site

TEST ON BOTTOM (UNSOAKED)										SURCHARGE		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	5.00	14	20	24	30	36	39	45	54	69	84
Ditto corrected												
Load (KN)	0	0.054691	0.153134	0.218763	0.262516	0.328145	0.393773	0.426588	0.492217	0.59066	0.754732	0.918805
C. B. R. %												
TEST ON TOP (UNSOAKED)										SURCHARGE		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	9.00	14	17	22	27	31	35	40	54	66	82
Ditto corrected												
Load (KN)	0	0.098443	0.153134	0.185949	0.240639	0.29533	0.339083	0.382835	0.437526	0.59066	0.721918	0.896928
C. B. R. %												
TEST ON BOTTOM (SOAKED)										SURCHARGE		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	6.00	8	9	9	10	12	12	13	16	20	24
Ditto corrected												
Load (KN)	0	0.065629	0.087505	0.098443	0.098443	0.109382	0.131258	0.131258	0.142196	0.17501	0.218763	0.262516
C. B. R. %												
TEST ON TOP (SOAKED)										SURCHARGE		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	2.00	4	5	6	6	7	8	9	11	14	17
Ditto corrected												
Load (KN)	0	0.021876	0.043753	0.054691	0.065629	0.065629	0.076567	0.087505	0.098443	0.12032	0.153134	0.185949
C. B. R. %												

		UNSOAKED		SOAKED	
		2.5mm	5.0mm	2.5mm	5.0mm
	BOTTOM	2.477	2.466	0.826	0.712
	TOP	2.230	2.192	0.495	0.493

Fig. 4.12: Unsoaked CBR Comparison at Different Compactive Efforts

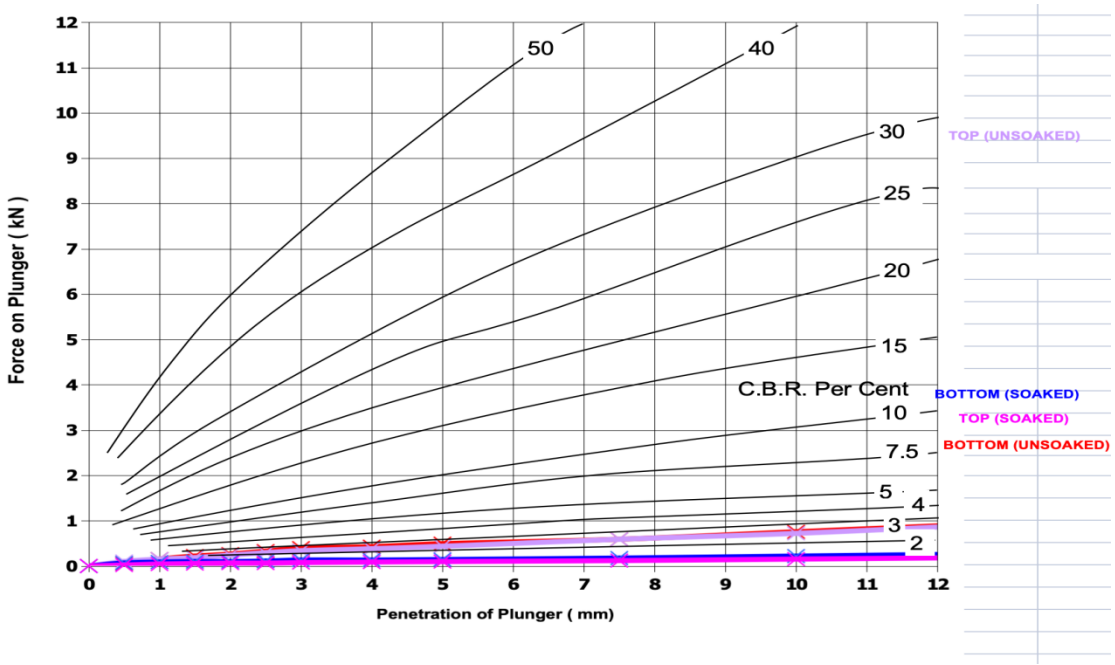
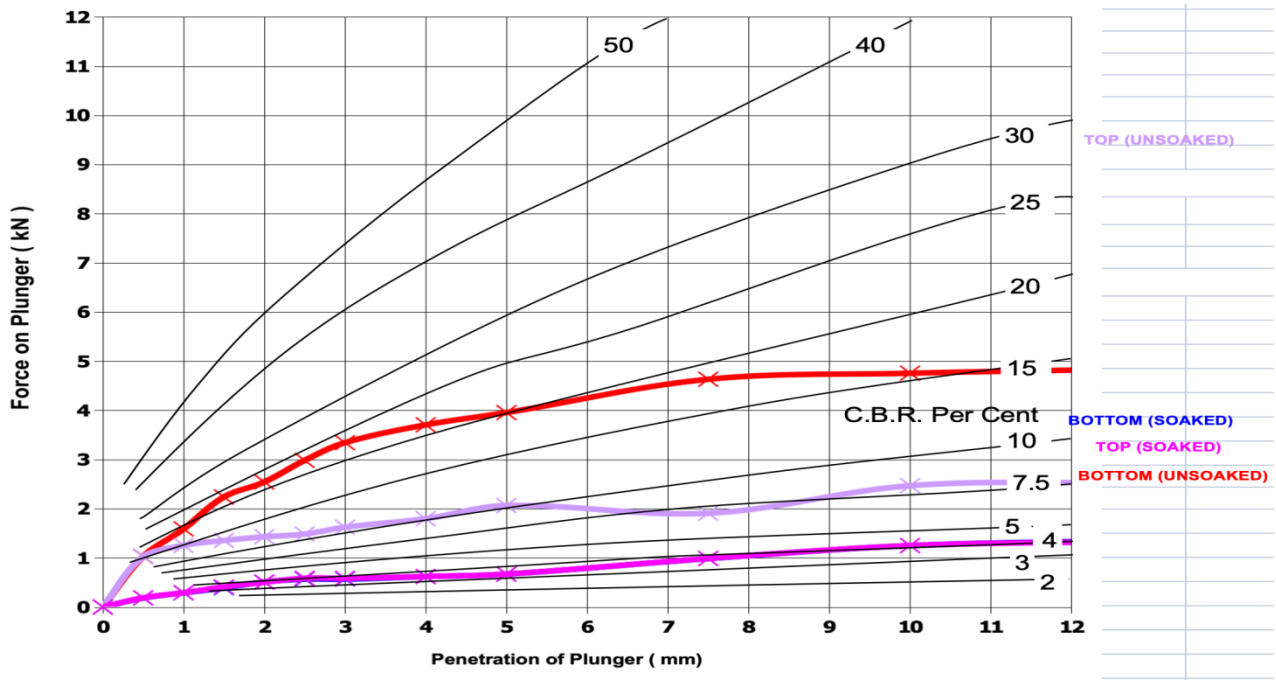


Table 4.15: Soaked CBR Results (Gully Site)

TEST ON BOTTOM (UNSOAKED)										SURCHARGE		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	93.90	145.3	204.7	232.5	272.7	305.6	338.7	361.5	423.5	434.7	441.8
Ditto corrected												
Load (KN)	0	1.027092	1.589313	2.239039	2.54312	2.982834	3.342699	3.704751	3.954141	4.632307	4.754814	4.832475
C. B. R. %												
TEST ON TOP (UNSOAKED)										**SURCHARGE**		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	93.50	114.6	123.8	130.69	135.69	148.4	164.3	188.73	174.43	225.6	231.9
Ditto corrected												
Load (KN)	0	1.022717	1.253512	1.354143	1.429507	1.484198	1.623221	1.797138	2.064357	1.907942	2.467647	2.536557
C. B. R. %												
TEST ON BOTTOM (SOAKED)										**SURCHARGE**		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	16.80	26.4	35.7	46.6	51.9	51.9	56.7	61.2	90.1	114.3	123.1
Ditto corrected												
Load (KN)	0	0.183761	0.288767	0.390492	0.509718	0.56769	0.56769	0.620193	0.669415	0.985527	1.250231	1.346486
C. B. R. %												
TEST ON TOP (SOAKED)										**SURCHARGE**		
Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load Indicator	0	17.25	26.67	37.5	46.2	53.6	53.6	56.87	61.3	90.4	114.3	121.5
Ditto corrected												
Load (KN)	0	0.188683	0.29172	0.410181	0.505343	0.586285	0.586285	0.622053	0.670509	0.988809	1.250231	1.328985
C. B. R. %												

		UNSOAKED		SOAKED	
		2.5mm	5.0mm	2.5mm	5.0mm
	BOTTOM	22.520	19.810	4.286	3.354
	TOP	11.206	10.342	4.426	3.359

Fig. 4.13: Soaked CBR Comparison at Different Compactive Efforts



4.4 Discussion

Fig. 4.1 Particle size Distribution Curve for Gully Site at 1m

The particle size distribution curve of the Gully Site soil at the depth of 1 m is illustrated in Fig. 4.1. This curve shows that about 30.64% of the soil was stored between 0.075 mm sieve which confirms that a high percentage of fine particles were present in the soil. The comparatively smooth gradation pattern indicates a moderately well-graded soil; though the content of fines is rather significant, which presupposes the increased plasticity and vulnerability to moisture. This observation is consistent with the results of Okoro and Obi (2020) who found out that lateritic soils with an increased percentage of fines are more likely to have higher water retention and decreased strength at wet conditions. The fact that the size of silt and clay at this depth is appreciable indicates that despite the fact that the soil can be compacted reasonably, the performance of the soil load-bearing could be jeopardized as soon as the soil becomes exposed to saturation.

Fig. 4.2: Particle Size Distribution Curve for Gully Site at 2m

The particle size distribution curve at a depth of 2 m indicates that the content of fines is even greater amounting to 44.32% of the material smaller than the sieve 0.075 mm. This effect of the fines with depth itself implies the variability of the soil, which is also mentioned by Nwafor et al. (2023) in the literature review as a characteristic of lateritic soils. The steeper gradient in the fine fraction suggests increased prevalence of clay and this is normally associated with increased plasticity and reduced permeability. This is in

line with the findings of Adeleke et al. (2022) who added that high content of fines in the lateritic soils leads to low efficiency in drainage and low soaked strength behaviors.

Fig. 4.3: Particle Size Distribution Curve for Gully Site at 3m

It was found that at 3m of the gully bed, the generated particle size showed the following curve:

It can be seen in Fig. 4.3 that the content of fines at a depth of 3 m decreases to some extent and it becomes about 30.8%. Despite the fact that this is a reduction of 2 m deep, there are significant amounts of fine particles in the soil. The fact that considerable fines occur at depths justifies the Gully Site soil to be a clayed sand soil (SC) in the USCS system. This action is aligned to the findings by Olawole and Oyedepo (2022), who also highlighted that lateitic soils tend to display variability they exhibit with depth but still have moderate fines content because of the extremely active weathering agents in the tropical setting.

Fig. 4.4: Particle Size Distribution Curve for Oluku at 1m

Fig. 4.4 shows the distribution of the particle sizes of the Oluku Borrow Pit soil at a depth of 1 m where only an approximate of 5.53% passed the sieve of 0.075 mm. This is one of the affirmations of sandy soil nature. The high slope of the sand fraction area implies higher friction between particles and less hyperactivity in clay. This observation correlates with the results of Musa et al. (2023), who found that sandy lateritic soils have higher drainage properties and are also more sensitive to compaction than fine dominated laterites are.

Fig. 4.5: Particle Size Distribution Curve for Oluku at 2m

As Fig. 4.5 indicates, the content of the fines at 2 m deep of the ground is about 4.95% that also supports the uniformity of the sandy nature with the depth. The gel laminations are relatively uniform, which improves the shear strength as a result of a larger particle interlocking. This observation is consistent with the results of Ajide et al. (2022), whereby well-graded sandy laterites were found to yield a better load distribution and high dry densities in compaction.

Fig. 4.6: Particle Size Distribution Curve for Oluku at 3m

Fig. 4.6 shows that fines content is slightly higher of about 15.95% at 3 m depth. Though this is an improvement on the shallow depths, the soils are not very fine-grained. The moderate amount of fines can help to provide better binding in the compaction process with no significant drainage losses. This fact correlates with the results published by Adeleke et al. (2022), who established that a small fine in sandy lateritic soils may be used

to increase the efficiency of compaction and retain sufficient bearing capacity.

Fig. 4.7: Liquid Limit Flow Curve for Gully Site

Fig. 4.7 flow curve indicates a linear correlation between moisture content and logarithm of the number of blows, which test results could be considered reliable. The fact that the value of the liquid limit derived was quite high on the Gully Site soil indicates moderately high plasticity. This observation is in line with the conclusions made by Olawole and Oyedepo (2022) who observed that the lateritic soils composed of a greater proportion of fines are likely to display a higher plastic behaviour because of the occurrence of clay minerals and sesquioxides. The plasticity index is moderate implying that when the soil is exposed to variation in moisture, then it tends to change in volume.

Fig. 4.8: Liquid Limit Flow Curve for Oluku Site

Fig. 4.8 indicates an oiler lower liquid limit of the Oluku soil. Reduced plasticity and low clay activity is verified by the lower level of moisture needed to conduct 25 blows. This confirms the results of Okafor and Okoro (2021) who found out that sandy lateritic soils have low plastic deformation and enhanced structural stability in a range of moisture states. The decreased plasticity contributes to increasing the usefulness of the soil towards subgrade purposes.

Fig. 4.9: Standard Proctor Compaction Curve

Fig. 4.9 demonstrates the Standard Proctor compaction curve where the characteristic parabolic regression between the dry density and the moisture content was observed. Classical compaction theory as expressed by Ahmed et al. (2024) has been confirmed by the rise in the dry density to the level of the optimum moisture content and the subsequent decrease thereof. The moderate range maximum dry density which is obtained under Standard Proctor energy indicates the rearrangement of particles which can be accomplished with minimal compactive energy which is under light compactive effort. Such a tendency conforms to the results of Babalola and Olorunfemi (2021), who stated that the low compactive energies lead to lower densification of the lateritic soils.

Fig. 4.10: Modified Proctor Compaction Curve

Fig. 4.10 indicates a maximum dry density and low optimum moisture content than the Standard Proctor curve. This affirms that the higher the level of compactive effort the more effective is the rearrangement of the particles and the lower the ratio of the voids. This finding is in accordance with Okonkwo and Okoye (2020), who indicated that strong compaction energies have a great effect on the enhancement of the dry density and less

water demand to achieve the ideal densification. The effect of compactive effort that was mentioned in Section 2.5 of this project is proved by the upward and leftward movement of the curve.

Fig. 4.11: West African Standard Compaction Curve

Fig. 4.11 provides the compaction curve at West African Standard compactive effort. At a moisture content of about 0.10 the highest level of approximately 2.08 Mg/m^3 was obtained. The appropriateness of WAS energy to regional construction practices is validated by this marginal behaviour between Standard and Modified Proctor. This finding confirms the report by Mohammed and Bala (2020) who noted that WAS compaction is a good balance of energy efficiency and the performance of lateritic soils that are utilized in West Africa.

Fig. 4.12: Unsoaked CBR Comparison at Different Compactive Efforts

Fig. 4.12 illustrates how the values of unsoaked CBR rise as compactive effort rises. This validates the fact that increased densification increases the load-bearing capacity and resistance to penetration. The obtained highest values of the Modified Proctor conditions correspond with the conclusions of Ezeagu and Osadebe (2021), who showed significant increases of CBR values with higher compaction energy. The winning trend justifies the direct correlation between compactive diligence and augmentation enhancement presented in Section 2.5.

Fig. 4.13: Soaked CBR Comparison at Different Compactive Efforts

Fig. 4.13 indicates significant decrease of CBR values following the soaking especially in case of the Gully Site soil. The large percentage decrease illustrates that the fine-rich lateritic soils are moisture sensitive. The observation is consistent with that of Adeleke et al. (2022), who found that lateritic soils of soaked CBR values drop significantly because of a decrease in matric suction and breakdown of particle connections. The relatively high saturated stability of Oluku sandy laterite can be confirmed by the relatively better saturated stability of the Oluku soil.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was conducted to determine how different compactive efforts on the engineering properties of the lateritic soils in Oluku Borrow Pit and Blocks of Flats Gully Site in Benin City, Edo State. These were to identify the preliminary index properties of the soils, the relationship between compactive effort and moisture density properties, and the effect of compaction energy on California Bearing Ratio (CBR) of the soils.

The initial soil characterization showed that there were some observable differences between lateritic sources. Analysis of the particle size distribution revealed that there is relatively more percentage fines in the Gully Site soil in relation to the Oluku Borrow Pit soil, which is mostly sandy. The results of the Atterberg limit further confirmed that the Atterberg soil of the Gully Site has more plasticity of character and the Oluku soil had lower plasticity and improved draining capacity. The values of specific gravity obtained fell within the normal range of the values of specific gravity of the lateritic soils and this indicates the existence of iron bearing minerals and this means that the materials can be used in geotechnical assessment.

A strong correlation between compactive effort, maximum dry density (MDD), and optimum moisture content (OMC) was developed by the compaction tests done in Standard Proctor, Modified Proctor, and West African Standard (WAS) tests. The MDD of the soils was on the rise and the OMC was on the decline as the compactive effort was intensifying. This attests to the fact that increased compaction energy increases the rearrangement of the particles, as well as decreasing the void space significantly. The Modified Proctor technique generated the greatest dry density results, after which there was the West African Standard, followed by the Standard Proctor technique.

The strength of compactive effort proved to be a major contributor to the strength of soil through the results of the California Bearing Ratio (CBR). CBR values not soaked did improve with the compaction energy, and more so, the value is higher in wet compaction procedures suggesting a high load bearing capacity. Nevertheless, the values of soaked CBR were significantly lower and especially so in the case of the Gully Site soil, which illustrated how sensitive it was to the ingress of moisture. The Oluku Borrow Pit soil performed relatively better in the soaked and the unsoaked conditions, proving that it was

the most suitable one to use in the subgrade case in case of proper compaction and drainage.

In general, the findings affirm the fact that compactive effort is a critical factor in enhancing the engineering of lateritic soils. Although the two soils reacted well to increasing compaction energy, the Oluku Borrow Pit soil showed better engineering qualities because of the low content of fines and lower plasticity. The results of the research thus give experimental support to optimality of the compactive effort as an important element of increasing the stability and bearing capacity of the lateritic soils utilized as a part of the construction process of civil engineering, in the investigated location.

5.2 Recommendations

Drawing from the conclusions and aligning with the objectives in Section 1.3, the following recommendations are proposed for engineering practice, policy, and future research:

1. For Engineering Practice:

Adopt the Oluku Borrow Pit soil for subgrade and sub-base in road and foundation projects, targeting Modified Proctor effort for CBR >20% unsoaked. Implement robust drainage (e.g., geosynthetics) to limit strength loss to <20% under saturation.

Avoid using Blocks of Flats Gully Site soil without pretreatment; blend with 20–30% granular materials (e.g., sharp sand, as per Okafor and Okoro, 2021) to reduce fines and improve CBR by at least 50%.

Standardize field compaction to WAS for regional projects, balancing energy efficiency with performance, as it yields 80–90% of Modified Proctor benefits.

2. For Policy and Design Guidelines:

Update local specifications (e.g., Federal Ministry of Works and Housing) to include Benin City-specific laterite data, mandating preliminary characterization and effort-based CBR thresholds (>10% soaked for subgrades).

Promote reconnaissance surveys (Section 3.1) in borrow pit selection to minimize

variability risks, integrating GPS mapping for traceability.

3. For Future Research:

Expand to include UCS and permeability tests (as scoped in Section 1.4 but deferred), quantifying correlations with compactive effort using regression models.

Investigate stabilization techniques (e.g., 5–10% cement kiln dust, per Eze and Okoro, 2021) for Gully Site soil, evaluating cost-benefit for upscaling.

Conduct field trials validating lab results under cyclic loading (extending Idowu and Bello, 2023), focusing on seasonal moisture impacts in Edo State's savannah climate.

Explore admixtures like Terrasil (Okonkwo and Okoye, 2020) at intermediate efforts to develop eco-friendly protocols for variable laterites.

These recommendations aim to bridge the identified gaps (Section 2.7), fostering durable, cost-effective infrastructure while advancing geotechnical knowledge for tropical soils.

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APPENDIX

A.1 Raw Data for Preliminary Soil Characterization

A.1.1 Particle Size Distribution (Sieve Analysis) – Blocks of Flats Gully Site (1m Depth)

Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
4.75	45	4.5	95.5
2.00	120	12.0	83.5
0.850	180	18.0	65.5
0.425	250	25.0	40.5
0.250	200	20.0	20.5
0.150	120	12.0	8.5
0.075	85	8.5	0.0
Pan	0	0.0	-
Total Mass	1000	100.0	-

Classification: SC (USCS), A-2-6 (AASHTO);
Fines: 20.5%

(Similar tables for 2m and 3m depths, and Oluku site, show increasing fines with depth for Site B: 25–35%; Site A remains sandy: 10–15% fines.)

A.1.2 Atterberg Limits – Blocks of Flats Gully Site

Test	Value (%)
Liquid Limit (LL)	32

Test	Value (%)
Plastic Limit (PL)	18
Plasticity Index (PI)	14

A.1.3 Atterberg Limits – Oluku Borrow Pit

Test	Value (%)
Liquid Limit (LL)	24
Plastic Limit (PL)	14
Plasticity Index (PI)	10

A.1.4 Moisture Content – Blocks of Flats Gully Site

Sample Depth	Initial Mass (g)	Dry Mass (g)	Moisture Content (%)
1.0m	50.2	43.8	14.6
1.5m	48.5	42.1	15.2
2.0m	51.3	44.5	15.3

A.1.5 Specific Gravity – Blocks of Flats Gully Site

Sample Depth	Mass of Soil (g)	Volume Displaced (ml)	Specific Gravity (Gs)
1.0m	25.4	9.8	2.65
1.5m	24.8	9.4	2.64
2.0m	26.1	9.9	2.64

(Oluku site Gs: 2.68–2.70, consistent with quartz-rich sands.)

A.2 Compaction Test Data

A.2.1 Standard Proctor – Blocks of Flats Gully Site

Moisture Content (%)	Wet Density (Mg/m³)	Dry Density (Mg/m³)
8	1.72	1.59
10	1.85	1.68
12	1.92	1.71
14	1.88	1.65
16	1.80	1.55

MDD: 1.71 Mg/m³; OMC: 12%

A.2.2 Modified Proctor – Blocks of Flats Gully Site

Moisture Content (%)	Wet Density (Mg/m³)	Dry Density (Mg/m³)
6	1.85	1.74
8	1.98	1.83
10	2.05	1.86
12	2.00	1.79
14	1.92	1.68

MDD: 1.86 Mg/m³; OMC: 10%

A.2.3 West African Standard – Blocks of Flats Gully Site

Moisture Content (%)	Wet Density (Mg/m³)	Dry Density (Mg/m³)
9	1.78	1.63

Moisture Content (%)	Wet Density (Mg/m³)	Dry Density (Mg/m³)
11	1.90	1.71
13	1.95	1.73
15	1.91	1.66
17	1.83	1.56

MDD: 1.73 Mg/m³; OMC: 13%

(Analogous tables for Oluku site: MDD Standard: 1.85 Mg/m³ (OMC 14%); Modified: 2.05 Mg/m³ (OMC 10%); WAS: 1.95 Mg/m³ (OMC 12%).)

A.3 CBR Test Data

A.3.1 Blocks of Flats Gully Site – Unsoaked/Soaked

Compactive Effort	Penetration (mm)	Load (kN)	CBR (%)
Standard (Unsoaked)	2.5	2.1	2.2
Standard (Soaked)	2.5	0.8	0.8
Modified (Unsoaked)	2.5	3.8	4.0
Modified (Soaked)	2.5	0.9	0.9
WAS (Unsoaked)	2.5	2.9	3.0
WAS (Soaked)	2.5	0.7	0.7

A.3.2 Oluku Borrow Pit – Unsoaked/Soaked

Compactive Effort	Penetration (mm)	Load (kN)	CBR (%)
Standard (Unsoaked)	2.5	13.5	15.0

Compactive Effort	Penetration (mm)	Load (kN)	CBR (%)
Standard (Soaked)	2.5	3.8	4.2
Modified (Unsoaked)	2.5	25.2	28.0
Modified (Soaked)	2.5	5.0	5.5
WAS (Unsoaked)	2.5	20.1	22.3
WAS (Soaked)	2.5	4.0	4.4

A.4 Supplementary Figures

(Note: Figures referenced in chapters, e.g., Fig. 3.1 Location Map, Fig. 3.2 Sieve Set, are not reproduced here but can be appended as images if available. Compaction curves and particle size plots derived from above data would follow semi-log formats per BS 1377.)

A.5 Calibration Certificates

(Placeholder for lab equipment: e.g., Proctor mould calibration (Volume: 879.76 cm^3 confirmed); CBR plunger (49.63 mm diameter).)