

**GEOTECHNICAL PROPERTIES OF LATERITE SOIL FOR ROAD
CONSTRUCTION FROM OVBIOGIE BORROW PIT**

BY

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IN

THE DEPARTMENT OF STRUCTURAL ENGINEERING

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN

BENIN CITY.

FEBRUARY 2025

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF STRUCTURAL
ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE**

IN

**THE DEPARTMENT OF STRUCTURAL ENGINEERING, FACULTY OF
ENGINEERING,**

UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

FEBRUARY 2025

PLAGIARISM

This work **ASSESSMENT OF SUITABILITY OF LATERITIC SOIL FOR ROAD CONSTRUCTION IN BENIN CITY**, by FASINA, James Adekitan with Mat Number ENG1905253 of the Department of Structural Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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CERTIFICATION

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DEDICATION

In humble reverence, I dedicate this work to my family, whose enduring love and encouragement have been my foundation, I dedicate this project to my parents, Pastor DELE FAYEMI, Pastor YEMISI ISRAEL, Pastor BUKOLA BADMUS, your sacrifices and belief in my abilities have fueled my determination to strive for excellence.

To my mentors and educators, whose guidance has shaped my intellectual growth, I express my deepest gratitude. Your wisdom and insights have been a guiding light, steering me towards the pursuit of knowledge.

In essence, this dedication is a heartfelt acknowledgment of the collective influence of those who have touched my life. May this work stand as a testament to the shared values of resilience, collaboration, and the pursuit of a better future

ACKNOWLEDGEMENT

I would like to express my appreciation to my heroes who made it possible for me to finish this report. I wish to recognize the department's head, Engr. Dr. (Mrs.) Ngozi Ihimekpen, for her firm values, wise counsel, and genuine love for us students. Ma, God bless you. I would like to thank my project supervisor, Engr. Dr. (Mrs.) Ngozi Kayode Ojo and co-project supervisor, Engr. Janet O. Odemerho, for their wonderful suggestion, time spent proofreading and helping me see my errors, and better solutions that made sure this project a success. All of these things helped me write this report successfully.

I will not fail to express my gratitude for the significant role played by the Civil Engineering Department staff, who have done more than required to impact us with knowledge and guarantee that we learn all it takes to be an engineer. Prof. O.C Izinyon, Prof O.U. Orie, Prof. H. A. P Audu, Prof. S.O. Osuji, Engr. Prof. S.D. Iyeke , Dr R.I Umasabor, Engr. Dr. R.O Ogirigbo, Engr. Dr. R.I Ilaboya, Dr (Mrs.) L.O Bobor, Engr. Dr. A. Agbonaye, Engr. Dr (Mrs.) A. Rawlings, Engr. Dr. E.S. Okonofua and Engr. J.O Ekhodiaehi (late) , Engr. U. Ukeme, Engr.E Oria- Usifo, Engr C. Okolie, Engr. P.N. Ogbeifun, Engr. S.A. Adegbemileke, Engr. N. Kent Oghoyafedo, Engr. O. Osasu, Engr. (Mrs) E. Ambrose-Agabi, Engr. U. Ogbonna Engr. B. Omosefe, Engr. O. Oriakhi, Engr. (Mrs) G.E. Evbaru-Okhuaehesuyi and all the Laboratory staff.

Finally, to my brothers and sisters this institution blessed me with colleagues, whose camaraderie and shared experiences have made this journey memorable, I dedicate this endeavor. Ohis Igeleke, Lucky Aigbedion, Success Harrison, Igiehon Nelson and Kenechukwu Edeme, Ayomide Jamgbadi, Richard Adun, Abdulmalik Zaytuni, Akele Peace, and many more

Your friendship has been a source of strength and joy, reminding me that challenges are best faced together.

And finally, to the one that made my decision of schooling in Benin worth it and steered me in the right direction. Osarugue Eden Jegede, thank you for everything.

ABSTRACT

This project aimed to conduct a comprehensive geotechnical analysis of laterite soil from the Obviogie Borrow Pit, with the goal of assessing its suitability for use in road construction and developing a data bank for future reference. Laterite soils were commonly used in road construction, particularly as sub-base and sub-grade materials, due to their availability and cost-effectiveness. However, it was crucial to evaluate the physical properties of the soil to ensure it met the engineering requirements for long-lasting and stable roads. For this study, a soil sample was collected from the borrow pit and subjected to various laboratory tests to determine its key physical characteristics.

The analysis focused on fundamental properties such as moisture content, specific gravity, and particle size distribution. These factors played a significant role in understanding the behavior of the soil under load and during compaction. These parameters were essential for establishing the soil's ability to support heavy loads when used as a sub-base or sub-grade material in road construction. The data gathered from the physical and compaction tests were compiled into a detailed data bank. This data bank served as a valuable resource for engineers and road construction professionals, providing them with critical information to guide the selection, preparation, and compaction of the soil for use in road building projects. By offering a clear understanding of the soil's load-bearing capacity and compaction behavior, this project helped ensure that roads constructed in the Obviogie region were built on a solid foundation, enhancing their durability and reducing the need for costly repairs in the future.

The overall goal of this project was to support the use of local materials in road construction while ensuring that they met the necessary engineering standards. This study contributed to the efficient

use of laterite soils, which were widely available in the Obviogie area, and helped reduce construction costs by minimizing the need for imported materials. In doing so, the project provided valuable insights that promoted more sustainable and cost-effective infrastructure development in the region.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study.

1.2 Lateritic Soil

Laterite soils are widely used in road construction across tropical regions, including Nigeria, due to their availability and cost-effectiveness. These soils are commonly employed as sub-base and subgrade materials in highways and other road projects. However, the suitability of laterite soils for construction purposes depends largely on their geotechnical properties, such as moisture content, particle size distribution, and compaction behavior. These characteristics are critical in determining the soil's ability to support heavy loads, maintain stability, and perform well under traffic stress and varying environmental conditions. Therefore, it is essential to thoroughly evaluate these properties before using laterite soils in construction projects to ensure long-term durability and performance.

The Obviogie Borrow Pit, located in a region known for its rich deposits of lateritic soils, presents an opportunity to source materials for road construction in the area. However, limited data exists on the geotechnical properties of the soil from this site, making it difficult for engineers and road construction professionals to determine its suitability for use. Without proper testing and evaluation, using lateritic soil from this site may result in suboptimal road performance, leading to early failures, increased maintenance, and higher long-term costs. To prevent these issues, it is crucial to conduct a thorough investigation of the soil's physical properties and compaction behavior to ensure that it meets the required engineering standards.

This study aims to provide a detailed analysis of a laterite soil sample from the Obviogie Borrow Pit, focusing on key geotechnical properties such as moisture content, particle size distribution, specific gravity, and compaction characteristics using the modified Proctor method. By determining the soil's Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), this study will provide critical insights into its load-bearing capacity and ideal compaction conditions. These results will be compared to the standards and specifications set by the Federal Ministry of Works in Nigeria for road construction. The Ministry's guidelines serve as a benchmark for evaluating whether locally sourced laterite soils meet the criteria for use in sub-base and subgrade layers of highways and other infrastructure projects.

The comparison with the Federal Ministry of Works' standards will ensure that the soil from the Obviogie Borrow Pit is not only technically viable but also compliant with national engineering and construction regulations. This aspect of the study is crucial, as adherence to these standards is necessary for ensuring the longevity, stability, and safety of roads built with these materials.

By creating a data bank of the physical and compaction properties of the lateritic soil, this study will provide valuable information to engineers, road designers, and construction planners. This data will guide the selection and preparation of locally available materials for infrastructure projects, reducing reliance on more expensive imported materials and contributing to the sustainability of road construction efforts. In doing so, the project will not only facilitate cost-effective construction but also promote the use of local resources in a responsible and efficient manner.

In conclusion, this study will serve as a vital step toward ensuring that laterite soil from the Obviogie Borrow Pit can be confidently used in road construction, with comparisons to national standards providing additional assurance of its suitability. By understanding the soil's geotechnical

properties and comparing them to established benchmarks, this research will help improve decision-making in material selection, leading to better-quality and longer-lasting roads in the Obviogie region and beyond.

1.3 Statement of Problem

The suitability of laterite soil from the Obviogie Borrow Pit for road construction is uncertain due to a lack of data on its geotechnical properties. Without this information, there is a risk of using unsuitable materials, which could lead to poor road performance and costly repairs. Furthermore, it is essential to determine whether the soil meets the standards set by the Federal Ministry of works to ensure safe and durable road construction.

1.4 Aim and Objectives

The aim of the work is to carry out the geotechnical properties of laterite soil obtained from Obviogie borrow pit.

The objectives include:

- i. Classification of soil samples according to its index properties.
- ii. Determine the engineering properties of soil samples.

1.5 Scope of Study.

- a. Reconnaissance survey
- b. Determine the Atterberg limit
- c. Determination of specific gravity.
- d. Sieve analysis
- e. Compaction Test
- f. California bearing ratio

1.6 Justification of Study

The increasing demand for infrastructure development in Nigeria, particularly in the construction of highways and other road networks, underscores the need for reliable and locally sourced construction materials. Laterite soils are widely available in many parts of Nigeria and are commonly used in road construction as sub-base and subgrade materials. However, despite their prevalence, not all laterite soils possess the necessary geotechnical properties to meet the engineering standards required for road durability and stability. As a result, proper testing and analysis are essential before these materials can be confidently used in construction projects.

The Obviogie Borrow Pit presents a promising source of laterite soil for road construction in the region. However, there is a lack of comprehensive data on the geotechnical properties of the soil from this site, making it difficult for engineers and planners to assess its suitability for use in highway sub-base and subgrade layers. Conducting a detailed study of the soil's physical properties and compaction characteristics will provide crucial insights into its performance under traffic loads and varying environmental conditions.

This study is justified by the potential benefits it offers to road construction projects in the Obviogie region and beyond. By evaluating the geotechnical properties of the soil and comparing them to the standards set by the Federal Ministry of Works, the research will ensure that the laterite soil from the Obviogie Borrow Pit meets the required specifications for road construction. Adhering to these standards is vital for ensuring that roads built with this material are safe, durable, and capable of withstanding heavy traffic over time.

Furthermore, the results of this study will contribute to the creation of a data bank, providing engineers and construction professionals with valuable reference information for future projects. This will allow for more informed decision-making in the selection and use of locally available

materials, reducing the need for costly imports and supporting more sustainable construction practices. By promoting the use of local resources, the study also aligns with efforts to lower construction costs while maintaining high standards of quality.

In conclusion, this study is justified by its potential to provide essential data on the suitability of laterite soils from the Obviogie Borrow Pit for road construction. The comparison to national standards will offer added assurance of the material's reliability, supporting the efficient and effective development of road infrastructure in the region. This research will ultimately contribute to the sustainability, cost-effectiveness, and longevity of road construction projects in Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Synopsis

This project aims to assess the suitability of laterite soil from the Obviogie Borrow Pit for road construction, particularly in Nigeria. Laterite soil is a prevalent material in road construction due to its availability and cost-effectiveness. However, comprehensive evaluations of its geotechnical properties are essential to ensure compliance with the necessary standards. The study will focus on critical geotechnical properties, including moisture content, particle size distribution, specific gravity, maximum dry density (MDD), and optimum moisture content (OMC), as specified in the British Standard BS 1377 (1990), which outlines methods for testing soils for engineering purposes. Results will be compared with guidelines provided by the Federal Ministry of Works in Nigeria, which serve as benchmarks for evaluating construction materials. This study will offer valuable insights for engineers and policymakers, improving the technical understanding of laterite soils while supporting sustainable practices in infrastructure development.

2.2 Theoretical Framework

This study is anchored in the principles of soil mechanics and geotechnical engineering, exploring various theories and models that contextualize the behavior of laterite soils under different loading conditions.

2.2.1 Soil Structure and Composition

Laterite soils are typically formed under tropical weather conditions and are characterized by their unique mineralogical composition, primarily consisting of oxides of iron and aluminum. This

distinct composition influences their engineering properties (Gidigas, 1976). The soil's behavior can be described using the principles from the “Soil Behavior Model”, which explains how soils react under different stress states based on loading, drainage conditions, and soil structure.

2.2.2 Compaction Theory

The **Modified Proctor Test**, developed by Proctor (1933), is integral for determining the optimal moisture content and maximum dry density of laterite soils, as outlined in BS 1377-4 (1990). This method provides insight into how compaction affects soil density, which is crucial for establishing the load-bearing capacity required in road construction. The ideal moisture content allows for optimal compaction, ensuring that the soil achieves adequate strength and stability.

2.2.3 Effective Stress Principle

Based on Terzaghi's (1943) effective stress theory, the load-bearing capacity of lateritic soils can be understood by examining the interaction between pore water and soil particles. This principle is significant for understanding how lateritic soils behave under saturation conditions and the impact on their engineering properties.

2.2.4 Shear Strength of Soils

The **Mohr-Coulomb Failure Criterion** provides a theoretical basis for understanding the shear strength of lateritic soils, which is critical when assessing their suitability for road construction. According to this criterion, the shear strength of the soil can be expressed as a function of effective normal stress and cohesion, indicating the soil's ability to resist failure under load (Das, 2010).

2.2.5 Soil Classification Systems

The **Unified Soil Classification System (USCS)** and **AASHTO Soil Classification System** will be used to classify the laterite soil and establish its suitability for road construction based on its engineering properties. This is essential for determining the appropriate application and expected performance of the soil in infrastructural projects.

2.2.6 Environmental and Sustainability Considerations

The framework will also consider the importance of sustainability in infrastructure development, particularly in utilizing locally available materials such as lateritic soil. Research indicates that the use of local materials can significantly reduce transportation costs, minimize environmental impact, and enhance the economic viability of construction projects (Ashraful et al., 2018).

2.3 Empirical Framework

The empirical framework is constructed through a thorough review of existing literature and past studies evaluating the geotechnical properties of laterite soil.

Kumar and Joshi (2013) emphasized the importance of laboratory testing for laterite soil properties, including compaction tests and shear strength analysis. Methodologies from BS 1377-2:1990, which details tests for determining the physical properties of soil, will be employed to derive empirical data for this study.

Research by **Adeyemi et al. (2016)** and **Murthy (2006)** on the engineering characteristics of laterite soils demonstrates varied findings in terms of their load-bearing capacity and moisture retention capabilities. Such studies indicate that region-specific tests are necessary to provide

accurate assessments of laterite suitability in road construction. This study will utilize empirical data collected from the Oluku Borrow Pit, aligning testing methods with BS codes to ensure reliability and comparability with previous research.

Research conducted by **Gidigasu (1976)** provided foundational insights into the mineralogical and engineering characteristics of lateritic soils. His comprehensive analysis revealed that the formation process of lateritic soils leads to significant variations in their physical and hydraulic properties. This emphasizes the need for localized testing to accurately assess suitability for applications like road construction.

In a comparative study, **Al-Mukhtar et al. (2015)** investigated the mechanical behavior of laterite soils under different states of saturation and compaction. Their findings highlighted the detrimental effects of excessive moisture content on shear strength, suggesting that effective drainage and moisture management are critical when using laterite soils for pavement layers. This aligns with the hypothesis that the performance of laterite soil can be significantly improved when appropriate moisture levels are maintained during construction.

In another significant contribution, **Oladele and Ojo (2020)** explored the potential for stabilizing lateritic soil with cement to enhance its structural properties. Their experimental results indicated that optimal cement content could markedly increase the load-bearing capacity and reduce the plasticity index of lateritic soils, making them more viable for heavy traffic roads. This practice underscores the importance of soil treatment techniques, which can transform the mechanical properties of lateritic soils, ensuring their reliability in construction.

Moreover, a study by **Zainudin et al. (2018)** focused on the environmental sustainability of using local laterite soil in construction. They found that, when properly utilized, laterite soil can serve as a sustainable alternative to conventional materials, reducing transportation costs and environmental impact. Their research supports the notion that with adequate testing and stabilization techniques, laterite soils can provide both economic and ecological benefits in road construction projects.

Research by **Murthy (2006)** also emphasizes the geotechnical variability within lateritic soils based on geographical factors. Murthy's findings illustrate that different regions exhibit distinct properties concerning compaction, cohesion, and friction angle. This reinforces the need for region-specific studies, as local soil characteristics can lead to different performance outcomes, thereby influencing design practices in road engineering.

Afolagbade et al. (2017) examined the geotechnical properties of lateritic soil in southwestern Nigeria. They carried out extensive laboratory testing, including unconfined compressive strength, shear strength, and CBR tests, to assess the load-bearing capacities of lateritic soils under different compaction efforts. Their findings indicated that while lateritic soils generally exhibited good engineering properties, the performance was highly dependent on the specific soil profile and its compaction history, echoing the necessity for localized investigations in the design of road infrastructures.

Further supporting the empirical framework, research by **Atta-Obeng et al. (2018)** focused on the effects of varying the plasticity characteristics of lateritic soils mixed with additives like lime and fly ash. Their results demonstrated that such stabilization techniques could enhance the workability and strength of lateritic soils, thus improving their suitability for construction applications

significantly. This study highlights the potential for resourceful engineering solutions that optimize the use of locally available materials while providing cost-effective options for infrastructure development.

Additionally, the comprehensive review by **Babu and Ramana (2014)** summarized several regional studies on the engineering behavior of lateritic soils across various climates and geological settings. They underscored the need for standardized testing protocols tailored to capture the unique characteristics of local lateritic soils, which often involve complex interactions between mineral composition and environmental factors. Their work reinforces the significance of developing site-specific approaches for the empirical evaluation of laterite soils in civil engineering.

Another pertinent study by **Akinmusuru and Tayo (2019)** explored the long-term performance of lateritic subgrades under repeated loading conditions, mimicking the scenarios faced by roads subjected to vehicular traffic. Their findings revealed that while lateritic soils demonstrate reasonable resilience under such conditions, the long-term structural integrity is notably influenced by moisture variations and the existing compaction state. This insight is critical for designing sustainable road infrastructures that can withstand environmental changes over time.

In summary, these studies collectively reinforce the necessity of conducting detailed empirical analyses that account for the unique characteristics of lateritic soils in specific locations. The gathered insights underscore the importance of applying relevant engineering methodologies, such as those provided in the BS 1377 standards, to derive accurate and reliable data. This research will, therefore, advance knowledge concerning the effective use of laterite soil from the Oluku Borrow Pit, contributing to the sustainable development of road construction practices in the region.

(Olofinyo et al., 2019) in their paper “Engineering properties of residual soils in part of Southwestern Nigeria: implication for road foundation” after conducting some technical tests which included moisture content, particle size distribution, specific gravity, Atterberg limit, compaction, consolidation, and California bearing ratio. The result revealed that the soil samples are essentially granular and clayey soils, incompressible, easily compacted with good drainage. The soil samples indicate a general cohesive nature with variable high moisture content due to hydrological and climatic conditions of the study area. This geotechnical investigation also revealed that the subsoils are poor road construction materials, but its strength can be improved when subjected to stabilization measures as indicated from the strength tests (compaction, California bearing ratios and consolidation tests). This should be put into consideration during the Isinbode–Ara road foundation design and construction.

(Amadi et al., 2015) in their paper “Assessment of the Geotechnical Properties of Lateritic Soils in Minna, North Central Nigeria for Road design and Construction” reveals that The evaluation reveals that the lateritic soils have higher plastic limits, Maximum Dry Densities (MDD) and California Bearing Ratios (CBR) while their liquid limits, plasticity indices and Optimum Moisture Contents (OMC) are lower. The lateritic soils were classified as A-3, A-2-4 and A-2-6 and are adjudged suitable for sub-grade, good fill and sub-base and base materials. The study opined that the geotechnical information obtained will serve as base-line information for future road foundation design and construction in the study area.

(Ademila 2017) in his paper “Engineering evaluation of lateritic soils of failed highway sections in South-western Nigeria” indicated that the poor geotechnical properties of the lateritic soils of failed sections imply that they are unsuitable for use as subgrade materials in road construction and even in other engineering structures. Twenty-eight bulk soil samples of lateritic soil were

collected from five failed sections and two stable sections for index and strength tests related to road construction. The strength drop following the soaking of compacted samples demonstrates the considerable fall in shear strengths that occurs when subgrade and subbase soils contact with water. Instability is a result of lateritic soils' high particle concentration, low CBR values, and poor strength traits. Stabilization may increase strength and increase the stability of buildings. These results were found to be useful in rehabilitation and reconstruction works of the failed sections of the road.

(Oluyinka and Olubunmi, 2018) in their study “Geotechnical properties of lateritic soil as subgrade and base material for road construction in Abeokuta, Southwest Nigeria” discussed the samples collected at 0.25m deep at different locations and were subjected to the following laboratory tests; Particle size analysis, Atterberg limits test, Compaction test, Californian Bearing Ratio test, Moisture content and Specific gravity test. The result showed that the studied soil samples are classified as clay, silty clay easily compactable with good drainage. The soil samples tested from the study area indicate a general cohesive nature with low moisture content, high granular material, which is suitable for use as sub-base and base materials for road construction since the geotechnical properties are fairly within the regulatory standards of Nigeria. These valuable data obtained from the geotechnical analysis can be useful for civil engineers in the design and construction of roads in Abeokuta and environs for maximum durability and efficiency.

(Okoyeh et al., 2017) in their paper “Evaluation of Ihiala laterites for use as subgrade material in road construction” dealt with Ten soil samples collected randomly from Ihiala area at a depth of about 1m using hand auger and shovel for evaluation as a sub-grade material in road construction. These samples were analyzed to determine their chemical and geotechnical properties of pH, natural moisture content, specific gravity, particle size distribution, atterberg limits, Optimum

Moisture Content (OMC), Maximum Dry Density (MDD) and California Bearing Ratio (CBR). The study concluded that soil samples should undergo appropriate tests to determine their suitability for particular purposes and strength improved where necessary before it can be used as subgrade material.

(Oghenero et al., 2014) in their paper “Classification and compaction characteristics of lateritic soils of Warri, Delta state, Nigeria” stated that Soil samples were collected from eight locations and subjected to Geotechnical test programs; Sieve analysis, Consistency tests, Compaction and California Bearing Ratio (CBR) Tests. Classification tests (sieve analysis and consistency tests) revealed that the Lateritic soils are of A6, A3 and dominantly A2- 4 type characteristics based on the American Association of State Highway and Transport Officials (AASHTO) Classification Scheme. CBR values indicated that the soils are suitable sub-grade materials yet in order to be a good sub-base and base course for road building, the right stabilization would be needed.

(Omorogieva and Okiti, 2018) in their paper “Geotechnical appraisal and geological influence on road failure: a new perspective in geotechnical engineering. International journal of earth sciences knowledge and applications” sampled Red tropical soils (RTSs) four times along the 164-kilometer Benin-Auchi-Igarra Highway at significant locations, namely Etete (Benin City), Sabo (Auchi), Ikpesi, and Igarra. The purpose of the sampling was to determine the geotechnical characteristics of the RTSs in order to determine the causes of the frequent road failures observed along the road network as well as the environment's geology. The Atterberg limits tests; particle size distribution (PSD), specific gravity (Gs), compaction characteristics, and California Bearing Ratio (CBR) are among the tests conducted in compliance with the British Standard Institution (BSI), Unified Soil Classification System (USCS), and American Association of State Highway and Transportation Officials (AASHTO). The study finds that the improper use of TRSs as base

and sub bases, as well as the disregard for the geological effect of the source material, are to blame for the constant road failure.

2.4 Terminologies

2.4.1 Road/Pavement Construction

Road pavement is a composite construction that distributes traffic loads to the subgrade to offer a safe, dependable, and smooth surface for cars to travel. A road pavement is a multi-layered structure intended to produce a long-lasting road surface and is supported by the subsoil. It has sturdy surface materials and is built to resist high vehicle traffic. However, a closer look is necessary due to the intricacy of its construction. The main function of the road surface is to disperse the weight of motor vehicles uniformly over the layers of underlying soil. In order to convey normal stresses to the underlying soils and provide friction for the cars, pavement construction refers to the actual surface that vehicles move on (Otti et al., 2016). A sturdy, long-lasting road surface that can bear heavy loads is necessary for a good driving experience (Adenika et al., 2018). Any country's road system is vital to its economy, but this is especially true for developing nations like Nigeria where roads are the primary way of moving people as well as products and services around the nation (Okechukwu and Celestine, 2011).

A pavement system is a dynamic structure that interacts with several forces, not only a static layer of materials. These forces include;

- i. Vehicle loads: These affect pavement stresses and strains and consist of both static and dynamic loads from various vehicle types.
- ii. Environmental loads: The performance of pavements may be greatly impacted by variables including temperature changes, precipitation, and frost.

- iii. Subgrade conditions: Properties like strength, moisture content, and compressibility of the underlying soil affect how a pavement behaves.

For the subgrade to withstand wheel load stresses there must be enough soil thickness. It also needs to have strong structural integrity to withstand all kinds of stresses. Adequate friction is needed to keep cars from sliding. The surface needs to be comfortable for drivers, even when traveling at high speeds. Finally, it needs to reduce noise when cars pass over it. In the absence of dust-proofing, dust might jeopardize traffic safety. An impermeable surface is necessary to protect the sub-grade soil. A lengthy lifespan is also a need for a low-maintenance product.

To ensure the success of the project, it is important to take into account the soil's ability to expand and contract with various levels of moisture when building roads (Osuolale et al., 2012). As a result, constructing a sturdy sub base and a stable subgrade is crucial for the successful and long-lasting construction of a pavement system (Schaefer et al., 2008).

2.4.2 Components of Road Construction

Laterite is a material that is widely accessible and may be used for a variety of road-building tasks. Its suitability is determined by its engineering features and the specific requirements of the road section. The several components that comprise a road structure include the following:

- i. Base Course or Foundation Course.
- ii. Base Coat or Intermediate Course.
- iii. Sub-grade or Formation.
- iv. Sub-base.

v. Wearing Course.

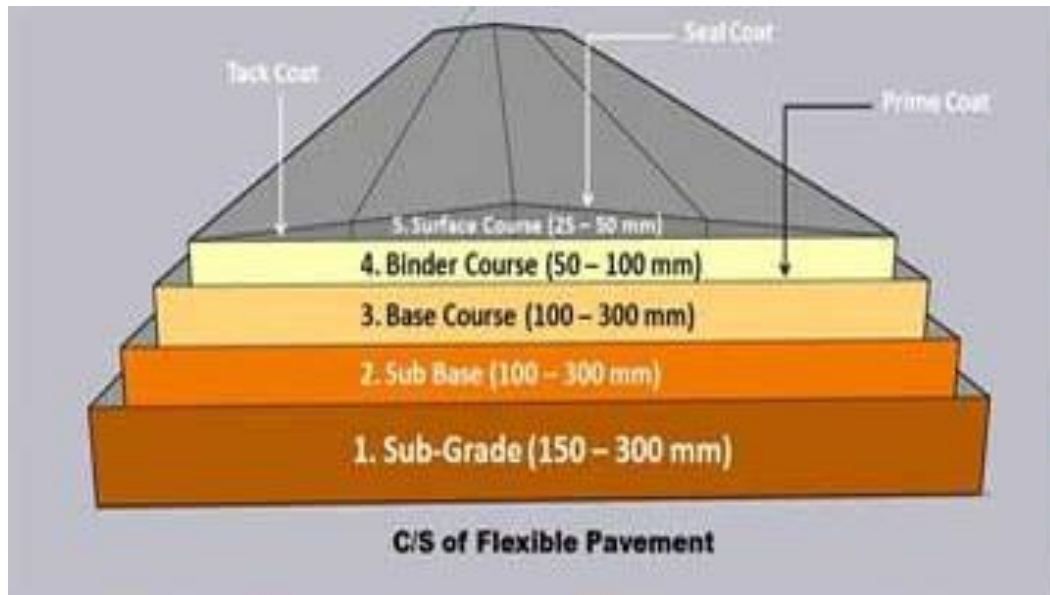


Figure 2.1 Components of flexible pavement

(Source: <https://www.constructioncost.co/road-pavement.html>)

2.4.2.1 Base Course

Because it bridges the space between the subgrade and the higher layers, the base course is an essential component of road pavement construction.

Its primary duties include distributing loads to lessen the strain on the subgrade by distributing the weight of the traffic over a wider area; offering structural support to improve the strength and stability of the pavement; facilitating drainage to remove water and stop frost damage and erosion; and enhancing ride quality by making driving more comfortable.

The most often utilized materials include recycled materials, gravel, which can be utilized but may not provide the same strength as crushed stone, and crushed stone, which is well-known for its strength, durability, and outstanding drainage qualities. A material's capacity to transmit axle loads through mechanical interlock to the sub-soil or subgrade determines whether or not it is suitable

for use as a base course or sub-base course. Any building material's efficacy and longevity are based on how effectively it withstands imposed stresses (Oke et al., 2009b; Nwankwoala and Amadi, 2013).

2.4.2.2 Base Coat or Intermediate Course

In flexible pavement design, the binder course, which is positioned between the base and surface courses, is essential for supplying structural support, lowering reflective cracking, and stopping water penetration. Furthermore, it guarantees a solid connection between the surface and foundation courses. Its composition and construction, which are typically based on asphalt concrete, are influenced by variables such as climate and traffic volume. Compaction, material quality, and mix design are critical to its longevity and performance.

2.4.2.3 Subgrade

The subgrade, also known as the formation, is a completed and compacted earthwork that is the foundation for road pavements. The subgrade supports all pavement loads, including those from traffic. Potholes, uneven settlements, and cracking are examples of early pavement failures that can be caused by a weak or unstable subgrade. The subgrade's technical characteristics are essential for pavement design and construction.

The ability to withstand deformation under stress is one of the key qualities, and it is often assessed using the California Bearing Ratio (CBR) test. It is also important because moisture content affects the volume and strength of the subgrade. The right subgrade quality can only be achieved by careful construction techniques, such as adequate compaction and moisture management. Given the critical importance of the subgrade (Vaibhav Mittal et al., 2023; Tsado et al., 2018; Kowalczyk et al., 2017; Souley et al., 2022), not understanding its characteristics before road construction can pose significant risks.

2.4.2.4 Subbase

Between the base course and the subgrade, there is a granular layer called the sub-base that improves drainage, stabilizes capillary water rise, and fortifies the subgrade. It helps with drainage, maintains the structure, and keeps small particles off of the pavement. The sub-base may not be needed if the subgrade is high-quality and sufficiently hard and is evaluated and determined to be adequate given the needs of the project. For structural support, drainage, and load distribution, there must be a granular layer between the base course and subgrade. This layer is called the subbase. It offers extra stability, separates tiny particles, and stops water from penetrating the subgrade (Garber and Hoel, 2009).

2.4.2.5 Wearing Course

Grade beams, also known as pile caps, carry loads from bearing walls to a spaced foundation, providing essential structural support. The wearing course, the top pavement layer exposed to traffic, is intended to keep water from reaching the base course and guarantee uniform load distribution. The wearing course (the top layer of pavement that is exposed to traffic) offers a safe, long-lasting, and smooth driving surface. It guarantees comfort, is durable, provides skid resistance, stops water from penetrating deeper layers, and improves the look of the road (Garber and Hoel, 2009)..

2.4.3 Types of Road Pavement

Design concerns distinguish two categories of pavements: rigid and flexible pavements. The following gives thorough explanations of both rigid and flexible pavements.

2.4.3.1 Flexible Pavement

The components of flexible pavement are aggregates and asphalt or bituminous materials mixed together and layered over a suitable-quality bed of compacted granular material above the

subgrade. Examples include stabilized soil roads with or without asphaltic overlays and macadam roads that are bound by water. Based on the idea that load intensity decreases as it moves from the surface, flexible pavement is designed to spread across a greater surface area and descend via successive layers of granular material deeper into the ground. The flexible pavement can resist only very small tensile stresses because of limited rigidity. However, because of high traffic volumes and unfavorable weather, flexible pavements frequently develop rutting. Because of its multilayer construction, flexible pavements bend under the weight of vehicles. Using a layered system idea, flexible pavements are designed with enough flexibility to absorb shocks (Yazdani, 2018). According to Mohod and Kadam (2016), there are three main types of flexible pavements that are often used: full-depth asphalt pavement, contained rock asphalt mat (CRAM), and standard layered flexible pavement.

Because each layer of flexible pavements has a different strength, the weight distribution pattern varies from one layer to the next. The strongest but least flexible materials make up the uppermost layer, while the weaker but more flexible elements make up the bottom layer. This configuration allows for the use of less durable materials because the wheel load, which is focused on a small area near the surface where tension is high, spreads across a greater area deeper in the pavement where stress is reduced (Gurule et al., 2022).

2.4.3.2 Rigid Pavement

Because the substance is more rigid than asphalt pavement, this kind of pavement acts as though it is hard. By using its flexural strength, it transfers wheel loads to the underlying layers in a manner similar to that of a rigid plate (Wimsatt et al., 2009). The design of rigid pavement focuses on creating a structural cement concrete slab strong enough to withstand traffic loads. Rigid pavement is made of cement concrete or reinforced concrete slabs; grouted concrete roads fall under semi-

rigid pavements. Rigid pavement's high modulus of elasticity and rigidity allow it to distribute loads over a wide area of soil. Usually made of Portland cement concrete, rigid roadway pavements may have a base course between the subgrade and the concrete surface (Garber and Hoel, 2009).

Rigid pavements that are expertly planned and built have long service lifetimes and often require less maintenance than flexible pavements. Highway concrete pavements are usually 6 to 13 inches thick. Prestressed concrete pavement (PCP), jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP) are the four main types of concrete pavements that are often utilized (Mohod and Kadam, 2016).

Rigid pavement slabs are most commonly constructed using Portland cement concrete (PCC). Various referred to as cement and concrete, PCC is identified by its design and production techniques. Since the material was created in the 19th century and the first PCC pavement was built in 1889, its appeal has been attributed to its accessibility and affordability (Soedirdjo et al., 2003).

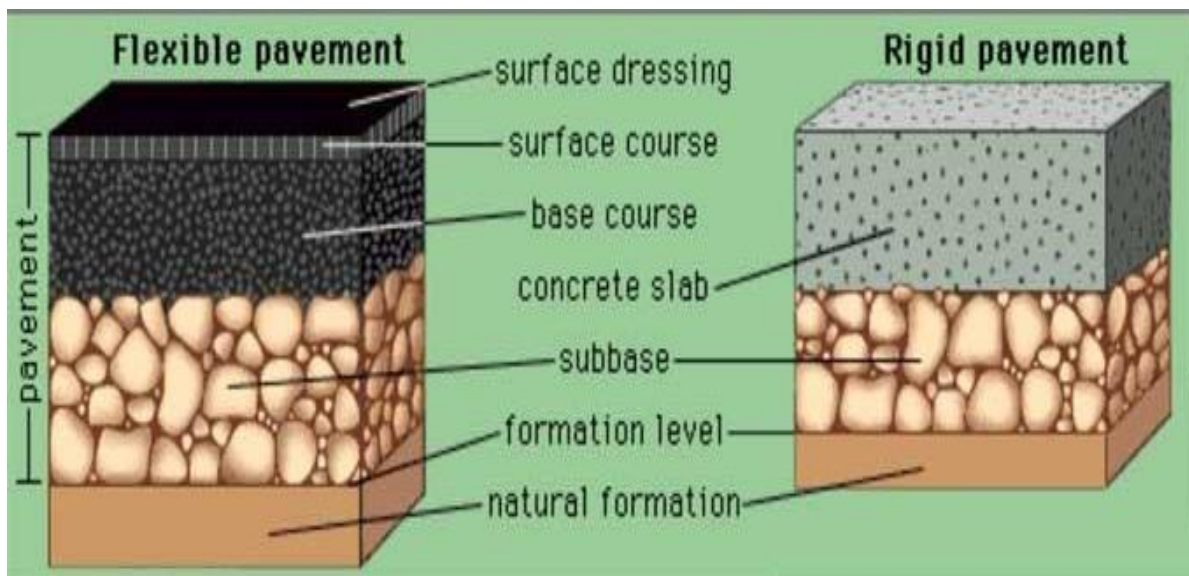


Figure 2.2: Flexible and Rigid Pavement (Differences)

(Source: <https://www.constructioncost.co/flexible-and-rigid-pavement.html>)

Table 2.1: Difference between Flexible & Rigid Pavement

(Source: <https://civiconcepts.com/blog/difference-between-rigid-and-flexible-pavement>)

S/No	Flexible Pavement	Rigid Pavement
1	In flexible pavement, deformation in the subgrade is transferred to the upper layers	In Rigid pavement deformation in the subgrade is not transferred to layers
2	Design is based on load distributing characteristics of the component layers	Design is based on flexural strength or slab action
3	Flexible pavement has a low flexural strength	Rigid pavement has a high flexural strength
4	Inflexible pavement, the load is transferred by grain to grain contact	In Rigid pavement, no such phenomenon of grain to grain load transfer exists
5	Flexible pavement have low completion cost but repairing cost is high	Rigid pavement have low repairing cost but completion cost is high
6	Flexible pavement have a low life span	Rigid pavement life span is more as compared to flexible

7	In flexible pavement surfacing cannot be laid directly on the subgrade but a subbase is needed	In Rigid pavement, the surfacing can be directly laid on the subgrade
8	In flexible pavement, no thermal stresses are induced as the pavement can contract and expand freely	In Rigid pavement thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete
9	That's why expansion joints are not needed in Flexible pavement	That's why expansion joints are needed in Rigid pavement
10	In Flexible pavement strength of the road is highly dependent on the strength of the subgrade	In Rigid pavement strength of the road is less dependent on the strength of the subgrade
11	Rolling of the surfacing is needed in flexible pavement	Rolling of the surfacing is not needed in Rigid pavement
12	The road can be used for traffic within 24 hours in flexible pavement	The road cannot be used until 14 days of curing in rigid pavement

13	In flexible pavement, friction forces are less, and deformation in the subgrade is not transferred to the upper layers.	In Rigid pavement, the force of friction is high
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2.4.4 Road Construction Materials

For a road pavement to be constructed and function well, the right materials must be chosen. The selection of materials is influenced by variables including availability, cost, climate, and traffic volume. A vast range of materials are used in the building of roads, including processed or naturally existing soils, fine and coarse rock aggregates, binders like bitumen, cement, and lime, and different admixtures to improve road performance under high traffic volumes. Materials used for road construction are;

2.4.4.1 Soil

The primary building material for low-cost country roads with little traffic is soil, which is also used for subgrades and even pavements. Soil is the main building material for roadways constructed on embankments. In addition, rock and soil are necessary foundation elements since all constructions rest on and transfer loads to the ground. Climate conditions, inadequate knowledge of the physical characteristics of the soil or materials used for road pavement construction and maintenance, coupled with the heavy demands of manoeuvring vehicles on poorly engineered road pavement surfaces without maintenance, have led to many roads becoming untrafficable in a short period of time (O. Eze et al., 2017).

In order to improve road performance, soil is usually employed after going through stabilization procedures like compaction and strengthening with appropriate admixtures. For almost all kinds of roadway pavements, the main building blocks of bases and sub-bases are mineral aggregates extracted from rocks. Various elements, including soil type, weathering degree, topography, drainage conditions, foundation type, and the magnitude of imposed loads, might affect the performance of lateritic soils as foundations for structures. (Ojo et al., 2016). Geotechnical factors such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity, and petrographic properties are influenced by the mineralogical composition of lateritic soil (Amadi et al., 2012).

2.4.4.2 Bituminous Materials

Although bitumen has been utilized for thousands of years for bonding and waterproofing, it wasn't until the nineteenth century that it gained popularity in the construction of roads. Bitumen and tar leftovers are commonly used to create bituminous surfaces, which improve the quality of riding surfaces. Bitumen is a viscous, dark material that may be obtained from distilling crude oil or it can occur naturally. Its primary constituents are polycyclic aromatic hydrocarbons, making up around 95% of its composition. Sulfur, nitrogen, oxygen, and metals are present in trace levels. Bitumen, the largest portion of crude oil, bonds aggregates in bituminous mixtures thanks to its high boiling point of 525°C. The American Society for Testing and Materials (ASTM) defines bitumen as a hydrocarbon substance that is entirely soluble in carbon disulfide (CS₂), naturally occurring or pyrogenous, and present in gaseous, liquid, semi-solid, or solid phases. Moreover, it dissolves rather well in carbon tetrachloride (CCl₄). Bitumen is an intricate organic substance that may be produced by petroleum distillation or it can arise spontaneously. It is usually not volatile and resistant to the majority of salts, acids, and alkalis. Bitumen is called asphalt when natural rock

intrusions have left behind inert inorganic elements or minerals. It is referred to as "lake asphalt" when it is found in lakes like Trinidad.

2.4.4.3 Cement

The hydraulic binder cement mixes with aggregates and water to make concrete, which is a common material for building roads because of its strength, endurance, and durability. There are several types of concrete pavements: Continuously Reinforced Concrete Pavement (CRCP), which uses a continuous layer of steel for improved load distribution; Reinforced Concrete Pavement (RCP) with steel reinforcement to resist cracking; and Jointed Plain Concrete Pavement (JPCP) with expansion joints for temperature-induced movement.

Concrete pavements have several advantages, including great strength and durability that allow them to survive harsh weather and large loads. When properly maintained, they have a long service life and need fewer repairs than asphalt pavements, and offer superior reflectivity and skid resistance.

2.4.4.4 Aggregates.

Aggregates can be coarse (e.g. granite, crushed stone, gravel) or fine (e.g. sand, crushed stone fine). For road pavements, aggregates are essential because they provide durability, strength, and stability. Base courses, subbases, and asphalt concrete all employ them. Because of its hardness and longevity, crushed stone is frequently used in subbases and base courses. Although sand serves as a fine aggregate in asphalt and concrete mixes, gravel is utilized in subbases due to its lower strength.

Pavement performance is affected by the quality of the aggregates, which have important characteristics including strength, durability, shape, and cleanliness of the particle size distribution.

In subbases, gravel or crushed stone is utilized; in base courses, crushed stone is preferable due to

its strength and drainage capabilities. Coarse and fine materials must be combined to make asphalt concrete.

2.4.4.5 Geotextiles

Permeable materials, either natural or synthetic, called geotextiles are employed in geotechnical engineering to improve the performance of soil. They are essential for enhancing pavement stability, drainage, and durability in road building. Geotextiles work by keeping soil layers from mixing, letting water through while holding onto soil particles, strengthening the soil, assisting with pavement drainage, and shielding underneath layers from harm. Depending on how they are made, they are divided into nonwoven, woven, and knitted categories.

Geotextiles are used in road construction to stabilize embankments, help in water drainage, separate soil layers, reinforce weak subgrades, and manage erosion.

2.5 Introduction to Laterite

According to Abebaw (2005), the parent rock's type, degree of lateralization, drainage conditions, and climate all affect the geotechnical characteristics of RTSs, which are frequently referred to as laterite. Additionally, according to Jiregna (2008) and Aginam et al. (2015), these characteristics set laterite apart from other soils that are formed in cold or moderate climates. Rich in iron oxides, laterite is a soil layer that develops from different rocks degrading in situations of extreme oxidation and leaching. Typically, this kind of soil grows in humid, tropical, and subtropical regions. According to Oyelami and Van (2016), lateritic soil is a subtropical residual soil that has a variety of particle sizes. Although clay minerals can be found in lateritic soils, silica is often low in these soils because water leaches it away.

Laterite, which contains iron oxide minerals such hematite (Fe_2O_3), lepidocrocite ($\text{FeO}(\text{OH})$), and goethite (HFeO_2), is characterized by its porous and clay-like texture. In addition, it contains

oxides of titanium and oxides of aluminum that have been hydrated; the most frequent mineral that is rich in aluminum is gibbsite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). Bauxite is a kind of laterite that is high in aluminum. Laterite can have a blackish-brown to reddish tint on exposed surfaces and frequently has a pisolitic (pea-like) look. It can also occasionally have a slaggy or scoriaceous appearance. It is usually softer and lighter in color (red, yellow, and brown) when it is first cracked, but it hardens when exposed. No particular parent rock, geological age, formation process, climate, or location is associated with laterite. Rather, it is the result of certain physiochemical circumstances, such as a parent rock that is rich in iron, a topography that is well-drained, a lot of moisture for weathering, a high oxidation potential, and the persistence of these circumstances over an extended length of time. The physical weathering of rocks into smaller particles by means of mechanisms including frost action, temperature variations, and plant roots is the first stage in the production of lateritic deposits. The next step is chemical weathering, in which silica is released and soluble minerals are dissolved by the reaction of minerals in the rocks with water. Through water percolation, leaching subsequently extracts these soluble components especially silica enriching the leftover material with oxides of iron and aluminum. When minerals are broken down by hydrolysis in the presence of water, secondary minerals like kaolinite are created. Iron oxides, which are created when oxygen is added to iron-bearing minerals, are what give lateritic deposits their distinctive reddish-brown hue. Different soil layers form throughout time; the topsoil is rich in organic matter, while the lateritic horizon underneath it has significant levels of aluminum and iron oxides.

In Nigeria, the incorrect use of lateritic soil, especially when backfilling subgrade and sub-base layers, is a major contributor in the degradation of roads. When building a roadway, the strength of the sub-base is essential, and laterite is essential for this. Tropical climates give rise to lateritic soils, which are often stiff and can get stronger via cycles of soaking and drying. However, the

engineering properties of lateritic soils, such as compaction characteristics, shear strength parameters, and compressibility, vary widely with the season. Highway failures frequently observed during the wet season are linked to the poor geotechnical properties of lateritic soil (O. Eze et al., 2017), leading to the frequent rehabilitation of the failed sections at a huge cost to the government.

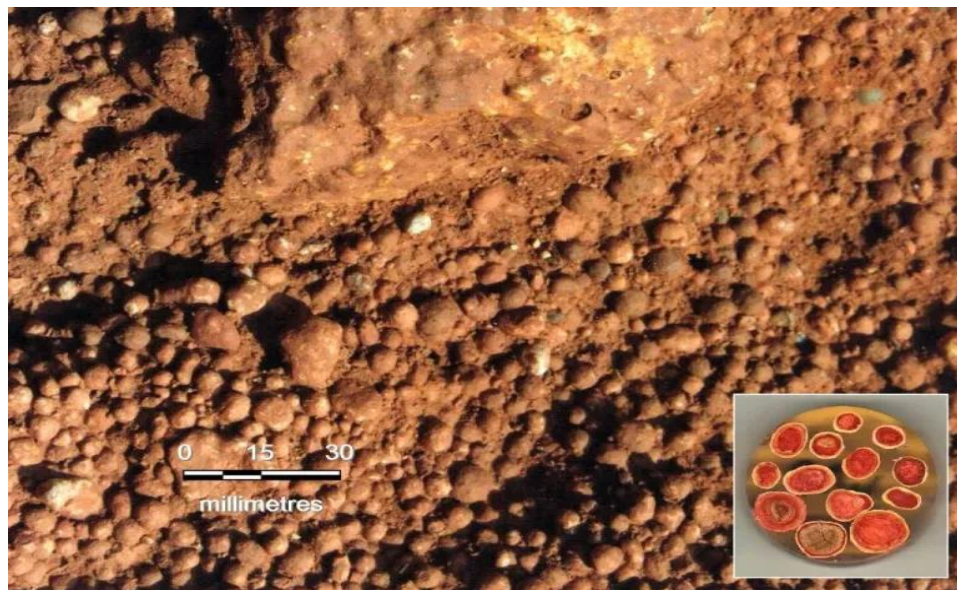


Figure 2.3 Formation Processes of Lateritic Deposits

(Source: <https://geologyscience.com/geology-branches/mining-geology/lateritic-deposits/>)

2.5.1 Properties of Laterite Soils

Laterite soils are critical in the construction industry, particularly in tropical regions like Nigeria, due to their availability and favorable engineering properties. Recent studies have examined various geotechnical properties of laterite soils, including compaction, strength, and permeability, providing valuable insights for their effective use in road construction.

Compaction is a fundamental property of laterite soils that affects their load-bearing capacity and stability in construction applications. Abam et al. (2018) investigated the compaction characteristics of laterite soils in the Niger Delta region of Nigeria, noting that moisture content

significantly influences the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The study found that compaction properties varied with the soil's mineralogy and texture, emphasizing the need for site-specific evaluations. Similarly, Adeyemi and Olusola (2020) highlighted that lateritic soils from southwestern Nigeria exhibited varying compaction behaviors, with MDD ranging from 1.80 to 2.00 g/cm³, depending on the soil composition and moisture conditions.

The geotechnical analysis conducted by Enaworu et al. (2017) on lateritic soils in the Anambra Basin revealed that these soils possess considerable potential for use in construction applications, particularly in road building. Their study focused on both geochemical and geotechnical properties, establishing a comprehensive profile of lateritic soils that could serve as a reference for evaluating similar materials across different regions. The findings indicated that the soils from the Anambra Basin exhibited adequate strength characteristics and compaction properties suitable for sub-base and sub-grade applications, further reinforcing the need for localized studies to ascertain the suitability of lateritic soils for construction purposes.

The engineering properties of laterite soils, such as shear strength and plasticity, are crucial for determining their suitability in construction. Omoniyi et al. (2019) conducted a study on laterite soils in Ekiti State, Nigeria, and reported that the soils displayed high shear strength parameters, making them suitable for sub-grade and sub-base applications. Their findings indicated that the plasticity index was low, suggesting that the soils had good workability for construction purposes. In a related study, Ogunyemi et al. (2021) examined the unconfined compressive strength of lateritic soils in southwestern Nigeria, establishing that the addition of stabilizing agents like cement significantly improved the strength characteristics of the soils.

Permeability is another essential property of laterite soils that affects their behavior under loading and during drainage. Afolabi et al. (2020) investigated the permeability of lateritic soils in central Nigeria, finding that the permeability coefficient varied significantly based on the soil's compaction and moisture content. The study concluded that properly compacted lateritic soils could effectively manage water drainage, making them suitable for road construction where effective drainage is critical. Additionally, a study by Olaniyan and Adekola (2019) emphasized the importance of understanding the permeability of lateritic soils in design considerations for pavement structures, as high permeability could lead to erosion and structural failures.

The mineral composition of laterite soils significantly influences their engineering properties. Recent research by Kogbe et al. (2021) analyzed the mineralogical composition of lateritic soils in Nigeria and found that the presence of specific minerals, such as iron oxides and kaolinite, correlated with improved compaction and strength characteristics. The study recommended that soil classification should consider mineral composition alongside traditional tests to enhance the reliability of laterite soils in construction.

This aligns with findings from diaspora studies, such as those by Gomez and Adedeji (2019), who noted that lateritic soils in Brazil showed similar trends in mineral composition affecting their engineering properties.

Furthermore, comparative studies have highlighted the need to align local laterite soil properties with international standards. Adebayo et al. (2022) compared lateritic soils in Nigeria with those from other tropical regions, emphasizing that while local soils possess favorable properties for construction, variations exist that necessitate further evaluation against established standards. Their research underscored the importance of adhering to specifications set by the Federal Ministry of Works in Nigeria to ensure quality and safety in construction practices.

Other notable studies on laterite soils from borrow pits have also contributed to understanding their properties. For instance, Adegbite et al. (2020) examined the geotechnical properties of lateritic soils sourced from various borrow pits in Lagos State, demonstrating that the soils exhibited diverse engineering characteristics suitable for different construction applications. This research highlighted the potential of local borrow pits as reliable sources of materials for infrastructure development, echoing the findings of Enaworu et al. (2017) regarding the importance of localized geotechnical analysis.

The literature demonstrates that laterite soils possess valuable engineering properties that can be optimized for road construction. Understanding the compaction characteristics, strength parameters, and permeability of these soils is crucial for their effective application in infrastructure projects. Continued research is needed to establish comprehensive databases of laterite soil properties and align them with national and international standards, ensuring the sustainability and reliability of road construction in Nigeria and other tropical regions.

2.5.2 Particle Size Distribution

Particle size analysis is also called mechanical analysis. Two stages involved are sieve analysis and sedimentation method. The former is meant for coarse grained soils (particle size greater than 75 micron) which can easily pass through a set of sieve. The latter is for fine grained soils (particle size less than 75 micron). Lateritic soil's suitability for road construction is largely dependent on its particle size distribution (PSD), which influences the soil's gradation and, in turn, compaction characteristics, strength, permeability, and overall performance in pavement structures. A well-graded lateritic soil displays a balanced distribution of particle sizes, from coarse to fine, facilitating optimal packing and interlocking of particles, which enhances strength and stability. Because of their high strength and load-bearing capacity, coarse-grained laterites are usually

preferred for base and subbase layers, while fine-grained laterites frequently need to be stabilized or blended with coarser materials to improve their engineering properties. Pavement performance is substantially impacted by the PSD. Higher maximum dry densities are attained by well-graded soils, which improves pavement stability. Additionally, a balanced particle size distribution improves water drainage and lowers the chance of erosion and frost heave. Additionally, the fraction of fine particles effects plasticity which affects workability and stability while the distribution of particle sizes affects the strength and load-bearing capability of the soil.

The particle size distribution of laterite soil of Benin City, Nigeria is generally known to be made up of both granular (sands and gravels) and fine (silt and clay) soil particles (Kayode-Ojo & Odemerho, 2023; Omorogieva & Okiti, 2021). Sieve analysis is frequently used to calculate the PSD of lateritic soil. In order to determine the percentage of particles in various size ranges, the soil is passed through a succession of sieves with increasingly smaller apertures. The weight retained on each sieve is used to calculate this percentage.

Table 5.1. AASHTO Classification System

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

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

Fig 2.4: AASHTO SOIL CLASSIFICATION SYSTEM – AASHTO CHART

(Source: <https://www.aboutcivil.org/aashto-soil-classification-system>)

2.5.3 Plasticity

Assessing the suitability of lateritic soil for road construction requires an understanding of plasticity, a property of soil that describes its capacity to deform under stress without breaking and to retain the new shape after the stress is removed. The key plasticity indices or more preferably, Atterberg limits are:

- i. Liquid Limit (LL): The liquid limit test (ASTM standard D4318) determines the moisture content at which clay soil gradually changes from a plastic to a liquid state not at zero shear strength. The Casagrande cup method is commonly used in the United States, while the cone penetrometer method is more frequently used in Europe.
- ii. Plastic Limit (PL): The water content at which soil changes from a plastic to a semi-solid state. As moisture content decreases due to evaporation, the wire gradually breaks at larger diameters. The plastic limit is determined as the moisture content at which a wire with a diameter of 3.2 mm (approximately 1/8 inch) breaks. If the wire cannot be rolled to a moisture content of 3.2 mm, the material is considered non-plastic. The plastic limit test procedures are outlined in ASTM Standard D4318 and involve rolling a wire across a substantial portion of soil on a flat, impermeable surface. Plasticity Index (PI) is the difference between the liquid and plastic limits, indicating the soil's plasticity range.
- iii. Shrinkage Limit: The shrinkage limit test, which is less frequent than the liquid and plastic limit tests, is described in ASTM D4943 and determines the moisture content at which further moisture loss causes the soil volume to decrease.

An ideal plasticity index strikes a balance between workability and stability. For road construction, high plasticity in lateritic soils can cause swelling, shrinkage, and instability, frequently requiring

stabilization or alternative materials. Low plasticity soils, while providing good drainage, may lack sufficient cohesion.

2.5.4 Strength

Because laterite's strength affects the pavement's ability to support traffic loads and maintain structural integrity, its effectiveness in road construction depends on a number of factors, including its mineral composition (iron and aluminum oxides can increase laterite strength, while clay minerals can decrease it), its microstructure (porosity and density are important components), proper compaction (which is critical for boosting stability), and moisture content (which can have a major impact on laterite strength).

During road and pavement construction, the California Bearing Ratio (CBR) is used to assess the strength of the subgrade soil or base materials (Katte, et al., 2019). It determines the soil's bearing capacity relative to a standard crushed stone material. Higher CBR values indicate stronger soils that can withstand heavy loads without deformation or failure, while lower values indicate the need for soil improvement or replacement with better materials. CBR testing is performed to ensure that the compacted soil or base materials meet design requirements. The distribution of soil particle sizes affects soil particle packing density and interlocking (Ibrahim, et al., 2022).

2.5.5 Shrinkage and Swelling

Changes in soil volume and the ensuing variations in the soil's water content cause soil to swell and shrink. The kind and amount of clay minerals in the soil control how much the soil swells and contracts. Even soils with a significant propensity for shrinkage and swelling won't often cause any issues as long as the water content of the soil remains relatively consistent. This depends on the water content fluctuations, the stiffness and geometry of the construction constructed on top of the soil, as well as the mineralogy and water status of the soil (Houston et al. 2011). Suction and

changes in water content in a saturated soil might increase the danger of damage, but the behavior of swelling and shrinkage in a saturated soil is completely controlled by the clay mineralogy. As the lateritic soils contain clay, they are naturally prone to swelling and shrinkage. They may thus seriously affect the performance of road pavements that are constructed over subgrades made from laterites. In a wide range of instances, it can be noticed that swelling and shrinkage of lateritic soils resulted in serious adverse effects on road pavements that cause various types of distress associated with premature failure in the forms of potholes, cracks, and joint displacement.

2.5.6 Moisture Content

Lateritic soil's moisture content affects its workability, compressibility, strength, and other engineering properties. It is important to understand the relationship between moisture content and compaction in order to design and build pavements that are as optimal as possible. High moisture content can lead to frost heave, increased plasticity, and decreased strength, while low moisture content can result in poor compaction and reduced stability. The compaction curve illustrates the relationship between moisture content and dry density, with OMC serving as the point of maximum dry density. Having too much moisture content can cause poor compaction and reduced stability.

2.5.7 Specific Gravity

This is the ratio of the mass of a soil to the mass of an equal volume of water at 4°C. Water is usually used as the reference substance while discussing lateritic soil. Laterite's specific gravity sheds light on its density and compaction properties. The methods of determining specific gravity of soil are pycnometer and specific gravity bottle method. The basic idea behind the pycnometer method is to weigh a known volume of dry soil and compare it to the weight of the same volume

of water. The latter is the same as with the pycnometer approach, but it makes use of a particular bottle with a short neck.

2.5.8 Compaction

This is the process of applying mechanical methods to soil in order to remove air voids thereby increasing density and reducing compressibility of the soil. The degree of compaction of a given soil is determined by its dry density, maximum dry density at optimum water content, and curve between water content and dry density. Several tests are commonly used to evaluate the compaction properties of lateritic soil. The Standard Proctor Test is a laboratory technique that uses a standard hammer to determine the ideal moisture content and maximum dry density. For compacted fill and base courses, the Modified Proctor Test provides a more thorough evaluation. The in-situ density of compacted soil is often measured in the field using a nuclear density gauge.

Table 2.2: FMWH Specifications for laterite soil as road construction material

(Source: Government Of The FRN General Specifications(Roads & Bridges) Vol. II, pp. 144-146.)

	FMWH Properties & Specifications			
Road Layers	CBR(24hrs soaked) (%)	%Passing No. 200	LL(%)	PI(%)
Subgrade(filling)	≥ 10	25-50	30-50	10-25
Sub-base	≥ 30	≤ 35	≤ 35	≤ 12
Base Course	≥ 80		≤ 25	≤ 6 for

				stoneb ase <=12 for lateriti c materi al
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2.6 Laterite in Road Construction

2.6.1 Stability for Road Components

When designing and building a road pavement, stability is crucial since it establishes the pavement's resistance to deformation brought on by traffic volumes and environmental factors. A stable pavement reduces maintenance costs, extends the life of the pavement, and guarantees a smooth riding surface.

Stability-Relating Factors:

- i. Subgrade: The subgrade forms the pavement's structural base. Critical elements affecting the overall stability of the pavement are its compressibility and strength. The layers above a robust, well-compacted subgrade have a firm foundation to sustain them. Uneven pavement surfaces, rutting, and structural failures can result from a weak or easily deformed subgrade. Engineers frequently replace poor-quality soil with more acceptable subgrade through compaction, stabilization with additions like lime or cement, or other means.

- ii. **Base Course:** The base course is in charge of distributing loads and provide structural support. It is located directly above the subgrade. Crushed stone, gravel, or stabilized laterite are examples of materials that must have excellent drainage qualities and great strength when used as the foundation course. By distributing traffic loads uniformly, a well-built base course lessens the strain on the subgrade and stops pavement deformation. For the foundation course material to effectively sustain the pavement structure, proper gradation and compaction are crucial.
- iii. **Materials:** Stability is greatly impacted by the selection of materials for the various pavement layers. Depending on its mineral content and level of weathering, laterite, which is frequently used in road building, has different qualities. The applicability of laterite must be evaluated by engineers based on its robustness, resilience, and well-compaction and interlocking qualities. A sturdy pavement construction also requires other components, such as aggregates and binders (such as bitumen or cement). Superior materials possessing uniform qualities provide enhanced functionality and durability of the pavement.
- iv. **Construction Methods:** To provide the best possible pavement stability, proper construction methods are essential. Enhancing the density and strength of the materials used in pavement construction, compaction is an essential stage. The pavement's capacity to support loads may be compromised by inadequate compaction, which can result in voids and weak areas. To further avoid problems like settling and cracking, careful layering, the right amount of moisture during compaction, and adherence to design standards are necessary. Pavement layers that are consistent and sturdy are achieved with the use of sophisticated construction techniques including mechanical compaction and quality control procedures.

- v. **Environmental Factors:** The weather and environment have an effect on pavement stability. For instance, frost can heave and contract the base course and subgrade, resulting in surface deformations and fissures. Severe rains have the potential to saturate the subgrade, weakening it and creating instability. In order to control water flow and avoid water buildup in the pavement layers, proper drainage systems are essential. Pavement stability in areas subject to harsh weather is contingent upon the selection of construction materials and processes that are resistant to temperature and moisture fluctuations.

2.7.2 Performance Considerations

The following are some of the major elements that affect pavement performance:

- i. **Traffic Loading:** An important factor influencing the stresses and strains a pavement endures is its weight and amount of traffic. Heavy vehicles such as trucks can result in considerable deterioration of the pavement surface due to high traffic loads. Fatigue and structural problems like rutting and cracking can result from repeated loads. Designing pavements that can endure these pressures over time thus requires an understanding of traffic patterns and loads. The lifespan of pavements and the proper thickness and material kinds are determined by engineers using data on traffic loads often.
- ii. **Climatic Conditions:** The performance of pavements is greatly affected by extreme temperatures, precipitation, and frost. Variations in temperature have the potential to cause pavement materials to expand and contract, which can result in thermal cracking. Water infiltration can erode pavement foundations in areas experiencing high rainfall. Frost can result in frost heave, a condition in which the surface of the pavement raises as a result of water expanding during freezing, and thawing can lead to settlement and cracking. For pavements to last a long time and be durable, its design must take into account the local environment.

- iii. **Material Properties:** A pavement's total performance is greatly influenced by the engineering qualities of its materials, such as strength, elasticity, and durability. For instance, superior binders and aggregates in asphalt can strengthen the pavement's resistance to cracking and deformation. Critical aspects include the qualities of the material, such as its resistance to abrasion, water absorption, and thermal stability. The pavement can endure loads and environmental pressures if the right materials are chosen based on their characteristics.
- iv. **Construction Quality:** To have the best possible pavement performance, proper building methods must be used. This entails making certain that materials are placed correctly, that compaction is sufficient, and that design standards are followed. Weak areas, uneven surfaces, and early breakdowns can be caused by subpar construction. A sturdy pavement structure may be achieved during construction by using methods including controlled compaction, exact layering, and quality assurance testing. Sustaining good standards also depends on providing construction workers with adequate training and supervision.

2.6.3 Geological Variations of Laterite

Due to variables like climate, weathering conditions, and geology, laterite characteristics fluctuate greatly between locations.

- i. **Composition of Soil:** The stability and appropriateness of laterite for building are largely dependent on its mineral composition and particle size distribution. Road bases and subbases benefit greatly from the excellent strength and durability that laterites rich in iron and aluminum oxides often display. On the other hand, changes in the mineral composition, such as the inclusion of clay minerals, can have a detrimental effect on stability by making the material more flexible and prone to deformation. Another important factor is the distribution of particle

sizes; well-graded laterite with a balanced mixture of fine and coarse particles offers superior compaction and interlocking properties.

- ii. **Climate:** The weathering and erosion processes that result in laterite are greatly influenced by climate. High temperatures and copious amounts of rainfall in tropical and subtropical climates hasten the chemical weathering of parent rocks, enriching the laterite with oxides of aluminum and iron while leaching away silica. The engineering qualities of laterite likewise exhibit fluctuation as a result of these climate circumstances. For instance, heavy rainfall areas may provide laterite that is wet, which lessens its strength and increases its malleability. On the other hand, laterite may be harder and more solid in areas with extended dry seasons.
- iii. **Geomorphology:** The features of laterite deposits are greatly influenced by the geography and geological development of a region. The quality and distribution of laterite are determined by several factors, including the parent rock type, the extent of weathering, and topographical characteristics including drainage patterns and slopes. For example, laterite that has developed on plateaus with good drainage is frequently more stable and appropriate for building than laterite that has formed in low-lying places that are prone to erosion and waterlogging.

2.6.4 Economic Feasibility

When used as a building material for roads, laterite can have major financial advantages. These benefits include lower material prices and the possibility of creating jobs, both of which have a favorable effect on regional economies.

- i. **Lower Material Expenses:** Because laterite is frequently readily available in tropical and subtropical areas, it is an affordable choice for building roads. Because laterite is readily available locally, less long-distance material transportation is required, which lowers project expenses overall. Long-distance construction material transportation might be one of the biggest

costs associated with infrastructure projects. These expenses can be reduced by acquiring laterite locally, opening the door to more affordable building methods.

- ii. **Possibility of Creating Jobs:** In nearby areas, the mining and processing of laterite can lead to a multitude of work possibilities. Laterite is frequently used in road construction projects, which need a variety of labor-intensive tasks, including mining, processing, transportation, and building application. These operations may boost regional economies by creating jobs and assisting associated businesses.

2.7 Research Gap

Since laterite soil is readily available locally and is reasonably priced, it is frequently used in road construction; however, because of its variable properties, it can be difficult to ensure consistent performance. In Benin City, therefore, it is necessary to evaluate the suitability of laterite soil in particular, paying particular attention to its engineering qualities, resilience, and behavior in the context of the local environment. Previous research has not always provided detailed information on the unique characteristics of laterite in this area, so it is critical to close this information gap in order to improve pavement design and construction methods.

CHAPTER THREE

METHODOLOGY

3.1 Reconnaissance Survey

Reconnaissance survey is a fundamental phase in any research or investigative process, serving as the initial step to gather preliminary data and insights. This type of survey involves a broad and quick examination of the study area or subject, aiming to identify key features, patterns, and potential areas of interest. Typically conducted at the outset of a project, reconnaissance surveys play a crucial role in shaping the subsequent phases of detailed investigations or research efforts. By providing an overview of the terrain, resources, and contextual factors, reconnaissance surveys inform decision-making and guide the development of more in-depth studies.



Figure 3.1: Borrow pit, Obviogie, Ugbowo, Benin city

The purpose of conducting a reconnaissance survey is to assess the overall characteristics of an area with the aim of identifying the optimal route or routes for subsequent, more detailed investigations. The data gathered during this survey is integral to conducting feasibility studies for various routes, creating rough estimates of quantities and costs. This information proves instrumental in the selection of the most viable alternatives. Additionally, the reconnaissance survey aids in identifying any necessary deviations from the basic geometric standards that should be applied to the highway facility. Typically, reconnaissance surveys are not necessary for projects involving improvements to existing roads unless bypass roads are part of the project scope.

3.2 Collection of Samples

Soil samples were collected from 10 different spots of a burrow pit using shovel as shown in the map area above. The burrow pit is located at latitude 6.4983834 and longitude 5.4668147. After collection, all 10 samples were then transported to the laboratory in bags to be spread and dried effectively. The samples are said to be disturbed samples.

3.3 Laboratory Tests

3.3.1 Specific Gravity

The weight of soil particles divided by the weight of an equivalent amount of water is measured by the specific gravity test. It is a crucial metric in soil mechanics as it aids in figuring out a soil's density and void ratio. Different types of soils have different specific gravities; laterite and other soils with a high mineral content tend to have greater specific gravities.

Apparatus:

- i. density bottle
- ii. Distilled water

- iii. Vacuum pump
- iv. Weighing balance (accurate to 0.01g)
- v. Stopper

Procedure:

- i. Clean the density bottle and dry it.
- ii. Weigh the empty density bottle and record as W1.
- iii. Fill the density bottle with dry soil sample, weigh and record bottle + soil as W2.
- iv. Add distilled water to the soil-filled density bottle and ensure that there are no air bubbles.
- v. Leave until the soil has settled completely.
- vi. Weigh the content as W3.
- vii. Empty the content of the bottle and rinse thoroughly to remove residual soil particles.
- viii. Fill the density bottle with water, weigh and record as W4.

The specific gravity will be calculated using the formula:

$$\text{Specific Gravity} = \frac{W1 - W2}{(W4 - W1) - (W3 - W2)}$$

3.3.2 Compaction Test

The optimum moisture content (OMC) and maximum dry density (MDD) of a soil under controlled compacting conditions are assessed by the compaction test. In order to guarantee the stability and load-bearing capability of pavements and foundations, the Compaction Properties of Soils are

ascertained by the Standard Proctor and Modified Proctor tests, which are extensively employed in the civil engineering field.

Apparatus:

- i. Proctor mold and collar
- ii. Standard Proctor hammer (2.5 kg)
- iii. Modified Proctor hammer (4.5 kg)
- iv. Moisture cans
- v. Weighing balance
- vi. Drying oven
- vii. Straight edge
- viii. Graduated cylinder
- ix. Sieve (4.75 mm)

Procedure:

- i. Sieve the soil through 4.75mm sieve and prepare the sample.
- ii. Add water to the soil rto reach the desired moisture content.
- iii. Fill the proctor mould in three layers and compact each layer with 25 blows from the Proctor hammer (or the modified hammer for the modified test).
- iv. Level the surface of the soil using a straight edge.
- v. Weigh the mould with the compacted soil and calculate the bulk density.
- vi. Take a small sample to determine the moisture content.
- vii. Repeat the process with varying moisture contents, and develop a compaction curve using the following formula for dry density

$$\text{dry density} = \frac{\text{bulk density}}{1 + w}$$

where: w = water content.

3.3.3 Sieve Analysis

By putting the soil through a number of sieves, sieve analysis may be used to determine the soil's particle size distribution. Understanding soil texture and forecasting how it will behave under stress requires the ability to classify soil into several groups, such as gravel, sand, silt, and clay, which is what this test does. A simple yet essential test for classifying soil and choosing building materials is sieve analysis.

Apparatus:

- i. Set of sieves (4.75 mm, 2 mm, 1 mm, 0.425 mm, 0.075 mm, etc.)
- ii. Mechanical sieve shaker
- iii. Weighing balance
- iv. Oven
- v. Pan and cover
- vi. Brushes

Procedure:

- i. Weigh 100g of the sample and pour water in a container of the sample and leave for at least 24 hours.
- ii. Carry out wet sieving by washing out the clay content.
- iii. Take the sample to the oven for drying.
- iv. Weigh the dry sample and place in the top sieve of the sieve stack.

- v. Place the sieve stack in a mechanical shaker and run for approximately 10 minutes.
- vi. Remove the stack of sieves from the shaker and record the weight of each sieve and receiving tray separately.
- vii. The percentage passing through each sieve is calculated by dividing the weight retained by the total sample weight, and the particle size distribution curve plotted.

3.3.4 Atterberg Limit Test

The Atterberg limits test assesses the plasticity of soil by defining its liquid limit (LL), plastic limit (PL), and shrinkage limit (SL). These bounds delineate the limits of several soil consistency states and are employed in evaluating the soil's workability and behavior in response to fluctuating moisture levels. knowledge of the compressibility and strength of cohesive soils requires a knowledge of the plasticity index (PI), which is derived from LL and PL.

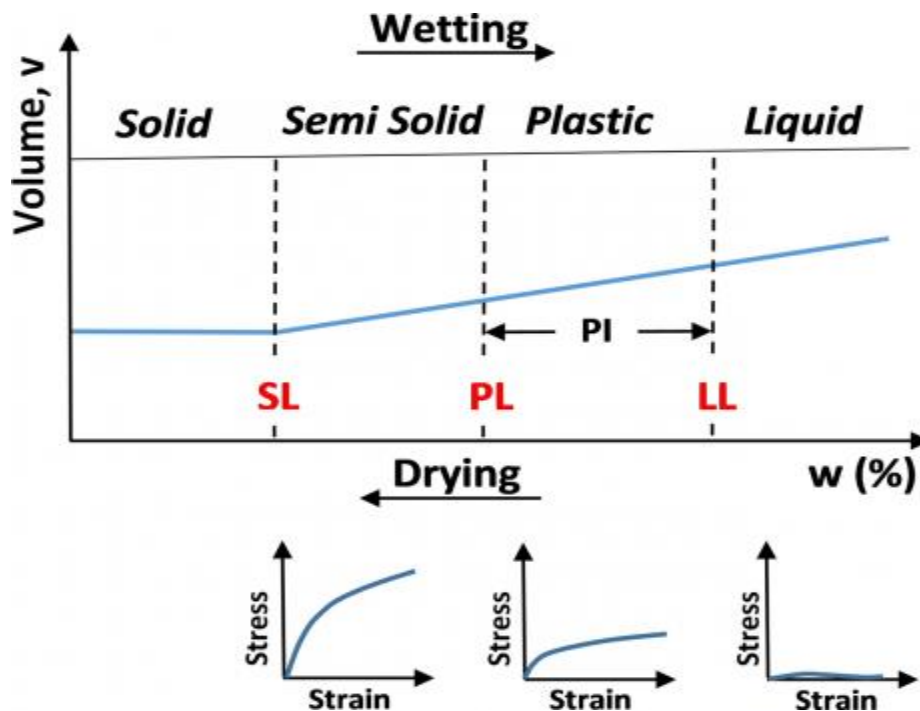


Figure3.1: Atterberg Limits of a Silt or Clay

3.3.4.1 Factors Affecting Atterberg Limits

The main factors that affect how a silt or clay behaves in relation to its moisture content, and hence affect the Atterberg Limits, are the size and distribution of the solid particles within a soil. Pure clay, for example, will have all its solid particles less than 0.002 mm, and pure silt is 0.06 to 0.002 mm (although exact definitions vary from country to country). The smaller the particle size, the more soil will retain moisture. So a clayey soil will have a higher PI than a silty soil. Atterberg Limits are measured by laboratory testing. In the UK this is done in accordance with BS 1377-2:1990 and equivalent standards are used throughout the world.

3.3.4.1.1 Plastic Limit (PL)

The Plastic Limit Test is performed by rolling a moist clay or silt soil into the shape of a 3 mm diameter 'worm' by hand, then remoulding the sample into a ball and repeating. Each time the worm is rolled, the moisture content will be reduced due to loss of water by evaporation. The plastic limit is reached when the 'worm' first crumbles when reaching 3 mm in diameter. Once this first crumble has occurred, the sample has its moisture content measured as described earlier in BS 1377-2:1990. The measured moisture content is the Plastic Limit.

3.3.4.1.2 Liquid Limit (LL)

The Liquid Limit is measured by either the Casagrande cup method or a cone penetrometer.

3.3.4.1.3 Casagrande Cup Method

This involves using standardized equipment to ensure consistent measurement. Essentially, the test involves spreading a soil sample in a cup of standard size, then cutting a groove through the middle. The cup is then dropped repeatedly and the number of blows required for the groove to close up again is measured. Once the groove has closed the sample has its moisture content measured as described earlier in BS 1377-2:1990. The procedure is repeated and the number of drops vs

moisture content for each test is plotted on a graph. The estimated water content corresponding to 25 blows is the Liquid Limit.

3.3.4.1.4 Cone Penetrometer Method

The Cone penetrometer method is based on the measurement of penetration into the soil of a standardized stainless steel cone of specific apex angle, length and mass. Soil samples at a variety of moisture contents are tested and the results plotted on a graph. The estimated water content corresponding to a 20 mm penetration of the cone is the Liquid Limit. Note that BS 1377-2 recommends the cone penetrometer method in favor of the Casagrande cup method.



Fig 3.2 Casagrande Cup measurement of the Liquid Limit



CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The results of the laboratory tests performed on the ten soil samples collected from the Ovbiogie borrow pit are presented below.

Table 4.1 Summary of geotechnical test performed Sample 1

Geotechnical Test	Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Specific Gravity	dimensionless	2.56	2.76	2.79	2.66	2.61	2.52	2.68	2.63	2.58	2.72
Atterberg limit	L(%)	26.18	23.57	39.91	26.86	28.52	23.75	30.25	27.32	28.30	24.88
	PL(%)	N.P	N.P	0	0	N.P	0	0	0	0	0
Sieve Analysis	%	4.43	5.89	9.46	10.46	6.63	8.34	5.46	5.89	7.72	7.41

Com pacti on	M D D (g /c m ³)	1. 76	1 . 7 5	1 . 7 0	1 . 7 9	1 . 7 9	1 . 6 9	1 . 6 8	1 . 7 4	1 . 7 2	1 . 7 1
	O M C (%)	12 .7 7	1 1 . 9 6	1 4 . 2 2	1 0 . 2 0	1 4 . 9 3	1 4 . 9 3	1 5 . 3 6	1 3 . 7 3	1 2 . 3 3	1 3 . 5 4
Calif ornia Beari ng Ratio	%	15 .8 92	8 . 8 7 8	5 6 . 4 8 8 7	2 4 . 8 2 4	3 0 . 6 8 8	6 4 . 0 0 2	5 1 . 5 3 2	5 4 . 0 0 9	3 2 . 6 7 6	5 6 . 5 6 7

4.1 Specific Gravity Results Analysis

For Sample 1-10; From table 4.1, the average range of values of specific gravity for the samples are from 2.58 – 2.75.

4.2 Compaction Results Analysis

For Sample 1-10; From table 4.1, the values of Maximum Dry Density (MDD) for all the samples ranges from 1.66g/cm³ – 1.79g/cm³ and that of the Optimum Moisture Content ranges from 10.2% - 16.52%. From table 4.1, these samples can be said to be fair as a subgrade material.

Table 4.4: Soil compaction classification

MDD (g/cm³)	General values as a subgrade material
>2.1	Excellent
1.9-2.1	Good
1.7-1.9	Fair
1.6-1.7	Poor
1.1-1.6	Very poor

4.3 Sieve Analysis Results Analysis

Sample 1 is composed of sandy soil having 13.57% fines, 64% medium sand and 20% coarse. It has 4.43% passing 0.075mm sieve. The soil is classified as A-3(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 2 is composed of sandy soil having 13.38% fines, 54.22% medium sand and 22.82% coarse. It has 7.59% passing the 0.075mm sieve. The soil is classified as A-3(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 3 is composed of sandy soil having 1.83% fines, 52.72% medium sand and 37.69% coarse. It has 7.21% passing the 0.075mm sieve. The soil is classified as A-1-b(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 4 is composed of sandy soil having 9.67% fines, 52.02% medium sand and 25.93% coarse. It has 10.46% passing the 0.075mm sieve The soil is classified as A-2-4(0) and Silty Sand(SM). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 5 is composed of sandy soil having 11.47% fines, 58.08% medium sand and 21.56% coarse. It has 6.63% passing the 0.075mm sieve. The soil is classified as A-3(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 6 is composed of sandy soil having 1.78% fines, 49.8% medium sand and 34% coarse. It has 4.17% passing 0.075mm sieve. The soil is classified as A-3(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 7 is composed of sandy soil having 16.98% fines, 59.22% medium sand and 30.82% coarse. It has 8.59% passing the 0.075mm sieve. The soil is classified as A-3(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 8 is composed of sandy soil having 1.83% fines, 52.72% medium sand and 37.69% coarse. It has 7.21% passing the 0.075mm sieve. The soil is classified as A-1-b(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 9 is composed of sandy soil having 10.67% fines, 65.02% medium sand and 38.93% coarse. It has 17.46% passing the 0.075mm sieve. The soil is classified as A-2-4(0) and Silty Sand (SM). It is therefore suitable for subgrade and subbase material if properly compacted.

Sample 10 is composed of sandy soil having 14.47% fines, 58.08% medium sand and 29.56% coarse. It has 8.63% passing the 0.075mm sieve. The soil is classified as A-3(0) and poorly graded sand (SP). It is therefore suitable for subgrade and subbase material if properly compacted.

4.5 California Bearing Ratio Results Analysis

For Sample 1-10; From table 4.1, the CBR values for the samples are 8.787 and 64.02%. The Highway Design Manual, Federal Ministry of Works and Housing specifications of soil

characteristics for flexible pavement specifies a minimum value of 10%, 30% and 80% for subgrade, subbase and base course materials respectively. From these, most samples from this location are suitable for subgrade and subbase respectively.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study evaluated the suitability of laterite soil from a single site for road construction by assessing its geotechnical properties. The test results indicate that the soil passing the 0.075mm sieve ranges from 4.43% to 15.99% across the ten samples. The liquid limit ranges from 21.36% to 39.91%. The soil is predominantly composed of sand, with trace amounts of clay and silt in some samples. The majority of the samples classify as A-3 soils, while others fall under A-1-b, A-2-4, and A-2-6 classifications. Based on these findings, the soil is suitable for use as subgrade and subbase material in road construction. The compaction test results show that the Maximum Dry Density (MDD) ranges from 1.63 g/cm³ to 1.86 g/cm³, with Optimum Moisture Content (OMC) ranging from 11.4% to 16%. The California Bearing Ratio (CBR) values range from 24.88% to 63.84%, except for one sample with a CBR of 1.86%, likely due to contamination. According to the Federal Ministry of Works and Housing specifications, the soil characteristics meet the requirements for subgrade and subbase materials.

5.2 Recommendation

Based on the experimental results from the ten soil samples, the following recommendations are made:

1. Continuous Monitoring and Maintenance: Implement preventive maintenance to protect the soil and preserve its desirable properties with minimal variation.
2. Contamination Control: Minimize contamination to ensure the soil remains suitable for economic development.
3. Soil Stabilization: Since the soil is predominantly sandy, stabilization methods such as cement stabilization or geosynthetics should be employed to increase Maximum Dry Density (MDD) and enhance road layer performance.
4. Further Research: Investigate new stabilization techniques to improve the long-term utilization of laterite soil for road construction in Benin City.
5. Effective Drainage Systems: Incorporate proper drainage in road designs to prevent waterlogging, which can negatively impact CBR values and soil stability over time.

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APPENDIX

CBR ANALYSIS FOR SAMPLE 1 - 10

NB:

The Blue trend line: Bottom (Soaked)

The red trend line: Bottom (Unsoaked)

The Pink trend line: Top (Soaked)

The Purple trend line: Top (Unsoaked)

The “-” symbol in the data points indicates that the soil failed before reaching the corresponding penetration depth

The horizontal lines extending to the end of the graph signify that the soil failed prior to achieving the full 12.5mm penetration

The loads at 2.5mm and 5.0mm penetration are important because they are used to calculate the CBR value

The smallest table

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM				
TOP				

Contains the CBR value for 2.5mm and 5.0mm penetration (if you divide them by 100 you get it in percentage%)

Detail: Sample 1

TEST ON BOTTOM (UNSOAKED)

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	54.00	61	63	67	69	69	79	86	111	147	173
Load (KN)	0	0.590 6601	0.667 22715	0.689 10345	0.732 85605	0.754 73235	0.754 73235	0.864 11385	0.940 6809	1.2141 3465	1.607 90805	1.892 29995

TEST ON TOP (UNSOAKED)

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	23.00	27	38	47	52	57	63	69	92	107	131
Load (KN)	0	0.251 57745	0.295 33005	0.415 6497	0.514 09305	0.568 7838	0.623 47455	0.689 10345	0.754 73235	1.0063 098	1.170 38205	1.432 89765

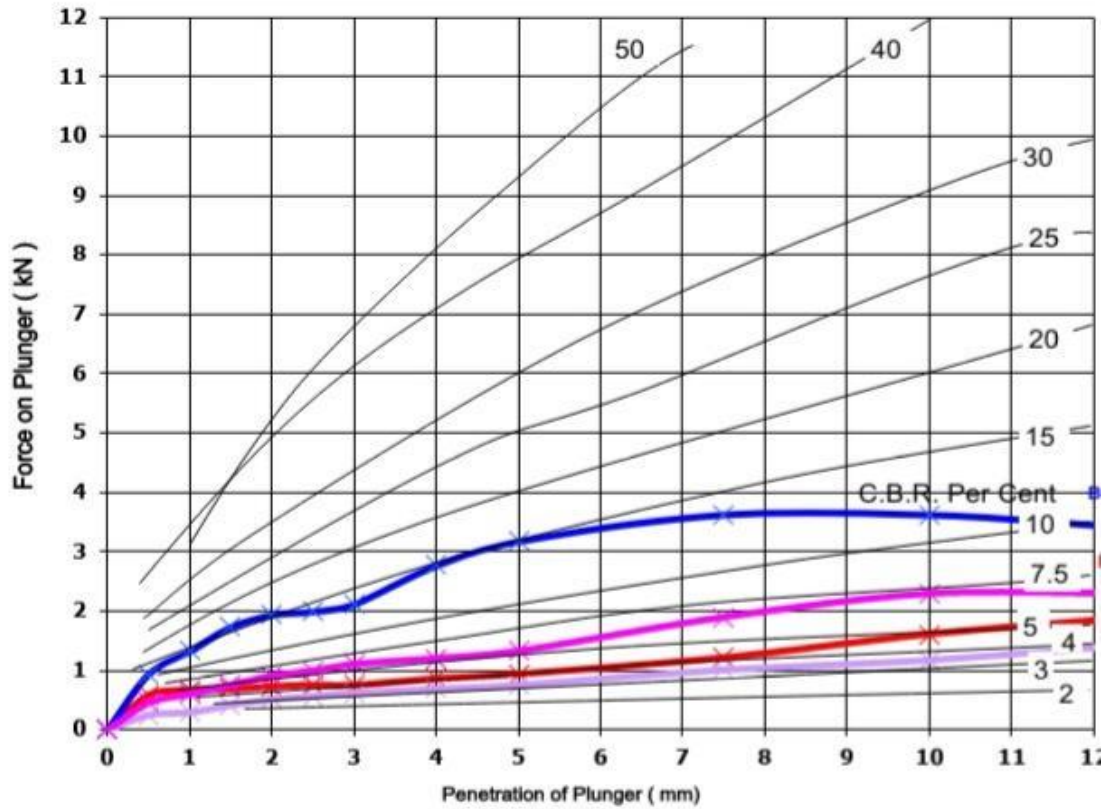
TEST ON BOTTOM (SOAKED)

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	86.00	121	158	177	182	193	253	290	331	-	-
Load (KN)	0	0.940 6809	1.323 51615	1.728 2277	1.936 05255	1.990 7433	2.111 06295	2.767 35195	3.172 0635	3.6205 2765	3.620 52765	3.401 76465

TEST ON TOP (SOAKED)

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	42.00	55	69	83	91	101	110	121	173	209	-
Load (KN)	0	0.459 4023	0.601 59825	0.754 73235	0.907 86645	0.995 37165	1.104 75315	1.203 1965	1.323 51615	1.8922 9995	2.286 07335	2.286 07335

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	5.698	4.713	15.030	15.892
TOP	4.294	3.781	7.515	6.631



Detail: Sample 2

TEST ON BOTTOM (UNSOAKED)

Penetration (mm)	0	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	21	34	63	89	113	145	162	246	323	-
Load (KN)	0	0.05469075	0.22970115	0.3718971	0.68910345	0.97349535	1.23601095	1.58603175	1.7719803	2.6907849	3.53302245	3.53302245

TEST ON TOP (UNSOAKED)

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	39.00	56	73	90	101	107	126	143	201	241	272
Load (KN)	0	0.42658785	0.6125364	0.79848495	0.9844335	1.10475315	1.17038205	1.3782069	1.56415545	2.19856815	2.63609415	2.9751768

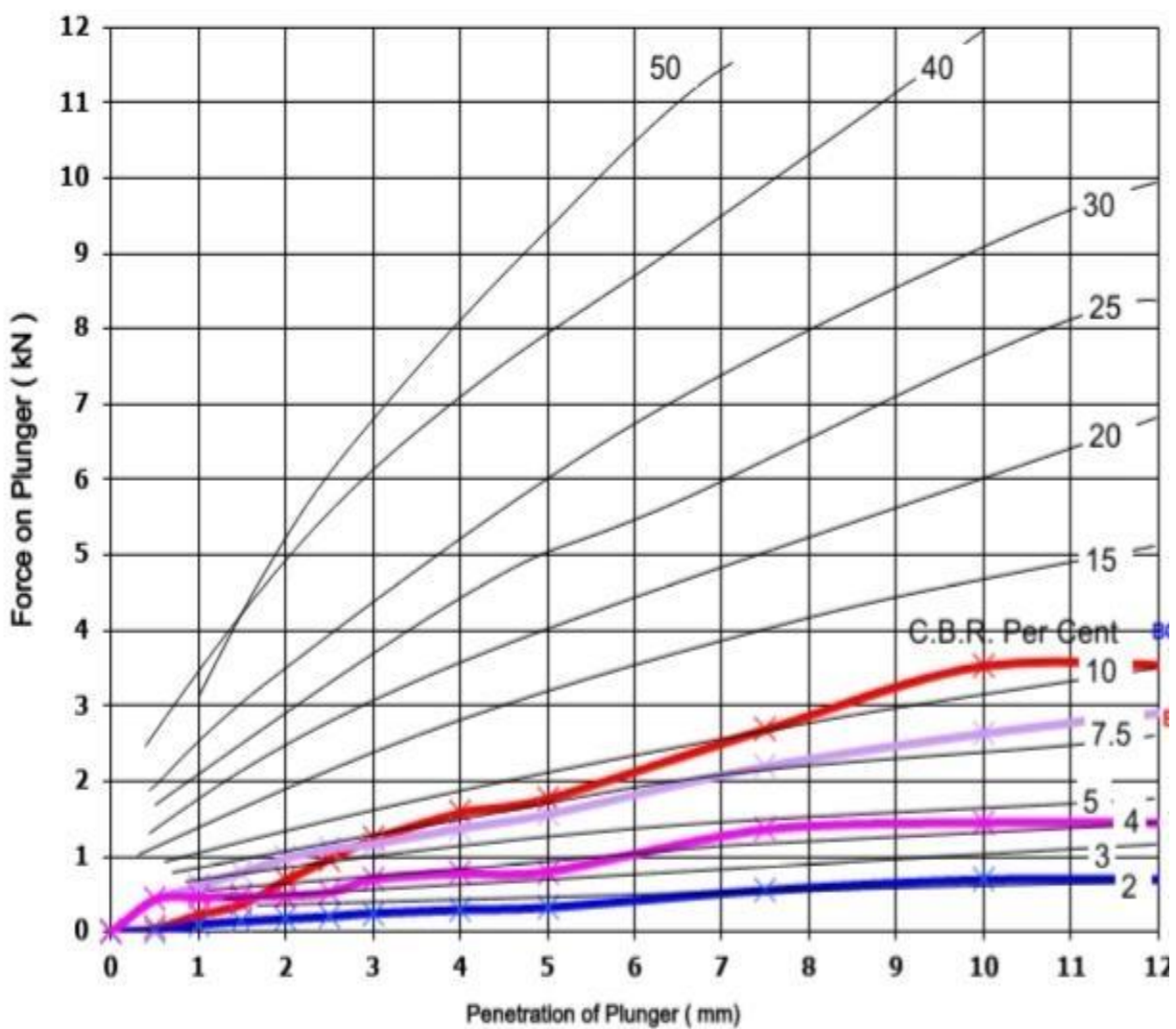
TEST ON BOTTOM (SOAKED)

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	1.00	9	13	16	19	23	27	30	51	64	-
Load (KN)	0	0.01093815	0.09844335	0.14219595	0.1750104	0.20782485	0.25157745	0.29533005	0.3281445	0.55784565	0.7000416	0.7000416

TEST ON TOP (SOAKED)

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	40.00	42	43	44	48	64	71	73	124	132	-
Load (KN)	0	0.437526	0.4594023	0.47034045	0.4812786	0.5250312	0.7000416	0.77660865	0.79848495	1.3563306	1.4438358	1.4438358

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	7.350	8.878	1.569	1.644
TOP	8.341	7.836	3.964	4.000



Detail: Sample 4

TEST ON BOTTOM (UNSOAKED)

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	22.00	51	90	102	134	155	218	243	325	419	-
Load (KN)	0	0.240 6393	0.557 84565	0.984 4335	1.115 6913	1.465 7121	1.695 41325	2.384 5167	2.657 97045	3.5548 9875	4.583 08485	4.583 08485

TEST ON TOP (UNSOAKED)

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	39.00	58	73	99	117	138	174	205	314	416	486
Load (KN)	0	0.426 58785	0.634 4127	0.798 48495	1.082 87685	1.279 76355	1.509 4647	1.903 2381	2.242 32075	3.4345 791	4.550 2704	5.315 9409

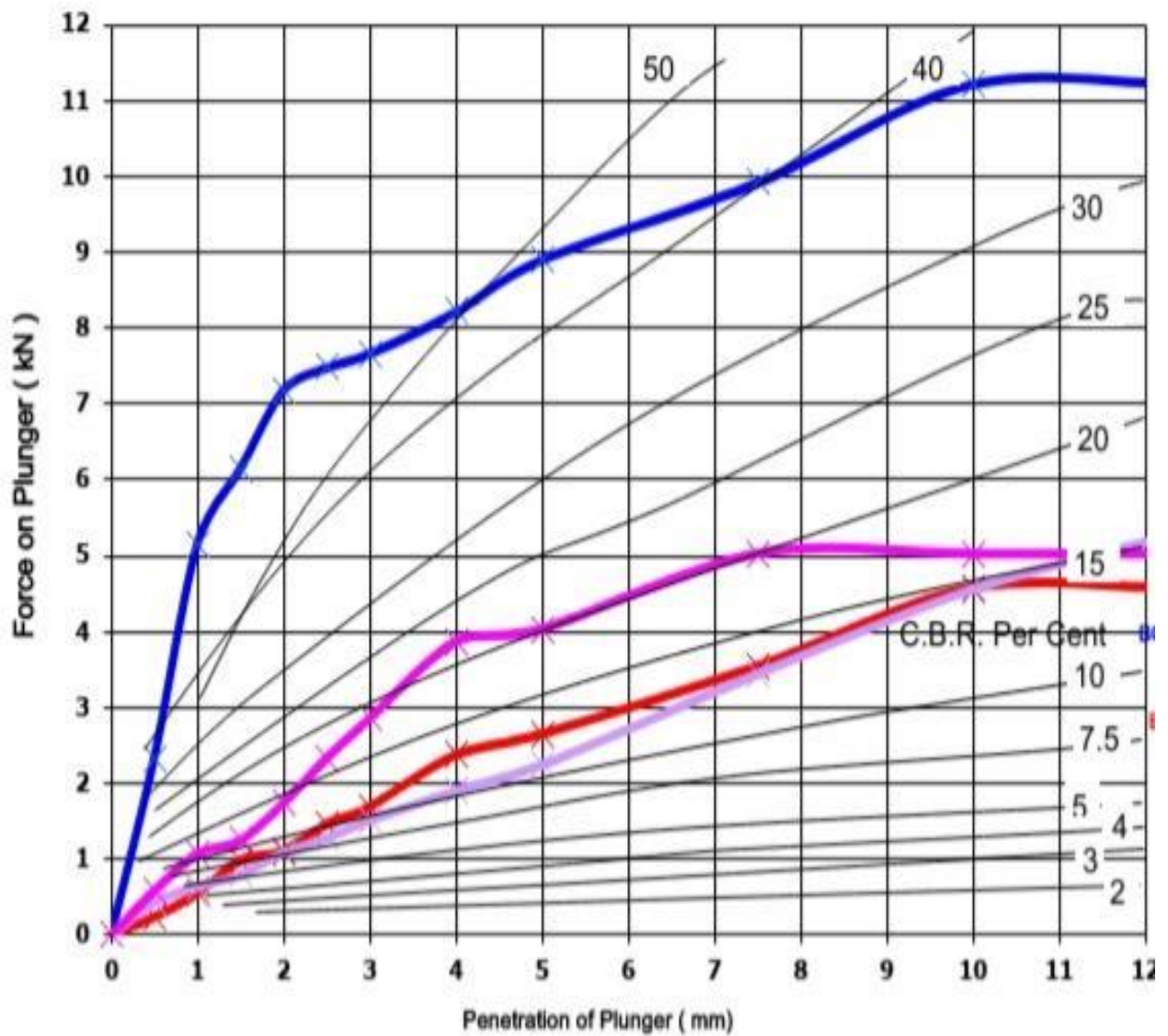
TEST ON BOTTOM (SOAKED)

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	213.0 0	471	562	657	684	701	751	814	907	1026	-
Load (KN)	0	2.329 82595	5.151 86865	6.147 2403	7.186 36455	7.481 6946	7.667 64315	8.214 55065	8.903 6541	9.9209 0205	11.22 25419	11.22 25419

TEST ON TOP (SOAKED)

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	53.00	98	114	159	213	261	354	369	460	-	-
Load (KN)	0	0.579 72195	1.071 9387	1.246 9491	1.739 16585	2.329 82595	2.854 85715	3.872 1051	4.036 17735	5.0315 49	5.031 549	5.031 549

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	11.066	13.316	56.487	44.607
TOP	9.662	11.234	17.590	20.221



Detail: Sample 5

TEST ON BOTTOM (UNSOAKED)

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	11.00	37	48	61	73	94	104	131	182	217	311
Load (KN)	0	0.120 31965	0.404 71155	0.525 0312	0.667 22715	0.798 48495	1.028 1861	1.137 5676	1.432 89765	1.9907 433	2.373 57855	3.401 76465

TEST ON TOP (UNSOAKED)

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	51.00	72	87	104	168	182	237	269	416	-	-
Load (KN)	0	0.557 84565	0.787 5468	0.951 61905	1.137 5676	1.837 6092	1.990 7433	2.592 34155	2.942 36235	4.5502 704	4.550 2704	4.550 2704

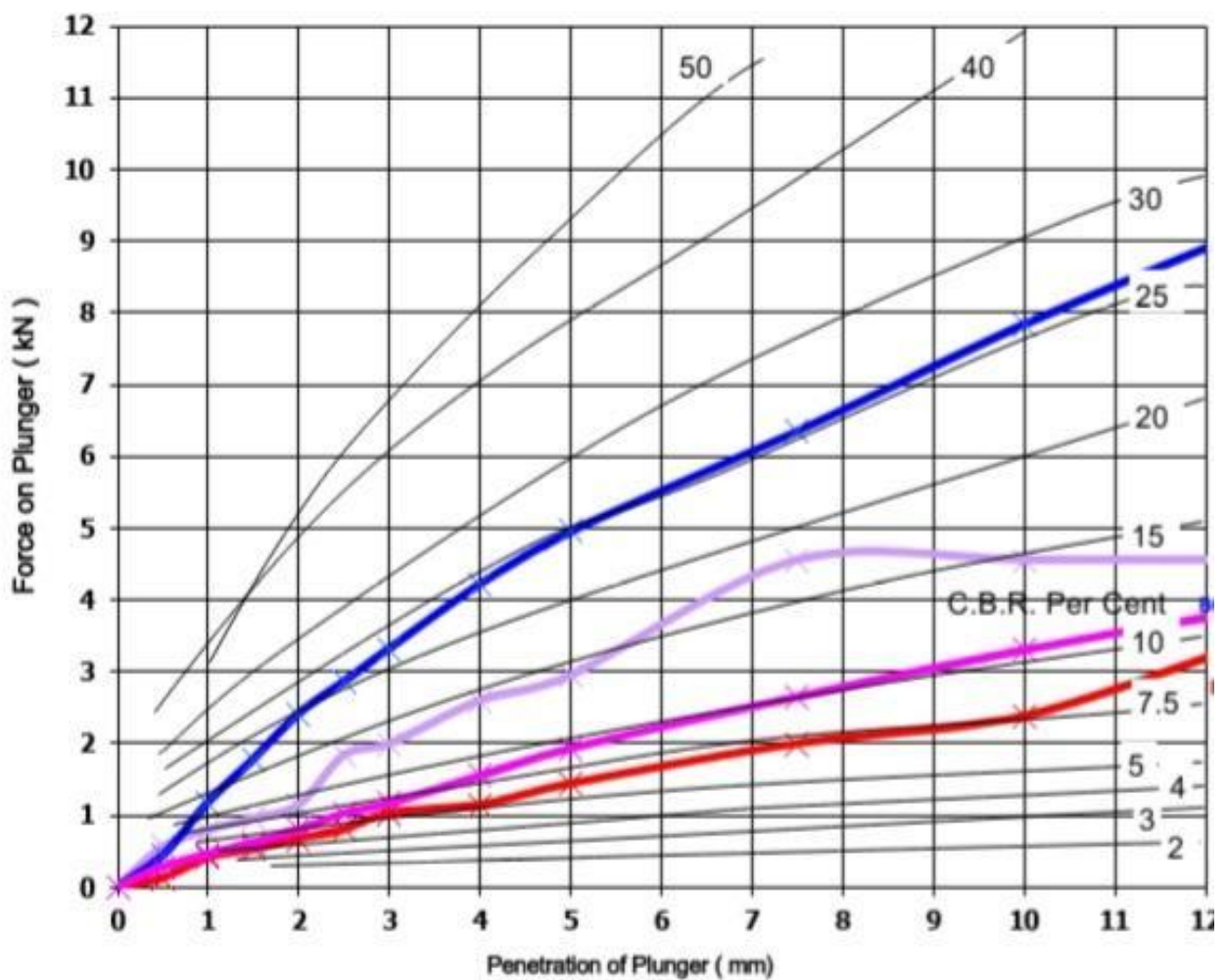
TEST ON BOTTOM (SOAKED)

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	40.00	108	163	221	262	304	386	453	581	717	839
Load (KN)	0	0.437 526	1.181 3202	1.782 91845	2.417 33115	2.865 7953	3.325 1976	4.222 1259	4.954 98195	6.3550 6515	7.842 65355	9.177 10785

TEST ON TOP (SOAKED)

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	25.00	42	56	73	94	107	142	177	243	303	355
Load (KN)	0	0.273 45375	0.459 4023	0.612 5364	0.798 48495	1.028 1861	1.170 38205	1.553 2173	1.936 05255	2.6579 7045	3.314 25945	3.883 04325

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	6.029	7.179	21.637	24.824
TOP	13.874	14.741	7.763	9.700



Detail: Sample 6

TEST ON BOTTOM (UNSOAKED)

Penetration (mm)	0.0	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	13.00	50	75	96	106	120	148	169	213	295	357
Load (KN)	0	0.142 19595	0.546 9075	0.820 36125	1.050 0624	1.159 4439	1.312 578	1.618 8462	1.848 54735	2.3298 2595	3.226 75425	3.904 91955

TEST ON TOP (UNSOAKED)

Penetration (mm)	0.0	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	52.00	89	106	213	345	443	543	560	-	-	-
Load (KN)	0	0.568 7838	0.973 49535	1.159 4439	2.329 82595	3.773 66175	4.845 60045	5.939 41545	6.125 364	6.1253 64	6.125 364	6.125 364

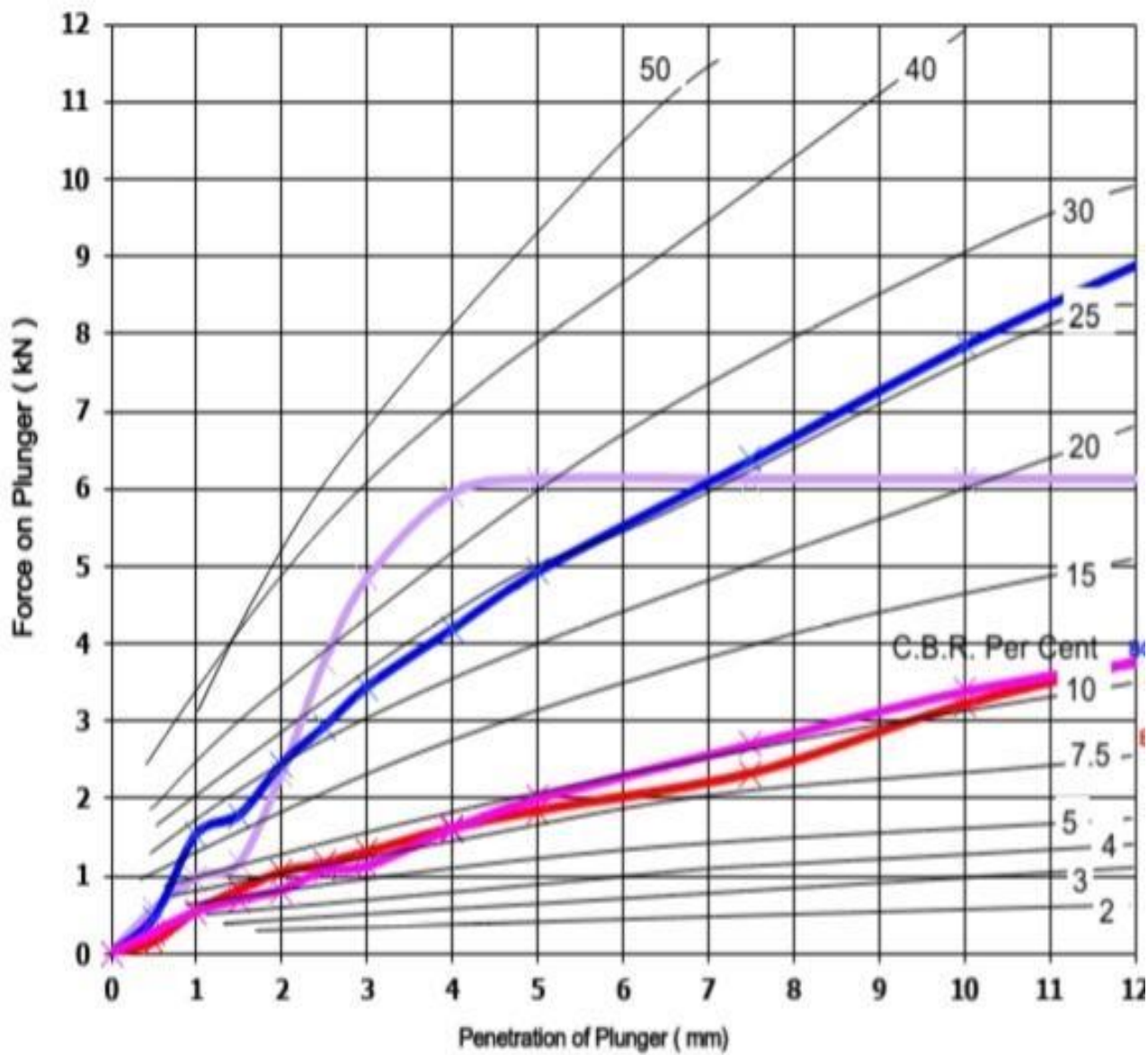
TEST ON BOTTOM (SOAKED)

Penetration (mm)	0.0	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	41.00	141	163	224	268	315	383	451	583	718	837
Load (KN)	0	0.448 46415	1.542 27915	1.782 91845	2.450 1456	2.931 4242	3.445 51725	4.189 31145	4.933 10565	6.3769 4145	7.853 5917	9.155 23155

TEST ON TOP (SOAKED)

Penetration (mm)	0.0	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	25.00	49	63	75	98	103	147	183	247	310	352
Load (KN)	0	0.273 45375	0.535 96935	0.689 10345	0.820 36125	1.071 9387	1.126 62945	1.607 90805	2.001 68145	2.7017 2305	3.390 8265	3.850 2288

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	8.754	9.261	22.132	24.715
TOP	28.491	30.688	8.093	10.028



Detail: Sample 7

TEST ON BOTTOM (UNSOAKED)

Penetration (mm)	0.0	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	1.00	53	142	263	367	418	524	537	-	-	-
Load (KN)	0	0.01093815	0.057972195	0.155321735	0.287673345	0.401430105	0.457214675	0.57315906	0.587378655	0.587378655	0.587378655	0.587378655

TEST ON TOP (UNSOAKED)

Penetration (mm)	0.0	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	102.00	178	235	347	386	400	417	-	-	-	-
Load (KN)	0	1.1156913	1.9469907	2.57046525	3.79553805	4.2221259	4.37526	4.56120855	4.56120855	4.56120855	4.56120855	4.56120855

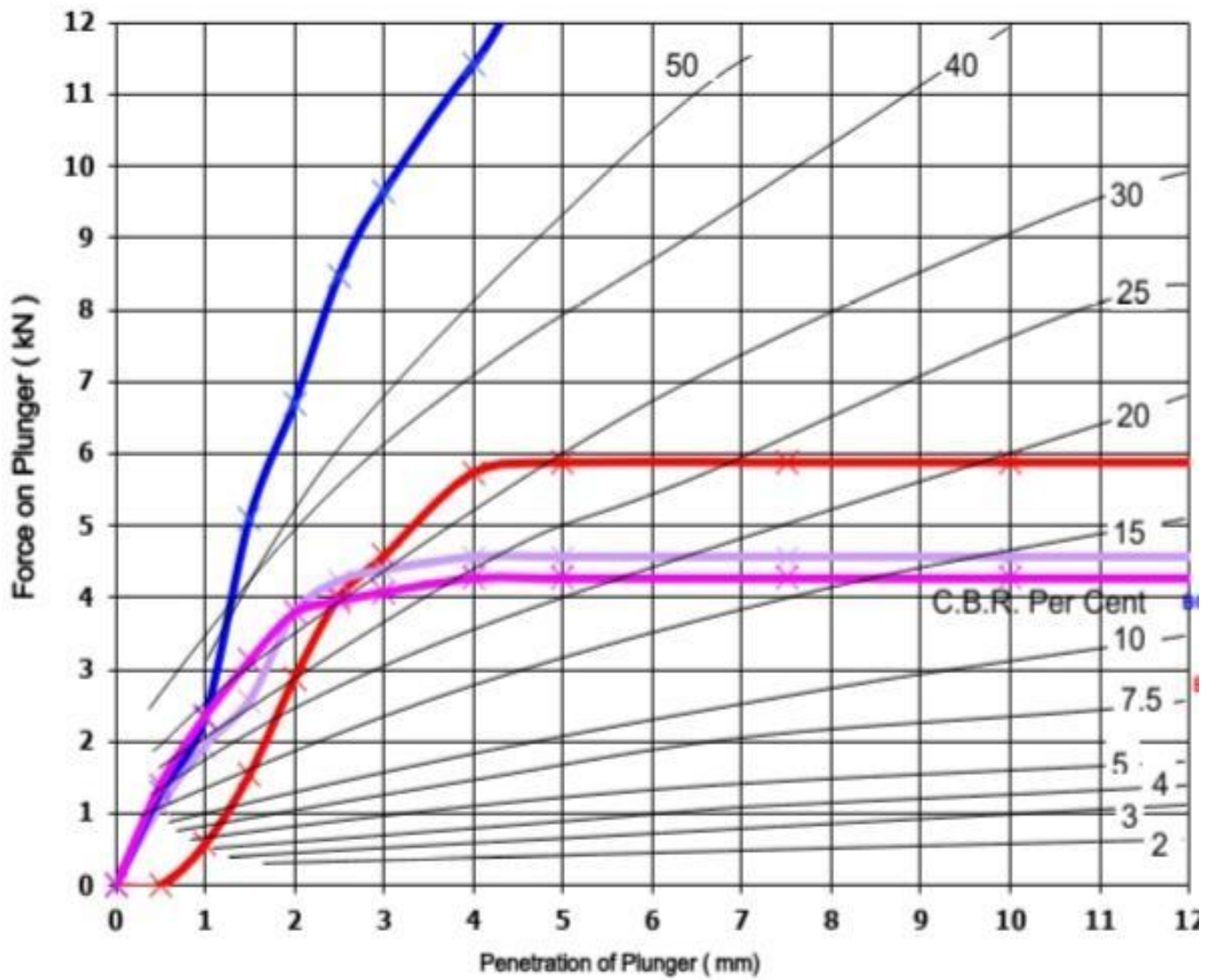
TEST ON BOTTOM (SOAKED)

Penetration (mm)	0.0	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	118.00	213	467	612	775	881	1043	1165	-	-	-
Load (KN)	0	1.2907017	2.32982595	5.10811605	6.69406625	8.47706625	9.63651015	11.40849045	12.74294475	12.74294475	12.74294475	12.74294475

TEST ON TOP (SOAKED)

Penetration (mm)	0.0	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	128.00	215	286	347	362	373	391	-	-	-	-
Load (KN)	0	1.4000832	2.35170225	3.12831095	3.79553805	3.95961035	4.07992995	4.27681665	4.27681665	4.27681665	4.27681665	4.27681665

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	30.308	29.428	64.002	63.842
TOP	31.877	22.852	29.895	21.427



Detail: Sample 8

TEST ON BOTTOM (UNSOAKED)

Penetration (mm)	0.0											
	0	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	85.00	133	212	289	358	416	521	637	697	714	751
Load (KN)	0	0.929	1.454	2.318	3.161	3.915	4.550	5.698	6.967	7.6238	7.809	8.214
		74275	77395	8878	12535	8577	2704	77615	60155	9055	8391	55065

TEST ON TOP (UNSOAKED)

Penetration (mm)	0.0											
	0	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	123.0										
		0	253	447	561	624	712	765	772	-	-	-
Load (KN)	0	1.345	2.767	4.889	6.136	6.825	7.787	8.367	8.444	8.4442	8.444	8.444
		39245	35195	35305	30215	4056	9628	68475	2518	518	2518	2518

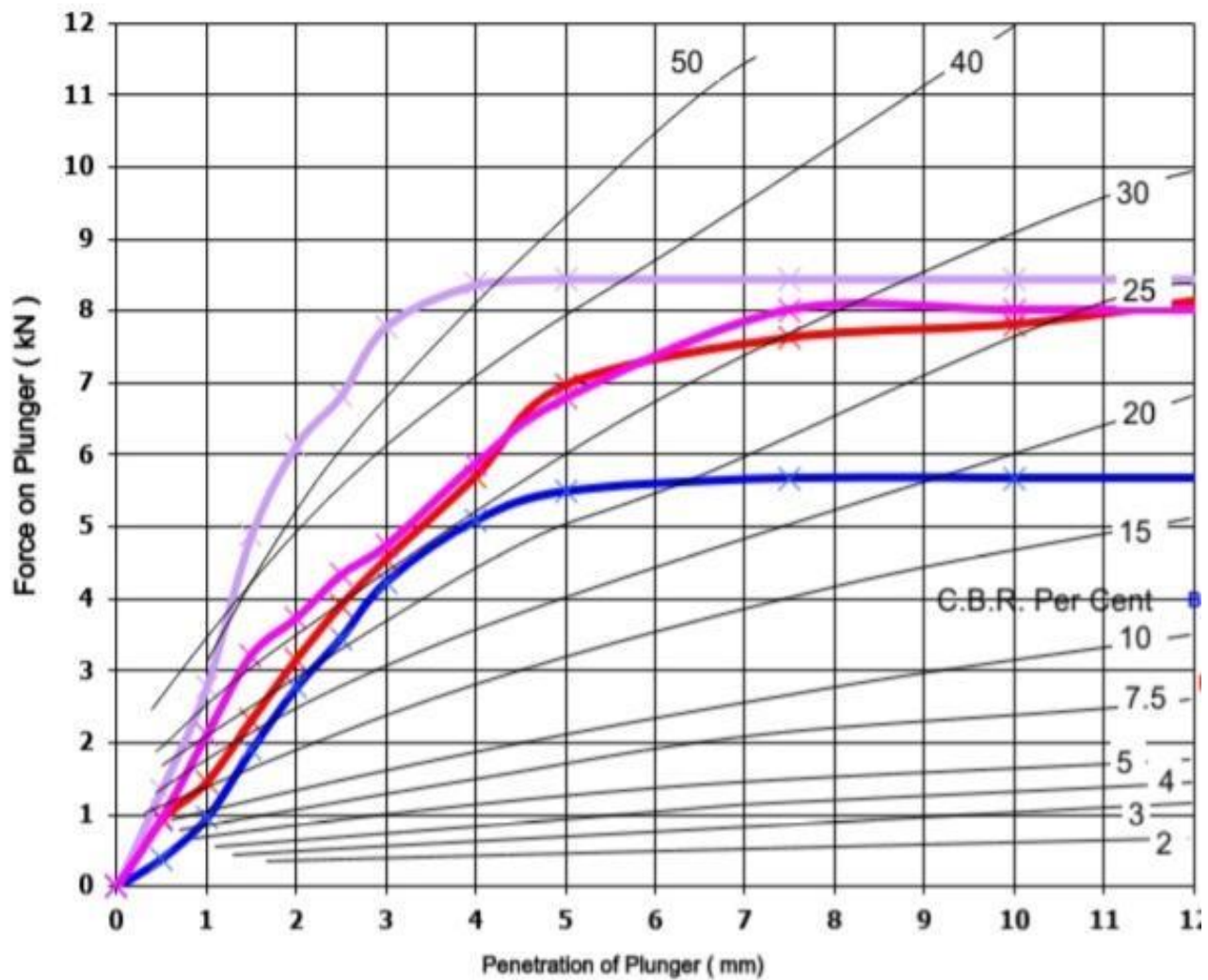
TEST ON BOTTOM (SOAKED)

Penetration (mm)	0.0											
	0	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	36.00	87	174	253	316	387	465	502	519	-	-
Load (KN)	0	0.393	0.951	1.903	2.767	3.456	4.233	5.086	5.490	5.6768	5.676	5.676
		7734	61905	2381	35195	4554	06405	23975	9513	9985	89985	89985

TEST ON TOP (SOAKED)

Penetration (mm)	0.0											
	0	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	87.00	193	295	341	396	433	537	620	732	-	-
Load (KN)	0	0.951	2.111	3.226	3.729	4.331	4.736	5.873	6.781	8.0067	8.006	8.006
		61905	06295	75425	90915	5074	21895	78655	653	258	7258	7258

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	29.565	34.908	26.096	27.510
TOP	51.532	42.306	32.703	33.976



Detail: Sample 9

TEST ON BOTTOM (UNSOAKED)

Penetration (mm)	0.0											
	0	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	22.00	52	87	119	152	182	251	290	436	575	693
Load (KN)	0	0.240	0.568	0.951	1.301	1.662	1.990	2.745	3.172	4.7690	6.2894	7.580
		6393	7838	61905	63985	5988	7433	47565	0635	334	3625	13795

TEST ON TOP (UNSOAKED)

Penetration (mm)	0.0											
	0	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	40.00	75	116	152	185	224	290	355	436	575	693
Load (KN)	0	0.437	0.820	1.268	1.662	2.023	2.450	3.172	3.883	4.7690	6.2894	7.580
		526	36125	8254	5988	55775	1456	0635	04325	334	3625	13795

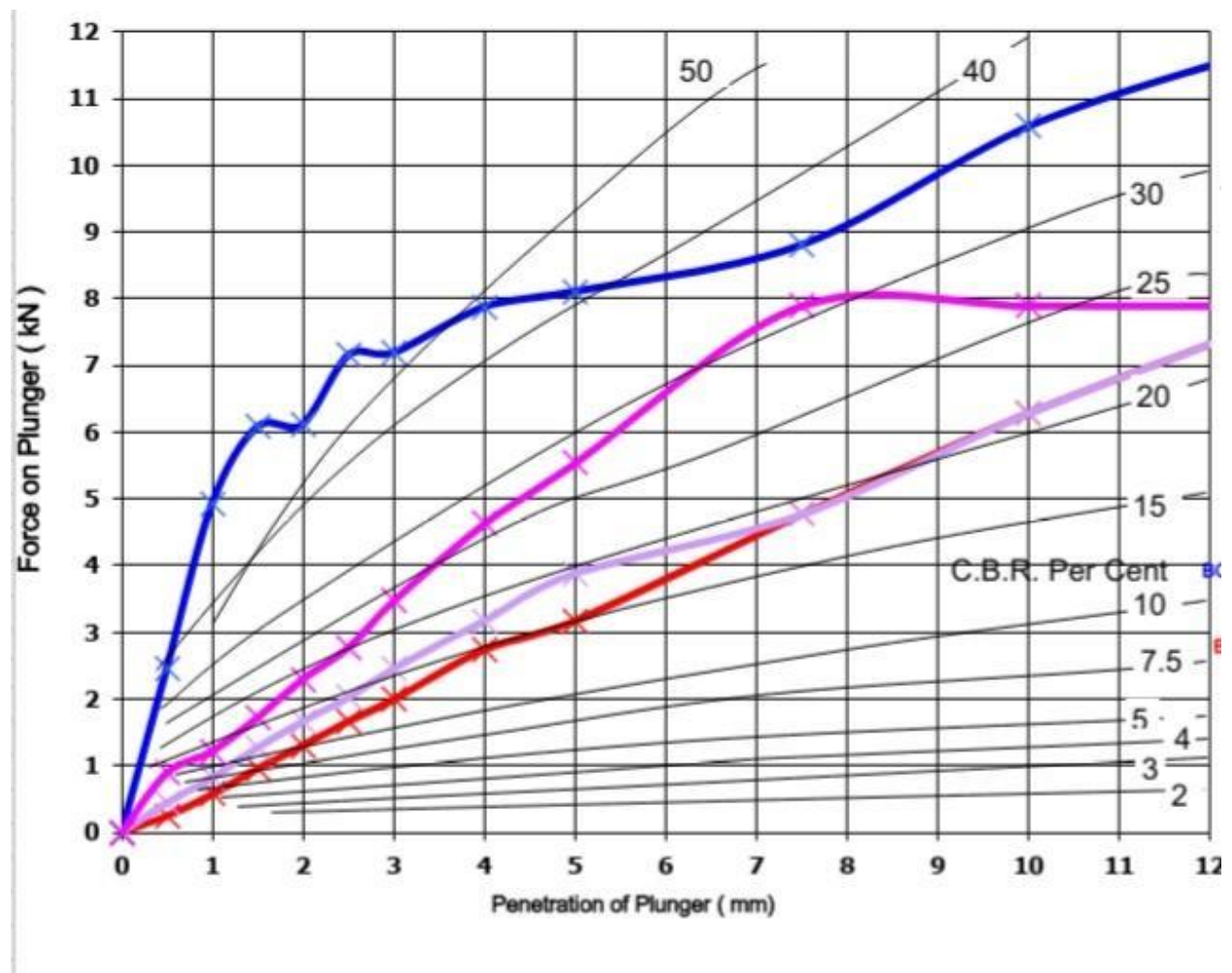
TEST ON BOTTOM (SOAKED)

Penetration (mm)	0.0											
	0	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	225.0	451	556	559	654	657	720	741	805	967	1070
Load (KN)	0	2.461	4.933	6.081	6.114	7.153	7.186	7.875	8.105	8.8052	10.577	11.70
		08375	10565	6114	42585	5501	36455	468	16915	1075	19105	38205

TEST ON TOP (SOAKED)

Penetration (mm)	0.0											
	0	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	81.00	111	157	210	253	317	423	506	722	-	-
Load (KN)	0	0.885	1.214	1.717	2.297	2.767	3.467	4.626	5.534	7.8973	7.8973	7.897
		99015	13465	28955	0115	35195	39355	83745	7039	443	443	3443

	UNSOAKED		SOAKED	
	2.5mm	5.0mm	2.5mm	5.0mm
BOTTOM	12.553	15.892	54.009	40.607
TOP	15.278	19.454	20.894	27.729



COMPACTION FOR SAMPLE 1 - 10

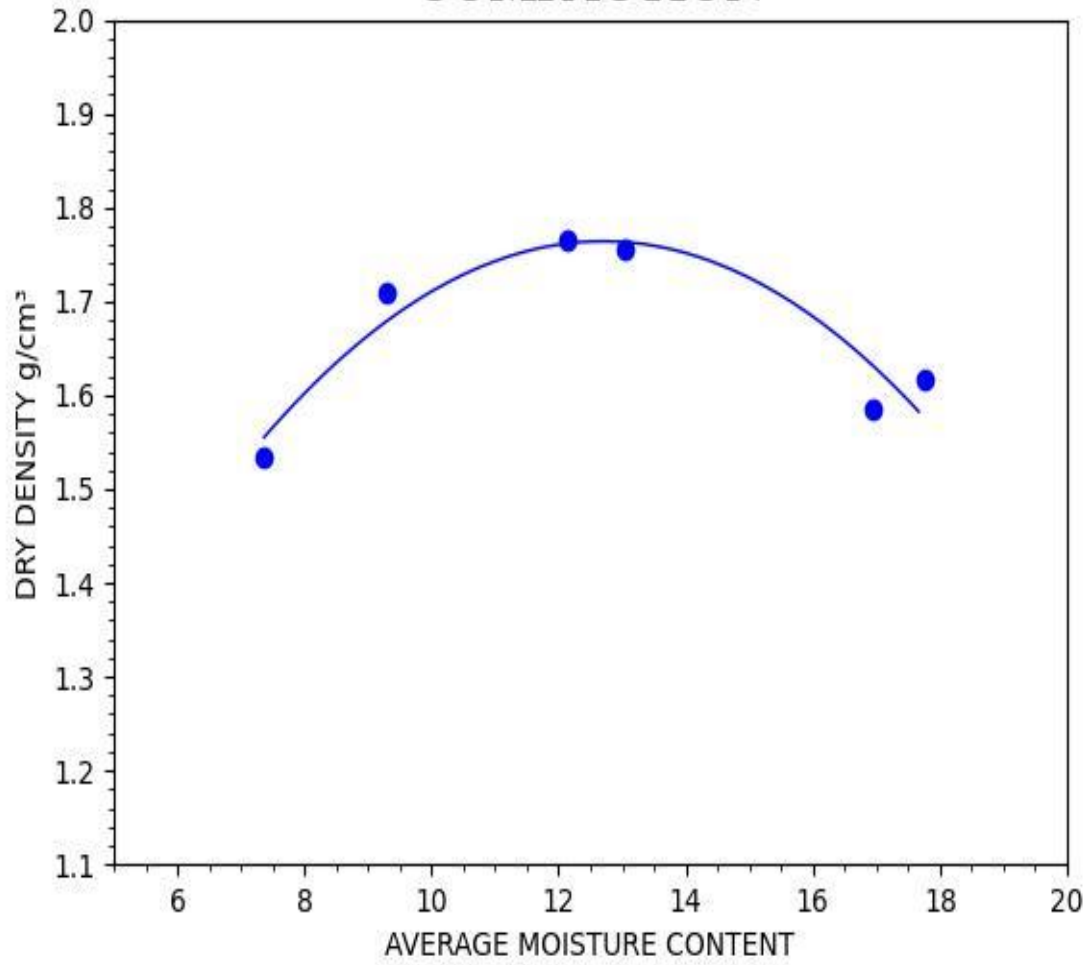
Sample 1

OMC: 12.77%

MDD: 1.76 g/cm³

COMPACTED SOIL-SAMPLE NO.	s1		s2		s3		s4		s5		s6	
MASS OF MOULD	4589		4589		4589		4589		4589		4589	
MASS OF COMPACTED SOIL + MOULD	6230		6450		6559		6564		6485		6434	
WATER CONTENT AND DRY DENSITY DETERMINATION												
WATER CONTENT SAMPLE NO.	GM Z	VT	I35	O.3	O.17	O.1 O	IO2	SUE	GMI	Z	O24	TA2
MASS OF EMPTY CAN	26.5	23.4	21.1	21.4	23.4	23.0	22.8	22.6	21.4	23.4	17.9	17.4
MASS OF CAN + MOIST SOIL	39.1	46.2	43.5	52.7	55.8	56.2	49.7	53.5	77.9	71.7	47.0	46.3
MASS OF CAN + DRY SOIL	38.2	44.7	41.7	49.9	52.5	52.4	46.9	49.6	69.4	64.4	42.8	42.1
WATER CONTENT (%)	7.69	7.04	8.74	9.82	11.34	12.93	11.62	14.44	17.71	17.8	16.87	17.0
WET MASS OF SOIL IN MOULD	1641		1861		1970		1975		1896		1845	
WET DENSITY (g/cm ³)	1.65		1.87		1.98		1.98		1.9		1.85	
AVE. WATER CONTENT (%)	7.37		9.28		12.13		13.03		17.76		16.94	
DRY DENSITY (g/cm ³)	1.53		1.71		1.76		1.75		1.62		1.58	

COMPACTION



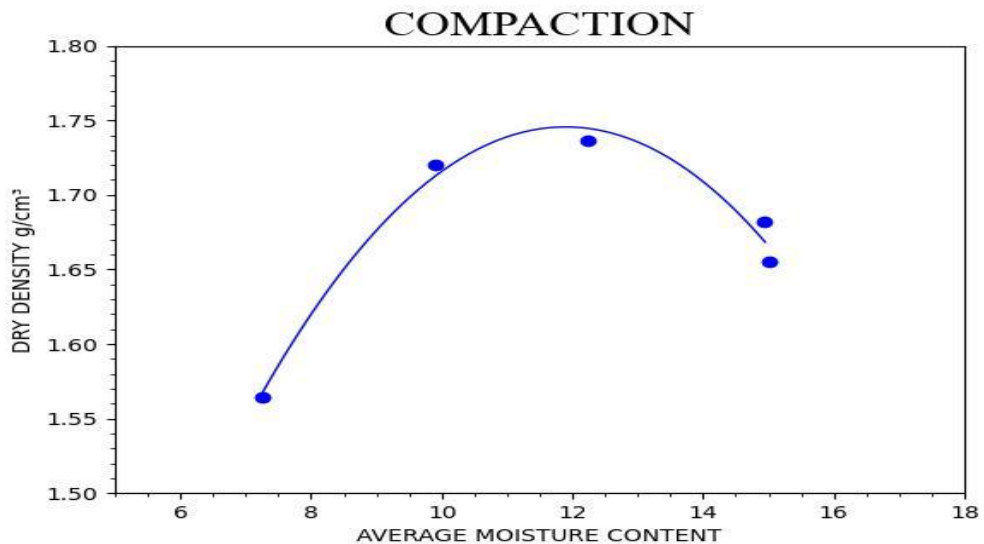
Sample 2

OMC: 11.96%

MDD: 1.75 g/cm³

COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4	s5
MASS OF MOULD	4589	4589	4589	4589	4589
MASS OF COMPACTED SOIL + MOULD	6260	6471	6530	6514	6485

WATER CONTENT AND DRY DENSITY DETERMINATION										
WATER CONTENT SAMPLE NO.	RX2	RX4	XA	O.21	SE	RX5	I52	LUU P	GE	V14
MASS OF EMPTY CAN	23.1	23.0	23.5	23.4	25.1	23.0	21.4	24.6	21.8	24.4
MASS OF CAN + MOIST SOIL	61.4	50.4	47.7	59.3	63.5	63.5	46.5	55.8	48.9	51.7
MASS OF CAN + DRY SOIL	58.6	48.7	45.5	56.1	59.2	59.2	43.2	51.8	45.5	48.0
WATER CONTENT (%)	7.89	6.61	10.0	9.79	12.61	11.88	15.14	14.71	14.35	15.68
WET MASS OF SOIL IN MOULD	1671		1882		1941		1925		1896	
WET DENSITY (g/cm ³)	1.68		1.89		1.95		1.93		1.9	
AVE. WATER CONTENT (%)	7.25		9.89		12.24		14.92		15.01	
DRY DENSITY (g/cm ³)	1.56		1.72		1.74		1.68		1.66	



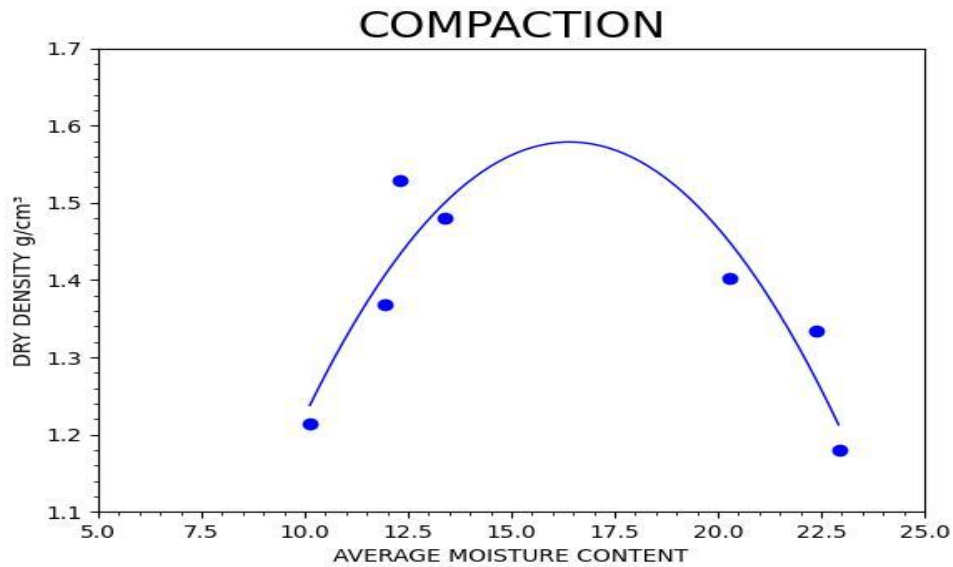
Sample 3

OMC: 16.52%

MDD: 1.58 g/cm³

COMPACTED SOIL-SAMPLE NO.	ss1	s2	s3	s4	s5	s6	s7							
MASS OF MOULD	4589	4589	4589	4589	4589	4589	4589							
MASS OF COMPACTED SOIL + MOULD	5920	6033	6114	6261	6298	6269	6215							
WATER CONTENT AND DRY DENSITY DETERMINATION														
WATER CONTENT SAMPLE NO.	TIT	V15	XB	R1	V18	O.12	RRY	GJ	V6	O.38	G M8	R26	Y5	O.1Z
MASS OF EMPTY CAN	23.1	21.8	24.3	21.4	21.5	24.9	21.3	18.8	16.8	18.0	21.4	21.4	23.0	2.2
MASS OF CAN + MOIST SOIL	61.4	52.3	50.8	60.4	62.7	63.5	46.5	56.9	47.9	51.7	59.1	56.4	50.8	5.5
MASS OF CAN + DRY SOIL	58.8	48.8	44.6	55.2	58.5	59.2	43.2	52.9	44.5	48.0	50.6	52.8	44.3	5.6
WATER CONTENT(%)	7.28	12.96	30.54	15.38	11.35	12.54	15.07	11.73	12.27	12.33	29.11	11.46	30.52	1.43
WET MASS OF SOIL IN MOULD	1331		1444		1525		1672		1709		1680		1626	

WET DENSITY(g/cm ³)	1.34	1.45	1.53	1.68	1.72	1.69	1.63
AVE. WATER CONTENT(%)	10.12	22.96	11.94	13.4	12.3	20.29	22.38
DRY DENSITY(g/cm ³)	1.21	1.18	1.37	1.48	1.53	1.4	1.33



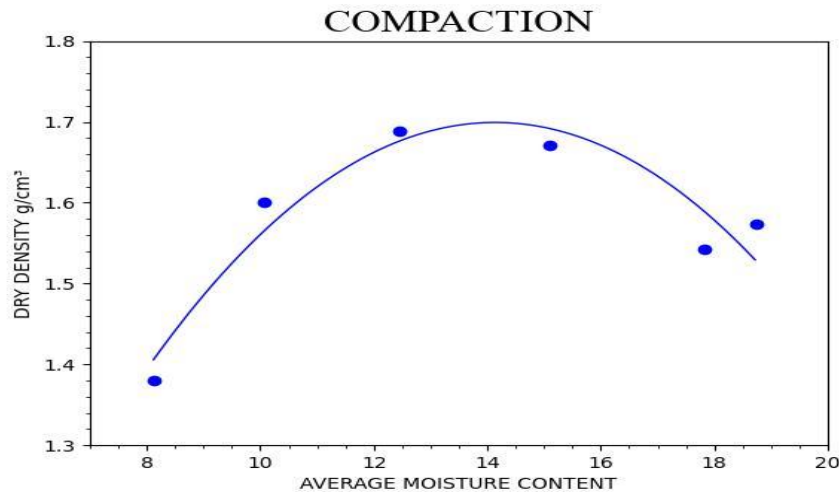
Sample4

OMC: 14.22%

MDD: 1.70g/cm³

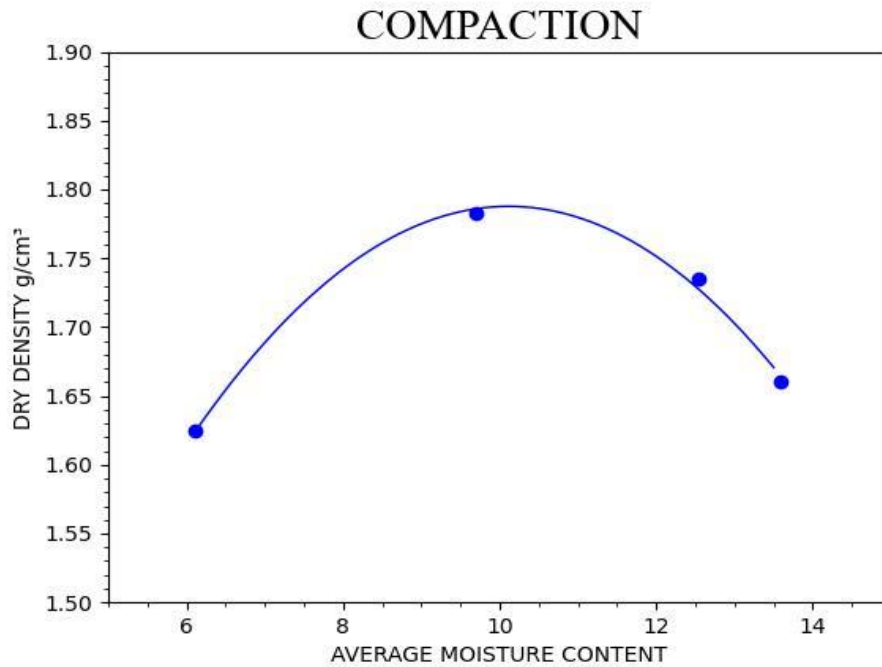
COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4	s5	s6
MASS OF MOULD	4589	4589	4589	4589	4589	4589
MASS OF COMPACTED SOIL + MOULD	6075	6343	6480	6504	6450	6398

WATER CONTENT AND DRY DENSITY DETERMINATION												
WATER CONTENT SAMPLE NO.	BY	VE G	AD I	GMI O	XO	AA N	LP	SAN	HAT	POI	IID	SI
MASS OF EMPTY CAN	21.8	22.2	23.1	21.7	23.4	22.9	23.4	23.0	23.0	23.0	21.5	21.8
MASS OF CAN + MOIST SOIL	41.3	54.1	47.9	47.2	48.7	48.2	46.9	42.3	48.7	49.9	48.1	52.7
MASS OF CAN + DRY SOIL	39.9	51.6	45.8	44.7	45.9	45.4	43.9	39.7	44.7	45.6	44.1	48.0
WATER CONTENT (%)	7.73	8.5	9.25	10.87	12.44	12.44	14.63	15.57	18.43	19.03	17.7	17.94
WET MASS OF SOIL IN MOULD	1486		1754		1891		1915		1861		1809	
WET DENSITY(g/cm ³)	1.49		1.76		1.9		1.92		1.87		1.82	
AVE. WATER CONTENT (%)	8.12		10.06		12.44		15.1		18.73		17.82	
DRY DENSITY (g/cm ³)	1.38		1.6		1.69		1.67		1.57		1.54	



Sample 5: OMC: 10.2% , MDD: 1.79g/cm³

COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4				
MASS OF MOULD	4589	4589	4589	4589				
MASS OF COMPACTED SOIL + MOULD	6305	6536	6533	6467				
WATER CONTENT AND DRY DENSITY DETERMINATION								
WATER CONTENT SAMPLE NO.	SXD	BIO	XU	VI7	12.O	D	NN	RX4
MASS OF EMPTY CAN	20.9	23.0	21.7	23.4	21.9	26.1	21.4	21.4
MASS OF CAN + MOIST SOIL	49.0	50.6	55.0	60.1	59.5	62.0	59.8	59.1
MASS OF CAN + DRY SOIL	47.5	48.9	52.2	56.7	55.2	58.1	55.1	54.7
WATER CONTENT (%)	5.64	6.56	9.18	10.21	12.91	12.19	13.95	13.21
WET MASS OF SOIL IN MOULD	1716	1947	1944	1878				
WET DENSITY(g/cm ³)	1.72	1.96	1.95	1.89				
AVE. WATER CONTENT (%)	6.1	9.7	12.55	13.58				
DRY DENSITY (g/cm ³)	1.62	1.78	1.73	1.66				



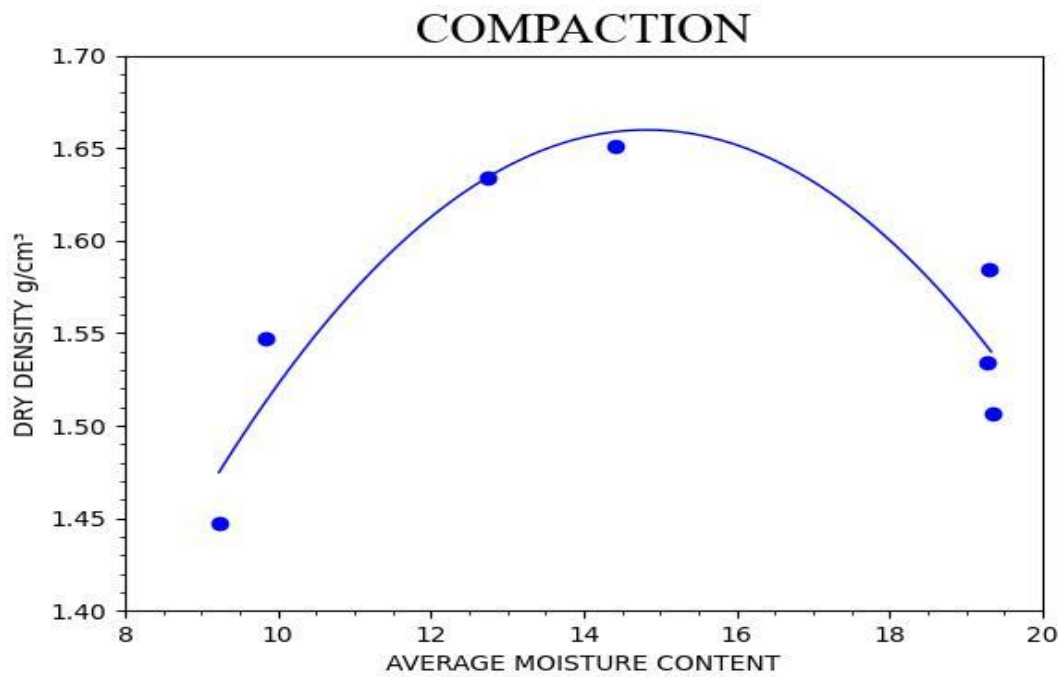
Sample 6: OMC: 14.93% , MDD: 1.66g/cm³

COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4	s5	s6	s7
MASS OF MOULD	4589	4589	4589	4589	4589	4589	4589
MASS OF COMPACTED SOIL + MOULD	6163	6281	6423	6470	6471	6411	6380

WATER CONTENT AND DRY DENSITY DETERMINATION

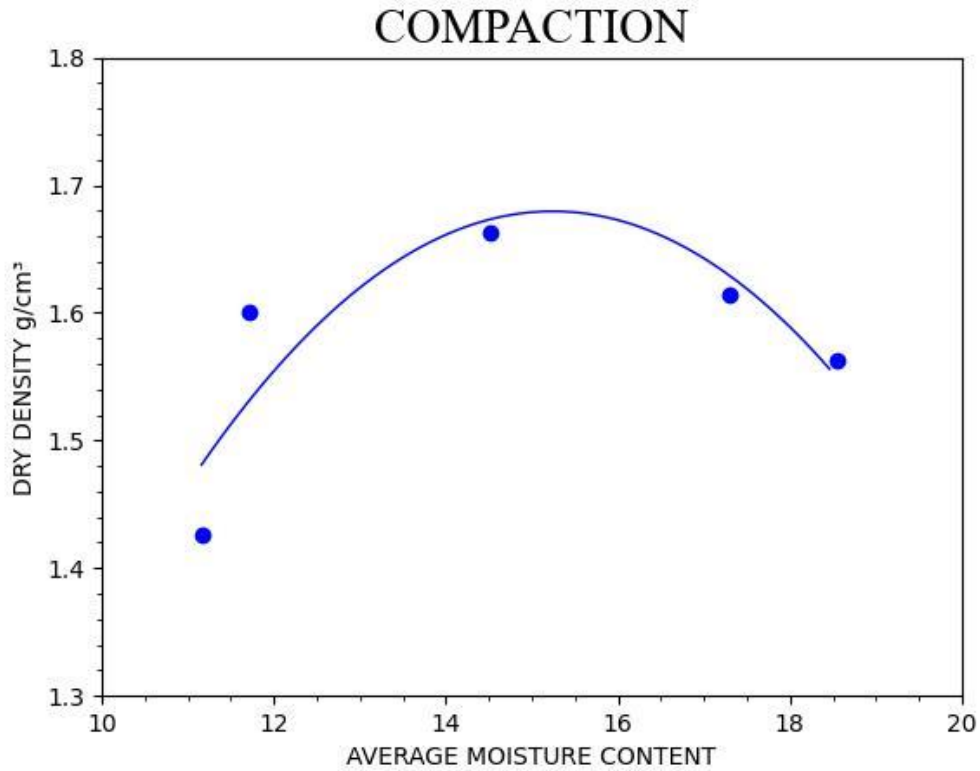
WATER CONTENT SAMPLE NO.	SSG	YE	20 I	B	2Q	R4	O.1	O.32	O.22	UBZ	AK A	RM D	YO U	TIU
MASS OF EMPTY CAN	22.4	23.6	22.1	21.4	24.6	21.9	21.8	21.6	21.6	23.3	24.1	21.9	21.5	23.2
MASS OF CAN + MOIST SOIL	36.3	60.8	52.9	49.8	50.7	48.0	49.8	44.3	58.6	57.3	52.6	45.5	56.9	53.9

MASS OF CAN + DRY SOIL	35.0	58.0	50.2	47.2	47.7	45.1	46.2	41.5	52.4	52.0	48.1	41.6	51.3	48.8
WATER CONTENT(%)	10.32	8.14	9.61	10.08	12.99	12.55	14.75	14.07	20.13	18.47	18.75	19.85	18.79	19.92
WET MASS OF SOIL IN MOULD	1574		1692		1834		1881		1882		1822		1791	
WET DENSITY(g/cm ³)	1.58		1.7		1.84		1.89		1.89		1.83		1.8	
AVE. WATER CONTENT(%)	9.23		9.84		12.74		14.41		19.3		19.27		19.36	
DRY DENSITY(g/cm ³)	1.45		1.55		1.63		1.65		1.58		1.53		1.51	



Sample 7: OMC: 15.36% , MDD: 1.68g/cm³

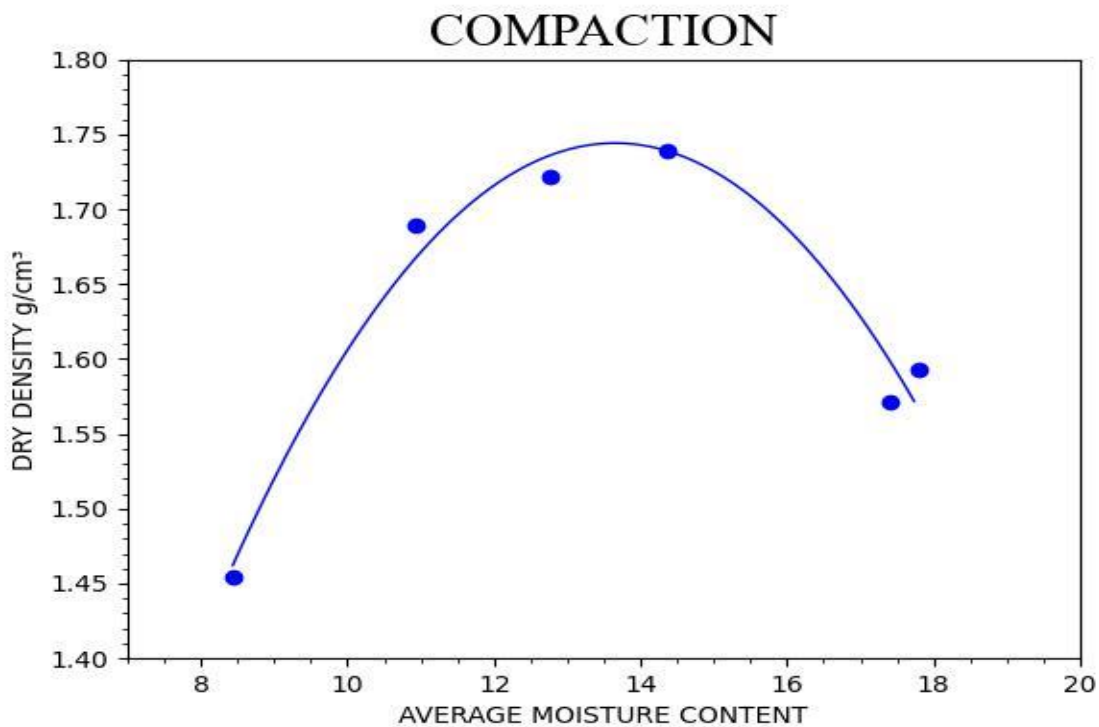
S	s1	s2	s3	s4	s5					
MASS OF MOULD	4589	4589	4589	4589	4589					
MASS OF COMPACTED SOIL + MOULD	6168	6369	6485	6474	6433					
WATER CONTENT AND DRY DENSITY DETERMINATION										
WATER CONTENT SAMPLE NO.	O.24	PAY	MO	O.A	TA 5	V11	V3	PLU	TAZ	B3
MASS OF EMPTY CAN	16.4	17.3	18. 2	16.3	17. 4	17.0	16.7	17.7	17.1	17. 1
MASS OF CAN + MOIST SOIL	34.5	32.1	36. 2	37.4	40. 5	41.3	45.0	45.0	51.9	55. 3
MASS OF CAN + DRY SOIL	32.7	30.6	34. 3	35.2	37. 4	38.4	40.9	40.9	46.3	49. 5
WATER CONTENT (%)	11.0 4	11.2 8	11. 8	11.6 4	15. 5	13.5 5	16.9 4	17.6 7	19.1 8	17. 9
WET MASS OF SOIL IN MOULD	1579		1780		1896		1885		1844	
WET DENSITY(g/cm ³)	1.59		1.79		1.9		1.89		1.85	
AVE. WATER CONTENT (%)	11.16		11.72		14.53		17.31		18.54	
DRY DENSITY (g/cm ³)	1.43		1.6		1.66		1.61		1.56	



Sample8: OMC: 13.73% , MDD: 1.74/cm³

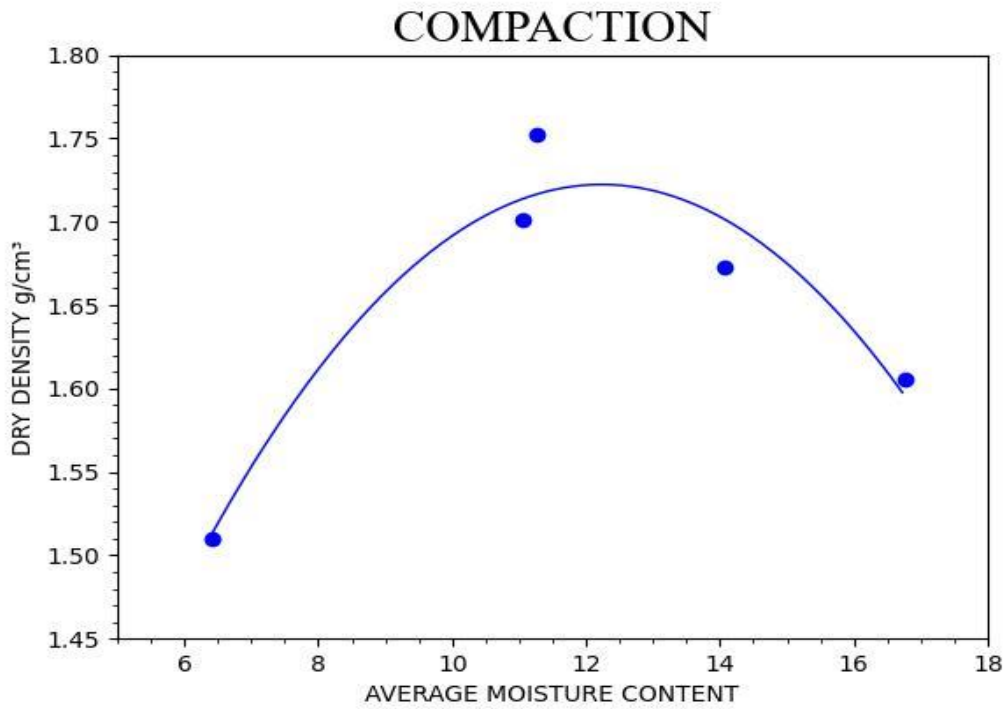
COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4	s5	s6						
MASS OF MOULD	4589	4589	4589	4589	4589	4589						
MASS OF COMPACTED SOIL + MOULD	6159	6455	6522	6570	6457	6426						
WATER CONTENT AND DRY DENSITY DETERMINATION												
WATER CONTENT SAMPLE NO.	LF	2T	IB	O.19	V13	RX 6	2O	GA N	2E	IX	RXR	O.O 1
MASS OF EMPTY CAN	23. 1	24. 8	22. 1	23.6	21.8	23. 6	24.4	21. 6	23.3	21.7	21.5	22.0
MASS OF CAN + MOIST SOIL	49. 1	42. 6	51. 6	52.0	54.8	58. 7	62.0	48. 3	60.3	60.8	46.7	65.9

MASS OF CAN + DRY SOIL	47.1	41.2	48.7	49.2	51.0	54.8	57.2	45.0	54.8	54.8	42.9	59.5
WATER CONTENT(%)	8.33	8.54	10.9	10.94	13.01	12.5	14.63	14.1	17.46	18.13	17.76	17.07
WET MASS OF SOIL IN MOULD	1570		1866		1933		1981		1868		1837	
WET DENSITY(g/cm ³)	1.58		1.87		1.94		1.99		1.88		1.84	
AVE. WATER CONTENT(%)	8.43		10.92		12.76		14.37		17.79		17.41	
DRY DENSITY(g/cm ³)	1.45		1.69		1.72		1.74		1.59		1.57	



Sample 9: OMC: 12.33% , MDD: 1.72/cm³

COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4	s5					
MASS OF MOULD	4589	4589	4589	4589	4589					
MASS OF COMPACTED SOIL + MOULD	6189	6470	6530	6489	6456					
WATER CONTENT AND DRY DENSITY DETERMINATION										
WATER CONTENT SAMPLE NO.	AA A	5	0.32	2Q	B	2E	2O	GMI O	BY	AD1
MASS OF EMPTY CAN	22.8	21.6	21.4	24.4	21.4	23.2	24.3	21.6	21.7	23.2
MASS OF CAN + MOIST SOIL	47.2	48.2	74.6	69.6	48.7	60.6	51.1	61.3	64.0	56.9
MASS OF CAN + DRY SOIL	46.1	46.2	69.3	65.1	45.8	57.0	47.6	56.7	58.0	52.0
WATER CONTENT (%)	4.72	8.13	11.06	11.06	11.89	10.65	15.02	13.11	16.53	17.01
WET MASS OF SOIL IN MOULD	1600	1881	1941	1900	1867					
WET DENSITY(g/cm ³)	1.61	1.89	1.95	1.91	1.87					
AVE. WATER CONTENT (%)	6.43	11.06	11.27	14.06	16.77					
DRY DENSITY (g/cm ³)	1.51	1.7	1.75	1.67	1.61					

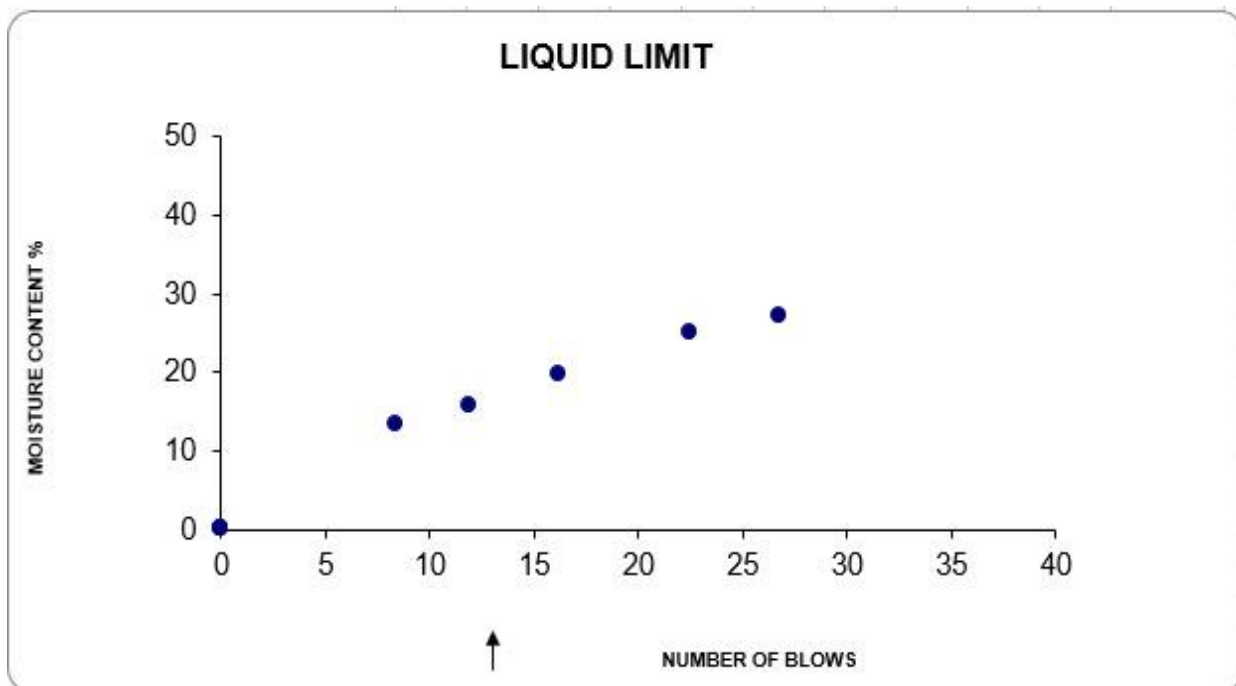


Sample 10
 OMC: 13.54%
 MDD: 1.71 g/cm³

COMPACTED SOIL-SAMPLE NO.	s1	s2	s3	s4	s5					
MASS OF MOULD	4589	4589	4589	4589	4589					
MASS OF COMPACTED SOIL + MOULD	6182	6469	6537	6480	6430					
WATER CONTENT AND DRY DENSITY DETERMINATION										
WATER CONTENT SAMPLE NO.	VEE	RX6	AKA	YE	RY	LF	YOU	201	RXR	V13
MASS OF EMPTY CAN	22.1	23.7	24.2	23.6	21.9	23.2	21.5	22.2	21.6	21.9
MASS OF CAN + MOIST SOIL	47.5	47.2	75.2	69.1	48.3	60.1	52.1	61.2	63.0	55.9

MASS OF CAN + DRY SOIL	45.1	46.2	69.1	64.1	44.8	57.2	46.6	56.8	58.1	53.0
WATER CONTENT (%)	10.43	4.44	13.59	12.35	15.28	8.53	21.91	12.72	13.42	9.32
WET MASS OF SOIL IN MOULD	1593		1880		1948		1891		1841	
WET DENSITY (g/cm ³)	1.6		1.89		1.96		1.9		1.85	
AVE. WATER CONTENT (%)	7.44		12.97		11.91		17.31		11.37	
DRY DENSITY (g/cm ³)	1.49		1.67		1.75		1.62		1.66	

ATTERBERG RESULTS FOR SAMPLE 1-10



Location: Ovbiogie Borrow Pit

Liquid Limit: 26.18%

Plastic Limit: 0

Sample ID: 1

Plastic Index: 0

Operator: FASINA JAMES ADEKITAN

Date: 05/02/2025.

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	8.40	11.90	16.20	22.50	26.8
Container No.	CAR	SUE	B4	2P	VEG
Wt of wet soil & container (g)	43.26	43.32	51.30	57.18	58.39
Wt of dried soil & container (g)	41.00	40.50	47.00	50.20	50.67
Wt of container (g)	24.08	22.68	25.08	22.06	22.19
Wt of dry soil (Wd) (g)	16.92	17.82	21.92	28.14	28.48
Wt of moisture (Wm) (g)	2.26	2.82	4.30	6.98	7.72
Moisture contain 100 (Wm/Wd)	13.36	15.82	19.62	24.80	27.11
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					

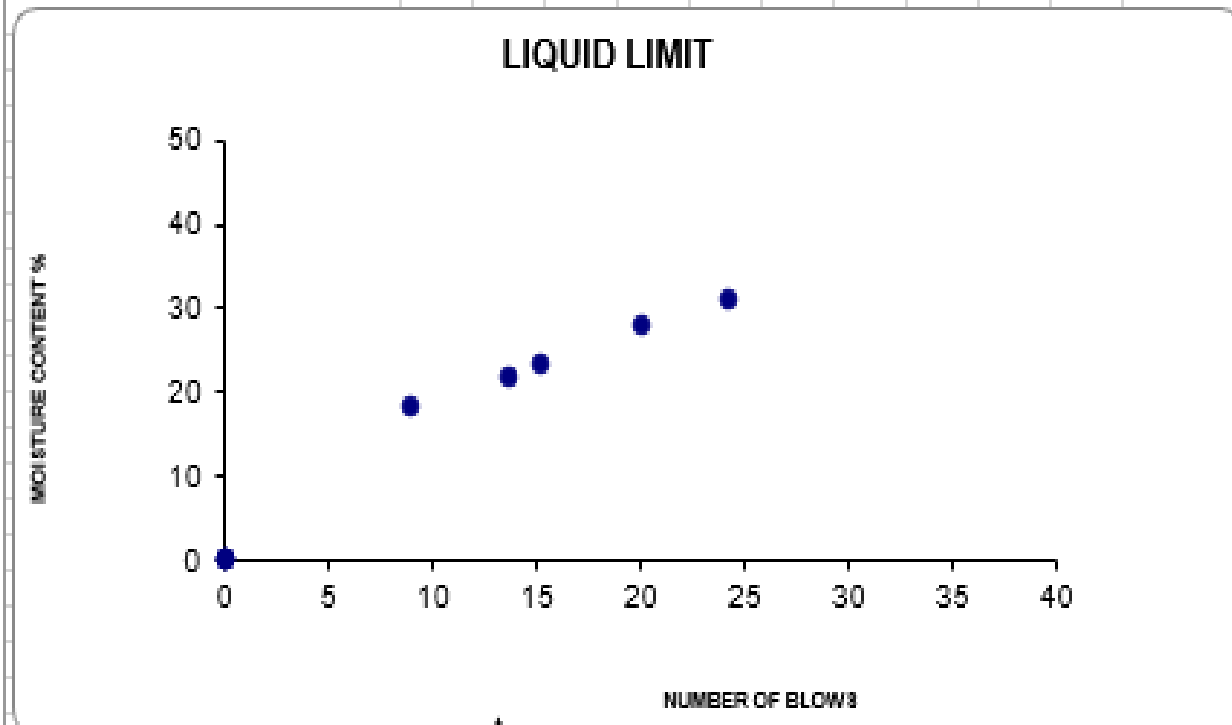
Operator: FA SINA JAMES ADEKITAN

Date: 05/02/2025.

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL		LL		LL		LL		LL
No. of Blows/shrinkage %	8.90		13.70		15.20		20.10		24.3
Container No.	U		13S		LOV		GE		RMD
Wt of wet soil & container (g)	42.75		40.71		57.40		55.31		54.49
Wt of dried soil & container (g)	39.45		37.70		51.20		48.47		47.30
Wt of container (g)	21.59		24.01		24.75		24.24		24.22
Wt of dry soil (Wd) (g)	17.86		13.69		26.45		24.23		23.08
Wt of moisture (Wm) (g)	3.30		3.01		6.20		6.84		7.19
Moisture contain 100 (Wm/Wd)	18.48		21.99		23.44		28.23		31.15
Type of Test	PL		PL		PL				
No. of Blows/shrinkage %									
Container No.									
Wt of wet soil & container (g)									
Wt of dried soil & container (g)									
Wt of container (g)									
Wt of dry soil (Wd) (g)									
Wt of moisture (Wm) (g)									
Moisture contain 100 (Wm/Wd)									



LIQUID AND PLASTIC LIMITS TEST

Location: Ovbiojie Borrow Pit

Liquid Limit: 21.36%

Plastic Limit: 0

Sample ID: 3

Plastic Index: 0

Operator: FA SINA JAMES ADEKIRAN.

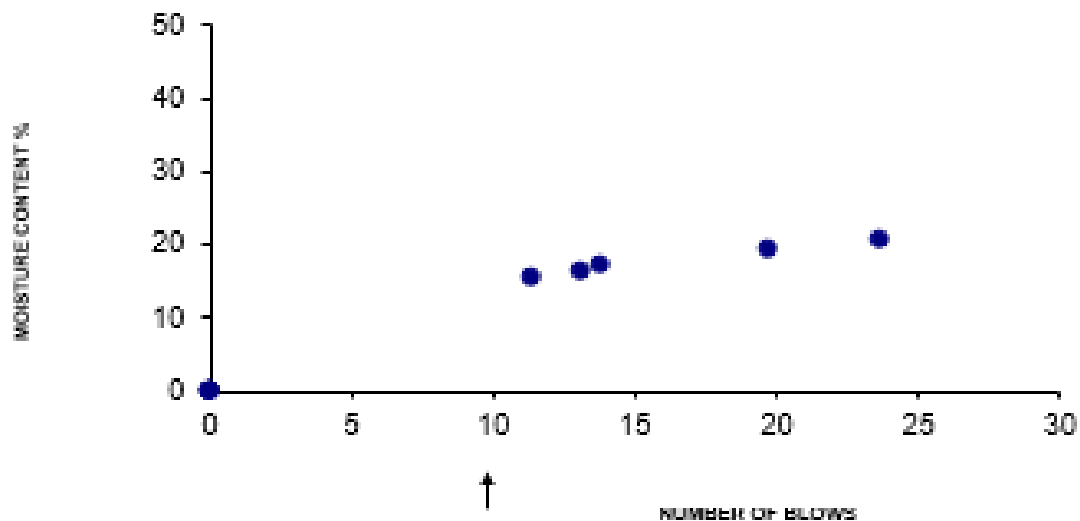
Date: 05/02/2025.

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	11.30	13.10	13.80	19.70	23.8
Container No.	PIO	OG	D/AD	O8	MI
Wt of wet soil & container (g)	29.29	41.15	45.81	46.07	46.29
Wt of dried soil & container (g)	27.30	37.85	41.80	41.36	41.37
Wt of container (g)	14.81	17.77	17.02	17.08	17.54
Wt of dry soil (Wd) (g)	12.69	20.08	24.58	24.28	23.83
Wt of moisture (Wm) (g)	1.99	3.30	4.21	4.71	4.92
Moisture contain 100 (Wm/Wd)	15.68	16.43	17.13	19.40	20.65
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					

LIQUID LIMIT



Location: **Ovbiogie Borrow Pit**

Liquid Limit: **26.86%**

Plastic Limit: **0**

Sample ID: **4**

Plastic Index: **0**

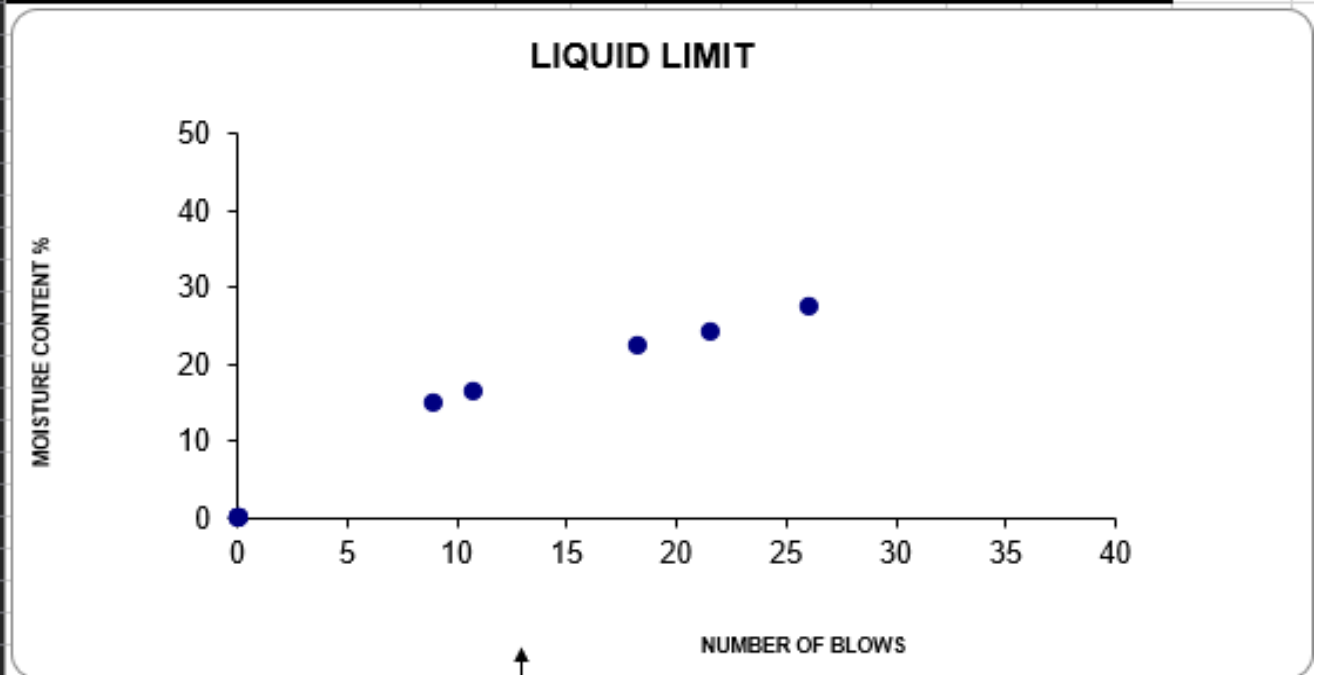
Operator: **FASINA JAMES ADEKITAN**

Date: **05/02/2025.**

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	9.00	10.70	18.20	21.60	26
Container No.	D+	POR	B1	MU	BIO
Wt of wet soil & container (g)	60.66	49.04	52.92	52.29	63.87
Wt of dried soil & container (g)	55.90	45.50	47.65	45.65	55.10
Wt of container (g)	24.20	23.80	24.17	18.27	23.07
Wt of dry soil (Wd) (g)	31.70	21.70	23.48	27.38	32.03
Wt of moisture (Wm) (g)	4.76	3.54	5.27	6.64	8.77
Moisture contain 100 (Wm/Wd)	15.02	16.31	22.44	24.25	27.38
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					



LIQUID AND PLASTIC LIMITS TEST

Location: **Ovbiogie Borrow Pit**

Liquid Limit: **28.52%**

Plastic Limit: **0**

Sample ID: **5**

Plastic Index: **0**

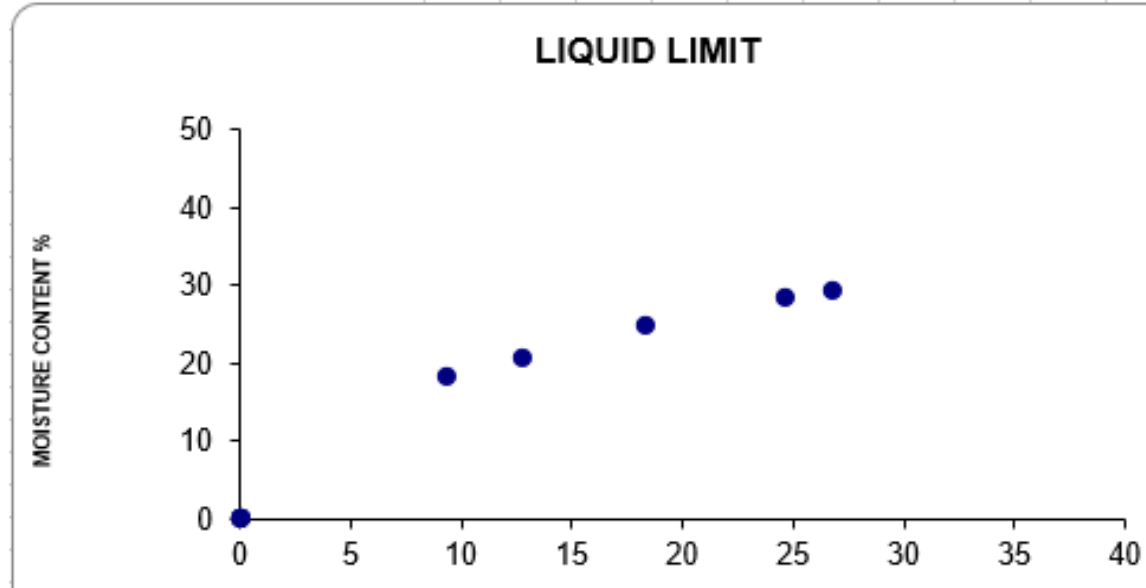
Operator: **FASINA JAMES ADEKITAN.**

Date: **05/02/2025.**

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL		LL		LL		LL		LL
No. of Blows/shrinkage %	9.30		12.80		18.30		24.70		26.8
Container No.	MR		SUK		B5		A+		B4
Wt of wet soil & container (g)	39.61		37.50		49.77		57.27		57.37
Wt of dried soil & container (g)	37.20		35.20		44.70		49.94		50.04
Wt of container (g)	24.04		24.02		24.35		24.08		25.06
Wt of dry soil (Wd) (g)	13.16		11.18		20.35		25.86		24.98
Wt of moisture (Wm) (g)	2.41		2.30		5.07		7.33		7.33
Moisture contain 100 (Wm/Wd)	18.31		20.57		24.91		28.34		29.34
Type of Test	PL		PL		PL				
No. of Blows/shrinkage %									
Container No.									
Wt of wet soil & container (g)									
Wt of dried soil & container (g)									
Wt of container (g)									
Wt of dry soil (Wd) (g)									
Wt of moisture (Wm) (g)									
Moisture contain 100 (Wm/Wd)									



LIQUID AND PLASTIC LIMITS TEST

Location: **Ovbiogie Borrow Pit**

Liquid Limit: **23.57%**

Plastic Limit: **0**

Sample ID: **6**

Plastic Index: **0**

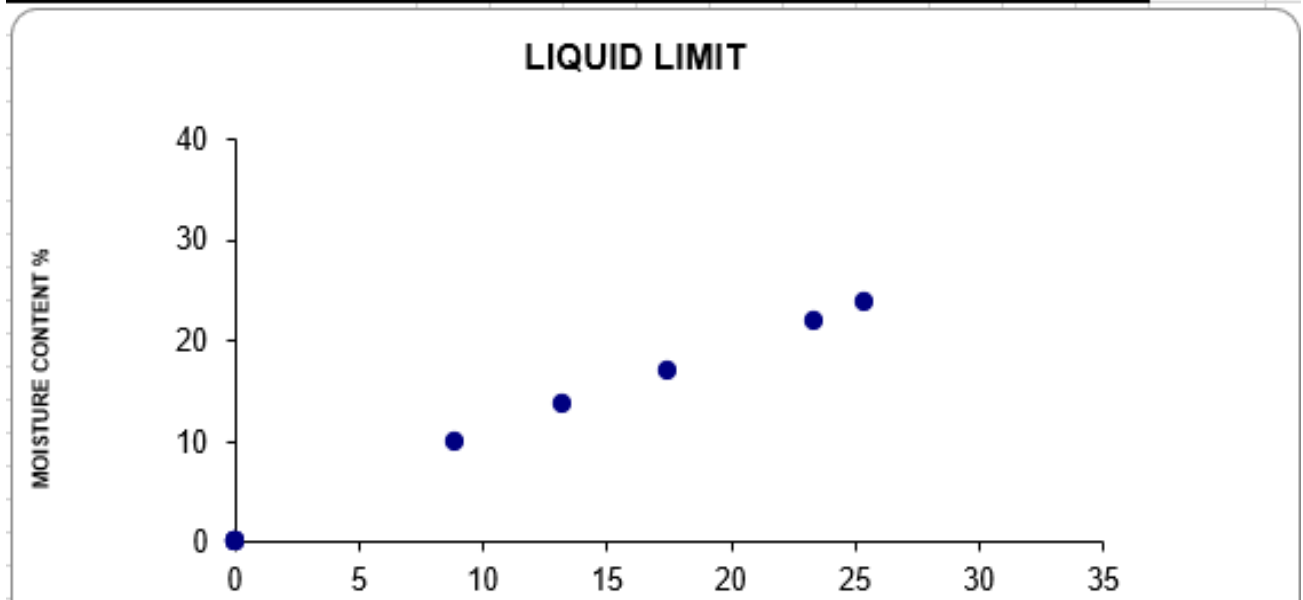
Operator: **FASINA JAMES ADEKITAN**

Date: **05/02/2025.**

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	8.90	13.20	17.40	23.40	25.3
Container No.	XJ	O5	GRE	O28	O3
Wt of wet soil & container (g)	42.99	44.22	49.08	45.54	47.47
Wt of dried soil & container (g)	41.35	41.70	45.65	40.40	42.44
Wt of container (g)	24.83	23.20	25.50	17.15	21.45
Wt of dry soil (Wd) (g)	16.52	18.50	20.15	23.25	20.99
Wt of moisture (Wm) (g)	1.64	2.52	3.43	5.14	5.03
Moisture contain 100 (Wm/Wd)	9.93	13.62	17.02	22.11	23.96
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					



LIQUID AND PLASTIC LIMITS TEST

Location: **Ovbiogie Borrow Pit**

Liquid Limit: 30.25%

Plastic Limit: 0

Sample ID: 7

Plastic Index: 0

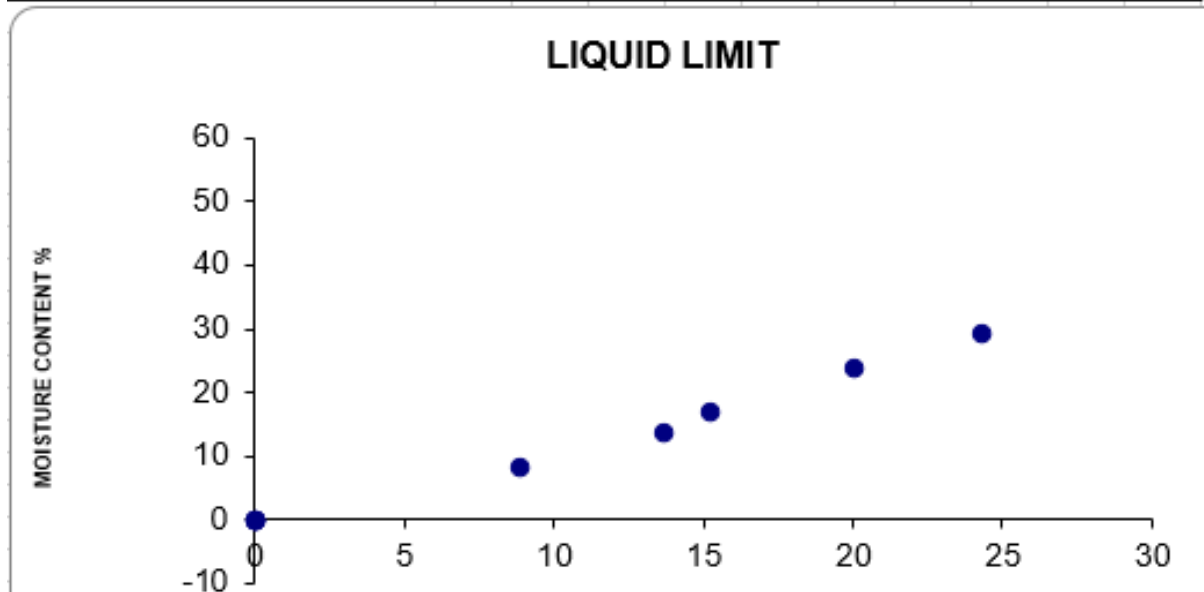
Operator: **FASINA JAMES ADEKITAN**

Date: 05/02/2025.

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	8.90	13.70	15.20	20.10	24.3
Container No.	U	13S	LOV	GE	RMD
Wt of wet soil & container (g)	42.75	40.71	57.40	55.31	54.49
Wt of dried soil & container (g)	41.20	38.42	52.20	48.95	47.20
Wt of container (g)	21.59	21.32	21.63	21.94	22.24
Wt of dry soil (Wd) (g)	19.61	17.10	30.57	27.01	24.96
Wt of moisture (Wm) (g)	1.55	2.29	5.20	6.36	7.29
Moisture contain 100 (Wm/Wd)	7.90	13.39	17.01	23.55	29.21
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					



LIQUID AND PLASTIC LIMITS TEST

Location: **Ovbiogie Borrow Pit**

Liquid Limit: **27.32%**

Plastic Limit: **0**

Sample ID: **8**

Plastic Index: **0**

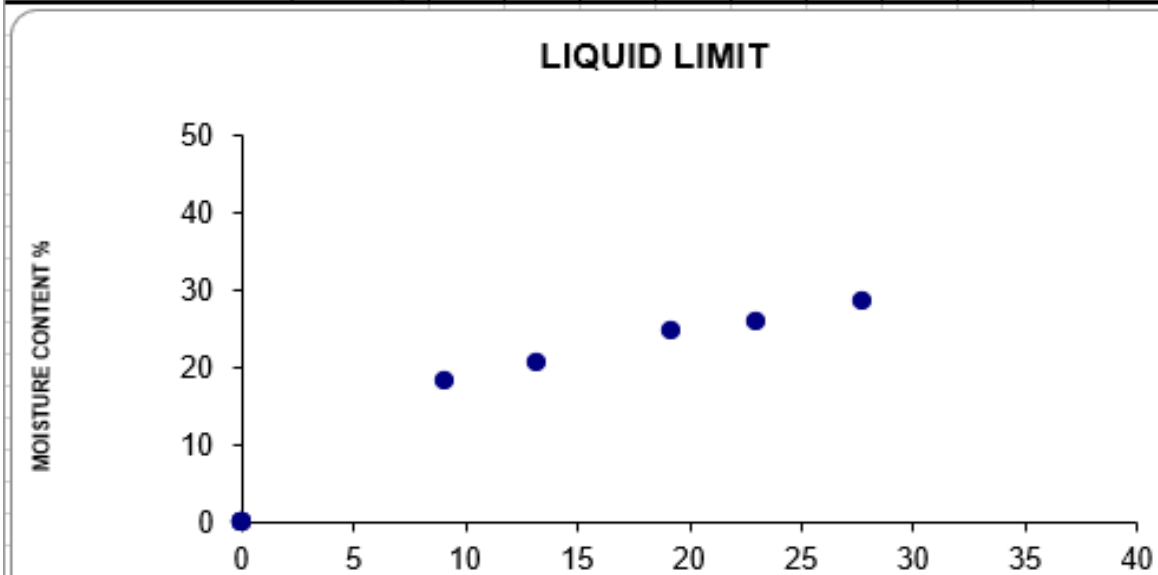
Operator: **FASINA JAMES ADEKITAN**

Date: **05/02/2025.**

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	9.10	13.20	19.20	23.00	27.7
Container No.	SB	D3	PVC	O13	R+
Wt of wet soil & container (g)	48.35	52.07	61.06	53.12	68.75
Wt of dried soil & container (g)	44.50	47.34	53.82	46.60	58.87
Wt of container (g)	23.56	24.44	24.59	21.59	24.32
Wt of dry soil (Wd) (g)	20.94	22.90	29.23	25.01	34.55
Wt of moisture (Wm) (g)	3.85	4.73	7.24	6.52	9.88
Moisture contain 100 (Wm/Wd)	18.39	20.66	24.77	26.07	28.60
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					



LIQUID AND PLASTIC LIMITS TEST

Location: **Ovbiogie Borrow Pit**

Liquid Limit: 28.3%

Plastic Limit: 0

Sample ID: 9

Plastic Index: 0

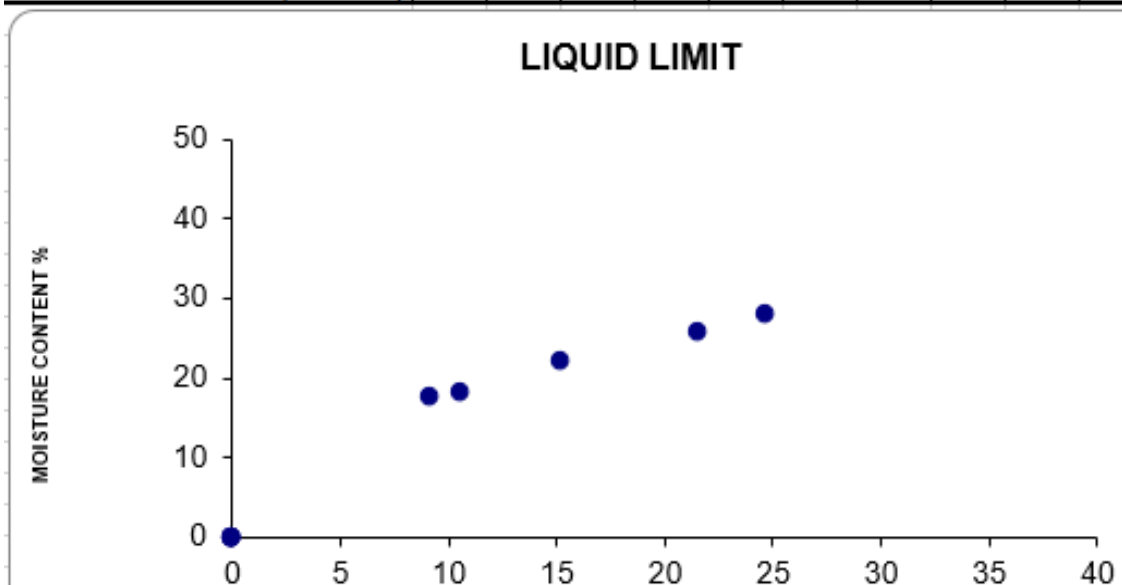
Operator: **FASINA JAMES ADEKITAN**

Date: 05/02/2025.

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL	LL	LL	LL	LL
No. of Blows/shrinkage %	9.10	####	####	####	24.6
Container No.	NTA	0.15	LF	O51	13S
Wt of wet soil & container (g)	####	####	####	####	####
Wt of dried soil & container (g)	####	####	####	####	####
Wt of container (g)	####	####	####	####	####
Wt of dry soil (Wd) (g)	####	####	####	####	####
Wt of moisture (Wm) (g)	3.32	3.60	4.09	8.46	7.08
Moisture contain 100 (Wm/Wd)	####	####	####	####	####
Type of Test	PL	PL	PL		
No. of Blows/shrinkage %					
Container No.					
Wt of wet soil & container (g)					
Wt of dried soil & container (g)					
Wt of container (g)					
Wt of dry soil (Wd) (g)					
Wt of moisture (Wm) (g)					
Moisture contain 100 (Wm/Wd)					



LIQUID AND PLASTIC LIMITS TEST

Location: **Ovbiogie Borrow Pit**

Liquid Limit: **24.88%**

Plastic Limit: **0**

Sample ID: **10**

Plastic Index: **0**

Operator: **NDUKA CHUKWUKA G.**

Date: **05/0/22025.**

No. of blows refers to liquid limit determination.

Liquid limit marked L.L. plastic limit marked P.L.

Type of Test	LL		LL		LL		LL		LL
No. of Blows/shrinkage %	10.30		14.20		19.70		24.50		28.2
Container No.	A+		Nt		GX		V15		2N
Wt of wet soil & container (g)	47.58		61.58		65.87		58.97		66.57
Wt of dried soil & container (g)	44.00		56.70		58.14		51.69		57.25
Wt of container (g)	24.17		31.99		24.61		22.01		21.64
Wt of dry soil (Wd) (g)	19.83		24.71		33.53		29.68		35.61
Wt of moisture (Wm) (g)	3.58		4.88		7.73		7.28		9.32
Moisture contain 100 (Wm/Wd)	18.05		19.75		23.05		24.53		26.17
Type of Test	PL		PL		PL				
No. of Blows/shrinkage %									
Container No.									
Wt of wet soil & container (g)									
Wt of dried soil & container (g)									
Wt of container (g)									
Wt of dry soil (Wd) (g)									
Wt of moisture (Wm) (g)									
Moisture contain 100 (Wm/Wd)									

