ROLE OF GEOTECHNICAL PROPERTIES OF UNIBEN SOIL ON ENGINEERING STRUCTURES

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UNIVERSITY OF BENIN

BENIN CITY

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A PROJECT SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF BENIN, BENIN CITY. IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE (B.SC HONS) IN GEOLOGY.

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DEDICATION

This project work is dedicated to God Almighty for His love, grace, strength and also to my family and friends for their continuous support and encouragement

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I am sincerely grateful to God for the strength, wisdom, and perseverance that enabled me to complete this research successfully. My profound appreciation goes to my supervisor, Dr. (Mrs.) Andre Obayanju, whose guidance, patience, and valuable insights greatly shaped the quality of this work. I also extend my thanks to the Head of Department, Dr. S. A. Salami, for his steady leadership and support throughout my academic program. My heartfelt gratitude goes to my parents, Mr. and Mrs. Temi-Okoro, whose encouragement, prayers, and unwavering support have been my foundation both academically and personally.

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURES **PAGES**

ABSTRACT

This study examines how important geotechnical properties of soil affect the stability, safety, and overall performance of engineering structures. Soil samples were taken from depths of 1.0 m, 2.0 m, 3.0 m, and 4.0 m, and tested for moisture content, grain size distribution, Atterberg limits, specific gravity, compaction behaviour, and triaxial shear strength. These tests helped to determine the soil's physical and mechanical characteristics and how they respond to different loading and environmental conditions. Grain size results showed that the soil is mainly sandy, which explains its high permeability and low tendency to compress. The Atterberg limits indicated low to moderate plasticity, meaning the soil has limited swelling and shrinking capability. Specific gravity values suggested the presence of quartz-rich materials, while compaction tests provided the optimum moisture content (OMC) and maximum dry density (MDD) needed for proper construction. The triaxial test also gave the shear strength values required for evaluating bearing capacity and slope stability. The results shows that the soil has good engineering qualities when properly compacted, making it suitable for foundations, road bases, embankments, and similar structures. The study highlights the need for thorough geotechnical investigation before construction to avoid structural failures and recommends continuous monitoring and soil improvement methods where weaker layers occur.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL STATEMENT

Soil is one of the most important natural materials in engineering, as it directly influences the safety, performance, and durability of structures such as buildings, roads, dams, and bridges. The mechanical and physical behavior of soil is largely controlled by its geotechnical properties, including strength, compressibility, permeability, plasticity, and bearing capacity. These properties determine how soil responds to loads, water infiltration, and environmental changes, which in turn affects the design and stability of engineering projects (Das & Sobhan, 2018).

In many developing regions, including Nigeria, a significant number of engineering structures have experienced distress and failure, often linked to inadequate site investigations and a poor understanding of soil mechanics. These problems manifest as excessive settlement, differential settlement, shear failure of foundations, and structural cracks, leading to significant financial losses and, in some cases, loss of life.The complexity and diversity of soil, which can vary greatly even over short distances, make the issue worse. Engineers run the danger of making crucial design mistakes that jeopardize a structure's long-term integrity if they don't conduct a thorough investigation of the geotechnical characteristics of a soil. Thus, the study of soil's geotechnical properties plays a central role in engineering, ensuring that construction practices are safe, cost-effective, and sustainable.

1.2 SCOPE OF STUDY

This research will focus on the geotechnical properties of soil samples collected from a specific location within the University of Benin,Benin city,Edo State, Nigeria. The study will be limited to laboratory analysis of the soil samples to determine their index properties (grain size distribution, Atterberg limits, and specific gravity) and engineering properties (shear strength and consolidation). The project will not involve in-situ testing or the design of a specific structure but will discuss the implications of the results for common engineering structures like residential buildings, roads, and embankments.

1.3 AIM AND OBJECTIVES

The primary aim of this work is to examine how the essential geotechnical properties of soil influence the performance, stability and safety of engineering structure. The objectives are;

1. Identifying and determining the index properties (grain size distribution, Atterberg limits, specific gravity) of collected soil samples.
2. Assessing the engineering properties of the soil samples, including shear strength and consolidation characteristics.
3. Establishing a relationship between the determined geotechnical properties and their implications for different types of foundations and structures.
4. Providing recommendations for the design and construction of civil engineering structures based on the findings from the soil analysis.

1.4 LOCATION

This project was carried out at the University of Benin, Benin City, Edo state. Samples were taken from N6^{o}23’42.1” to N6^{o}39’52.5" and E5^{o}37’2.4” to E5^{o}61’3.1"

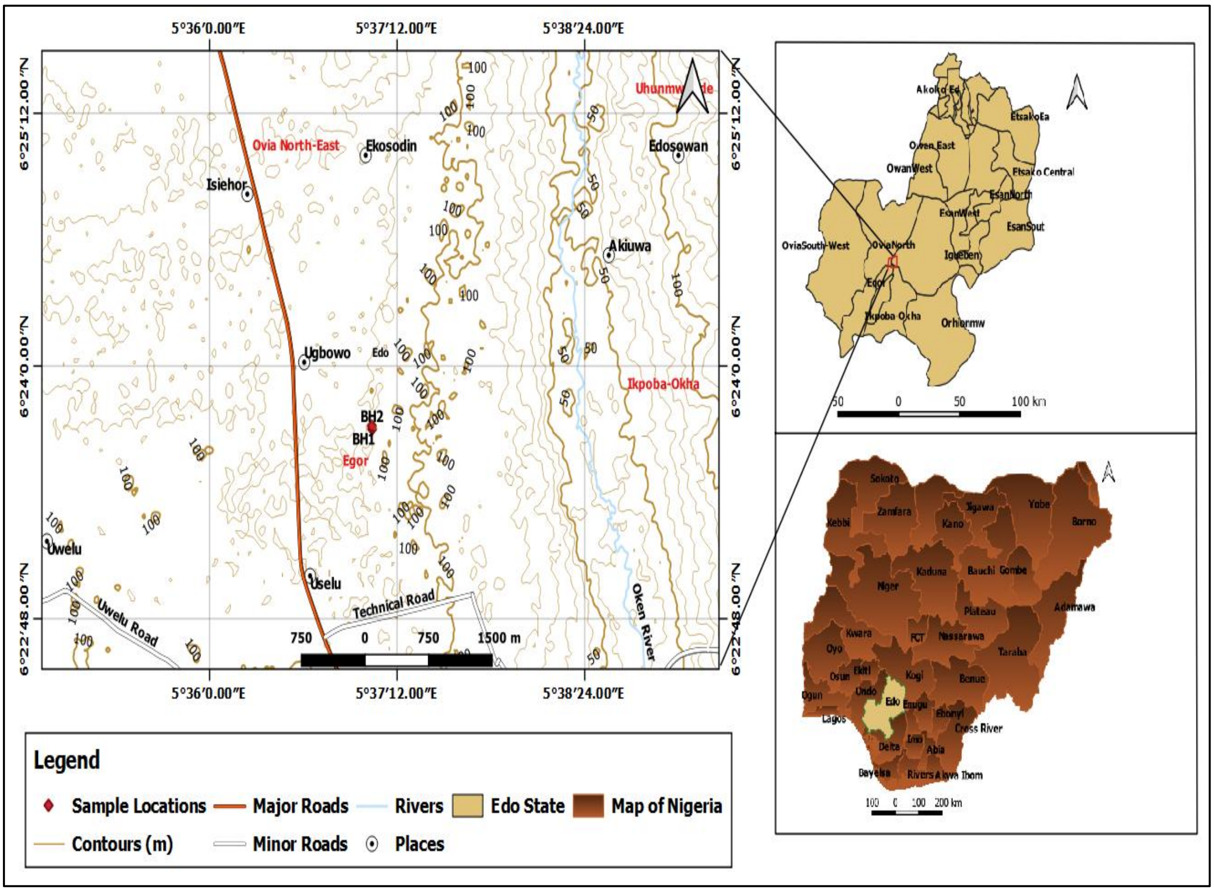

Figure 1.0: Topographic map of the study area

CHAPTER TWO

GEOLOGICAL SETTING AND LITERATURE REVIEW

2.1 GEOTECHNICAL PROPERTIES OF SOIL

Geotechnical properties are the physical and mechanical characteristics of soils that influence their behavior when subjected to different engineering loads and environmental conditions. These properties determine how soils can be used in the design and construction of engineering structures such as foundations, embankments, pavements, and retaining walls. Understanding them is essential in predicting soil performance, ensuring stability, and preventing structural failures (Das, 2016; Coduto et al., 2011).

2.1.1 Specific Gravity (Gs)

This is the ratio of the unit weight of soil solids to the unit weight of water at a standard temperature. It provides insight into the mineral composition of soils, which in turn affects strength and stability.

Specific gravity helps in identifying soil type and is used in calculations of void ratio, porosity, and degree of saturation which is critical in foundation design and stability analysis (Murthy, 2003).

2.1.2 Particle Size Analysis

Particle size analysis determines the proportion of gravel, sand, silt, and clay in a soil sample. It is performed through sieve analysis for coarse soils and hydrometer analysis for fine soils. Grain size distribution influences soil permeability, compaction, and shear strength. Well-graded soils (broad range of particle sizes) exhibit better strength and lower compressibility compared to poorly graded soils (uniform particles). This property is crucial in selecting materials for embankments, filters, and pavement layers (Lambe & Whitman, 1979).

2.1.3 Compaction and Consolidation

Compaction is the artificial densification of soil by mechanical means to reduce voids and increase strength. Consolidation is the time-dependent reduction in soil volume due to expulsion of water from pores under sustained loading. Compaction is necessary for constructing embankments, road bases, and earth dams, as it improves load-bearing capacity and reduces permeability. Consolidation is critical in predicting settlement of structures, especially those built on clay deposits, to prevent uneven settlement and structural damage (Terzaghi et al., 1996).

2.1.4 Permeability

This refers to the ease with which water flows through soil pores. It depends on pore size, particle arrangement, and void ratio. Permeability is vital in drainage design, slope stability analysis, and assessing seepage beneath earth dams and retaining structures. Low permeability soils, such as clays, reduce drainage, while high permeability soils, like sands, facilitate rapid flow. Proper evaluation prevents issues such as piping, erosion, and structural failure (Holtz et al., 2011).

2.1.5 Shear Strength

Shear strength is the soil's ability to resist sliding or shear stresses. It is governed by two main components: cohesion (c) and angle of internal friction (φ), expressed in the Mohr-Coulomb failure criterion. Shear strength is one of the most critical soil properties, as it determines the stability of slopes, bearing capacity of foundations, and the design of retaining walls and embankments. A reduction in shear strength often leads to slope failures, landslides, and foundation collapse (Das, 2016).

2.1.6 Consistency Limits

The consistency limits, also known as Atterberg Limits, describe the moisture content levels at which fine-grained soils change their states. They include:

1. **Liquid Limit (LL):** Moisture content at which soil changes from plastic to liquid state.
2. **Plastic Limit (PL):** Moisture content at which soil changes from semi-solid to plastic state.
3. **Shrinkage Limit (SL):** Moisture content where further drying does not cause volume reduction.

These limits are essential in classifying fine-grained soils and predicting their behaviour under varying moisture conditions. They are critical for assessing the potential for swelling, shrinkage, and settlement, especially in clayey soils used in road subgrades and foundations (Craig, 2004).

2.2 PREVIOUS WORK DONE

Several researchers have investigated the influence of geotechnical properties of soil on the performance of engineering structures.

Ekeocha and Okagbue (2012) investigated the geotechnical behaviour of lateritic soils in southeastern Nigeria, commonly used in road construction. They observed that soils with high plasticity index and poor compaction quality led to early pavement failures such as rutting and cracking. This indicates that soil index properties and compaction characteristics play a significant role in road performance, especially in tropical regions where lateritic soils are predominant.

Adeyemi (2013) conducted a comprehensive geotechnical appraisal of soils in southwestern Nigeria and revealed that poor understanding of soil compressibility and bearing capacity was a key factor contributing to frequent foundation settlement and cracking in residential buildings. His findings highlighted the need for detailed site-specific soil studies before foundation design.

Al-Khaili and Al-Shamrani (2015) examined the permeability of clay deposits in the Middle East. They found that low-permeability clays tend to trap excess pore water pressure during construction, which increases the risk of slope failures and instability in embankments and retaining walls. Their study underscores the importance of permeability analysis in geotechnical design, particularly in hydraulic structures such as dams and drainage systems.

Budhu (2015) emphasized the role of soil shear strength parameters (cohesion and angle of internal friction) in slope stability and bearing capacity design. He explained that soils with low shear strength are highly susceptible to slope failure and require reinforcement or ground improvement techniques. Likewise, Terzaghi, Peck, and Mesri (1996) laid the foundation for modern soil mechanics by providing theories on consolidation, settlement, and bearing capacity, which remain relevant in today's engineering practice.

Onyelowe (2017) focused on soil stabilization as a means of improving weak soils for engineering purposes. His study demonstrated that lime and cement stabilization enhanced shear strength, reduced compressibility, and increased the load-bearing capacity of subgrade soils. This aligns with global best practices where soil improvement techniques are adopted to extend the life span of road pavements and ensure foundation stability.

Onyelowe and Bui Van (2020) evaluated expansive soils in West Africa and highlighted that soil swell–shrink behavior due to seasonal moisture variation was responsible for severe foundation heaving and road surface cracking. Their findings are especially significant because expansive soils are widespread in tropical regions and pose major challenges to infrastructure durability.

Andre-Obayanju, Edegbai & Imarhiagbe (2022) examined clay deposits from Oduna, Okada, and Etsako in Southwestern Nigeria. Their findings showed that many of these soils are fine-grained, with plasticity ranging from medium to very high, and that their compaction and California Bearing Ratio values often fall below standard specifications. They conclude that these clay deposits may be unsuitable for construction without stabilization.

Andre-Obayanju & Ireaja (2022) also performed a geotechnical analysis of road failure along 20th Street, BDPA, Benin City. The study included tests like grain size distribution, Atterberg limits, compaction, and California Bearing Ratio. The results showed significant deviation from the standards of the Federal Ministry of Works, and the authors attributed road failure in part to poor sub-grade soil geotechnical properties.

Dimgba, C., Nwankwo, M., and Okolie, U. (2023) conducted an investigation on the prediction of undrained shear strength of soft clays within the Niger Delta region of Nigeria. The study utilized soil index properties such as natural moisture content and Atterberg limits to estimate undrained shear strength. Their results revealed a strong correlation ($R^2 \approx 0.805$) between these parameters, suggesting that simple soil index tests can effectively predict strength characteristics in cohesive soils, which is particularly useful for foundation design and slope stability analysis.

Falowo, O., Akintola, A., and Ogunniyi, T. (2024) carried out a geo-geotechnical assessment of Okeigbo area, Ondo State, Nigeria, using integrated geophysical and geotechnical methods. Their findings showed that the subsoil was mainly clayey with low activity (≈ 0.36), poor permeability (3.67×10^{-8} cm/s), and deep weathering up to 20.9 m. The study emphasized the need for adequate foundation design and possible soil treatment before construction to prevent structural failure.

Segun, B., Okojie, D., and Ede, A. (2025) conducted a case study of subgrade soil properties in Benin City, Nigeria, to identify causes of persistent pavement failures. Laboratory tests (compaction, CBR, and moisture content) revealed clay content above 50% and low maximum dry density, making the soils weak for supporting pavements. They recommended stabilization with lime or cement before construction to improve structural integrity

From these previous studies, it is evident that geotechnical properties such as permeability, shear strength, plasticity, compaction, compressibility, and bearing capacity are critical determinants of structural performance. Where these properties are not properly considered, civil engineering structures are prone to failure, resulting in loss of resources and sometimes lives. Therefore, these works provide a strong foundation for the present research, which aims to reinforce the role of geotechnical investigations in the safe and sustainable design of engineering projects.

2.3 GEOLOGY OF BENIN CITY

Benin City is situated within the Benin Formation, which represents the youngest geological unit of the Niger Delta sedimentary sequence. The formation mainly consists of coarse-grained sands, gravelly sands, and occasional clay or shale lenses deposited during the late

Tertiary to early Quaternary periods. The sediments are of continental origin and were formed predominantly through fluvial and deltaic processes (Avbovbo, 1978; Short & Stauble, 1967). The soils in Benin City are largely lateritic and ferruginous, resulting from extensive tropical weathering of the underlying sandy formations. These lateritic soils are typically reddish-brown due to the presence of iron and aluminum oxides. They possess variable engineering properties, depending on the degree of weathering and clay content. In general, they exhibit moderate plasticity and good bearing capacity when well-compacted, but they can lose strength when exposed to prolonged moisture (Okosun, 1998). Topographically, the city lies on slightly undulating terrain, ranging in elevation from about 60 m to 150 m above sea level. The drainage pattern is controlled mainly by the Ikpoba and Ogba Rivers and several smaller tributaries, which influence the groundwater regime and erosion patterns within the area (Offodile, 2002). Geologically, the Benin Formation is characterized by poorly consolidated sands, sometimes interbedded with clay lenses. The sands are usually medium to coarse-grained, sub-angular to sub-rounded, and moderately sorted. The clayey layers act as impermeable zones, which affect groundwater flow and the soil's engineering response under load. Because of the high sand fraction, the formation exhibits high permeability, which allows rapid infiltration of water during rainfall (Akpokodje, 1987). The subsurface conditions across Benin City generally consist of lateritic topsoil underlain by sandy strata that extend to considerable depths. These geological characteristics have a direct influence on foundation behavior, slope stability, and erosion potential. Hence, understanding the geology of the Benin Formation is essential for proper geotechnical assessment and sustainable civil engineering design within the region.

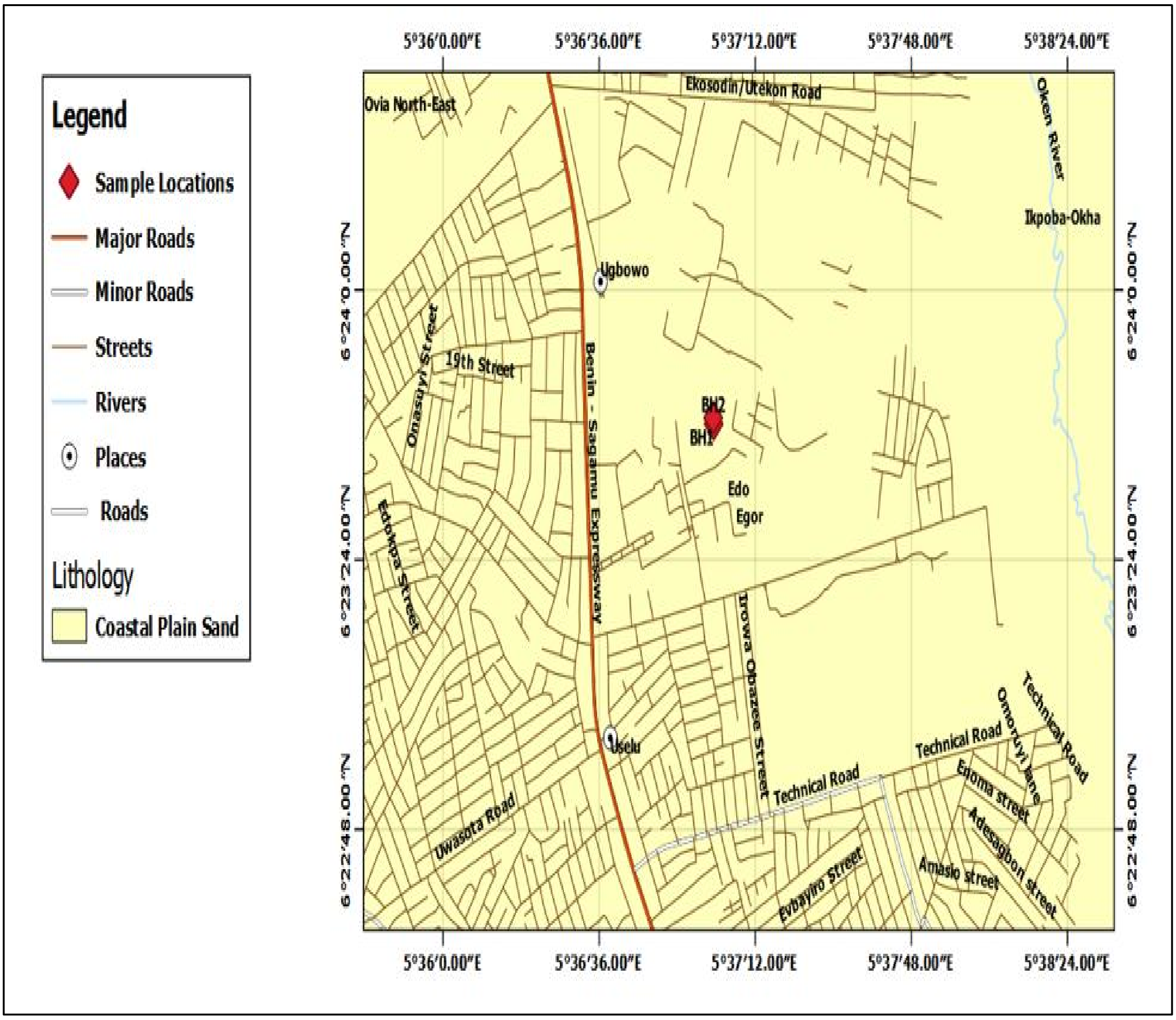

Figure 2.0: Geologic map of Benin City

CHAPTER THREE

MATERIALS AND METHODS

This involves the materials, sampling procedure, and laboratory methods used in carrying out the research work. The laboratory analyses were conducted to determine the essential geotechnical properties of the soil samples collected from the study area. These tests include the determination of natural moisture content, grain size distribution, Atterberg limits (liquid and plastic limits), specific gravity, compaction, and triaxial compression tests. Each of these tests provides valuable data on soil behavior, strength, and suitability for engineering structures. Soil samples were collected at depths of **1.0 m, 2.0 m, 3.0 m, and 4.0 m** from the study site using a hand auger. Both **disturbed** and **undisturbed** samples were obtained. Disturbed samples were used for index property tests such as moisture content, particle size distribution, Atterberg limits, and specific gravity, while undisturbed samples were reserved for strength tests such as compaction and triaxial compression. All samples were properly labeled, sealed in airtight polythene bags to retain natural moisture, and transported to the geotechnical laboratory for analysis.

3.1 MOISTURE CONTENT

The moisture content of a soil is the ratio of weight of water in the soil to dry weight of solid particles expressed in percentage. The **moisture content test** was carried out to determine the percentage of water present in the soil as it exists in its natural condition. The test followed the **BS 1377 (Part 2, 1990)** standard. A small portion of each soil sample was weighed (wet weight), dried in an oven at a constant temperature of **105–110°C for 24 hours**, and then reweighed (dry weight). The moisture content was calculated using the formula:

$$moisture\ content\ (w) = \frac{w1-w2}{w2} \times 100$$

Where:

W1 = weight of wet soil

W2 = weight of dry soil

This test provides insight into the soil's compressibility, bearing capacity, and behaviour under loading.

3.2 GRAIN SIZE DISTRIBUTION TEST

The **grain size analysis** was conducted to determine the proportion of different particle sizes within the soil sample. This helps in classifying the soil and understanding its drainage and load-bearing behaviour. The test was performed in accordance with **BS 1377 (Part 2, 1990)**. The soil sample was oven-dried and passed through a series of standard sieves arranged in decreasing mesh size. The weight of soil retained on each sieve was recorded, and the percentage passing through each sieve was calculated. For finer particles (silt and clay), **hydrometer analysis** was carried out. A semi-logarithmic graph of percentage finer versus particle size was plotted to obtain the **particle size distribution curve**, which helps in determining whether the soil is well-graded or poorly graded.

3.3 ATTERBERG LIMITS TEST

The **Atterberg limits** define the moisture content ranges within which soil changes from one state to another from solid to semi-solid, plastic, and liquid states. Two tests were conducted following **BS 1377 (Part 2, 1990):**

Liquid Limit (LL): Determined using the **Casagrande apparatus**. A soil paste was placed in a brass cup, and a groove was cut through it. The cup was repeatedly dropped from a height of 10 mm until the groove closed over a length of 13 mm. The corresponding moisture content was recorded, and the **liquid limit** was determined as the moisture content at 25 blows.

Plastic Limit (PL): Determined by rolling the soil into threads until they crumbled at a diameter of 3 mm.

The **Plasticity Index (PI)** was calculated as:

PI = LL - PL

3.4 SPECIFIC GRAVITY TEST

The **specific gravity** of the soil solids was determined using the **density bottle method** according to **BS 1377 (Part 2, 1990)**. A clean, dry density bottle was weighed, filled with dry soil and water, and reweighed at each stage. The specific gravity (Gs) was calculated using:

$$Gs = \frac{w2-w1}{(w4-w1)-(w3-w2)}$$

Where:

$W1$ = weight of empty bottle

$W2$ = weight of bottle + dry soil

$W3$ = weight of bottle + soil + water

$W4$ = weight of bottle filled with water only

The specific gravity gives an idea of the mineral composition and helps classify soil type.

3.5 COMPACTION TEST

The **compaction test** was performed using the **Standard Proctor method** (BS 1377, Part 4, 1990) to establish the relationship between dry density and moisture content. A known quantity of soil was mixed with varying amounts of water and compacted in a mould in three layers, each layer receiving 25 blows from a 2.5 kg rammer dropped from a height of 300 mm. The bulk and dry densities were calculated, and a graph of **dry density versus moisture content** was plotted to obtain the **Optimum Moisture Content (OMC)** and **Maximum Dry Density (MDD)**. These parameters are essential in evaluating soil's compaction characteristics, which influence the strength and settlement behaviour of subgrade materials in engineering structures.

3.6 TRIAXIAL COMPRESSION TEST

The **triaxial compression test** was carried out on undisturbed cylindrical samples to determine the **shear strength parameters** — cohesion (c) and the angle of internal friction (φ). The procedure followed **BS 1377 (Part 8, 1990)** standards. The soil specimen was enclosed in a rubber membrane and placed in a triaxial cell. Different confining pressures were applied, and the sample was sheared until failure occurred. The deviator stress at failure was plotted against the confining pressure, and the **Mohr–Coulomb failure envelope** was drawn. The shear strength was computed from the relation:

$\tau = c + \sigma \tan(\varphi)$

Where;

τ = shear strength,

c = cohesion,

φ= angle of internal friction.

This test provides reliable data for foundation design, slope stability analysis, and retaining wall assessment.

CHAPTER FOUR

RESULTS AND DISCUSSION

The results of the analysis carried out are listed and discussed below

4.1 ATTERBERG LIMIT TEST RESULTS

LIQUID AND PLASTIC LIMITS,LINEAR SHRINKAGE

Sample No: **BH1, 1.0m** Liquid Limit: **58.70%** Plastic Limit: **30.72%**

Date: **07-10-2025** Plastic Index: **27.98%**

Location:

Operator: **BEMIGHO**

Proportion of sample retained on No. 36 B.S. Steve = Per cent
No. of blows refers to liquid limit determination.
Shrinkage % refers to linear Shrinkage.

Type of Test	LL		LL		LL		LL		LL	
No. of Blows/shrinkage %	42.00		32.00		22.00		16.00		8.00	
Container No.	RT		FO		MP		OB		OZ	
Wt of wet soil & container (g)	56.20		53.00		61.50		51.60		57.20	
Wt of dried soil & container (g)	43.10		40.10		45.20		37.70		41.20	
Wt of container (g)	17.40		16.80		18.00		15.60		17.20	
Wt of dry soil (Wd) (g)	25.70		23.30		27.20		22.10		24.00	
Wt of moisture (Wm) (g)	13.10		12.90		16.30		13.90		16.00	
Moisture contain 100 (Wm/Wd)	50.97		55.36		59.93		62.90		66.67	
Type of Test		PL		PL		PL				PL
No. of Blows/shrinkage %										
Container No.		VI		OZ		ZU				
Wt of wet soil & container (g)		25.90		25.50		27.80				
Wt of dried soil & container (g)		24.20		23.60		25.60				
Wt of container (g)		18.60		17.60		18.30				
Wt of dry soil (Wd) (g)		5.60		6.00		7.30				
Wt of moisture (Wm) (g)		1.70		1.90		2.20				
Moisture contain 100 (Wm/Wd)		30.36		31.67		30.14				

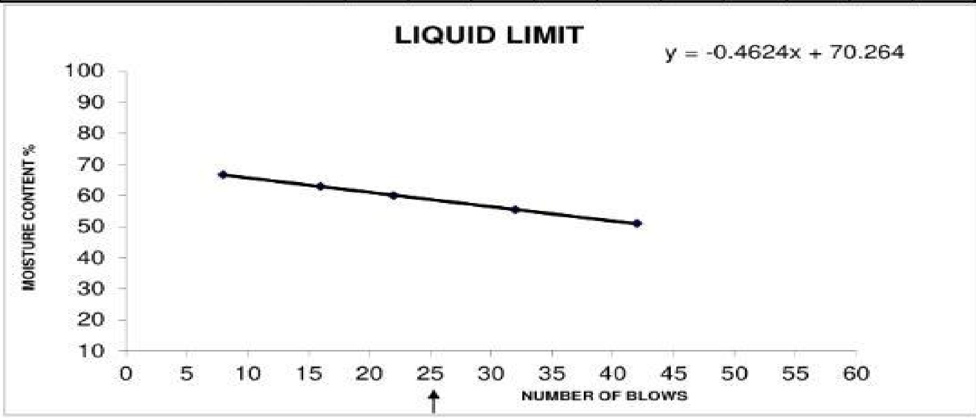

Figure 4.1.1: Atterberg limit results for BH1 at depth 1.0m

LIQUID AND PLASTIC LIMITS,LINEAR SHRINKAGE

Sample No: **BH1, 3.0m** Liquid Limit: **57.69%** Plastic Limit: **31.88%**

Date: **07-10-2025** Plastic Index: **25.82%**

Location:

Operator: **BEMIGHO**

Proportion of sample retained on No. 36 B.S. Steve = Per cent
No. of blows refers to liquid limit determination.
Shrinkage % refers to linear Shrinkage.

Type of Test	LL		LL		LL		LL		LL	
No. of Blows/shrinkage %	44.00		34.00		24.00		18.00		12.00	
Container No.	VP		XX		OH		TH		PA	
Wt of wet soil & container (g)	59.50		57.80		49.20		57.30		52.60	
Wt of dried soil & container (g)	45.20		44.10		37.00		41.50		38.80	
Wt of container (g)	16.10		18.10		16.00		15.60		17.30	
Wt of dry soil (Wd) (g)	29.10		26.00		21.00		25.90		21.50	
Wt of moisture (Wm) (g)	14.30		13.70		12.20		15.80		13.80	
Moisture contain 100 (Wm/Wd)	49.14		52.69		58.10		61.00		64.19	
Type of Test		PL		PL		PL				PL
No. of Blows/shrinkage %										
Container No.		DE		VZ		JA				
Wt of wet soil & container (g)		28.00		26.50		27.20				
Wt of dried soil & container (g)		25.50		24.10		24.80				
Wt of container (g)		17.80		16.50		17.20				
Wt of dry soil (Wd) (g)		7.70		7.60		7.60				
Wt of moisture (Wm) (g)		2.50		2.40		2.40				
Moisture contain 100 (Wm/Wd)		32.47		31.58		31.58				

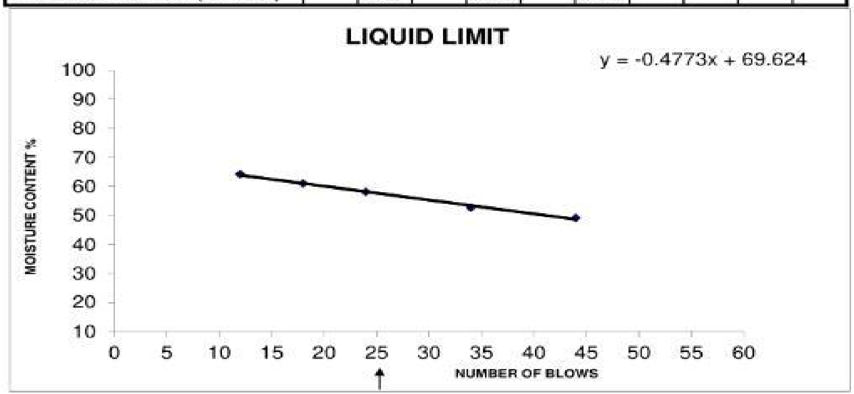

Figure 4.1.2: Atterberg limit results for BH1 at depth 3.0m

LIQUID AND PLASTIC LIMITS,LINEAR SHRINKAGE

Sample No: **BH2, 2.0m** Liquid Limit: **59.93%** Plastic Limit: **30.98%**

Date: **07-10-2025** Plastic Index: **28.95%**

Location:

Operator: **BEMIGHO**

Proportion of sample retained on No. 36 B.S. Steve = Per cent
No. of blows refers to liquid limit determination.
Shrinkage % refers to linear Shrinkage.

Type of Test	LL		LL		LL		LL		LL	
No. of Blows/shrinkage %	42.00		32.00		22.00		16.00		8.00	
Container No.	BZ		VX		PA		OZ		TB	
Wt of wet soil & container (g)	57.10		52.40		59.90		56.50		55.50	
Wt of dried soil & container (g)	43.10		39.60		43.80		41.30		39.90	
Wt of container (g)	17.20		17.30		17.20		17.20		16.40	
Wt of dry soil (Wd) (g)	25.90		22.30		26.60		24.10		23.50	
Wt of moisture (Wm) (g)	14.00		12.80		16.10		15.20		15.60	
Moisture contain 100 (Wm/Wd)	54.05		57.40		60.53		63.07		66.38	
Type of Test		PL		PL		PL				PL
No. of Blows/shrinkage %										
Container No.		RE		VT		ST				
Wt of wet soil & container (g)		28.30		29.00		28.00				
Wt of dried soil & container (g)		25.70		26.10		25.60				
Wt of container (g)		17.50		16.70		17.70				
Wt of dry soil (Wd) (g)		8.20		9.40		7.90				
Wt of moisture (Wm) (g)		2.60		2.90		2.40				
Moisture contain 100 (Wm/Wd)		31.71		30.85		30.38				

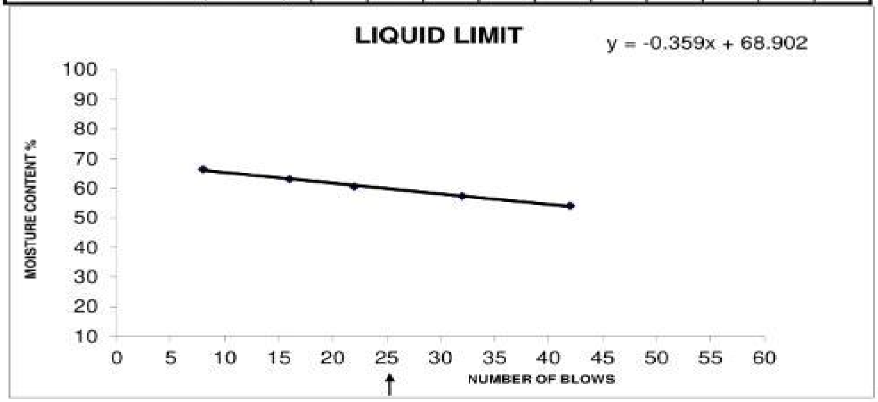

Figure 4.1.3: Atterberg limit results for BH2 at depth 2.0m

LIQUID AND PLASTIC LIMITS,LINEAR SHRINKAGE

Sample No: **BH2, 4.0m** Liquid Limit: **54.09%** Plastic Limit: **28.17%**

Date: **07-10-2025** Plastic Index: **25.91%**

Location:

Operator: **BEMIGHO**

Proportion of sample retained on No. 36 B.S. Steve = Per cent
No. of blows refers to liquid limit determination.
Shrinkage % refers to linear Shrinkage.

Type of Test	LL		LL		LL		LL		LL	
No. of Blows/shrinkage %	42.00		32.00		22.00		16.00		8.00	
Container No.	AE		OT		NO		PI		BS	
Wt of wet soil & container (g)	55.70		54.30		59.30		53.70		55.20	
Wt of dried soil & container (g)	43.40		41.90		44.90		39.80		40.90	
Wt of container (g)	17.60		17.40		19.00		15.60		17.50	
Wt of dry soil (Wd) (g)	25.80		24.50		25.90		24.20		23.40	
Wt of moisture (Wm) (g)	12.30		12.40		14.40		13.90		14.30	
Moisture contain 100 (Wm/Wd)	47.67		50.61		55.60		57.44		61.11	
Type of Test		PL		PL		PL				PL
No. of Blows/shrinkage %										
Container No.		AC		OM		OB				
Wt of wet soil & container (g)		26.30		31.70		27.60				
Wt of dried soil & container (g)		23.50		28.60		25.50				
Wt of container (g)		13.50		18.00		17.80				
Wt of dry soil (Wd) (g)		10.00		10.60		7.70				
Wt of moisture (Wm) (g)		2.80		3.10		2.10				
Moisture contain 100 (Wm/Wd)		28.00		29.25		27.27				

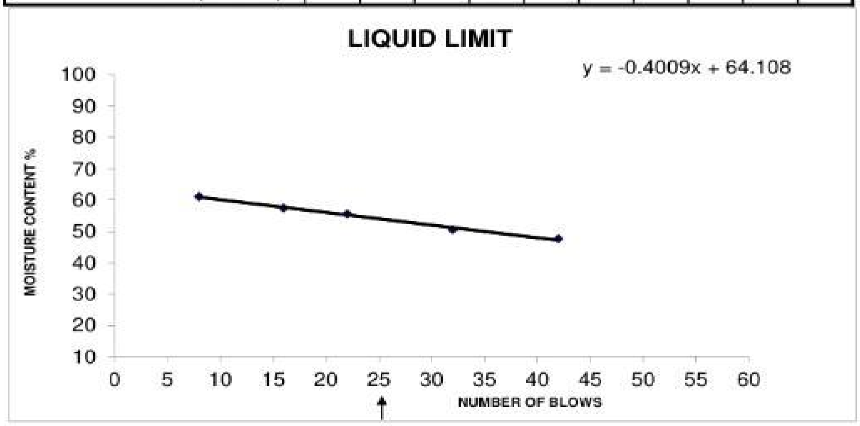

Figure 4.1.4: Atterberg limit results for BH2 at depth 4.0m

4.2 SPECIFIC GRAVITY

DETERMINATION OF SPECIFIC GRAVITY OF SOIL PARTICLES

DATE: **20-10-2025** PROJECT:

S/N	BOREHOLE ID	DEPTH (m)	BN	B+W	B+S+W	B+S	B	Ad. W	WWAS	WS	WOWDS	Gs	AGs
1	BH1	1.0m	BI	73.40	89.40	47.00	21.80	51.60	42.40	25.20	9.20	2.74	2.67
			DC	75.40	88.50	45.80	24.50	50.90	42.70	21.30	8.20	2.60	
2	BH1	3.0m	ZE	70.20	85.20	45.30	20.20	50.00	39.90	25.10	10.10	2.49	2.40
			PII	75.60	88.00	46.30	24.50	51.10	41.70	21.80	9.40	2.32	
3	BH2	2.0m	ZG	70.10	85.80	46.20	20.90	49.20	39.60	25.30	9.60	2.64	2.64
			U4	74.60	88.40	45.00	22.80	51.80	43.40	22.20	8.40	2.64	
4	BH2	4.0m	VE	73.90	86.80	43.80	22.80	51.10	43.00	21.00	8.10	2.59	2.61
			SNN	72.30	86.50	42.30	19.40	52.90	44.20	22.90	8.70	2.63	

B+W = Wt. of Bottle + Water (full) W4
B+S+W = Wt. of Bottle + Soil+ Water W3
B+S = Wt. of Bottle + Soil W2
B = Wt. of Bottle W1
Ad.W = Wt. of Added Water (full) (W4-W1)
WWAS = Wt. of Water added to Soil (W3-W2)
WS = Wt. of Soil (W2-W1)
WOWDS = Wt. of Water Displaced by Soil (W4-W1)-(W3-W2) = W
GS = Specific Gravity (W2-W1)/W

Figure 4.2: Specific gravity

4.3 GRAIN SIZE ANALYSIS

UNIBEN GEOTECH RESEARCH
GRAIN SIZE ANALYSIS BY WET-SIEVING

PROJECT:
SAMPLE ID: **BH1, 1.0m**
DATE: **06/10/2025**
TESTED BY:

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	0	100	100
10	2	0.3	99.7	99.7
14	1.18	3.6	96.1	96.1
25	0.6	13.7	82.4	82.4
36	0.425	5.7	76.7	76.7
52	0.3	6.4	70.3	70.3
72	0.212	17.7	52.6	52.6
100	0.15	3.1	49.5	49.5
200	0.075	4.4	45.1	45.1

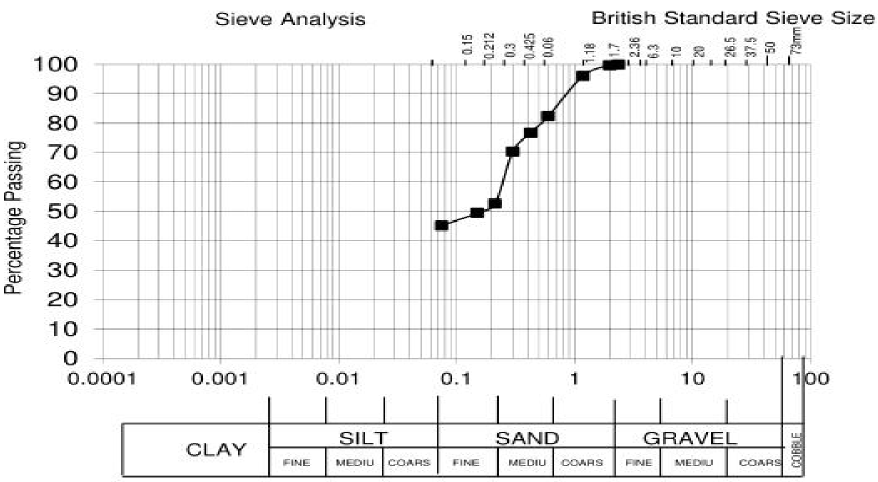

Figure 4.3.1: Grain size analysis result at BH1, 1.0m

UNIBEN GEOTECH RESEARCH
GRAIN SIZE ANALYSIS BY WET-SIEVING

PROJECT:
SAMPLE ID: **BH1, 3.0m**
DATE: **06/10/2025**
TESTED BY:

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	0	100	100
10	2	0	100	100
14	1.18	3.3	96.7	96.7
25	0.6	13	83.7	83.7
36	0.425	4.5	79.2	79.2
52	0.3	5.9	73.3	73.3
72	0.212	17.6	55.7	55.7
100	0.15	4.3	51.4	51.4
200	0.075	4.1	47.3	47.3

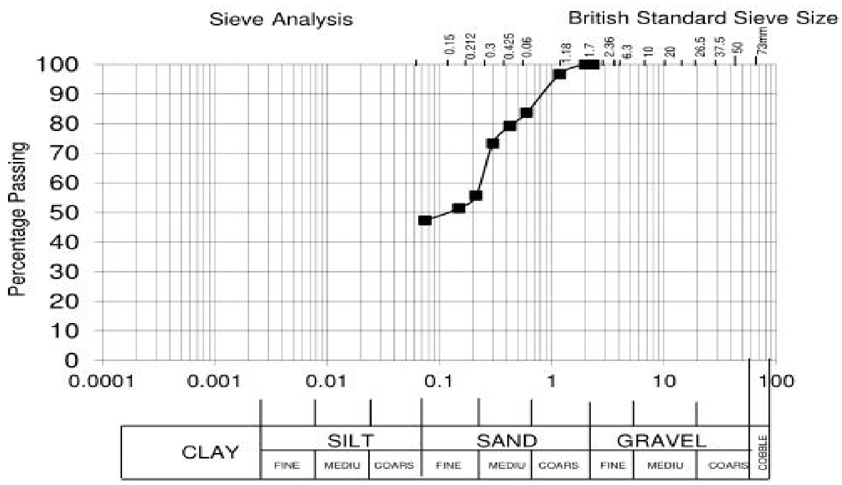

Figure 4.3.2: Grain size analysis result at BH1, 3.0m

UNIBEN GEOTECH RESEARCH
GRAIN SIZE ANALYSIS BY WET-SIEVING

PROJECT:
SAMPLE ID: **BH2, 2.0m**
DATE: **06/10/2025**
TESTED BY:

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	0	100	100
10	2	0.9	99.1	99.1
14	1.18	2.5	96.6	96.6
25	0.6	15.5	81.1	81.1
36	0.425	5.6	75.5	75.5
52	0.3	6	69.5	69.5
72	0.212	16.6	52.9	52.9
100	0.15	3.8	49.1	49.1
200	0.075	3.3	45.8	45.8

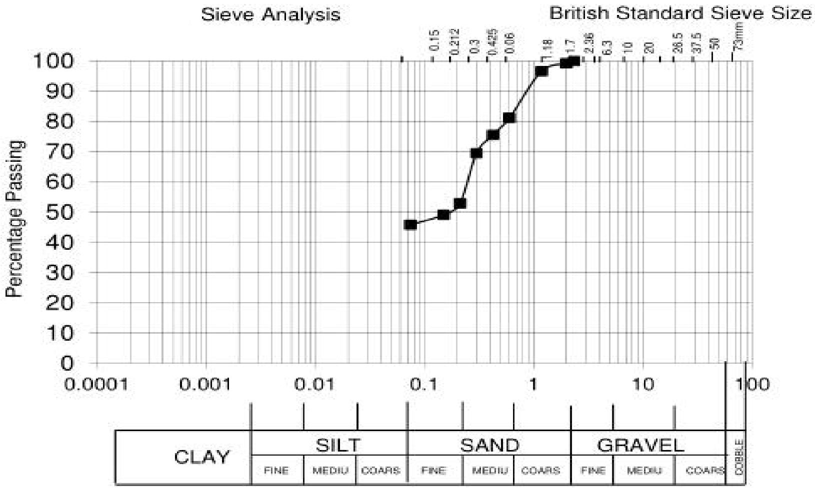

Figure 4.3.3: Grain size analysis result at BH2, 2.0m

UNIBEN GEOTECH RESEARCH
GRAIN SIZE ANALYSIS BY WET-SIEVING

PROJECT:

SAMPLE ID: **BH2, 4.0m**

DATE: **06/10/2025**

TESTED BY:

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	0	100	100
10	2	0	100	100
14	1.18	1.9	98.1	98.1
25	0.6	15.2	82.9	82.9
36	0.425	6.6	76.3	76.3
52	0.3	6.4	69.9	69.9
72	0.212	17.8	52.1	52.1
100	0.15	3.7	48.4	48.4
200	0.075	4.1	44.3	44.3

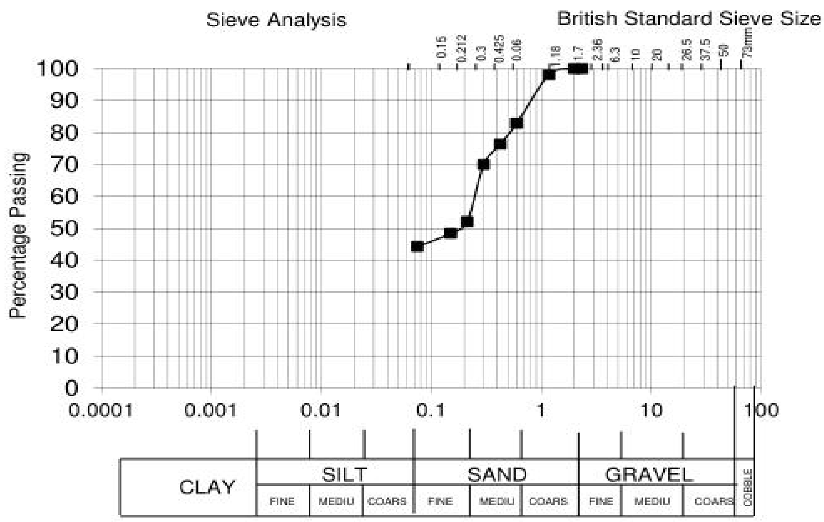

Figure 4.3.4: Grain size analysis result at BH2, 4.0m

4.4 MOISTURE CONTENT

DETERMINATION OF MOISTURE CONTENT OF SOIL PARTICLES
(STANDARD LABORATORY METHOD)

DATE: **03-10-2025** PROJECT:

S/N	LOCATION	DEPT	CN	WWS+WC	WDS+WC	WC	WDS	WM	MC	AMC
1	BH1	1.0m	OBE	184.46	160.10	29.00	131.10	24.36	18.58	18.55
			PRED	165.48	144.90	33.74	111.16	20.58	18.51	
2	BH1	3.0m	EYI	148.94	134.00	33.24	100.76	14.94	14.83	14.70
			ZF	193.67	173.64	36.21	137.43	20.03	14.57	
3	BH2	2.0m	ADY	168.83	149.31	31.64	117.67	19.52	16.59	16.62
			BX2	195.73	172.60	33.65	138.95	23.13	16.65	
4	BH2	4.0m	SLOT F	183.88	159.87	30.00	129.87	24.01	18.49	18.49
			ND	157.48	138.15	33.59	104.56	19.33	18.49	

WC = M1
WWS+WC = M2
WDS+WC = M3
WDS = Weight of dry soil (M3-M1)
WM = Weight of moisture (M2-M3)
MC = Moisture Content ((M2-M3)/(M3-M1))*100
AMC = Average moisture content (MC/2)

Figure 4.4: Moisture Content

4.5 COMPACTION TEST

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL
USING STANDARD/HEAVY COMPACTION

Project:

Sample ID: **BH1, 1.0m** Date:**07-10-2025** MDD: **1.67g/cm³**

Total weight of Sample:**...3000g......** OPT.MC: **17.4%**

B.S. / C.B.R. Mould**...3120g**

Wt. of mould & wet Soil (W2) g	4689.00		4920.00		4962.00		4954.00		4925.00					
Wt. of mould (W1) g	3120.00		3120.00		3120.00		3120.00		3120.00					
Wt. of wet soil (W2-W1) g	1569.00		1800.00		1842.00		1834.00		1805.00					
Bulk Density (Pb) (W2-W1)/x g/cm^3	1.67		1.92		1.96		1.95		1.92					
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X = 939.82 g/cm^3														
Container No.	TW	DX	ZM	ZA	VB	MO	WX	RT	SZ	IB				
Wt. of wet soil & container (g)	54.55	62.15	57.10	50.84	75.45	69.02	48.84	50.21	61.62	71.39				
Wt. of Dry soil & container (g)	50.87	57.68	52.41	47.14	69.30	63.80	44.96	46.07	57.16	65.23				
Wt. of Container (g)	24.02	24.95	23.73	24.52	34.14	34.08	24.40	23.66	33.92	33.30				
Wt. of dry soil (Wd) g	26.85	32.73	28.68	22.62	35.16	29.72	20.56	22.41	23.24	31.93				
Wt. of Moisture (Wm) g	3.68	4.47	4.69	3.70	6.15	5.22	3.88	4.14	4.46	6.16				
Moistur Content 100(Wm/Wd) %	13.71	13.66	16.35	16.36	17.49	17.56	18.87	18.47	19.19	19.29				
Average Moisture Content (m) %	13.68		16.36		17.53		18.67		19.24					
Dry Density = Pb/1+ (m/100) (g/cm^3)	1.47		1.65		1.67		1.64		1.61					
C.B.R. (mseen of top & bottom) %														

Figure 4.5.1: Dry and moisture values for BH1, 1.0m

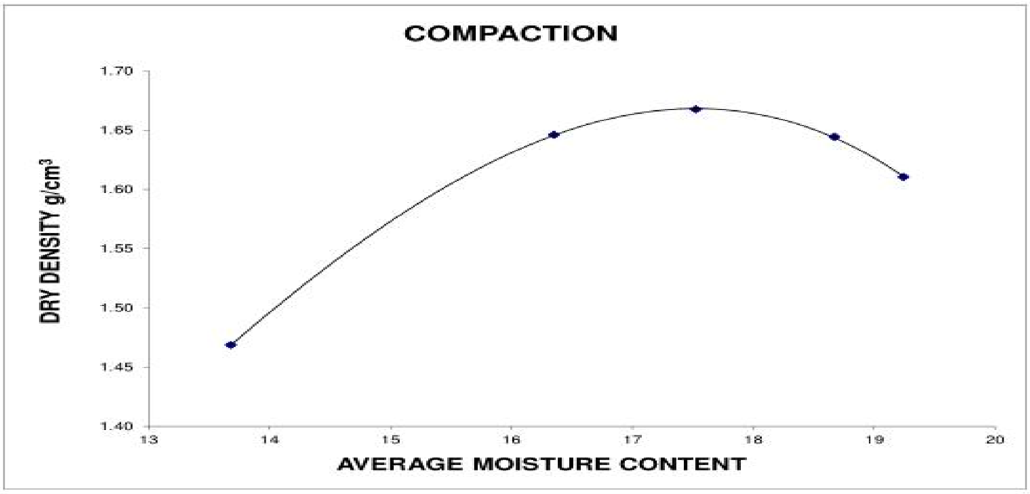

Figure 4.5.2: Compaction chart at BH 1,1.0m

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL
USING STANDARD/HEAVY COMPACTION

Project:

Sample ID: **BH1, 3.0m** Date:**07-10-2025** MDD: **1.70g/cm³**

Total weight of Sample:...**3000g**...... OPT.MC: **15.9%**

B.S. / C.B.R. Mould...**3120g**

Wt. of mould & wet Soil (W2) g	4619.00		4902.00		4972.00		4930.00		4887.00			
Wt. of mould (W1) g	3120.00		3120.00		3120.00		3120.00		3120.00			
Wt. of wet soil (W2-W1) g	1499.00		1782.00		1852.00		1810.00		1767.00			
Bulk Density (Pb) (W2-W1)/x g/cm^3	1.59		1.90		1.97		1.93		1.88			
MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X = 939.82 g/cm^3												
Container No.	TA	OV	MZ	OB	PA	ET	FF	BO	NP	LA		
Wt. of wet soil & container (g)	37.84	38.10	34.42	43.63	47.43	47.91	48.45	39.66	52.73	42.92		
Wt. of Dry soil & container (g)	35.50	35.72	31.80	40.42	43.20	43.60	43.61	36.25	47.13	38.80		
Wt. of Container (g)	17.35	16.14	13.93	18.22	17.38	17.69	17.52	17.73	18.72	17.73		
Wt. of dry soil (Wd) g	18.15	19.58	17.87	22.20	25.82	25.91	26.09	18.52	28.41	21.07		
Wt. of Moisture (Wm) g	2.34	2.38	2.62	3.21	4.23	4.31	4.84	3.41	5.60	4.12		
Moistur Content 100(Wm/Wd) %	12.89	12.16	14.66	14.46	16.38	16.63	18.55	18.41	19.71	19.55		
Average Moisture Content (m) %	12.52		14.56		16.51		18.48		19.63			
Dry Density = Pb/1+ (m/100) (g/cm^3)	1.42		1.66		1.69		1.63		1.57			
C.B.R. (mseen of top & bottom) %												

Figure 4.5.3: Dry and moisture values for BH1, 3.0m

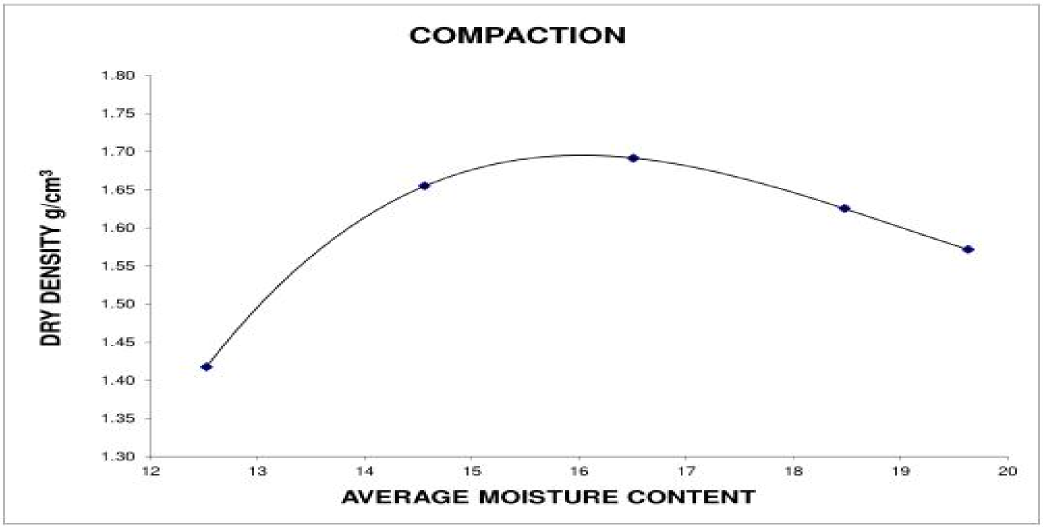

Figure 4.5.4: Compaction chart at BH1, 3.0m

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL
USING STANDARD/HEAVY COMPACTION

Project:

Sample ID: **BH2, 2.0m** Date:**07-10-2025** MDD: **1.65g/cm³**

Total weight of Sample:...**3000g**...... OPT.MC: **18.2%**

B.S. / C.B.R. Mould...**3120g**

Wt. of mould & wet Soil (W2) g	4599.00	4880.00	4950.00	4920.00	4857.00		
Wt. of mould (W1) g	3120.00	3120.00	3120.00	3120.00	3120.00		
Wt. of wet soil (W2-W1) g	1479.00	1760.00	1830.00	1800.00	1737.00		
Bulk Density (Pb) (W2-W1)/x g/cm^3	1.57	1.87	1.95	1.92	1.85		

MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X = 939.82 g/cm^3

Container No.	VI	TA	SU	IV	RT	IK	AB	TA	OZ	YT				
Wt. of wet soil & container (g)	47.37	46.80	52.29	52.33	41.91	52.92	55.84	57.76	45.79	44.70				
Wt. of Dry soil & container (g)	43.43	43.10	47.10	47.44	38.04	47.50	49.51	51.00	40.77	39.40				
Wt. of Container (g)	16.67	17.37	16.48	17.73	17.37	17.89	18.35	17.50	17.31	14.85				
Wt. of dry soil (Wd) g	26.76	25.73	30.62	29.71	20.67	29.61	31.16	33.50	23.46	24.55				
Wt. of Moisture (Wm) g	3.94	3.70	5.19	4.89	3.87	5.42	6.33	6.76	5.02	5.30				
Moistur Content 100(Wm/Wd) %	14.72	14.38	16.95	16.46	18.72	18.30	20.31	20.18	21.40	21.59				
Average Moisture Content (m) %	14.55		16.70		18.51		20.25		21.49					
Dry Density = Pb/1+ (m/100) (g/cm^3)	1.37		1.60		1.64		1.59		1.52					
C.B.R. (mseen of top & bottom) %														

Figure 4.5.6: Dry and moisture values for BH2, 2.0m

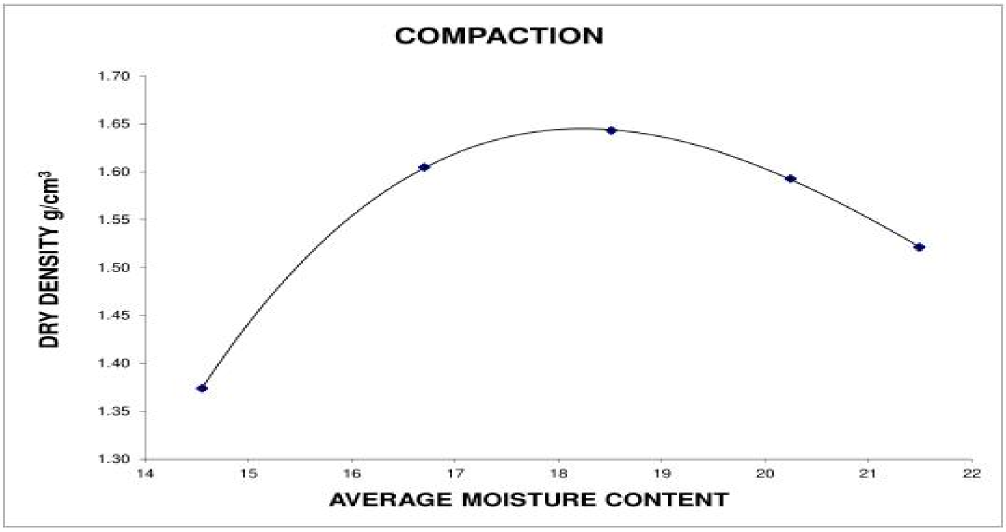

Figure 4.5.7: Compaction chart at BH2, 2.0m

DETERMINATION OF THE MOISTURE/DENSITY RELATION OF SOIL
USING STANDARD/HEAVY COMPACTION

Project:

Sample ID: **BH2, 4.0m** Date:**07-10-2025** MDD: **1.66g/cm³**

Total weight of Sample:...**3000g**...... OPT.MC: **19.6%**

B.S. / C.B.R. Mould...**4681g**

Wt. of mould & wet Soil (W2) g	6155.00	6414.00	6550.00	6510.00	6418.00		
Wt. of mould (W1) g	4681.00	4681.00	4681.00	4681.00	4681.00		
Wt. of wet soil (W2-W1) g	1474.00	1733.00	1869.00	1829.00	1737.00		
Bulk Density (Pb) (W2-W1)/x g/cm^3	1.57	1.84	1.99	1.95	1.85		

MOISTURE CONTENT DETERMINATIONS for B.S. Mould, X = 939.82 g/cm^3

Container No.	YO	GT	WZ	YZ	TE	RY	SI	LI	ZF	PE
Wt. of wet soil & container (g)	45.92	45.64	54.64	59.23	68.64	68.75	75.16	72.42	83.48	82.79
Wt. of Dry soil & container (g)	44.21	44.00	50.87	55.36	62.85	62.87	67.70	65.40	74.73	73.75
Wt. of Container (g)	33.01	33.72	29.24	33.04	33.89	33.41	32.91	32.61	35.96	34.42
Wt. of dry soil (Wd) g	11.20	10.28	21.63	22.32	28.96	29.46	34.79	32.79	38.77	39.33
Wt. of Moisture (Wm) g	1.71	1.64	3.77	3.87	5.79	5.88	7.46	7.02	8.75	9.04
Moistur Content 100(Wm/Wd) %	15.27	15.95	17.43	17.34	19.99	19.96	21.44	21.41	22.57	22.98
Average Moisture Content (m) %	15.61		17.38		19.98		21.43		22.78	
Dry Density = Pb/1+ (m/100) (g/cm^3)	1.36		1.57		1.66		1.60		1.51	
C.B.R. (mseen of top & bottom) %										

Figure 4.5.8: Dry and moisture values for BH2, 4.0m

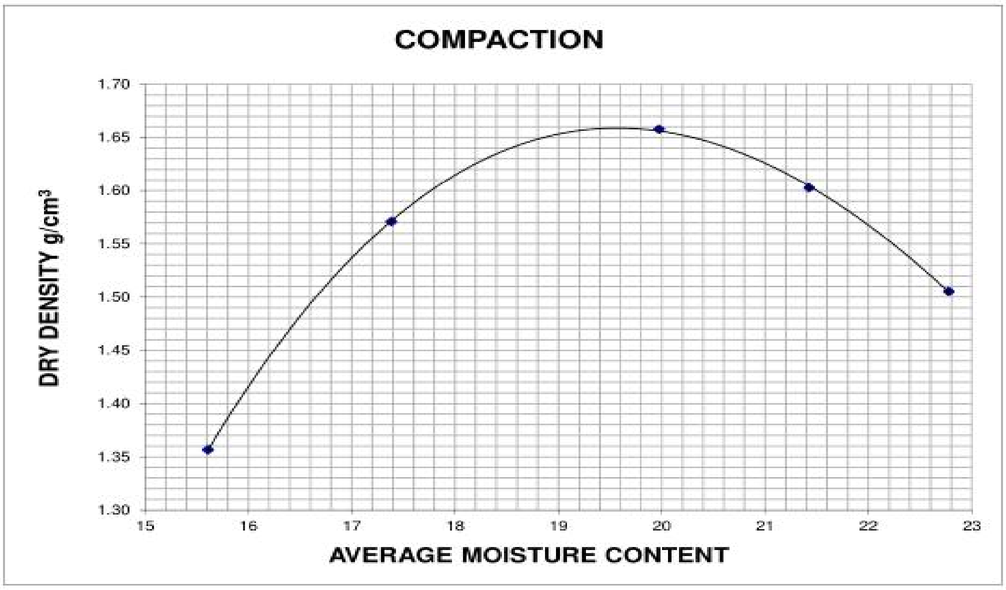

Figure 4.5.9: Compaction chart at BH2, 4.0m

4.6 TRIAXAL TEST CHART

GEOTECHNICAL ENGINEERING LABORATORY TEST

TRIAXIAL COMPRESSION TEST

PROJECT:...... DATE: **20/10/2025...** SAMPLE NO: **BH 1, 1m**

UNIT WEIGHT: **16.14 kN/m³** BULK DENSITY:...**1.64g/cm³**... CELL PRESSURE: **100, 205, 310KN/m²**

FRICTION ANGLE: ...**1.65°**..... COHESION :...**16.0KN/m²**..... WET WEIGHT:...**145g,142g,137g**..

Strain Dial	Stress Dial 1	SD2	SD3	Stress Dial Diff	SDD2	SDD3	Area Sq m	Compressive Stress	CS2	CS3	Strain %
0	0	0	0	0.00	0.00	0.00	0.00114	0.00	0.00	0.00	0.00
15	5.5	6	10	0.02	0.03	0.04	0.00115	20.41	22.26	37.11	0.50
30	6	6.5	11.8	0.03	0.03	0.05	0.00115	22.26	24.12	43.79	1.00
45	6.1	7	12	0.03	0.03	0.05	0.00116	22.44	25.75	44.15	1.50
60	6.3	7.2	12.5	0.03	0.03	0.05	0.00116	23.18	26.49	45.98	2.00
75	6.5	7.2	13	0.03	0.03	0.06	0.00117	23.71	26.26	47.42	2.50
90	7	7.8	13.8	0.03	0.03	0.06	0.00118	25.31	28.21	49.91	3.00
105	7.1	8	14.3	0.03	0.03	0.06	0.00118	25.68	28.93	51.71	3.50
120	7.3	8.1	15	0.03	0.03	0.06	0.00119	26.18	29.05	53.79	4.00
135	7.8	8.2	15.8	0.03	0.03	0.07	0.00119	27.97	29.41	56.66	4.50
150	7.9	8.5	16	0.03	0.04	0.07	0.00120	28.09	30.23	56.90	5.00
165	8	9	16.5	0.03	0.04	0.07	0.00121	28.21	31.74	58.19	5.50
180	8.1	9.3	17	0.03	0.04	0.07	0.00121	28.57	32.80	59.95	6.00
210	8.5	10	18	0.04	0.04	0.08	0.00122	29.73	34.98	62.96	7.00
240	9.0	10.3	18.5	0.04	0.04	0.08	0.00124	30.97	35.45	63.67	8.00
270	9	11.0	19	0.04	0.05	0.08	0.00125	31.07	37.55	64.86	9.00
300	9.1	11.1	19.8	0.04	0.05	0.08	0.00127	30.91	37.30	66.53	10.00
330	9.2	11.5	20	0.04	0.05	0.09	0.00128	32.34	38.34	66.68	11.00
360	9.7	12.0	20.7	0.04	0.05	0.09	0.00130	32.83	39.39	67.95	12.00
390	10.0	12.1	21.5	0.04	0.05	0.09	0.00131	32.90	39.42	70.04	12.00
420	10.1	12.5	22	0.05	0.05	0.09	0.00131	35.18	40.72	71.67	13.00
450	10.8	13	22.9	0.05	0.06	0.10	0.00133	35.94	41.71	73.48	14.00
480	11.2	13.5	22.9	0.05	0.06	0.10	0.00134	36.62	42.99	72.93	15.00
510	11.5	13.9	22.9	0.05	0.06	0.10	0.00136	37.65	43.61	71.85	16.00
540	12	14	22.9	0.05	0.06	0.10	0.00137	38.00	43.61	71.33	17.00
570	12.2	14.2	22.9	0.05	0.06	0.10	0.00139	38.38	43.59	70.30	18.00
600	12.5	14.5	22.9	0.05	0.06	0.10	0.00139	38.38	44.52	70.30	19.00
630	12.5	14.8	22.9	0.05	0.06	0.10	0.00143	38.20	44.17	68.34	20.00
660	12.8	15	22.9	0.06	0.06	0.10	0.00144	38.23	44.45	67.86	21.00
690	12.9	15	22.9	0.06	0.06	0.10	0.00146	38.00	43.84	66.93	22.00
720	13	15.1	22.9	0.06	0.06	0.10	0.00150	36.98	42.96	65.15	24.00
750	13	16	22.9	0.06	0.07	0.10	0.00152	36.50	44.92	64.29	25.00

DESCRIPTION OF SAMPLE

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SKETCH OF SAMPLE AFTER SHEAR

Compressive Sress

Corresponding Strain

	∂3	∂2	∂1	Radius	Centre							
1	100.00	38.38	138.38	19.1877	119.188							
	0.00	10.61	14.29	16.62	18.09	18.92	**19.19**	18.92	18.09	16.62	14.29	10.61	**0.00**
	100.00	103.20	106.39	109.59	112.80	115.98	**119.19**	122.39	125.58	128.78	131.99	135.17	**138.38**
2	205.00	44.92	249.92	22.4597	227.46							
	0.00	12.42	16.73	19.45	21.18	22.15	**22.46**	22.15	21.18	19.45	16.73	12.42	**0.00**
	205.00	208.75	212.48	216.23	219.98	223.71	**227.46**	231.21	234.94	238.69	242.44	246.17	**249.92**
3	310.00	73.48	383.48	36.7377	346.738							
	0.00	20.32	27.37	31.81	34.64	36.22	**36.74**	36.22	34.64	31.81	27.37	20.32	**0.00**
	310.00	316.14	322.23	328.37	334.50	340.60	**346.74**	352.87	358.97	365.11	371.24	377.34	**383.48**

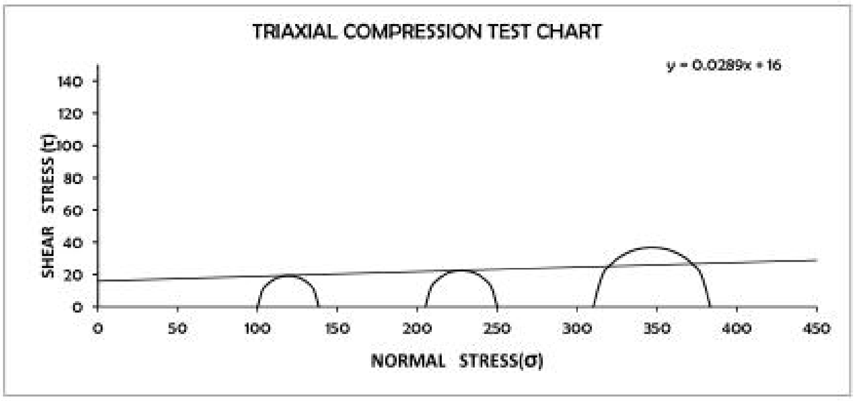

Figure 4.6.1: Triaxial compression test at BH1, 1.0m

GEOTECHNICAL ENGINEERING LABORATORY TEST

TRIAXIAL COMPRESSION TEST

PROJECT:.

DATE: **20/10/2025...**

SAMPLE NO: **BH 1, 3.0m**

UNIT WEIGHT: **16.08 kN/m³**

BULK DENSITY:...**1.61g/cm³...**

CELL PRESSURE: **100, 205, 310KN/m²**

FRICTION ANGLE: ...**3.05°.....**

COHESION :...**22.0KN/m².....**

WET WEIGHT:...**145g,137g,132g..**

Strain Dial	Stress Dial 1	SD2	SD3	Stress Dial Diff	SDD2	SDD3	Area Sq m	Compressive Stress	CS2	CS3	Strain %
0	0	0	0	0.00	0.00	0.00	0.00114	0.00	0.00	0.00	0.00
15	5.8	8.5	10.3	0.02	0.04	0.04	0.00115	21.52	31.54	38.22	0.50
30	6.2	9	12.8	0.03	0.04	0.05	0.00115	23.01	33.40	47.50	1.00
45	6.9	10	12.8	0.03	0.04	0.05	0.00116	25.38	36.79	47.09	1.50
60	7	10.3	13.8	0.03	0.04	0.06	0.00116	25.75	37.89	50.77	2.00
75	7.1	10.9	14.2	0.03	0.05	0.06	0.00117	25.90	39.76	51.79	2.50
90	7.8	11.5	15	0.03	0.05	0.06	0.00118	28.21	41.59	54.25	3.00
105	8	12	15.9	0.03	0.05	0.07	0.00118	28.93	43.40	57.50	3.50
120	8.5	12.9	16	0.04	0.06	0.07	0.00119	30.48	46.26	57.38	4.00
135	9	13	16.9	0.04	0.06	0.07	0.00119	32.27	46.62	60.60	4.50
150	9.2	13.3	17	0.04	0.06	0.07	0.00120	32.72	47.30	60.45	5.00
165	9.8	14.5	17	0.04	0.06	0.07	0.00121	34.56	51.14	59.95	5.50
180	10	15.0	17	0.04	0.06	0.07	0.00121	35.27	52.90	59.95	6.00
210	11	16	17.5	0.05	0.07	0.07	0.00122	38.48	55.97	61.21	7.00
240	12.0	17.0	18	0.05	0.07	0.08	0.00124	43.02	58.50	61.95	8.00
270	12.5	17.8	19	0.06	0.08	0.08	0.00125	44.38	60.77	64.86	9.00
300	13.0	18.0	19.8	0.06	0.08	0.08	0.00127	46.71	60.48	66.53	10.00
330	13.9	18.3	20	0.06	0.08	0.09	0.00128	47.34	61.01	66.68	11.00
360	14.2	18.9	20.3	0.06	0.08	0.09	0.00130	49.24	62.04	66.64	12.00
390	15.0	19.0	20.9	0.07	0.08	0.09	0.00131	51.47	61.89	68.08	12.00
420	15.8	19.5	21	0.07	0.08	0.09	0.00131	52.12	63.52	68.41	13.00
450	16.0	20	21.9	0.07	0.09	0.09	0.00133	52.94	64.17	70.27	14.00
480	16.5	20.2	22.2	0.07	0.09	0.09	0.00134	54.14	64.33	70.70	15.00
510	17	20.5	22.9	0.07	0.09	0.10	0.00136	54.91	64.32	71.85	16.00
540	17.5	20.9	23.2	0.08	0.09	0.10	0.00137	55.76	65.10	72.26	17.00
570	17.9	21.3	23.9	0.08	0.09	0.10	0.00139	55.26	65.39	73.37	18.00
600	18	21.8	24	0.08	0.09	0.10	0.00139	55.26	66.93	73.68	19.00
630	18	22	24	0.08	0.09	0.10	0.00143	53.71	65.65	71.62	20.00
660	18	22.8	24.2	0.08	0.10	0.10	0.00144	53.34	67.57	71.72	21.00
690	18	23.3	24.8	0.08	0.10	0.11	0.00146	52.61	68.10	72.49	22.00
720	18	23.9	25	0.08	0.10	0.11	0.00150	51.21	67.99	71.12	24.00
750	18	24	25.5	0.08	0.10	0.11	0.00152	50.53	67.38	71.59	25.00

	∂3	∂2	∂1	Radius	Centre								
1	100.00	55.76	155.76	27.8779	127.878								
	0.00	15.42	20.77	24.14	26.29	27.49	**27.88**	27.49	26.29	24.14	20.77	15.42	**0.00**
	100.00	104.66	109.28	113.94	118.59	123.22	**127.88**	132.53	137.16	141.82	146.47	151.10	**155.76**
2	205.00	68.10	273.10	34.0511	239.051								
	0.00	18.83	25.37	29.49	32.11	33.57	**34.05**	33.57	32.11	29.49	25.37	18.83	**0.00**
	205.00	210.69	216.34	222.03	227.71	233.36	**239.05**	244.74	250.39	256.08	261.76	267.42	**273.10**
3	310.00	73.68	383.68	36.8404	346.84								
	0.00	20.37	27.45	31.90	34.74	36.32	**36.84**	36.32	34.74	31.90	27.45	20.37	**0.00**
	310.00	316.15	322.27	328.42	334.57	340.69	**346.84**	352.99	359.11	365.26	371.41	377.53	**383.68**

DESCRIPTION OF SAMPLE

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SKETCH OF SAMPLE AFTER SHEAR

Compressive Sress

Corresponding Strain

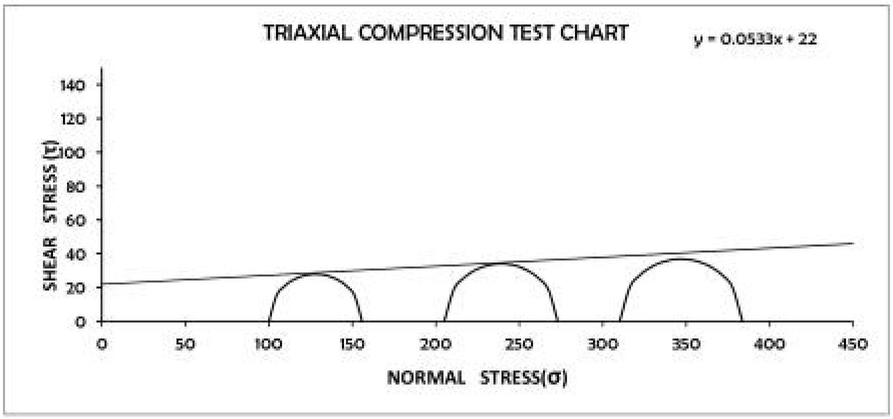

Figure 4.6.2: Triaxial compression test at BH1, 3.0m

GEOTECHNICAL ENGINEERING LABORATORY TEST

TRIAXIAL COMPRESSION TEST

LOCATION:

DATE:...20/10/2025

SAMPLE NO: **BH2, 2.0 m**

UNIT WEIGHT:...**16.64 KN/m³**

BULK DENSITY:...**1.70 g/cm³**...

CELL PRESSURE: **100, 205, 310KN/m²**

FRICTION ANGLE:...**5.40°**....

COHESION:...**26.0 KN/m²**....

WET WEIGHT:...**139 g,144 g,154 g**..

Strain Dial	Stress Dial 1	SD2	SD3	Stress Dial Diff	SDD2	SDD3	Area Sq m	Compressive Stress 1	CS2	CS3	Strain %
0	0	0	0	0.00	0.00	0.00	0.00114	0.00	0.00	0.00	0.00
15	8.5	8	10	0.04	0.03	0.04	0.00115	31.54	29.69	37.11	0.50
30	9	10	11.5	0.04	0.04	0.05	0.00115	33.40	37.11	42.67	1.00
45	9.2	10.9	12	0.04	0.05	0.05	0.00116	33.84	40.10	44.15	1.50
60	9.9	11.3	12.2	0.04	0.05	0.05	0.00116	36.42	41.57	44.88	2.00
75	10	12	12.9	0.04	0.05	0.06	0.00117	36.47	43.77	47.05	2.50
90	10.2	13	13	0.04	0.06	0.06	0.00118	36.89	47.01	47.01	3.00
105	10.5	13.8	14	0.04	0.06	0.06	0.00118	37.97	49.91	50.63	3.50
120	10.7	14.5	14.2	0.05	0.06	0.06	0.00119	38.37	52.00	50.92	4.00
135	10.9	15	14.5	0.05	0.06	0.06	0.00119	39.09	53.79	52.00	4.50
150	12	15.5	15	0.05	0.07	0.06	0.00120	42.67	55.12	53.34	5.00
165	12.5	16	15.5	0.05	0.07	0.07	0.00121	44.08	56.43	54.66	5.50
180	13	16.5	17	0.06	0.07	0.07	0.00121	45.85	58.19	59.95	6.00
210	13.5	18	19	0.06	0.08	0.08	0.00122	47.22	62.96	66.46	7.00
240	14.5	19.5	20.2	0.06	0.08	0.09	0.00124	52.31	67.11	69.52	8.00
270	15.2	21	21	0.07	0.09	0.09	0.00125	54.28	71.69	71.69	9.00
300	15.9	22	22	0.07	0.09	0.09	0.00127	57.12	73.92	73.92	10.00
330	17	23	23.5	0.08	0.10	0.10	0.00128	60.01	76.68	78.35	11.00
360	18	23.8	25	0.08	0.10	0.11	0.00130	62.37	78.13	82.06	12.00
390	19	24.5	27	0.08	0.10	0.12	0.00131	64.82	79.81	87.95	12.00
420	19.9	25	28.9	0.09	0.11	0.12	0.00131	68.08	81.44	94.14	13.00
450	20.9	26	30.5	0.09	0.11	0.13	0.00133	69.95	83.42	97.86	14.00
480	21.8	26.9	32.5	0.10	0.11	0.14	0.00134	71.02	85.67	103.50	15.00
510	22.3	27.5	34	0.10	0.12	0.15	0.00136	72.17	86.29	106.68	16.00
540	23	28.3	35	0.10	0.12	0.15	0.00137	74.76	88.15	109.02	17.00
570	24	29	36.9	0.10	0.12	0.16	0.00139	74.29	89.03	113.28	18.00
600	24.2	29.8	38	0.11	0.13	0.16	0.00139	76.44	91.49	116.66	19.00
630	24.9	30.5	39	0.11	0.13	0.17	0.00143	74.60	91.02	116.38	20.00
660	25	31	40	0.11	0.13	0.17	0.00144	74.09	91.87	118.54	21.00
690	25	31.5	41	0.11	0.13	0.17	0.00146	73.66	92.07	119.84	22.00
720	25.2	32	41.8	0.11	0.14	0.18	0.00150	73.40	91.04	118.92	24.00
750	25.8	32.8	42.5	0.11	0.14	0.18	0.00152	72.43	92.08	119.32	25.00

	∂3	∂2	∂1	Radius	Centre								
1	100.00	76.44	176.44	38.22195	138.2219								
	0.00	21.14	28.48	33.10	36.04	37.69	**38.22**	37.69	36.04	33.10	28.48	21.14	**0.00**
	100.00	106.38	112.73	119.11	125.49	131.84	**138.22**	144.61	150.95	157.33	163.72	170.06	**176.44**
2	205.00	92.08	297.08	46.04246	251.0425								
	0.00	25.46	34.30	39.87	43.42	45.40	**46.04**	45.40	43.42	39.87	34.30	25.46	**0.00**
	205.00	212.69	220.33	228.02	235.71	243.35	**251.04**	258.73	266.37	274.06	281.75	289.40	**297.08**
3	310.00	119.84	429.84	59.91827	369.9183								
	0.00	33.13	44.64	51.89	56.50	59.08	**59.92**	59.08	56.50	51.89	44.64	33.13	**0.00**
	310.00	320.01	329.95	339.96	349.97	359.91	**369.92**	379.92	389.87	399.88	409.88	419.83	**429.84**

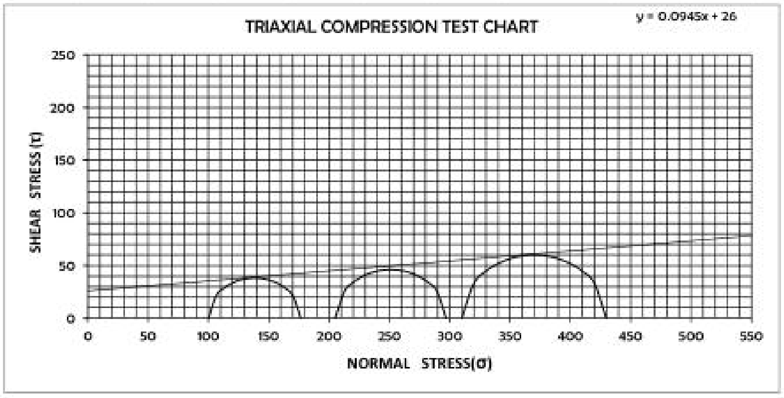

Figure 4.6.3: Triaxial compression test at BH2, 2.0m

GEOTECHNICAL ENGINEERING LABORATORY TEST

TRIAXIAL COMPRESSION TEST

LOCATION:........ DATE:....20/10/2025 SAMPLE NO: BH2, 4.0 m

UNIT WEIGHT:...16.10 KN/m³ BULK DENSITY:...1.64 g/cm³... CELL PRESSURE: 100, 205, 310KN/m²

FRICTION ANGLE:....1.37°..... COHESION:...30.0 KN/m²..... WET WEIGHT:...133 g,147 g,143 g..

Strain Dial	Stress Dial 1	SD2	SD3	Stress Dial Diff	SDD2	SDD3	Area Sq m	Compressive Stress 1	CS2	CS3	Strain %
0	0	0	0	0.00	0.00	0.00	0.00114	0.00	0.00	0.00	0.00
15	8	10.2	9	0.03	0.04	0.04	0.00115	29.69	37.85	33.40	0.50
30	8.2	11	10	0.03	0.05	0.04	0.00115	30.43	40.82	37.11	1.00
45	8.9	11.5	10.3	0.04	0.05	0.04	0.00116	32.74	42.31	37.89	1.50
60	9	11.9	10.9	0.04	0.05	0.05	0.00116	33.11	43.78	40.10	2.00
75	9.5	12	11	0.04	0.05	0.05	0.00117	34.65	43.77	40.12	2.50
90	9.9	12.5	11.5	0.04	0.05	0.05	0.00118	35.80	45.20	41.59	3.00
105	10	13	12	0.04	0.06	0.05	0.00118	36.16	47.01	43.40	3.50
120	10.5	13.2	12.3	0.04	0.06	0.05	0.00119	37.65	47.34	44.11	4.00
135	11	13.8	12.8	0.05	0.06	0.05	0.00119	39.45	49.49	45.90	4.50
150	11.2	14	13	0.05	0.06	0.06	0.00120	39.83	49.79	46.23	5.00
165	11.7	14	13.5	0.05	0.06	0.06	0.00121	41.26	49.37	47.61	5.50
180	12	14.1	14	0.05	0.06	0.06	0.00121	42.32	49.73	49.37	6.00
210	13	14.5	14.9	0.06	0.06	0.06	0.00122	45.47	50.72	52.12	7.00
240	13.8	15	15.5	0.06	0.06	0.07	0.00124	48.87	51.62	53.34	8.00
270	14.2	15.7	16	0.06	0.07	0.07	0.00125	51.21	53.60	54.62	9.00
300	15	16	16.8	0.07	0.07	0.07	0.00127	52.08	53.76	56.45	10.00
330	15.5	16.5	17.3	0.07	0.07	0.07	0.00128	53.34	55.01	57.68	11.00
360	16	17	18	0.07	0.07	0.08	0.00130	55.80	55.80	59.09	12.00
390	17	17.2	18.5	0.08	0.07	0.08	0.00131	57.98	56.03	60.26	12.00
420	17.8	18	19	0.08	0.08	0.08	0.00131	58.64	58.64	61.89	13.00
450	18	18	20	0.08	0.08	0.09	0.00133	60.96	57.75	64.17	14.00
480	19	18.5	20.8	0.08	0.08	0.09	0.00134	61.14	58.91	66.24	15.00
510	19.2	19	21.5	0.08	0.08	0.09	0.00136	62.44	59.62	67.46	16.00
540	19.9	19.5	22.5	0.09	0.08	0.10	0.00137	62.30	60.74	70.08	17.00
570	20	20	23	0.09	0.09	0.10	0.00139	62.94	61.40	70.61	18.00
600	20.5	20.8	23.9	0.09	0.09	0.10	0.00139	64.47	63.86	73.37	19.00
630	21	21.1	24.3	0.09	0.09	0.10	0.00143	63.56	62.97	72.52	20.00
660	21.3	21.9	25	0.09	0.09	0.11	0.00144	65.20	64.90	74.09	21.00
690	22	22	25.8	0.09	0.09	0.11	0.00146	64.59	64.30	75.41	22.00
720	22.1	22.5	26.5	0.10	0.10	0.11	0.00150	64.01	64.01	75.39	24.00
750	22.5	23	27	0.10	0.10	0.12	0.00152	63.17	64.57	75.80	25.00

	∂3	∂2	∂1	Radius	Centre								
1	100.00	65.20	165.20	32.59781	132.5978								
	0.00	18.03	24.29	28.23	30.74	32.14	**32.60**	32.14	30.74	28.23	24.29	18.03	**0.00**
	100.00	105.44	110.86	116.30	121.74	127.15	**132.60**	138.04	143.45	148.90	154.34	159.75	**165.20**
2	205.00	64.90	269.90	32.44964	237.4496								
	0.00	17.94	24.17	28.10	30.60	32.00	**32.45**	32.00	30.60	28.10	24.17	17.94	**0.00**
	205.00	210.42	215.81	221.22	226.64	232.03	**237.45**	242.87	248.26	253.67	259.09	264.48	**269.90**
3	310.00	75.80	385.80	37.90081	347.9008								
	0.00	20.96	28.24	32.82	35.74	37.37	**37.90**	37.37	35.74	32.82	28.24	20.96	**0.00**
	310.00	316.33	322.62	328.95	335.28	341.57	**347.90**	354.23	360.52	366.85	373.18	379.47	**385.80**

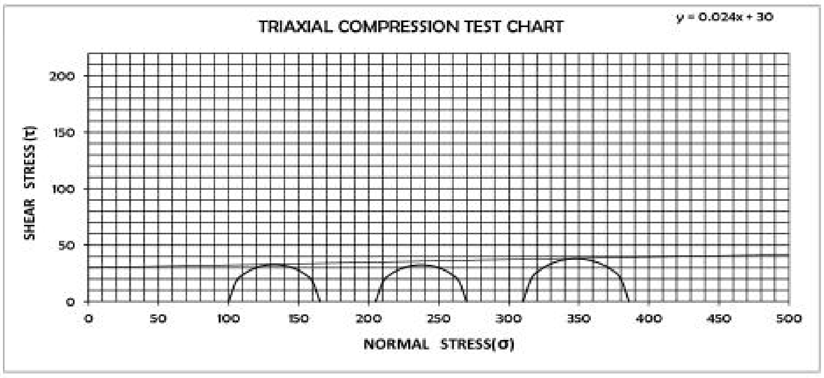

Fig 4.6.4: Triaxial compression test at BH2, 4.0m

4.7 DISCUSSION

The overall results from the laboratory investigations reveal that the soil samples obtained from the Medical Hostel area of the University of Benin exhibit characteristics typical of lateritic to silty clay soils (fig 2,5,7,10). The measured parameters, such as the Atterberg limits, natural moisture content, and specific gravity, suggest that the soil contains a considerable amount of fine particles with moderate plasticity and fair strength. The moderate to high plasticity index indicates that the soil possesses a noticeable clay fraction capable of undergoing changes in volume with varying moisture conditions. This property is important because, in tropical regions like Benin City, alternating wet and dry seasons can cause the soil to shrink or swell, which may affect the stability of lightly loaded structures if not properly managed. The specific gravity values obtained confirm the presence of lateritic minerals and iron oxides, which are consistent with residual soils formed from weathered sedimentary rocks of the Benin Formation. These values also reflect a stable and well-weathered material suitable for construction after adequate compaction. The compaction test results indicate that the soil achieves its maximum dry density at a moderate optimum moisture content. This means that, in practice, achieving good field compaction will require careful control of water during construction. Proper compaction at the optimum moisture level will improve the soil's load-bearing capacity and minimize settlement or deformation under applied loads.

Furthermore, the triaxial compression test (fig 22,23 and 24) shows moderate values of cohesion and internal friction angle, implying that the soil can offer reasonable shear resistance under loading conditions. However, since the strength parameters decrease when the soil becomes saturated, effective drainage around foundations or pavement subgrades is necessary to maintain long-term stability.

CHAPTER FIVE

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FURTHER STUDIES

5.1 SUMMARY

This study was carried out to examine the role of geotechnical properties of soil in relation to engineering structures, using samples collected from the Medical Hostel area of the University of Benin. The primary goal was to determine key soil parameters that influence the strength, stability, and suitability of the ground for construction purposes. The laboratory tests conducted include natural moisture content, Atterberg limits, specific gravity, compaction, and triaxial compression tests. Each test provided insight into the soil's behavior under varying environmental and loading conditions. Results from the moisture content test showed moderate water retention, suggesting the soil's tendency to absorb and retain moisture. The Atterberg limit tests indicated medium to high plasticity, revealing that the soil contains a considerable amount of clay minerals, making it somewhat prone to expansion and shrinkage. The specific gravity values (2.60–2.72) confirmed the presence of lateritic materials and well-weathered minerals typical of residual soils within the Benin Formation.

The compaction test revealed an optimum moisture content between 13–17% and maximum dry densities ranging from 1.80–1.95 Mg/m^3, implying that the soil can achieve adequate density and strength when compacted under controlled moisture conditions. The triaxial compression test further demonstrated moderate cohesion and frictional resistance, showing that while the soil can bear light to moderate loads, its strength reduces under excess moisture. Overall, the test results suggest that the soil in the Medical Hostel area can be suitable for engineering structures if proper site preparation, compaction, and drainage control are implemented.

5.2 CONCLUSION

This research emphasizes the significance of understanding geotechnical properties before the design and construction of any engineering structure. The soil around the Medical Hostel area exhibits moderate strength and plasticity, typical of lateritic and silty clay soils common in Benin City. While the soil can sustain light to medium structures, it is sensitive to moisture variations, which may lead to instability or settlement if not properly managed. Therefore, knowledge of geotechnical parameters such as moisture content, plasticity, specific gravity, and shear strength plays a vital role in evaluating the soil's bearing capacity and determining the most appropriate foundation type for construction. Proper geotechnical investigation not only ensures structural stability but also prevents premature failure of buildings and other engineering works.

5.3 SUGGESTIONS FOR FURTHER STUDIES

The soil from the study area demonstrates moderate engineering performance. While it can adequately support light to medium structures, its plasticity and sensitivity to moisture variations suggest that stabilization measures such as lime or cement treatment would be beneficial, especially for road subgrades, foundations, or areas exposed to water infiltration. With proper compaction, drainage control, and possibly chemical stabilization, the soil can perform satisfactorily for most civil engineering applications within the study area.

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