PERMEABILITY OF GRAIN SIZES IN SOIL IN EKOSODIN BENIN CITY, EDO STATE, NIGERIA.

BY

IGUNBOR, Samuel

ENG1905257

A PROJECT SUBMITTED BY PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR ENGINEERING (B.Eng) DEGREE.

IN

THE DEPARTMENT OF CIVIL ENGINEERING (STRUCTURAL ENGINEERING PROGRAMME), FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

FEBRUARY, 2025

PLAGIARISM

This work **PERMEABILITY OF GRAIN SIZES IN SOIL IN EKOSODIN** by IGUNBOR, Samuel with Matriculation Number ENG1905257 of the Department of Civil Engineering (Structural Engineering Program), University of Benin City, Edo State. Nigeria, has PASSED the **PLAGIARISM TEST.**

PROJECT COORDINATOR:

Name: ……………………………………………………………………………………….

Signature and Date: ....

CERTIFICATION

This is to certify that this work was carried out by Igunbor, Samuel, Mat. No. ENG1905257, of the Department of Civil Engineering (Structural Engineering Program), Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

SUPERVISOR:

Name: ……………………………………….

Signature and Date: ....

HEAD OF DEPARTMENT:

Name: ………………………………………………………………………………….

Signature and Date: ....

DEDICATION

This project is dedicated to God almighty who kept me alive and imbibed me with wisdom of understanding through each stage of my academic journey.

ACKNOWLEDGEMENT

My gratitude goes to Dr. (Mrs) N. I. Ihimekpen; my supervisor, who gave me the understanding, encouragement and assistance to carry out this work and my appreciation also goes to my lecturers Dr. (Mrs) N. K. OJO, Prof. H.A.P. Audu, Engr. U. Ogbonna, Dr. R.I. Umasabor, Engr. Dr. (Mrs) A. Rawlings, Engr. S.A. Adegbemileke, Engr. E. Musa, Engr. Dr. R. O. Ogirigbo and staff of the Department of Civil Engineering Department (Structural Engineering Program) for their guidance, mentorship and assistance.

Finally, my gratitude goes to my family for all the loves. May God continue to bless you all.

ABSTRACT

This study carried out an investigation on the permeability of grain sizes in soil in Ekosodin, Benin City, Edo State. Due to several collapse of structure in the geographical location and occurence of flooding during the past years, it was essential to investigate if the soil in the area is more or less permeable, To know the most approciate or suitable type of foumdation applicable and the right drainage system to be implemented.

The permeability of the soil was tested for by the application of an empirical formula called the kozeny carman equation. This equation is composed of the kozeny carman constant ranging between (0.8 to 1.0), specific surface area, and void ratio. The specific gravity and particle size distribution test was carried out to determine the specific surface area, the moisture content test was also carried out to determine the void ratio of the soil, including the atterberg limit test, the results obtained from the test was used to determine the approximate kozeny carman constant to be applied which was done in Civil/Structural Engineering Laboratory in the University of Benin, Benin City, Edo State. The soil sample used for the various test was taken from Ekosodin with the application of the auger to extract soil sample from four boreholes at 0.5m to 1m respesctively. Through this application the permeability of the soil was determined.

The results obtained for the permeability of the soil from the above tests listed, were $1.039\times10^{-10}m^2$, $1.002\times 10^{-10}\ m^2$, $1.123\times10^{-10}\ m^2$, $1.394\times10^{-10}m^2$, $3.797\times10^{-10}m^2$, $9.922\times10^{-11}m^2$, $2.476\times10^{-11}m^2$, and $6.024\times10^{-11}m^2$ respectively. Indicating that the soil has a very low permeability. Several mitigation and strategies are recommended, such as soil amendments with coarser materials like sand or organic matter to improve permeability, the installation of drainage systems such as perforated pipes or gravel trenches, and proper land management practices should be implemented in the area, Piles or piers, are strongly recommended to reach stable soil below the water table. Comprehensive drainage systems, including perimeter drains, free-draining backfill, and proper surface grading, are essential regardless of foundation type.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

USCS - Unified Soil Classification System

AASHTO - American Association of State Highway and Transportation Officials

SSA- Specific Surface Area

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Soil permeability, which refers to the soil's ability to allow the passage of fluids such as water and air, plays a critical role in numerous geotechnical and environmental processes. Grasping the connection between grain size distribution and permeability is vital for applications like soil erosion, groundwater flow, and pollutant transport. Typically, coarser soils, such as gravel and sand, exhibit higher permeability compared to finer soils like silts and clays. This difference arises from factors such as interparticle connectivity, pore size distribution, and surface area, all of which influence the movement of fluids through the soil. (Zhang et al., 2023).

Gravel and sand typically exhibit well-defined pore spaces between particles, facilitating rapid fluid flow (Zamara, 2024). In contrast, finer-grained soils have smaller pores and a larger surface area, resulting in reduced permeability and increased capillary action.

Previous research has explored the permeability of soils with varying grain sizes, offering significant insights into the hydraulic properties of different soil types. Understanding these interactions between water and soil is crucial for applications such as irrigation, flood control, soil conservation, and foundation design. Despite these advancements, there is still a need for detailed comparative studies to better understand the relative permeability of different grain sizes under controlled conditions (Vazirian and Niazkar 2024).

This study seeks to address this gap by systematically examining the permeability grain sizes(soil) to ensure structural stability, analyzing the impact of excessive water infiltration, and proposing solutions to drainage challenges. By conducting laboratory experiments under standardized conditions, the research aims to deepen our understanding of soil permeability in Ekosodin as a location, offering valuable insights for a range of engineering and environmental applications in the geographical location.

1.2 STATEMENT OF THE PROBLEM

Soil permeability is an essential measure affecting several geotechnical and environmental processes, nonetheless the interaction between soil permeability and grain size remains a topic of significant interest and investigation because the pore spaces in soil is as a result of the grain size. While it is primarily accepted that soils with larger grain sizes are susceptible to having higher permeability, the process facilitating this relationship and the extent of its influence remain subjects of inquiry.

This research seeks to address the following problems related to permeability in grain sizes (soil):

I. Foundation problems in construction.

II. Excessive water infiltration.

III. Drainage issues.

By addressing these problems, this study aims to optimize our comprehension of the complication in permeability of grain size(soil), providing invaluable insights into soil engineering, environmental management, and sustainable development initiatives.

1.3 AIM AND OBJECTIVES

The main aim of this research work is to determine the permeability of grain sizes in sand(soil) at Ekosodin, Benin City, Edo State.

The objectives of the work are:

I. To ascertain the void ratio of the soil.

II. Determination of specific surface area.

III. Determination how much water the soil can absorb, which can impact drainage.

IV. Investigating the permeability of the soil in the geographical location (Ekosodin).

1.4 SCOPE OF STUDY

The scope of this research work is to determine the permeability of grain size in soil at Ekosodin, Benin City, Edo State.

This work involves using empirical means to determine the permeability of the soil, collecting soil sample using an "Auger" from four boreholes with a depth of 0.5m, 1m respectively. which will be taken to the laboratory in the University of Benin (Civil/Structural Engineering Laboratory). Then test like moisture content, particle size distribution(sieve analysis), specific gravity, and atterbeg limit will be carried out with tools like oven, sieve, pycnometer, and the liquid limit machine. To draw conclusions like:

I. The void ratio of the soil.

II. How much water the soil can absorb.

III. If the soil is permeable or impermeable.

IV. The foundation type to be carried out on the soil if it is permeable or impermeable.

The excel software will be use to organize the data gotten from the instrument used in conducting the experiments.

1.5 JUSTIFICATION OF STUDY

Due to several collapse of buildings in Ekosodin, Beinin City, between the year 2020 till date, there have been several speculations for the cause of these building collapse which are differential settlement, poor design and engineeering, inadeqaute materials, natural disasters and overloading e.t.c. I will be Investigating the soil permeability of the geographical location to highlight the type of foundation suitable for the region base on the soil type.

Knowledge of permeability in the grain size(soil) will educate contractors or engineers to ascertain if the site soil they are working on is more permeable (doesn't retain water) or less permeable (i.e it retains water) which can lead to waterloggiing or flooding and to estimate the adequate foundation that is applicable for buildings in the area, which will prevent or reduce the collapse of structures, preserve life and properties leading to infrastructural development.

CHAPTER TWO

LITERATURE REVIEW

2.1 BACKGROUND

The intrinsic permeability is a key parameter for characterizing and quantifying fluid flow in porous media, yet it often remains uncertain even when the pore structure's geometry is known. In this study, we conduct a comparative analysis of experimental, semi-analytical, and numerical methods to estimate the permeability of a regular porous structure. Specifically, we employ the Kozeny–Carman relation, various homogenization techniques (3D, 2D, very thin porous media, and pseudo 2D/3D), pore-scale simulations (including the lattice Boltzmann method, smoothed particle hydrodynamics, and the finite-element method), and pore-scale experiments using microfluidics. A benchmark problem is established using a conceptual design of a periodic porous structure with regularly arranged solid cylinders, which is then analyzed using all the aforementioned methods. The results are evaluated in terms of the strengths and limitations of each approach. Both the applicable homogenization methods and the pore-scale models demonstrate their capability to predict the permeability of the benchmark problem. The underestimation observed in microfluidic experiments is thoroughly examined using the lattice Boltzmann method, enabling the quantification of the impact of experimental setup constraints (Song et al., 2023).

(Lu et al., 2019) This study explores the relationships between permeability, density, and grain size distribution indexes in sandy soils, focusing on effective particle size (D10), coefficient of uniformity (Cu), coefficient of curvature (Cc), coarse sand fraction (%C), medium sand fraction (%M), and fine sand fraction (%F). The aim was to assess whether these relationships could enable the estimation of sandy soil permeability based on grain size distribution. Six sandy soil samples, ranging from well-graded to poorly-graded, were analyzed to determine their grain size distribution, maximum dry density (MDD), and optimum water content (OWC). Using grain size distribution plots, D10, Cu, Cc, %C, %M, and %F values were calculated for each soil. Five replicate samples of each soil, prepared at varying dry densities using compaction curves, were tested for permeability using the constant head permeability test. The findings reveal that sandy soils exhibit the lowest permeability at or slightly below the OWC. Bivariate and stepwise regression analyses indicate that D10, density, and %M have the strongest correlations with permeability, accounting for 67% of the variability in permeability.

(Chudáček and Nádvorník 2023) The coefficient of permeability (k) for well-graded soils can be determined through various on-site and laboratory methods. A common approach for fine granular soil types involves indirect inference from the grading curve . However, inaccuracies in measurements and calculations can arise due to factors such as neglecting the coefficient of irregularity.

(Arson and Pereira 2020) The impact of damage on the pore size distribution (PSD) and permeability of rocks is explored through a model that links permeability to porosity measurements easily obtainable in laboratory settings. The PSD curve is adjusted based on strain and damage, with updated volumetric fractions of natural pores and cracks incorporated into the permeability expression. Unlike traditional permeability models that rely on PSD integrations, this model considers potential shifts in porosity modes: one mode for undamaged samples and two modes for cracked samples. Additionally, it accommodates varying damage states, in contrast to conventional fracture network models where the crack pattern remains fixed. The microstructure is described using only the lower and upper bounds of pore sizes for both natural pores and cracks, while other PSD parameters in the model are tied to macroscopic parameters, such as the initial void ratio, which can be readily measured in the lab. This framework can be integrated into any damage constitutive model to assess the permeability of brittle porous media. Simulations of drained triaxial compression tests show that permeability decreases as larger natural pores compress before crack initiation, but increases with crack density growth after damage occurs. The model effectively captures the influence of confining pressure on both damage progression and permeability changes.

2.3 DEFINITION OF TERMS

2.3.1 PERMEABILITY

The term "permeability" originates from the Latin word "permeare," meaning "to pass through" or "to penetrate." It is formed by combining the prefix "per," meaning "through," and the verb "meare," meaning "to pass" or "to go." According to Younes and Carriero (2022), permeability is defined as the property of a material that reflects its capacity to allow fluids (liquids or gases) to flow through it. Essentially, permeability measures how easily fluids can move through substances such as soil or rock. This concept is crucial in various fields, including hydrogeology (water flow), petroleum engineering (oil drilling), and civil engineering (construction).

Our understanding of permeability, especially concerning fluids moving through porous materials, is rooted in earlier studies in fluid mechanics and hydrogeology. A key breakthrough was made by Henry Darcy, a French engineer, in the mid-19th century. Picture water flowing through a sand filter. Darcy developed a method to describe this process, known as Darcy's Law. This law explains the rate at which water flows based on the pressure difference, the sand's permeability (how easily water moves through it), the filter's dimensions, and the water's viscosity (thickness). Mathematically, Darcy's Law states that the volumetric flow rate of a fluid through a porous medium is directly proportional to the pressure gradient, the medium's permeability, and the cross-sectional area available for flow, while being inversely proportional to the fluid's viscosity (Darcy, 1856). This relationship is expressed as:

$$Q = -\frac{KA \cdot \Delta P}{\mu L} \qquad \text{Eq(2.1)}$$

Where:

a) Q is the volumetric flow rate.
b) k is the permeability of the material.
c) A is the cross-sectional area.
d) ΔP is the pressure difference.
e) μ is the dynamic viscosity of the fluid.
f) L is the length over which the pressure difference is measured.

2.5 SOIL

Soil is a layered composition (horizons) of minerals, organic matter, water, and air that develops on the Earth's surface. It plays a crucial role in sustaining plant life by offering nutrients and structural support (McClellan, 2022). Additionally, soil acts as a natural filter for water and facilitates nutrient cycling, making it an essential component of the Earth's ecosystem.

2.5.1 KEY COMPONENTS OF SOIL

1) Organic matter: Decomposed plant and animal matter, referred to as humus, enhances the soil's structural integrity, supplies vital nutrients to support plant growth, and improves its capacity to retain moisture over time.

2) Mineral particles: The breakdown of rocks produces soil particles such as sand, silt, and clay. The size and combination of these particles influence the soil's drainage, determining how easily water can pass through it.
3) Water: Filling the gaps between soil particles is essential for the growth and survival of plants and microorganisms (microbes).
4) Air: The air pockets found in the gaps between soil particles, which are not occupied by water, are crucial for allowing plant roots to breathe and enabling soil organisms to flourish.

2.5.2 SOIL FORMATION FACTORS

1) Parent material
2) Climate
3) Organisms
4) Topography.

2.6 GRAIN SIZE

(Burhan, 2019) Grain size, defined as the diameter of individual particles in soil or sediment, is a fundamental property used to classify and characterize these materials. It plays a significant role in influencing key physical properties such as permeability (water flow), porosity (water retention capacity), and the mechanical behavior (strength) of the soil.

2.6.1 CATEGORIES OF GRAIN SIZE

1) Gravel: Particles larger than 2 mm in diameter (Burhan, 2019).
2) Sand: Particles ranging from 0.0625 mm to 2 mm in diameter (Burhan, 2019)

3) Silt: Particles ranging from 0.0039 mm to 0.0625 mm in diameter (Burhan, 2019).
4) Clay: Particles smaller than 0.0039 mm in diameter (Burhan, 2019).

2.6.2 IMPORTANCE OF GRAIN SIZE

1) Soil Mechanics: Variations in grain size affect several critical soil properties, including its strength to withstand pressure, its ability to maintain structural stability, and its compaction efficiency.(Ahmad, 2023).
2) Porosity: The size and arrangement of the grains affect the volume and dimensions of the voids (empty spaces) within the material. (Giao, 2022).
3) Permeability: The size of soil particles, or grain size, influences the ease with which fluids such as water can flow through the soil or sediment.(paltseva, 2024).

2.7 FOUNDATION

A foundation is the base load-bearing component of a building or structure, usually situated below ground level. It transfers the structure's weight to the underlying soil or rock, ensuring stability and preventing settlement or shifting. Foundations are crucial for supporting the structure, maintaining its level, and keeping it secure over time. They are categorized into shallow foundations (such as spread footings and mat foundations) and deep foundations (like piles and caissons), depending on the load demands and soil conditions.(Waghmare, 2024).

2.7.1 FOUNDATION CLASSIFICATION BASED ON SOIL PERMEABILITY

1. Foundations on Permeable Soils

Soils that allow water to pass through easily, such as sandy and gravelly soils, are considered highly permeable. Shallow foundations, including spread footings and strip footings, are typically used on these permeable soils, which have excellent drainage properties like coarse sands and gravels. The rapid water drainage in such soils reduces hydrostatic pressure on the foundation and lowers the risk of waterlogging. Raft or mat foundations can also be effective in permeable soils, provided the ground is strong enough to support the load despite some water movement beneath the foundation.

When the soil is permeable but lacks sufficient strength for shallow foundations, pile foundations, especially friction piles, are employed. These piles are driven deep into the soil, relying on skin friction between the pile and the surrounding permeable soil to support the load. This method is particularly useful in loose, sandy soils that may shift under load. Drilled shafts are another option, often used in soils with good permeability but requiring deep support due to load-bearing or environmental conditions.(Waghmare, 2024).

2. Foundations on Impermeable Soils

Impermeable soils like clay and silt have low permeability, making it difficult for water to pass through. These soils tend to retain water, which can generate hydrostatic pressure, causing problems such as uplift or soil swelling. In such conditions, deep foundations, such as pile foundations and caissons, are employed to transfer structural loads to deeper, more stable soil layers, avoiding the weak near-surface soil. Drilled shafts are also used in impermeable soils when the upper layers are unstable but deeper layers offer strong support. Additionally, mat or raft foundations are sometimes utilized in these areas to evenly distribute the load over a larger surface area, minimizing the risk of differential settlement, especially in clayey soils that shrink or expand with changes in moisture content.(Waghmare, 2024).

2.8 PREVIOUS STUDIES

Improving the engineering properties of soils to meet project specifications has long been a focus for civil engineers. Recently, environmentally friendly biological methods have gained attention for this purpose. These methods, which integrate knowledge from biology, biochemistry, and civil engineering, utilize biological products or organisms, such as bacteria, commonly found in soils. This study investigates the reduction of permeability or hydraulic conductivity in the base soil of the Shiraz landfill using the microbial-induced calcite precipitation (MICP) method. The soil was treated with Bacillus sphaericus, and falling head permeability tests were conducted to measure the permeability of soil samples before and after biological treatment. Key variables examined included curing time, bacterial density, optimal nutrient content, and soil unit weight. The results indicated that permeability decreased with longer curing times, higher calcium chloride solution concentrations, and increased bacterial density. This research demonstrates that MICP can serve as an innovative, eco-friendly approach to reducing soil permeability at landfill bases and walls, creating a protective barrier between waste materials and groundwater or substrata (Hataf and Baharifard 2020).

(Alzahrani et al., 2023), explored the estimation of soil permeability using easily measurable soil parameters and evaluated the performance of artificial intelligence (AI)-based models. The support vector machine (SVM) technique was employed to predict soil permeability, and its performance was compared with other AI methods, including Gaussian process (GP), random forest (RF), and multi-linear regression (MLR) models. While GP, RF, and MLR models demonstrated good estimation accuracy, the SVM model outperformed them. The SVM and GP regression models utilized two kernel functions: Pearson VII and radial basis kernel functions. The study utilized a dataset of

95 observations obtained from laboratory experiments, with 66 datasets used for training the algorithms and the remaining 29 datasets reserved for testing. Input variables included the percentage of sand (S), percentage of fly ash (Fa), specific gravity (G), time (T), and head (H), while the coefficient of permeability (k) served as the output. A comparison with previous studies revealed a weak correlation between permeability values. Sensitivity analysis identified time and water head as the most influential parameters for estimating soil permeability.

The permeability stability calculation model for foam-conditioned soil, based on the permeability constant (Wang et al., 2021), is essential for ensuring the low permeability of discharged muck persists for at least tens of minutes to prevent water spewing during earth pressure balance (EPB) shield tunneling. Foam, commonly added to soil to reduce permeability, exhibits time-varying characteristics, making it crucial to predict the stable permeability duration of foam-conditioned soil in EPB shield tunneling. By integrating theories of the effective permeation channel of pure foam and fluid mechanics, a constant is introduced to predict the initial period during which the permeability coefficient of conditioned soil remains stable. Large-scale permeation tests were conducted to determine the initial stable period for various foam-conditioned soils, confirming that the predicted results align well with measured data. Additionally, practical concepts such as duration reference curves, optimum fineness, optimum porosity, and critical particle size are proposed based on this constant to enhance spewing control in EPB shield tunneling.

A method and equipment for continuously measuring the permeability coefficient of rock and soil layers have been developed (Han, 2021). Traditional methods such as the water pressure test and steady-flow pumping test are still widely used to determine the permeability coefficient of rock and soil strata. However, these methods are limited to providing only an average value of the permeability coefficient, which often results in low accuracy for specific rock and soil layers. To address this limitation, a new on-site testing method and equipment have been proposed for continuous measurement of the permeability coefficient. This method is applicable to both water pressure testing in boreholes and steady-flow pumping tests.

The technical approach involves conducting a pumping test or water pressure test until the water penetration reaches a stable value. A high-precision current meter probe is then placed at the bottom of the test hole. For the pumping test, the current meter is uniformly raised from the bottom of the borehole testing section to the stable water level, while continuously measuring the flow rate within differential zones of the tested section. Similarly, for the water pressure test, the current meter is uniformly lifted from the bottom to the top of the borehole test section, with continuous detection of the flow rate in the differential section.

Through data analysis and processing, this method not only provides the average permeability coefficient of the tested sections but also calculates the permeability coefficient for each differential section of the rock and soil stratum. Additionally, it establishes the relationship between the permeability coefficient and the specific location within the tested section. This approach enables the precise identification of leakage points, their specific positions, and the quantity of leakage, significantly enhancing the accuracy of the test results.

Wang et al. (2019) studied the permeability of steel slag and its potential for modifying silt soil as a geo-backfill material in geotechnical and foundation treatment projects. The research examined three types of steel slag—fine, coarse, and gravel—through particle analysis, relative density, and specific gravity tests to determine their fundamental physical properties. To evaluate permeability, constant head permeability tests were conducted on pure steel slag, while variable head tests were performed on silt soil mixed with different proportions of steel slag. The study derived predictive formulas for the permeability coefficients of both pure steel slag and steel slag-modified silt soil. Results indicated that permeability in pure steel slag was significantly influenced by particle size and relative density, resembling the behavior of fly ash and fine sand in dense states, where higher relative density led to lower permeability. Additionally, the permeability coefficient of silt soil increased as the steel slag content rose, demonstrating that steel slag effectively enhances soil permeability. These findings offer valuable insights for the use of steel slag in roadbed backfill, silt soil improvement, and related engineering applications.

The permeability of unsaturated silt-sand soil plays a crucial role in various geotechnical and geoenvironmental challenges. Therefore, developing an effective method to assess silt-sand soil permeability is essential, especially in Iran, where it has received limited attention. This in vitro study investigates the impact of different fine silt contents on the behavior of unsaturated silt-sand soil with varying grain size distributions using a newly modified triaxial apparatus. Permeability was analyzed in relation to matric suction and volumetric water content, and the findings were compared with experimental models. The results revealed that the permeability of unsaturated sandy soil can be characterized as a function of matric suction, soil void size, and fine aggregate content. Moreover, the study suggests that increasing the fine content reduces permeability, particularly at higher suction levels. This decline in soil permeability is attributed to the increased presence of fine particles (Gup et al., 2024).

Study on the Permeability Characteristics of Polyurethane Soil Stabilizer Reinforced Sand (Smith and Doe 2023). A polyurethane-based soil stabilizer (PSS) is used to reinforce sand, and its permeability characteristics have been investigated through a series of tests, including reinforcement layer formation, single-hole permeability, and porous permeability tests. Scanning electron microscope images were analyzed to understand the reinforcement mechanism. The results show that PSS enhances the permeability resistance of sand by forming a reinforcement layer on the surface. The thickness and integrity of this layer increase with longer curing times and higher PSS concentrations. Additionally, the water flow rate decreases as curing time or PSS concentration increases. The permeability coefficient decreases with longer curing time and higher PSS concentration but increases with depth in the specimen. PSS fills sand voids and adheres to sand particle surfaces, reducing or blocking water flow channels and improving permeability resistance. These findings serve as a reference for chemical reinforcement in sandy soil engineering, particularly for surface protection applications such as embankments, slopes, and landfills.

Effects of grass roots on soil-water retention curve and permeability function (Smith and Brown 2020). The effects of Vetiver grass (Chrysopogon zizanioides) roots on soil-water retention curves (SWRCs), permeability (k) function, and saturated permeability (ksat) were examined in clayey sand (SC) and low-plasticity silt (ML). In ML soil, when root biomass per soil volume was below 6.5 kg/m^3, saturated permeability increased, air-entry suction slightly decreased, and the SWRC became steeper with increasing root content—likely due to crack formation caused by wetting and drying cycles during plant growth. However, once the root content exceeded approximately 6.5 kg/m^3, roots appeared to reduce saturated permeability and increase air-entry suction by occupying macropores and suppressing cracks and swelling. In SC soil, across all root content levels, only a slight variation in saturated permeability was observed at the upper bounds.

Estimating the permeability of naturally structured soil from percolation theory and pore space characteristics imaged by X-ray (Zhang et al., 2023). The saturated hydraulic conductivity of soil (Ks) is a crucial but challenging parameter to predict in hydrological models. This study evaluates a model based on percolation theory and critical path analysis to estimate Ks using measurements from 95 undisturbed soil cores collected from diverse soil types. The model incorporated one fitted parameter (the pore geometry factor), while two other parameters—the critical pore diameter (dc) and effective porosity—were derived from X-ray computed tomography. Although the model showed a highly significant fit to Ks measurements ($p < 0.0001$), it explained only about 47% of the variation. Additionally, the fitted pore geometry factor was one to two orders of magnitude larger than theoretical values from idealized porous media and pore network models. This discrepancy could be due to model assumptions that may not fully hold in reality or experimental errors caused by factors such as air entrapment and structural changes in soil pores during sample presaturation and Ks measurement. The variation in dc emerged as the primary source of variation in Ks, suggesting that dc is a meaningful length scale for predicting soil permeability. From a pedotransfer function perspective, future research should focus on investigating correlations between dc and fundamental soil properties or site attributes.

Soil Improvement of EPBS Construction in High Water Pressure and High Permeability Sand Stratum (Doe, 2024). In tunnel construction within high-permeability and high-water-pressure strata, a mud-water balance shield is typically preferred. However, when construction and environmental constraints make this infeasible, an earth pressure balance shield (EPBS) must be used. This approach poses a significant risk of slag spraying, which can create serious safety hazards for workers. Slag improvement is an effective method to mitigate this risk, drawing increasing research attention.

Based on the Shangteng-Dadao Section of Fuzhou Rail Transit Line 1, a ratio method is proposed for optimizing slag improvement. Through laboratory tests, a combined application of sodium bentonite, carboxymethyl cellulose (CMC), and polyacrylamide is evaluated to address residual soil spraying challenges associated with EPBS in high-permeability, high-water-pressure strata. The optimal improvement method includes:

Adding 2.5% and 0.5% (by sand volume) of swelling soil with a 10% concentration.
Using sodium bentonite-CMC mixed mud at a 5% concentration.
Applying a polyacrylamide solution with a concentration of 3% to 4%.
Field applications were randomly inspected to validate the effectiveness of this approach.

Colloid Mobilization in a Fractured Soil during Dry-Wet Cycles: Role of Drying Duration and Flow Path Permeability (Smith et al., 2023). Subsurface soils release colloids that are transported by infiltrating rainwater, but the sources of these colloids and the processes generating them between rainfall events remain uncertain. This study investigated how drying duration and spatial variations in soil permeability influence the mobilization of in situ colloids within intact soil cores of fractured and heavily weathered saprolite during dry-wet cycles. By measuring water flux at multiple sampling ports at the core base, we observed that water drained through flow paths with varying permeability. The duration of antecedent drying cycles notably impacted colloid mobilization, especially in high-flux ports connected to soil regions with numerous macro- and mesopores. In these high-flux ports, colloid mobilization increased with drying durations of up to 2.5 days but declined for longer drying periods. In contrast, low-flux ports, likely connected to soil regions with fewer large pores, showed limited changes in colloid mobilization with increasing drying duration. These findings suggest that drying duration influences colloid generation from dry pore walls and the distribution of colloids within flow paths, depending on soil moisture content and flow path permeability. This improved understanding of colloid mobilization is valuable for predicting soil behavior under fluctuating weather conditions.

CHAPTER THREE

METHODOLOGY

3.1 MATERIAL USED

3.1.1 Soil Sample

The soil sample was collected from four boreholes at a depth of 0.5m, 1m respectively with a distance of 30m length and 7.5m breath Ekosodin, Benin City, Nigeria.

Ekosodin is a semi-urban community located near the University of Benin in Benin City, Edo State, Nigeria. It is a densely populated area, largely inhabited by university students, local residents, and small-scale traders. This setting provides a unique context for various types of research, particularly in urbanization, socio-economic development, public health, environmental studies, and educational infrastructure.

3.2.2 Water

Water was used during each of the experiment such as the wet sieve analysis, moisture content, specific gravity, and atterberg limit. The way water interacted with the soils of grain sizes revealed crucial information about the soil's hydraulic properties.

3.2 APPARATUS

3.2.1 Hand Auger

Plate 1**: The Hand Auger**

The hand auger was used to collect samples from four boreholes at 0.5m and 1m depth each with a length of 30m and a breath of 7.5m.

3.3.2 Pycnometer

Plate 2: **The Pycnometer**

The pycnometer was used for determining specific gravity, it depends on the material being tested (liquids, and solids).

3.3.3 Oven

Plate 3: **The Oven**

The oven was used to remove the water from the soil by heating it to a specific temperature, typically around 105°C to 110°C, for a prolonged period (usually 24 hours).

3.4.4 Weighing Balance

Plate 4: **The Weighing Balance**

The weighing balance is an apparatus used to measure the weight of the soil sample, during the various tests carried out in this work in grams (g).

3.4.5 Casagrande Apparatus

Plate 5**: The Casangrande Apparatus**

The Casagrande Apparatus was used in the Liquid Limit (LL) Test to measure the moisture content at which soil changes from a plastic to a liquid state. It played a key role in classifying fine-grained soils based on their consistency and plasticity.

3.4.6 Spatula

Plate 6: **The Spatula**

The spatula was used in soil testing for various purposes, including sample preparation and handling.

3.5.7 Stopwatch

Plate 7: **The Stopwatch**

The stopwatch was used in the Casagrande Liquid Limit Test to ensure that the brass cup dropped at a standard rate of 2 drops per second. Proper timing with the stopwatch ensured that the test results were reliable and comparable across different soil samples.

3.5.9 Sieve Set

Plate 8: **The Sieve Set**

Sieve set will be use in the soil permeability for testing and classified the separate soil particles into different size fractions, which helped determined the permeability characteristics of the soil type.

3.2 SITE COORDINATES

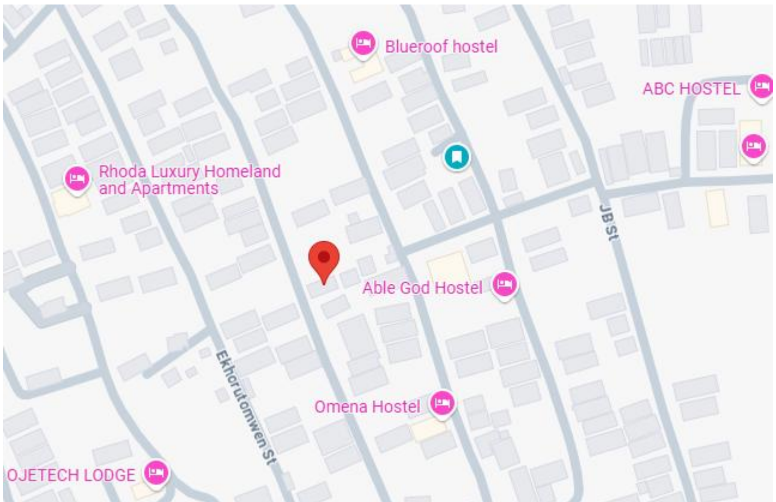

Plate 9: **The image of the site coordinates**

BH 1

Latitude : 6.4184341

Longitude: 5.6203323

BH 2

Latitude : 6.4192967

Longitude : 5.6212283

BH 3

Latitude : 6.4194457

Longitude : 5.6212589

BH 4

Latitude : 6.4220547

Longitude : 5.6226317

3.6 PROCEDURES AND EMPIRICAL FORMULARS APPLIED TO ESTIMATE PERMEABILITY.

The Kozeny Carman equation was used to determine the permeability of the soil, relating the kozeny carman constant, void ratio, and specific surface area as expressed mathematically below.

$$K = \frac{C}{(1+e)} \frac{e\,3}{S2} \qquad \text{Eq (3.1)}$$

Where

K = permeability (m^2)

C = kozeny carman contant (between 0.8 to 1.0)

e = void ratio

S = specific surface area (m^2/g)

Then the specific surface area was calculated for using another empirical formular relating specific gravity of the soil particle and median grain size as expressed mathematically below.

$$S = \frac{6}{G_s \times D_{50}}$$ Eq(3.2)

Where

S = specific surface area (m^2 /g)

G_S = specific gravity

D_{50} = median grain size (m)

And void ratio was calculated for using the formular below.

$$e \times S_t = w \times G_s$$ Eq(3.3)

Where

e = void raio

S_t = degree of saturation

W = moisture content (%)

G_s = specfic gravity

Since, the soil was fully saturated while carrying out the test St becomes one (1). Then the formular becomes,

$$e = w \times G_S$$ Eq(3.4)

3.7 DETERMINATION OF THE D50 IN THE SPECIFIC SURFACE AREA EMPIRICAL FORMULAR IS BY CARRYING OUT PARTICLE SIZE DISTRIBUTION TEST

3.7.1 LABOURATORY TEST PROCEDURE FOR PARTICLE SIZE DISTRIBUTION IN LINE BS 1377-2:1990

3.7.1.1 Wet Sieve

i. Placed the 75 µm (No. 200) sieve over a collection pan.

ii. Placed the fine fraction sample into a beaker and added clean water.

iii. Stirred the sample to create a suspension and disperse clay and silt particles.

iv. Poured the suspension onto the No. 200 sieve while gently spraying water.

v. Continued washing until clear water passes through the sieve (ensuring all fines are washed).

vi. Transferred the retained material to a drying pan.

3.7.1.2 Dry Sieve

i. Collected a dry representative sample (as per ASTM D75 or AASHTO T2).

ii. Weighed the total dried sample (W1).

iii. Recorded the weight before sieving.

iv. Arranged the sieves in decreasing mesh size, with the largest sieve on top and a pan at the bottom.

v. Poured the sample onto the top sieve.

vi. Shaked for 10–15 minutes (as per standard).

vii. Carefully removed each sieve and weighed the material retained on each sieve.

viii. Used a brush to remove fine particles stucked in the mesh.

ix. Weighed the material retained in the pan.

x. Computed the cumulative percentage retained and cumulative percentage passing for each sieve as expressed mathematically below.

$$\text{Percentage retained} = \frac{\text{Weight Retained on Sieve}}{\text{Total Sample Weighed}} \times 100$$

Eq (3.5)

xi. Plotted the particle size distribution curve (Semi-log graph with sieve size on x-axis and cumulative % passing on y-axis).

3.7.2 DETERMINATION OF THE SPECIFIC GRAVITY IN THE SPECIFIC SURFACE AREA EMPIRICAL FORMULAR IS BY CARRYING OUT A SPECIFIC GRAVITY TEST

3.7.2.1 LABOURATORY TEST PROCEDURE FOR SPECIFIC GRAVITY IN LINE WITH BS 1377-2:1990

i. Collected a representative soil sample

ii. Dried the soil sample in an oven at 110°C for 24 hours.

iii. Cooled it in a desiccator.

iv. Weighed the Pycnometer with a scale.

v. Recorded the mass of the empty, dry pycnometer (W_1).

vi. Filled the pycnometer with dry soil and recorded the mass (W_2).

vii. Filled the pycnometer halfway with distilled water and stirred to remove air bubbles.

viii. Filled completely and recorded the mass (W_3).

ix. Filled the pycnometer with distilled water only and recorded the mass (W_4).

x. Calculated for Specific Gravity (Gs) using the formula as expressed below.

$$G_s = \frac{(w_2 - w_1)}{(w_2 - w_1) - (w_3 - w_4)}$$

Eq (3.6)

3.7.3 DETERMINATION OF THE OF THE KOZENY CARMAN CONSTANT INCLUDES CARRYING OUT AN ATTERBERG LIMIT TEST

3.7.3.1 LABOURATORY TEST PROCEDURE FOR ATTERBERG LIMIT USING THE CASANGRANDE METHOD IN LINE WITH BS 1377-2:1990

3.7.3.2 LIQUID LIMIT

i. Air-dried and sieved soil through a 425-micron sieve.

ii. Placed about 200g of soil in an evaporating dish.

iii. Added distilled water gradually and mix to form a uniform paste.

iv. Spread soil paste into the cup to about 10mm depth.

v. Used the grooving tool to create a groove in the middle.

vi. Lifted and drop the cup at a rate of 2 drops per second.

vii. Counted the number of blows needed to close the groove by 12mm.

viii. Collected Moisture Samples

ix. Took a sample from the closed groove and placed it in a moisture tin.

x. Repeated the process for different moisture contents (about 4 data points).

xi. Weighed the moisture tins before and after oven drying at 105°C–110°C for 24 hours.

xii. Calculated the water content (%) for each test.

xiii. Plotted Flow Curve & Computed the Liquid Limit

xiv. Plotted a graph of water content (%) vs. the log of the number of blows.

xv. Drew the best-fit line and determined liquid limit (LL) at 25 blows.

3.7.3.3 PLASTIC LIMIT

i. Air-dried and sieved soil through a 425-micron sieve.

ii. Took about 20g of soil and mixed it with distilled water until it became plastic.

iii. Took a small portion and rolled it into a thread of 3mm diameter on a glass plate.

iv. If it crumbles before reaching 3mm, i recorded the moisture content as the PL.

v. If not, kneaded and repeated until crumbling occurs.

vi. Determined Moisture Content

vii. Placed crumbled soil in a moisture tin.

viii. Oven dried at 105°C–110°C for 24 hours.

ix. Weighed and calculated the water content.

x. Then, calculated for plasticity index using the formular below.

$$PL = LL - PL \qquad \text{Eq (3.7)}$$

3.7.4 LABOURATORY TEST PROCEDURE FOR SOIL MOISTURE CONTENT IN LINE WITH BS 1377: PART 2: 1990

i. Obtained a representative soil sample using proper sampling techniques to avoid contamination and ensured that the sample reflects the conditions of the field.

ii. Weighed the empty container using the weighing balance (recorded the mass as M_1).

iii. Added a known weight of the wet soil sample to the container (record the total weight as M_2).

iv. Calculated the initial mass of the wet soil by subtracting (M_2 - M_1).

v. Placed the container with the wet soil sample in an oven set at 105–110°C.

vi. Dried the sample for a minimum of 24 hours or until the mass is constant (no further weight loss).

vii. After drying, i removed the container from the oven and placed it in a desiccator to cool. This prevents moisture from being absorbed from the air.

viii. Once cooled, i weighed the container with the dry soil sample (recorded this weight as M_3).

ix. Calculated the final mass of the dried soil by subtracting (M_3 - M_1).

x. Calculated the moisture content using the formula below.

$$W = \frac{Ww}{Ws} \times 100\% \qquad \text{Eq(3.8)}$$

Where:

(W) = Moisture content in percentage (%)

(Ww) = weight of water in the soil sample (grams or kg)

(Ws) = weight of dry soil (g or kg)

xi. Reported the moisture content as a percentage, rounded to one decimal place.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1: PARTICLES SIZE DISTRIBUTION LABORATORY TEST RESULTS

Table 4.1: Sieves analysis parameters for borehole one at depth 0.5m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.07	99.93	99.93
10	2	0.1	99.83	99.83
14	1.18	1.63	98.2	98.2
25	0.6	12.61	85.59	85.59
36	0.425	3.98	81.61	81.61
52	0.3	7.4	74.21	74.21
72	0.212	28.4	45.81	45.81
100	0.15	0.64	45.17	45.17
200	0.075	6.44	38.73	38.73

Source: (Author, 2025)

Site detail: BH1, Depth: 0.5m, D50: 0.224983099 mm or 0.0002249831m

The table presents sieve analysis parameters for soil collected from borehole one (BH1) at a depth of 0.5m. It includes data on various sieve sizes, their equivalent British Standard sizes in millimeters, the weight of soil retained on each sieve, cumulative passing weight, and the percentage passing. The data helps in determining soil gradation, with a specific mention of D50 (median particle diameter) as 0.22498 mm. The results indicate the distribution of particle sizes, which is useful for soil classification and engineering applications.

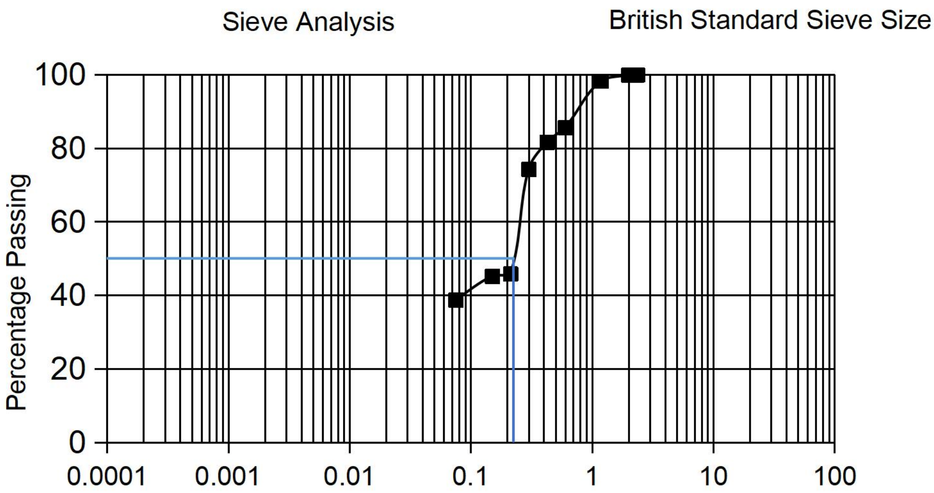

Figure 4.2: Graph of sieve analysis percentage passing (Author, 2025)

The sieve analysis curve confirms that the soil is poorly graded fine sand with a significant amount of fines, impacting its drainage, compaction, and strength characteristics. and is classified as SP (Poorly Graded Sand) or SM (Silty Sand) under USCS and A-2-4 or A-2-5 (Silty or Clayey Sand) under AASHTO.

Table 4.2: Sieves analysis parameters for borehole one at depth 1m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.08	99.92	99.92
10	2	0	99.92	99.92
14	1.18	1.84	98.08	98.08
25	0.6	20.45	77.63	77.63

36	0.425	0.12	77.51	77.51
52	0.3	6.44	71.07	71.07
72	0.212	27.89	43.18	43.18
100	0.15	0	43.18	43.18
200	0.075	6.31	36.87	36.87

Source: (Author, 2025)

Site detail: BH1, Depth: 1m, D50: 0.233518824 mm or 0.0002335188m

The table displays sieve analysis data for Borehole One at a depth of 1 meter, detailing sieve numbers, approximate imperial sizes (in inches), British standard sieve sizes (in mm), retained weight (in grams), and cumulative passing percentages. The results indicate the distribution of soil particles across various sieve sizes, with finer particles passing through smaller openings. The median particle size (D50) is recorded as 0.233518824 mm, reflecting the soil's gradation. The analysis reveals a mix of fine to coarse particles, with a notable portion passing through the finer sieves.

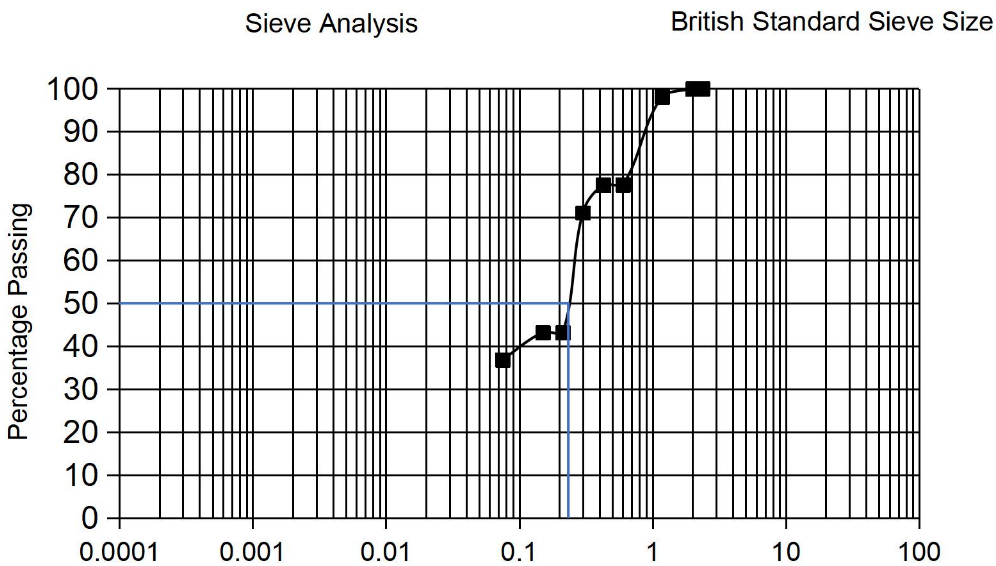

Figure 4.3: Graph of sieve analysis percentage passing (Author, 2025)

The graph illustrates the sieve analysis results for Borehole One (BH1) at a depth of 1 meter, showing the cumulative percentage of soil passing through various British Standard sieve sizes. The x-axis represents the sieve size (in mm) on a logarithmic scale, while the y-axis indicates the percentage passing. According to the USCS classification, the soil is identified as SC (Clayey Sand), and under the AASHTO system, it is classified as A-6 (Clayey Soil).

Table 4.4: Sieves analysis parameters for borehole two at depth 0.5m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.31	99.69	99.69
10	2	0	99.69	99.69
14	1.18	1.16	98.53	98.53
25	0.6	23.91	74.62	74.62
36	0.425	0.07	74.55	74.55
52	0.3	9.09	65.46	65.46
72	0.212	28.46	37	37

100	0.15	6.4	30.6	30.6
200	0.075	8.25	22.35	22.35

Source: (Author, 2025)

Site detail: BH2, Depth: 0.5m, D50: 0.252196767 mm or 0.0002521968m

The table displays sieve analysis parameters for Borehole Two (BH2) at a depth of 0.5 meters, including sieve numbers, their corresponding British Standard sieve sizes (in mm), the retained mass (in grams), and the cumulative percentage passing.

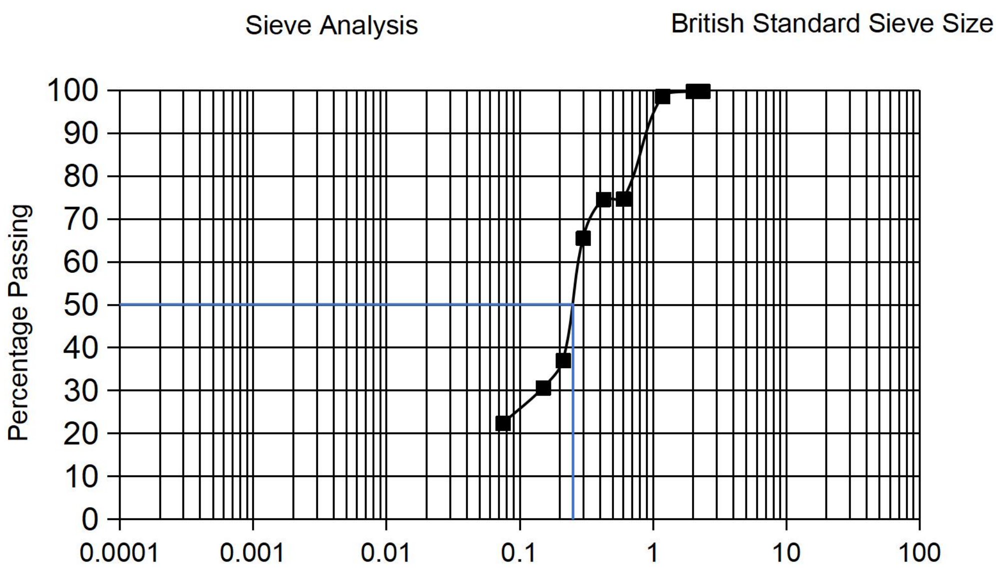

Figure 4.4: Graph of sieve analysis percentage passing (Author, 2025)

The graph illustrates the sieve analysis results for Borehole Two (BH2) at a depth of 0.5m, displaying the percentage of soil passing through various British Standard sieve sizes on a logarithmic scale. The soil is classified as SC (Clayey Sand) according to the USCS and A-2-4 (Silty or Clayey Sand) under the AASHTO system.

Table 4.5: Sieve analysis parameters for borehole two at depth 1m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.05	99.95	99.95
10	2	0	99.95	99.95
14	1.18	1.37	98.58	98.58
25	0.6	20.2	78.38	78.38
36	0.425	0.07	78.31	78.31
52	0.3	6.54	71.77	71.77
72	0.212	23.68	48.09	48.09
100	0.15	4.67	43.42	43.42
200	0.075	7.08	36.34	36.34

Source: (Author, 2025)

Site detail: BH2, Depth: 1m, D50: 0.219097973 mm or 0.000219098m

The table presents sieve analysis parameters for Borehole Two (BH2) at a depth of 1 meter, detailing the particle size distribution by listing different sieve sizes in both approximate imperial and British standard metric units, recording the weight of soil retained on each sieve in grams, and calculating the cumulative passing weight and percentage. Key observations include minimal soil retention on larger sieve sizes, such as 3.35 mm and 2.36 mm, indicating a fine-grained composition, with the most significant retention occurring on the 0.212 mm sieve at 23.68 grams and a passing percentage of 48.09%, while the smallest sieve size of 0.075 mm retains a notable amount of soil at 7.08 grams, with only 36.34% passing.

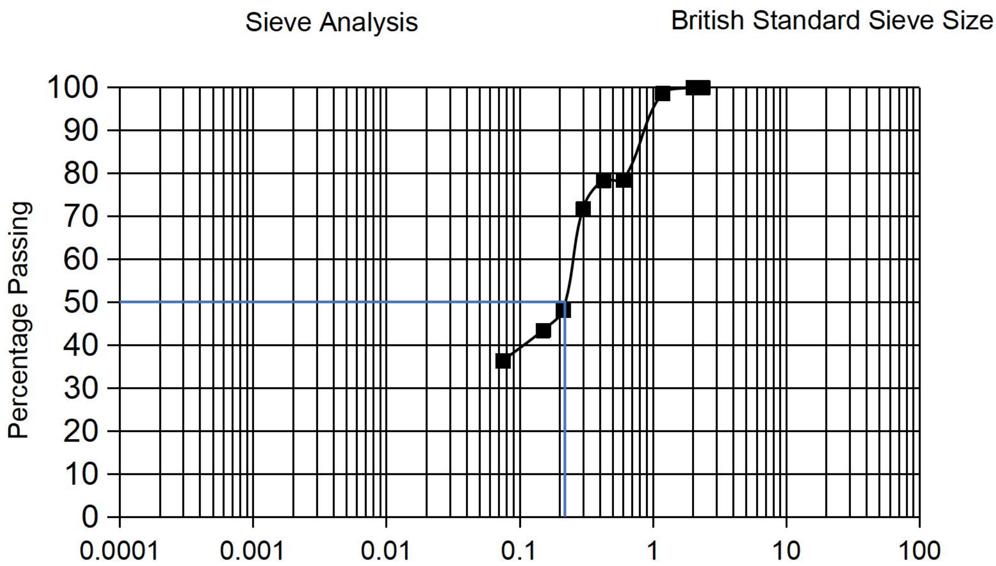

Figure 4.6: Graph of sieve analysis percentage passing (Author, 2025)

The graph presents a sieve analysis curve, plotting the percentage passing against the British Standard sieve size on a semi-logarithmic scale, illustrating the particle size distribution of the soil sample from Borehole Two (BH2) at a 1m depth. The soil is likely a low-plasticity silt (ML) or lean clay (CL) according to the USCS, and it falls into the A-4 or A-6 group in the AASHTO classification, indicating silty or clayey fine-grained soil. The relatively low plasticity suggests limited expansion and shrinkage, making it suitable for foundations with minimal settlement concerns.

Table 4.7: Sieve analysis parameters for borehole three at depth 0.5m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.52	99.48	99.48
10	2	0.11	99.37	99.37
14	1.18	1.56	97.81	97.81
25	0.6	16.52	81.29	81.29
36	0.425	0	81.29	81.29
52	0.3	6.27	75.02	75.02
72	0.212	24.1	50.92	50.92
100	0.15	5.09	45.83	45.83
200	0.075	6.9	38.93	38.93

Source: (Author, 2025)

Site detail: BH3, Depth: 0.5m, D50: 0.200793713 mm or 0.0002007937m

The table presents sieve analysis parameters for borehole three (BH3) at a depth of 0.5m, including sieve numbers, their approximate imperial and British standard sieve sizes (in mm), and the corresponding mass retained (in grams), mass passing (in grams), and cumulative percentage passing. Key observations reveal that the largest sieve size (3.35 mm) retained the most material initially, with 100% passing through. As sieve sizes decrease, more material is retained, reducing the cumulative percentage passing. The finest sieve (0.075 mm) retained 6.9g of material, with 38.93% passing, and the D50 value, indicating the median particle size, is approximately 0.20079 mm.

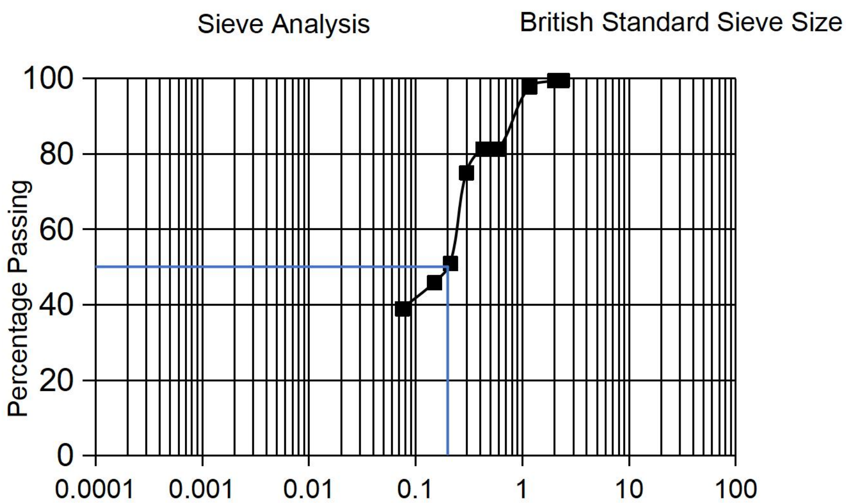

Figure 4.8: Graph of sieve analysis percentage passing (Author, 2025)

The graph displays a sieve analysis curve on a semi-logarithmic scale, illustrating the percentage of soil particles passing through various British Standard sieve sizes, corresponding to the data from the table. It represents the grain size distribution of the soil at a depth of 0.5m in borehole three (BH3). The soil is classified as nonplastic or slightly plastic, likely a silty or fine sand material in the USCS, while in AASHTO, it falls under the A-4 category (Silty Soil).

Table 4.8: Sieve analysis parameters for borehole three at depth 1m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.12	99.88	99.88
10	2	0	99.88	99.88
14	1.18	1.21	98.67	98.67
25	0.6	17.91	80.76	80.76
36	0.425	0	80.76	80.76
52	0.3	7.47	73.29	73.29
72	0.212	25.24	48.05	48.05
100	0.15	4.99	43.06	43.06
200	0.075	7.38	35.68	35.68

Source: (Author, 2025)

Site detail: BH3,   Depth: 1m,   D50: 0.218798732 mm or 0.0002187987m

The table presents sieve analysis parameters for borehole three (BH3) at a depth of 1 meter, showing the distribution of soil particle sizes by measuring the mass of material retained on different British Standard sieve sizes (mm) and calculating the percentage passing through each sieve. Key details include the weight of material retained on each sieve (in grams), the cumulative percentage of material passing through each sieve, and the D50 value, which represents the median particle diameter and is approximately 0.2188 mm. The results indicate a well-graded soil with a significant portion of particles passing through finer sieves, suggesting a mix of sand and silt-sized particles.

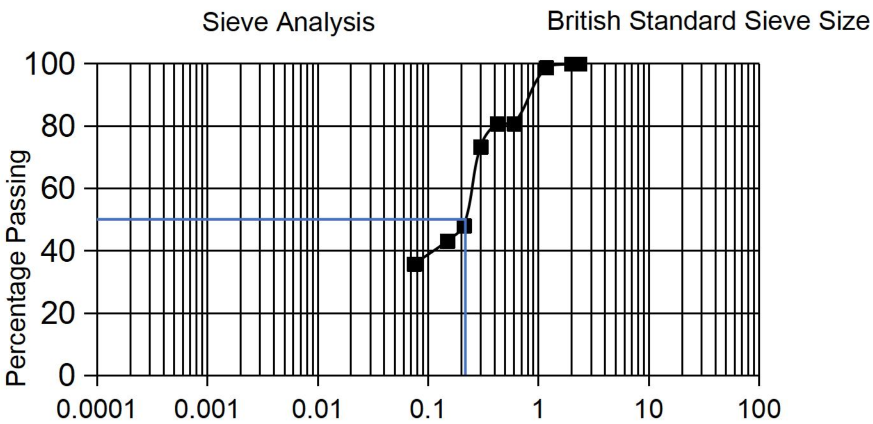

Figure 4.9: Graph of sieve analysis percentage passing (Author, 2025)

The graph presents the sieve analysis results for borehole three (BH3) at a depth of 1 meter, corresponding to the data in the table. It is a semi-logarithmic plot with the x-axis representing the British Standard sieve sizes on a logarithmic scale and the y-axis showing the percentage of material passing through each sieve. The curve follows an S-shape, indicating a well-graded soil sample with a range of particle sizes. Based on the analysis, the soil is classified as SM (Silty Sand) or SP-SM

(Poorly Graded Sand with Silt) according to the USCS, and A-2-4 (Granular soil with silt-clay fines, typically used for subgrade material in roads) under the AASHTO classification system.

Table 4.10: Sieve analysis parameters for borehole four at depth 0.5m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.36	99.64	99.64
10	2	0.13	99.51	99.51
14	1.18	1.26	98.25	98.25
25	0.6	16.22	82.03	82.03
36	0.425	0.2	81.83	81.83
52	0.3	7.8	74.03	74.03
72	0.212	25.46	48.57	48.57
100	0.15	4.93	43.64	43.64
200	0.075	6.22	37.42	37.42

Source: (Author, 2025)

Site detail: BH4, Depth: 0.5m, D50: 0.216942655 mm or 0.0001269427m

The table presents sieve analysis parameters for borehole four (BH4) at a depth of 0.5m. It provides data on different sieve sizes in both imperial and metric units, along with the corresponding retained and passing weights of soil particles. The percentage passing through each sieve is also recorded. The analysis indicates that finer particles dominate at deeper sieve levels, with 37.42% of the sample passing through the smallest sieve (200). The D50 value, representing the median particle diameter, is 0.2169 mm (or 0.0001269 m), suggesting a predominantly fine-grained soil composition.

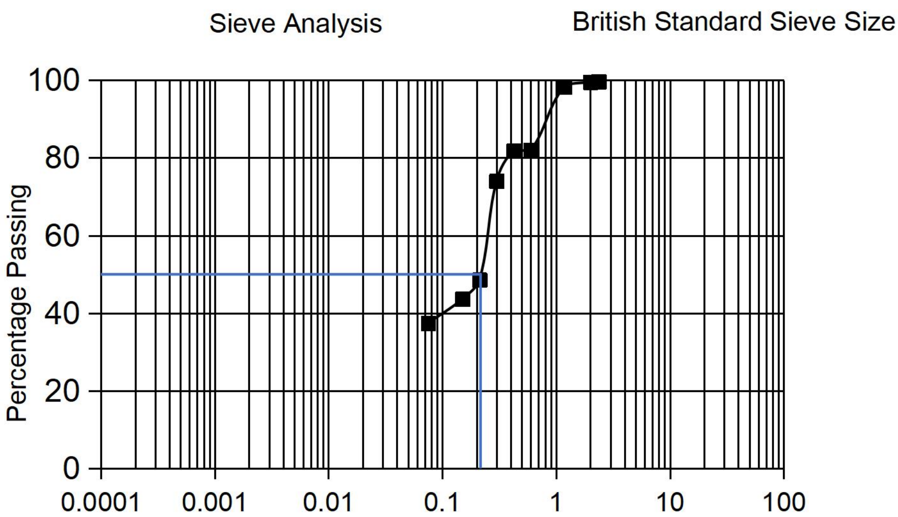

Figure 4.11: Graph of sieve analysis percentage passing (Author, 2025)

The graph illustrates the sieve analysis results, depicting the percentage of soil particles passing through various British Standard sieve sizes. It presents a semi-logarithmic particle size distribution (PSD) curve, with the x-axis showing the sieve size on a logarithmic scale and the y-axis representing the percentage passing on a linear scale. The curve exhibits a steep incline between approximately 0.1 mm and 1 mm, indicating that the majority of soil particles fall within this range. According to the USCS classification, the soil is categorized as SM (Silty Sand – Low Plasticity), while under the AASHTO system, it is classified as A-2-4 (Silty Sand, suitable for road subgrade).

Table 4.12: Sieve analysis parameters for borehole four at depth 1m

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
⅛	3.35		100	
7	2.36	0.31	99.69	99.69
10	2	0	99.69	99.69
14	1.18	1.45	98.24	98.24
25	0.6	23.42	74.82	74.82
36	0.425	0.07	74.75	74.75
52	0.3	6.45	68.3	68.3
72	0.212	25.47	42.83	42.83
100	0.15	4.87	37.96	37.96
200	0.075	6.74	31.22	31.22

Source: (Author, 2025)

Site detail: BH4, Depth: 1m D50: 0.236772674 mm or 0.0002367727m

The table presents sieve analysis parameters for Borehole 4 at a depth of 1 meter, listing sieve numbers, their corresponding British Standard sieve sizes (in mm), the weight of soil retained on each sieve (in grams), the cumulative weight passing through (in grams), and the percentage of material passing through. The coarsest sieve (3.35 mm) retains no material, with 100% passing, while the amount retained increases as sieve size decreases, indicating a finer soil distribution. The D50 (median particle size) is 0.2368 mm, suggesting a mix of sand and finer particles.

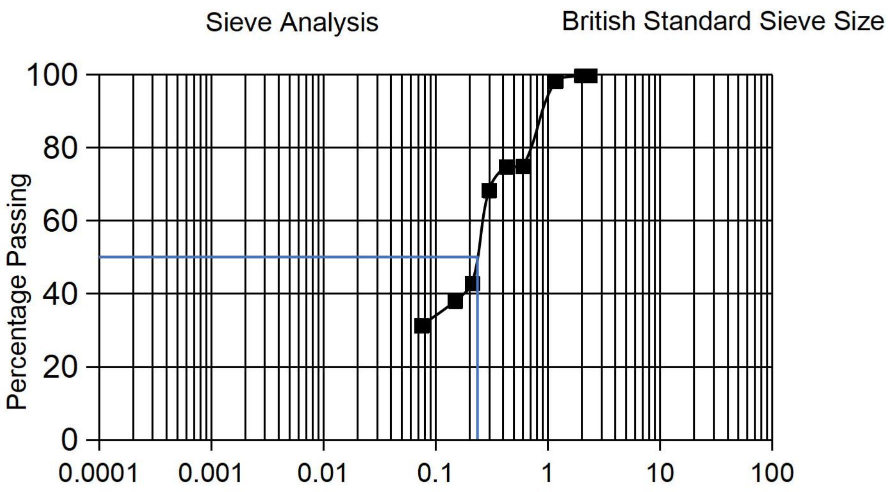

Figure 4.12: Graph of sieve analysis percentage passing (Author, 2025)

The graph is a sieve analysis curve, displaying the percentage of soil passing through various British Standard sieve sizes on a semi-logarithmic scale, with the x-axis representing sieve size in millimeters (logarithmic scale) and the y-axis showing the percentage of material passing. The curve follows an S-shape, typical of well-graded soils, and the percentage passing increases as sieve size decreases, indicating a finer particle distribution. The D50 (median particle size), around 0.2368 mm, aligns with the table data, suggesting a mix of sand and finer particles. According to the USCS classification, the soil is categorized as ML (Low plasticity silt) or CL (Low plasticity clay), while under the AASHTO system, it is classified as A-4 (Silty soil) or A-2-4 (Silty/Sandy soil with fines).

4.13.9: SPECIFIC GRAVITY LABORATORY TEST RESULTS

Table 4.13: Specific gravity parameters

Source: (Author, 2025)

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

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

S/N	LOCATION	DEPTH (m)	BN	B+W	B+S+W	B+S	B	Ad.W	WWAS	WS	WOWDS	Gs	AGs
1	**BH 1**	0.5	SI	75.70	91.70	50.30	20.50	55.20	41.40	29.80	13.80	2.16	2.21
			D4	76.20	92.10	53.00	24.40	51.80	39.10	28.60	12.70	2.25	
2		1.0	DI	71.10	84.10	44.00	19.40	51.70	40.10	24.60	11.60	2.12	2.13
			IN	74.50	88.40	47.40	21.30	53.20	41.00	26.10	12.20	2.14	
3	**BH2**	0.5	Jo4	70.60	86.10	49.30	20.30	50.30	36.80	29.00	13.50	2.15	2.19
			Mar	75.80	91.20	44.10	16.10	59.70	47.10	28.00	12.60	2.22	
4		1.0	DF	74.50	91.60	53.50	22.40	52.10	38.10	31.10	14.00	2.22	2.20
			GH	73.00	90.40	53.30	21.20	51.80	37.10	32.10	14.70	2.18	
5	**BH3**	0.5	ZG	71.30	91.90	58.20	21.00	50.30	33.70	37.20	16.60	2.24	2.23
			VI	78.00	101.30	64.70	22.30	55.70	36.60	42.40	19.10	2.22	
6		1.0	JJZ	75.60	93.00	59.30	25.70	49.90	33.70	33.60	16.20	2.07	2.14
			DA	75.90	92.40	52.20	22.00	53.90	40.20	30.20	13.70	2.20	
7	**BH 4**	0.5	DL	76.10	89.90	49.60	23.20	52.90	40.30	26.40	12.60	2.10	2.16
			ZF	72.00	90.30	53.20	19.90	52.10	37.10	33.30	15.00	2.22	
8		1.0	TQ	76.50	96.00	57.70	21.90	54.60	38.30	35.80	16.30	2.20	2.16
			ZD	73.30	91.40	55.60	21.30	52.00	35.80	34.30	16.20	2.12	

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

AGS = GS/2

Soil samples were collected from boreholes BH1, BH2, BH3, and BH4 at depths of 0.5m and 1.0m, and specific gravity tests were conducted to analyze their properties. The tests involved measuring the weight of an empty bottle (W1), the bottle with soil (W2), the bottle with soil and water (W3), and the bottle fully filled with water (W4). From these measurements, the weight of added water (Ad.W), the weight of water added to soil (WWAS), the weight of soil (WS), and the weight of water displaced by soil (WOWDS) were computed. The specific gravity (GS) was calculated as (W2 - W1) / W, with values ranging between 2.1 and 2.3, typical for sandy or silty soils. Variations in weight values indicated differences in soil composition across locations and depths. Additionally, the adjusted specific gravity (AGS), calculated as GS/2, provided a comparative measure of the soil properties, offering further insight into their characteristics.

4.14.10: ATTERBERG LIMIT LABORATORY TEST RESULTS

Table 4.14: Atterberg limit parameters for liquid limit test for borehole one at 0.5m

Type of Test	**Liquid Limit**				
No. of Blows/shrinkage %	47.00	36.00	26.00	15.00	9.00
Container No.	B	V15	DO4	VT	GE
Wt of wet soil & container (g)	56.50	54.30	53.90	51.70	50.00
Wt of dried soil & container (g)	49.00	47.70	48.20	45.00	42.90
Wt of container (g)	21.40	21.80	28.40	23.20	21.70
Wt of dry soil (Wd) (g)	27.60	25.90	19.80	21.80	21.20
Wt of moisture (Wm) (g)	7.50	6.60	5.70	6.70	7.10
Moisture contain 100 (Wm/Wd)	27.17	25.48	28.79	30.73	33.49

Source: (Author, 2025)

The table presents Atterberg limit parameters from a liquid limit test conducted at a depth of 0.5 meters in borehole one, which determines the moisture content at which soil transitions from a plastic to a liquid state. The test results include the number of blows, which decrease as moisture content increases, and the container number identifying the sample containers. The weights of wet and dried soil with the container, along with the weight of the container itself, are used to calculate the moisture content. The weight of dry soil (Wd) is obtained by subtracting the container weight from the dried soil and container weight, while the weight of moisture (Wm) is the difference between the wet and dry soil weights. Moisture content, expressed as a percentage, is calculated as (Wm/Wd) × 100. These results illustrate how moisture content varies with the number of blows, aiding in determining the soil's liquid limit.

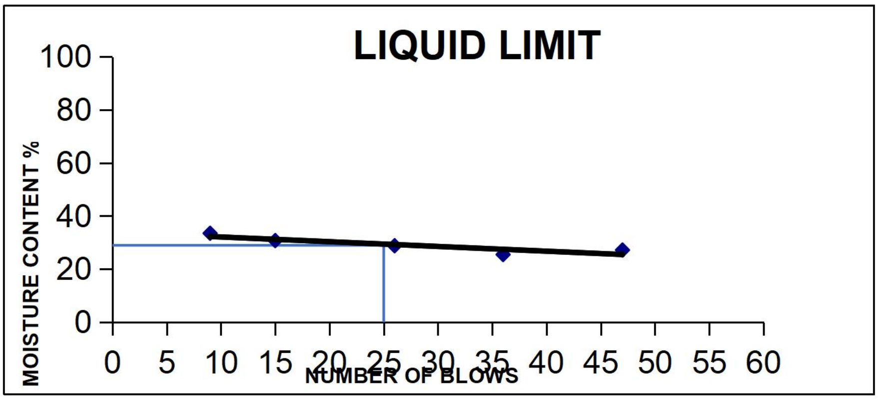

Figure 4.15 : Graph of moisture content against number of blows (Author, 2025)

The graph illustrates the results of a Liquid Limit test, depicting the relationship between moisture content (%) and the number of blows from the Casagrande apparatus, with the x-axis representing the number of blows and the y-axis showing the moisture content percentage. The plotted points, represented by blue diamonds, correspond to the moisture content values from the table at various blow counts. A trend line, shown in black, displays a slight downward slope, indicating that the moisture content decreases as the number of blows increases. The liquid limit is determined by extrapolating this trend line to identify the moisture content at 25 blows, which serves as a standard reference in Atterberg limit tests.

Table 4.16: Atterberg limit parameters for plastic limit test for borehole one at 0.5m

Type of Test	**Plastic Limit**		
Container No.	R1	2T	BY
Wt of wet soil & container (g)	28.50	30.10	27.10
Wt of dried soil & container (g)	27.60	29.30	26.30
Wt of container (g)	21.30	24.50	21.60
Wt of dry soil (Wd) (g)	6.30	4.80	4.70
Wt of moisture (Wm) (g)	0.90	0.80	0.80
Moisture contain 100 (Wm/Wd)	14.29	16.67	17.02
Plastic Limit (%)	15.99121918		

Source: (Author, 2025)

Site detail: BH 1, Depth: 0.5m, Liquid Limit: 28.96%, Plastic Limit: 15.99%, Plastic Index: 12.97%

The table displays the Atterberg limit parameters from the plastic limit test performed on soil samples taken from borehole one at a depth of 0.5 meters. This test identifies the moisture content at which soil changes from a plastic to a semi-solid state. The table is organized into three columns, each corresponding to different container numbers (R1, 2T, and BY). The first two rows indicate the weights of wet and dried soil along with their containers, while the third row lists the weights of the containers alone. The fourth row provides the weight of dry soil after subtracting the container weight, and the fifth row calculates the weight of moisture by finding the difference between the wet and dry soil weights. The sixth row presents the moisture content percentage, derived using the formula: Moisture Content = (Weight of Moisture / Weight of Dry Soil) × 100. Finally, the last row shows the calculated plastic limit, which averages approximately 15.99%.

Table 4.17: Atterberg limit parameters for liquid limit test for borehole one at 1m

Type of Test	**Liquid Limit**				
No. of Blows/shrinkage %	49.00	37.00	29.00	17.00	8.00
Container No.	XA	IB	V16	O.5	XO
Wt of wet soil & container (g)	43.90	46.50	49.50	51.40	42.40
Wt of dried soil & container (g)	39.90	40.90	38.70	44.60	37.80
Wt of container (g)	23.50	21.90	21.40	23.10	23.40
Wt of dry soil (Wd) (g)	16.40	19.00	17.30	21.50	14.40
Wt of moisture (Wm) (g)	4.00	5.60	10.80	6.80	4.60
Moisture contain 100 (Wm/Wd)	24.39	29.47	62.43	31.63	31.94

Source: (Author, 2025)

The table displays the Atterberg limit parameters from a liquid limit test performed on soil extracted from borehole one at a depth of 1 meter. It includes test results for varying numbers of blows, ranging from 49 to 8 blows, and provides measurements for different containers (XA, IB, V16, O.5, and XO). These measurements consist of the wet soil plus container weight, dried soil plus container weight, container weight, dry soil weight, moisture content (Wm), and moisture content percentage (Wm/Wd × 100). These parameters are essential for determining the liquid limit, which is the water content at which soil transitions from a plastic to a liquid state. The results demonstrate how soil moisture content changes with different blows, offering critical insights for soil classification and engineering applications.

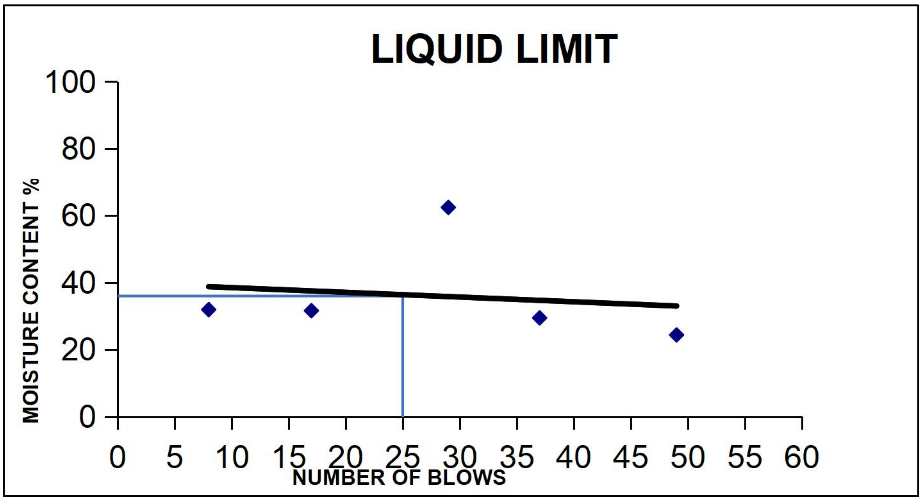

Figure 4.18: Graph of moisture content against number of blows (Author, 2025)

The graph illustrates the results of a Liquid Limit test by plotting Moisture Content (%) against the Number of Blows, with the x-axis representing the Number of Blows (ranging from 0 to 60) and the y-axis representing the Moisture Content (%), which indicates the amount of water in the soil. The blue data points, corresponding to the values from the table, depict the relationship between moisture content and blows, while the black trend line, showing a slight downward slope, suggests a decrease in moisture content as the number of blows increases. The liquid limit is determined by extrapolating the moisture content at 25 blows from the trend line, which aids in classifying soil consistency and assessing its suitability for construction or geotechnical applications.

Table 4.18: Atterberg limit parameters for plastic limit test for borehole one at 1m

Type of Test	**Plastic Limit**		
Container No.	VEG	2E	EIS
Wt of wet soil & container (g)	27.10	28.10	27.40
Wt of dried soil & container (g)	26.40	27.30	26.60
Wt of container (g)	22.00	23.00	20.90
Wt of dry soil (Wd) (g)	4.40	4.30	5.70
Wt of moisture (Wm) (g)	0.70	0.80	0.80
Moisture contain 100 (Wm/Wd)	15.91	18.60	14.04
Plastic Limit (%)	16.18294326		

Source: (Author, 2025)

Site detail: Point 1, Depth: 1m, Liquid Limit: 36%, Plastic Limit: 16.18%, Plastic Index: 19.82%

The Plastic Limit test determines the lowest moisture content at which soil remains plastic, and the results were obtained from tests conducted on three containers labeled VEG, 2E, and EIS. Key parameters measured include the wet soil and container weight, dried soil and container weight, container weight, dry soil weight (Wd), moisture weight (Wm), and moisture content (%), calculated as (Wm/Wd × 100). The Plastic Limit, calculated as 16.18%, represents the moisture content at which the soil begins to crumble when rolled into threads. Additional data includes a sampling depth of 1m, a Liquid Limit of 36%, and a Plastic Index (PI) of 19.82%, derived by subtracting the Plastic Limit from the Liquid Limit. This information is crucial for soil classification and engineering assessments, particularly in evaluating soil workability and stability.

Table 4.19: Atterberg limit parameters for liquid limit test for borehole two at 0.5m

Type of Test	**Liquid Limit**				
No. of Blows/shrinkage %	42.00	37.00	21.00	12.00	9.00
Container No.	V13	A	O.1	LF	SE
Wt of wet soil & container (g)	55.50	54.20	59.70	55.30	60.60
Wt of dried soil & container (g)	48.80	47.90	52.00	48.00	52.60
Wt of container (g)	21.60	21.50	21.80	23.30	24.70
Wt of dry soil (Wd) (g)	27.20	26.40	30.20	24.70	27.90
Wt of moisture (Wm) (g)	6.70	6.30	7.70	7.30	8.00
Moisture contain 100 (Wm/Wd)	24.63	23.86	25.50	29.55	28.67

Source: (Author, 2025)

The table presents Atterberg limit parameters from the liquid limit test conducted on borehole two at a depth of 0.5m, detailing measurements associated with varying numbers of blows, which decrease from 42 to 9, reflecting different moisture conditions. For each test, specific container numbers are used, and the weights of the wet and dried soil along with the container are recorded. The weight of the container alone is measured to determine the soil mass, enabling the calculation of the dry soil weight and the moisture weight (Wm). The moisture content is then computed using the ratio Wm/Wd × 100. This data is crucial for determining the liquid limit, which aids in classifying the soil's consistency and behavior under varying moisture conditions.

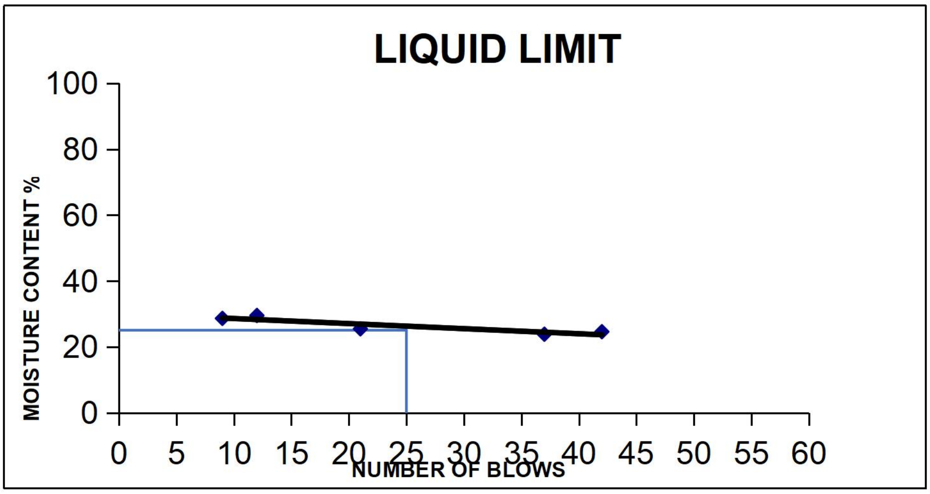

Figure 4.19: Graph of moisture content against number of blows (Author, 2025)

The graph illustrates the results of a liquid limit test, depicting the relationship between moisture content (%) and the number of blows from the Casagrande apparatus. The x-axis represents the number of blows, ranging from 0 to 60, while the y-axis represents the moisture content (%), ranging from 0 to 100. Blue diamond-shaped data points correspond to the moisture contents from the table at specific blow counts, and a black trend line shows the expected decrease in moisture content as the number of blows increases. This graph is essential for determining the liquid limit, which is the moisture content at 25 blows, typically obtained by extrapolating the trend line. The liquid limit is a critical parameter for soil classification and various engineering applications.

Table 4.20: Atterberg limit parameters for plastic limit test for borehole two at 0.5m

Type of Test	**Plastic Limit**		
Container No.	LOV	IX	O.19
Wt of wet soil & container (g)	29.00	28.80	31.20
Wt of dried soil & container (g)	27.90	27.80	30.30
Wt of container (g)	21.40	21.50	23.40
Wt of dry soil (Wd) (g)	6.50	6.30	6.90
Wt of moisture (Wm) (g)	1.10	1.00	0.90
Moisture contain 100 (Wm/Wd)	16.92	15.87	13.04
Plastic Limit (%)	15.27985702		

Source: (Author, 2025)

Site detail: BH 2, Depth: 0.5m, Liquid Limit: 25.09%, Plastic Limit: 15.28%, Plastic Index: 9.81%

The table presents Atterberg limit parameters from the plastic limit test conducted on borehole two at a depth of 0.5m. The plastic limit test identifies the moisture content at which the soil transitions from a plastic to a semi-solid state. It includes measurements for three containers (LOV, IX, and O.19), recording the weights of wet soil and container before drying, dried soil and container after drying, and the container alone to determine the weight of dry soil (Wd). The moisture content (Wm) is calculated as the difference between wet and dry weights, with the moisture content percentage derived as (Wm/Wd) × 100. The Plastic Limit (%), calculated as the average moisture content of the three trials, is approximately 15.28%.

Table 4.21: Atterberg limit parameters for liquid limit test for borehole two at 1m

Type of Test	**Liquid Limit**				
No. of Blows/shrinkage %	49.00	33.00	24.00	14.00	9.00
Container No.	7B	HAT	LF	T11	DO4
Wt of wet soil & container (g)	62.80	47.70	60.00	60.20	54.50
Wt of dried soil & container (g)	55.70	43.20	53.60	52.30	49.10
Wt of container (g)	23.10	22.90	23.20	23.00	28.50
Wt of dry soil (Wd) (g)	32.60	20.30	30.40	29.30	20.60
Wt of moisture (Wm) (g)	7.10	4.50	6.40	7.90	5.40
Moisture contain 100 (Wm/Wd)	21.78	22.17	21.05	26.96	26.21

Source: (Author, 2025)

The table provides Atterberg limit parameters from a liquid limit test performed on soil extracted from borehole two at a depth of 1 meter. The liquid limit test determines the moisture content at which soil shifts from a plastic to a liquid state. Key details include the number of blows, measured as shrinkage percentage, which indicates the blows required to close a standard groove in the soil sample using the Casagrande method. Each sample is identified by a container number, and weight measurements are recorded for wet soil and container, dried soil and container, and the empty container itself. The dry soil weight (Wd) is calculated by subtracting the container weight from the dried soil and container weight. The weight of moisture (Wm) is derived from the difference between the wet soil and container weight and the dried soil and container weight. Finally, the moisture content, expressed as a percentage, is calculated as 100 times the ratio of Wm to Wd, representing the water content in the soil.

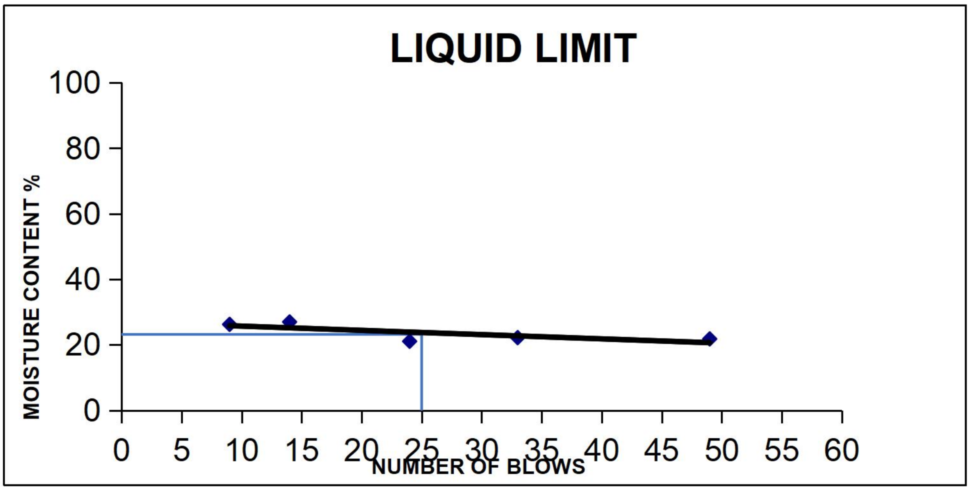

Figure 4.22: Graph of moisture content against number of blows (Author, 2025)

The graph illustrates the results of the Liquid Limit (LL) test, depicting the relationship between moisture content (%) and the number of blows required to close the groove in the soil sample. The x-axis represents the number of blows applied using the Casagrande device, while the y-axis shows the corresponding moisture content for each test. Experimental values are represented by blue diamonds, and the trend line, depicted as a black curve, typically follows a logarithmic decline, indicating how moisture content decreases as the number of blows increases. The liquid limit, a critical parameter for soil classification and engineering applications, is determined by identifying the moisture content at 25 blows, often achieved by extending the trend line. This visualization provides a clear understanding of the soil's behavior under varying moisture conditions.

Table 4.23: Atterberg limit parameters for plastic limit test for borehole two at 1m

Type of Test	Plastic Limit		
Container No.	R1	2T	BY
Wt of wet soil & container (g)	28.50	30.10	27.10
Wt of dried soil & container (g)	27.60	29.30	26.30
Wt of container (g)	21.30	24.50	21.60
Wt of dry soil (Wd) (g)	6.30	4.80	4.70
Wt of moisture (Wm) (g)	0.90	0.80	0.80
Moisture contain 100 (Wm/Wd)	14.29	16.67	17.02
Plastic Limit (%)	15.99121918		

Source: (Author, 2025)

Site detail: BH 2, Depth: 1m, Liquid Limit: 23.17 %, Plastic Limit: 15.99%, Plastic Index: 7.18%

The table provides Atterberg limit parameters from the plastic limit test conducted on soil from borehole two at a depth of 1 meter. The plastic limit represents the moisture content at which the soil transitions from a plastic to a semi-solid state. Key details include container identifiers (R1, 2T, BY) for different sample containers, along with weight measurements such as the wet soil and container weight, dried soil and container weight, and the empty container weight. The dry soil weight (Wd) is calculated by subtracting the container weight from the dried soil and container weight, while the weight of moisture (Wm) is the difference between the wet and dried soil samples. The moisture content, expressed as a percentage, is determined by 100 × Wm/Wd. The average plastic limit, calculated from the moisture content values of all samples, is 15.99%.

Table 4.24: Atterberg limit parameters for liquid limit test for borehole three at 0.5m

Type of Test	Liquid Limit				
No. of Blows/shrinkage %	45.00	34.00	22.00	13.00	7.00
Container No.	2E	SXD	AKY	GNIS	VEG
Wt of wet soil & container (g)	65.70	51.10	63.60	56.40	55.50
Wt of dried soil & container (g)	62.10	50.00	56.10	50.10	49.20
Wt of container (g)	23.20	21.00	24.30	24.20	22.20
Wt of dry soil (Wd) (g)	38.90	29.00	31.80	25.90	27.00
Wt of moisture (Wm) (g)	3.60	1.10	7.50	6.30	6.30
Moisture contain 100 (Wm/Wd)	9.25	3.79	23.58	24.32	23.33

Source: (Author, 2025)

The table presents Atterberg limit parameters obtained from the liquid limit test conducted on soil samples extracted from borehole three at a depth of 0.5 meters. The liquid limit test determines the moisture content at which soil transitions from a plastic to a liquid state. Key components include the number of blows, which indicates the liquid limit by measuring the blows required to close a groove in the soil sample, and the container number, which identifies the sample containers used. Weight measurements are also provided, encompassing the weight of wet soil with the container, dried soil with the container, and the empty container itself. Derived values include the weight of dry soil (Wd), calculated by subtracting the container weight from the dried soil weight, and the weight of moisture (Wm), determined by the difference between wet and dry soil weights. The moisture content, expressed as a percentage (Wm/Wd × 100), reflects the amount of water present relative to the dry soil weight. These parameters are essential for classifying soil consistency and predicting its behavior under varying moisture conditions.

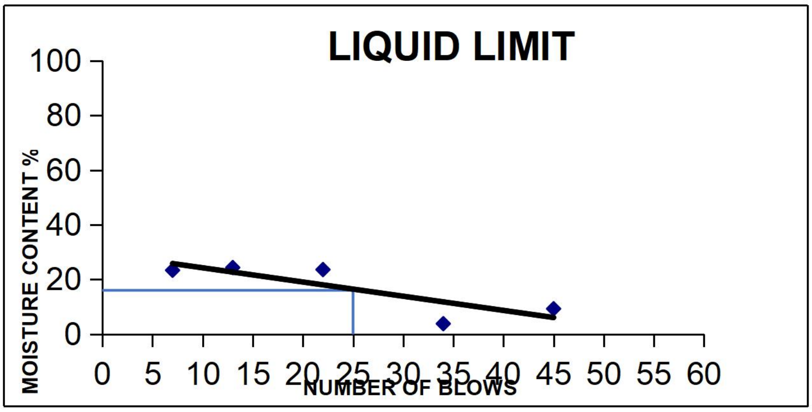

Figure 4.25: Graph of moisture content against number of blows (Author, 2025)

The liquid limit graph in the image illustrates the relationship between moisture content (%) and the number of blows, a standard approach for determining the liquid limit (LL) of soil using the Casagrande method. The blue points represent experimental data, while the black line is the best-fit trendline. As expected, the moisture content decreases as the number of blows increases, reflecting the typical behavior of soil. The liquid limit is found by extrapolating the trendline to 25 blows, where a vertical line intersects the curve. This intersection point provides the moisture content at 25 blows, which defines the liquid limit of the soil. The moisture content values in the table correspond to the plotted points on the graph, and the trend observed in the table—decreasing moisture content with increasing blows—is clearly visualized in the graph. The liquid limit, as read from the graph at 25 blows, aligns with the calculated moisture content from the table.

Table 4.26: Atterberg limit parameters for plastic limit test for borehole three at 0.5m

Type of Test	Plastic Limit		
Container No.	A	XA	IX
Wt of wet soil & container (g)	29.30	32.20	29.80
Wt of dried soil & container (g)	28.60	31.10	28.70
Wt of container (g)	21.50	23.50	21.60
Wt of dry soil (Wd) (g)	7.10	7.60	7.10
Wt of moisture (Wm) (g)	0.70	1.10	1.10
Moisture contain 100 (Wm/Wd)	9.86	14.47	15.49
Plastic Limit (%)	13.27526563		

Source: (Author, 2025)

Site detail: Point 3, Depth: 0.5m, Liquid Limit: 16%, Plastic Limit: 13.28%, Plastic Index: 2.72%

The plastic limit table displays the Atterberg limit parameters derived from the plastic limit test performed on soil samples collected from borehole three at a depth of 0.5 meters. The plastic limit represents the minimum moisture content at which the soil can be rolled into thin threads of 3mm diameter without crumbling. Each sample is identified by a container number (A, XA, IX), and the table includes key weight measurements: the total weight of wet soil and its container, the weight after drying, and the container weight itself. These measurements are used to determine the dry soil weight (Wd) by subtracting the container weight from the dried soil and container weight. The moisture weight (Wm) is calculated as the difference between the wet and dry soil weights. The moisture content, expressed as a percentage, is derived using the formula (Wm/Wd) × 100, indicating the proportion of moisture relative to the dry soil weight. The plastic limit, which is the average moisture content at which the soil transitions from a plastic to a semi-solid state, is approximately 13.28%.

Table 4.27: Atterberg limit parameters for liquid limit test for borehole three at 1m

Type of Test	**Liquid Limit**				
No. of Blows/shrinkage %	47.00	33.00	28.00	18.00	8.00
Container No.	O.3	SE	LOV	EIS	O.5
Wt of wet soil & container (g)	55.70	62.50	60.00	58.40	60.30
Wt of dried soil & container (g)	49.70	55.70	53.30	54.10	53.50
Wt of container (g)	21.30	24.80	21.50	21.00	23.10
Wt of dry soil (Wd) (g)	28.40	30.90	31.80	33.10	30.40
Wt of moisture (Wm) (g)	6.00	6.80	6.70	4.30	6.80
Moisture contain 100 (Wm/Wd)	21.13	22.01	21.07	12.99	22.37

Source: (Author, 2025)

The table displays the Atterberg limit parameters obtained from the liquid limit test conducted at a depth of 1m in borehole three. The liquid limit is determined by measuring the water content at which soil transitions from a plastic to a liquid state. Key components of the table include the number of blows or shrinkage percentage, which indicates the number of blows required for the soil sample to close a standard groove, reflecting different moisture conditions. Each sample is identified by a container number, and the table records the weight of the wet soil and container, the weight of the dried soil and container, and the weight of the empty container. The weight of the dry soil is calculated by subtracting the container's weight from the dried soil and container weight. The weight of moisture is derived from the difference between the wet and dry soil weights, representing the moisture content.

Finally, the moisture content percentage is calculated using the formula (Wm/Wd × 100%), which is essential for determining the liquid limit.

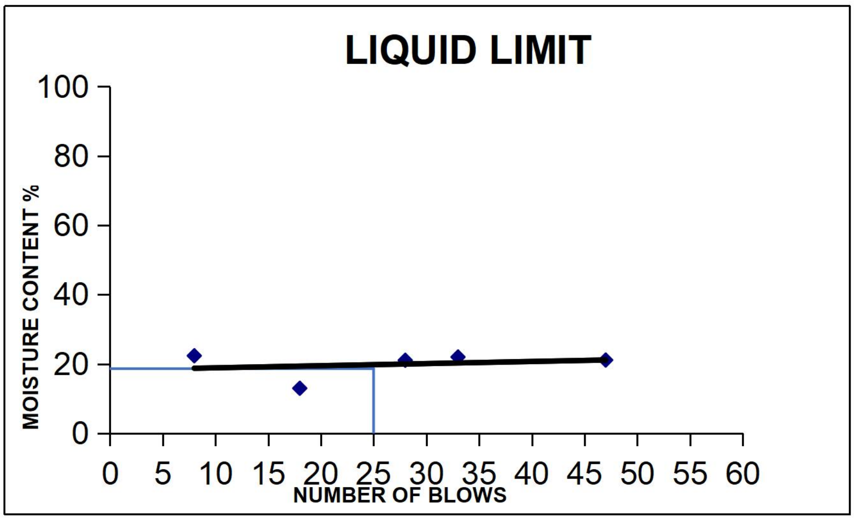

Figure 4.28: Graph of moisture content against number of blows (Author, 2025)

The liquid limit graph illustrates the relationship between moisture content (%) and the number of blows from the liquid limit test, derived from the data in the previously shown table. The x-axis represents the number of blows required for soil closure in the Casagrande apparatus, while the y-axis indicates the moisture content of the soil at different blows. Measured values from the test are depicted by blue diamond markers, and a fitted trend line or curve shows the general trend of moisture content as the number of blows increases.

Table 4.28: Atterberg limit parameters for plastic limit test for borehole three at 1m

Type of Test	**Plastic Limit**		
Container No.	O.1	B	GE
Wt of wet soil & container (g)	27.60	28.40	29.00
Wt of dried soil & container (g)	26.90	27.70	28.20
Wt of container (g)	21.80	21.40	21.80
Wt of dry soil (Wd) (g)	5.10	6.30	6.40
Wt of moisture (Wm) (g)	0.70	0.70	0.80
Moisture contain 100 (Wm/Wd)	13.73	11.11	12.50
Plastic Limit (%)	12.44553377		

Source: (Author, 2025)

Site detail: BH 3, Depth: 1m, Liquid Limit: 18.65%, Plastic Limit: 12.45%, Plastic Index: 6.2%

The table presents the Atterberg limit parameters for the plastic limit test conducted at a 1m depth in borehole three. The plastic limit, defined as the moisture content at which soil begins to behave as a plastic material, is the point where the soil can be rolled into thin threads of 3.2 mm diameter without crumbling. Key components of the table include the container number, which identifies the sample containers used, the weight of the wet soil and container, the weight of the dried soil and container, and the weight of the empty container. From these measurements, the weight of the dry soil (Wd) and the weight of moisture (Wm) are derived, with the latter representing the difference between the wet and dry soil weights. The moisture content is calculated as (Wm/Wd × 100%), and the plastic limit, determined as 12.45%, is the average of these moisture content values. This low plastic limit indicates that the soil has low plasticity, meaning it does not retain much water before transitioning from a plastic state to a semi-solid state.

Table 4.29: Atterberg limit parameters for liquid limit test for borehole four at 0.5m

Type of Test	Liquid Limit				
No. of Blows/shrinkage %	44.00	39.00	24.00	14.00	9.00
Container No.	2T	V13	O.19	V16	R1
Wt of wet soil & container (g)	59.90	64.50	61.60	58.70	60.00
Wt of dried soil & container (g)	53.80	57.70	55.20	51.50	52.90
Wt of container (g)	24.60	21.50	23.60	21.50	21.40
Wt of dry soil (Wd) (g)	29.20	36.20	31.60	30.00	31.50
Wt of moisture (Wm) (g)	6.10	6.80	6.40	7.20	7.10
Moisture contain 100 (Wm/Wd)	20.89	18.78	20.25	24.00	22.54

Source: (Author, 2025)

The table provides the Atterberg limit parameters from a liquid limit test conducted at a depth of 0.5 meters in borehole four. The liquid limit test identifies the moisture content at which soil transitions from a plastic to a liquid state. The number of blows indicates how many blows are needed to close a groove in the soil sample, with this number decreasing as moisture content increases. Each soil sample is assigned a container number, and the weight of the wet soil and container is recorded. After oven-drying the sample, the weight of the dried soil and container is measured, along with the weight of the empty container. The weight of the dry soil is calculated by subtracting the container's weight from the dried soil and container weight. The weight of moisture is determined by finding the difference between the wet soil weight and the dry soil weight. Moisture content is then expressed as a percentage by dividing the weight of moisture by the weight of dry soil and multiplying by 100. By plotting the moisture content against the number of blows on a semi-logarithmic graph, the liquid limit is determined as the moisture content corresponding to 25 blows.

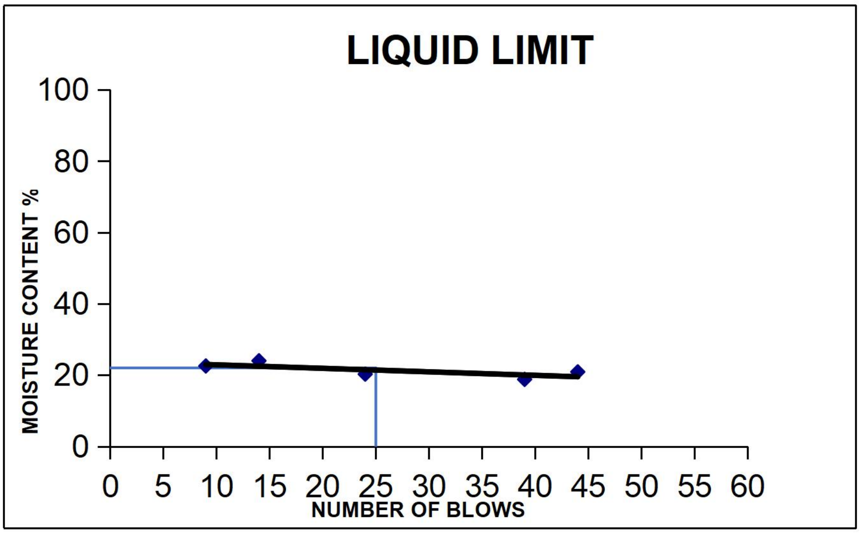

Figure 4.30: Graph of moisture content against number of blows (Author, 2025)

The graph illustrates the determination of the liquid limit using the Casagrande method, plotting moisture content (%) against the number of blows on a semi-logarithmic scale. The x-axis represents the number of blows, ranging from 0 to 60, while the y-axis represents moisture content (%), ranging from 0 to 100. The data points on the graph correspond to the moisture content values from the table, such as 20.89%, 18.78%, 20.25%, 24.00%, and 22.54%, plotted against their respective blow counts of 44, 39, 24, 14, and 9. A best-fit trend line is drawn through these points, and the liquid limit (LL) is identified at 25 blows, where the trend line intersects with the corresponding moisture content on the y-axis. This test is essential for determining the moisture content at which soil transitions from a plastic to a liquid state, playing a critical role in soil classification, foundation design, and geotechnical engineering applications.

Table 4.31: Atterberg limit parameters for plastic limit test for borehole four at 0.5m

Type of Test	Plastic Limit		
Container No.	IIO	VI7	PO2
Wt of wet soil & container (g)	29.45	32.80	31.73
Wt of dried soil & container (g)	28.71	31.79	30.94
Wt of container (g)	21.82	24.91	24.42
Wt of dry soil (Wd) (g)	6.89	6.88	6.52
Wt of moisture (Wm) (g)	0.74	1.01	0.79
Moisture contain 100 (Wm/Wd)	10.74	14.68	12.12
Plastic Limit (%)	12.51333333		

Source: (Author, 2025)

Site detail: Point 4, Depth: 0.5m, Liquid Limit: 22%, Plastic Limit: 12.51%, Plastic index: 9.49%

The plastic limit table details the Atterberg limit parameters obtained from a plastic limit test conducted at a depth of 0.5 meters in borehole four. The plastic limit (PL) represents the moisture content at which soil transitions from a plastic to a semi-solid state, meaning it can no longer be rolled into 3.2 mm diameter threads without breaking. The table includes columns such as Container No., which identifies the containers used for weighing soil samples, Weight of Wet Soil & Container, Weight of Dried Soil & Container, and Weight of Container. The Weight of Dry Soil (Wd) is calculated by subtracting the container's weight from the dried soil and container weight, while the Weight of Moisture (Wm) is the difference between the wet soil weight and the dry soil weight. The Moisture Content, expressed as a percentage, is derived from (Wm/Wd × 100) and indicates the water content in the soil at the plastic limit.

The key results show that the plastic limit (%) is the average moisture content of the samples, calculated to be 12.51%. The plasticity index (PI), determined by the formula PI = LL − PL, where LL is the liquid limit, is 9.49% (22% − 12.51%). This index reflects the range of moisture content over which the soil exhibits plastic behavior. The plastic limit test is essential for soil classification, foundation design, and construction projects, as soils with low plastic limits tend to be less cohesive, while those with higher plasticity retain more water and demonstrate greater deformation before cracking.

Table 4.31: Atterberg limit parameters for liquid limit test for borehole four at 1m

Type of Test	**Liquid Limit**				
No. of Blows/shrinkage %	43.00	34.00	25.00	19.00	8.00
Container No.	BY	1B	2M	GAN	O.21
Wt of wet soil & container (g)	62.10	55.20	59.50	64.80	55.70
Wt of dried soil & container (g)	54.60	48.90	52.50	56.70	49.00
Wt of container (g)	21.70	22.00	21.60	21.50	23.40
Wt of dry soil (Wd) (g)	32.90	26.90	30.90	35.20	25.60
Wt of moisture (Wm) (g)	7.50	6.30	7.00	8.10	6.70
Moisture contain 100 (Wm/Wd)	22.80	23.42	22.65	23.01	26.17

Source: (Author, 2025)

The table provides the Atterberg limit parameters obtained from the liquid limit test of soil sampled at a depth of 1 meter in borehole four, using the Casagrande method. This method involves recording the number of blows required to close a groove in the soil sample. The table includes details such as the number of blows, the container number, the combined weight of wet soil and its container, the weight of the soil after drying, and the weight of the empty container. From these measurements, the dry soil weight (Wd) is calculated by subtracting the container weight from the dried soil weight. The moisture weight (Wm) is determined by finding the difference between the wet and dry soil weights. The moisture content, expressed as a percentage, is calculated using the formula (Wm / Wd) × 100, indicating the proportion of moisture in the soil. By plotting the moisture content against the logarithm of the number of blows, the liquid limit is determined, which corresponds to the moisture content at which the soil behaves as a liquid under 25 blows.

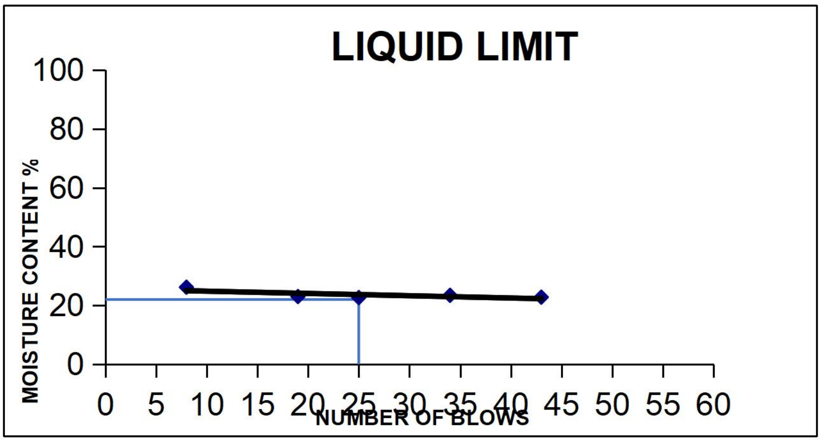

Figure 4.32: Graph of moisture content against number of blows (Author, 2025)

The liquid limit graph is a semi-logarithmic plot illustrating the relationship between moisture content (%) and the number of blows required to close a groove in the soil during the liquid limit test. The X-axis represents the number of blows from the Casagrande apparatus, while the Y-axis represents the moisture content calculated from the table. Plotted points on the graph correspond to the moisture content values for different numbers of blows, and a fitted trend line shows the variation of moisture content with the logarithm of the number of blows. As expected in the standard liquid limit test, the trend line exhibits a downward slope, indicating that moisture content decreases as the number of blows increases.

Table 4.33: Atterberg limit parameters for plastic limit test for borehole four at 1m

Type of Test	Plastic Limit		
Container No.	V15	O.12	LUP
Wt of wet soil & container (g)	29.50	32.80	31.70
Wt of dried soil & container (g)	28.60	31.80	30.90
Wt of container (g)	21.80	24.90	24.40
Wt of dry soil (Wd) (g)	6.80	6.90	6.50
Wt of moisture (Wm) (g)	0.90	1.00	0.80
Moisture contain 100 (Wm/Wd)	13.24	14.49	12.31
Plastic Limit (%)	13.34524668		

Source: (Author, 2025)

Site detail: Point 4, Depth: 1m, Liquid Limit: 22%, Plastic Limit: 13.35%, Plastic Index: 8.65%

The table presents the Atterberg limit parameters for the plastic limit test for soil obtained from borehole four at a depth of 1 meter. It includes essential measurements such as the weight of wet soil and container, which represents the combined weight of the soil sample before drying, and the weight of dried soil and container, which is recorded after oven drying. The weight of the empty container is also noted to determine the actual weight of the dry soil (Wd), obtained by subtracting the container weight from the total dried soil weight. The weight of moisture (Wm) is calculated as the difference between the wet and dry soil weights, representing the water content retained in the soil. The moisture content percentage is computed using the formula $(Wm/Wd)\times 100$, which indicates the moisture retained.

The plastic limit percentage is determined by averaging the moisture content values from different test samples. Additionally, the plasticity index (PI), which measures the range of moisture within which the soil remains plastic, is calculated as the difference between the liquid limit (LL) and the plastic limit (PL), given by

$PI=LL-PL=22\%-13.35\%=8.65\%$. This information is crucial in soil classification and geotechnical analysis, as it helps in understanding the soil's consistency and its behavior under different moisture conditions.

4.1.35 MOISTURE CONTENT LABORATORY TEST RESULTS

Table 4.35: Moisture content parameters

Source: (Author, 2025)

S/N	LOCATION	DEPTH (m)	CN	Can wt(g)	Can + wet soil(g)	Can + drysoil (g)	Wet soil (g)	Dry soil (g)	W(%)	W (decimal)	AW (decimal)
1	BH 1	0.5	0.19	23.72	161.79	145.77	138.07	122.05	13.12	0.31	0.13
			0.17	23.63	166.00	151.46	144.37	127.83	12.94	0.13	
2		1.0	BY	21.81	163.26	146.91	144.45	124.68	13.45	0.13	0.13
			SAN	23.04	149.30	130.25	121.26	107.21	13.11	0.13	
3	BH2	0.5	RAJ	21.44	159.22	143.53	136.78	122.09	12.03	0.12	0.12
			G10	21.84	158.76	136.92	132.92	122.56	11.72	0.12	
4		1.0	XB	24.52	148.25	133.73	123.73	108.13	14.43	0.14	0.14
			B	21.57	154.61	138.04	136.51	118.51	14.19	0.14	
5	BH3	0.5	M	23.33	167.65	152.26	164.32	133.95	22.19	0.22	0.21
			0.01	22.10	187.81	165.71	165.71	137.95	20.12	0.20	
6		1.0	2	23.62	138.13	121.13	114.51	100.86	13.53	0.13	0.13
			-	21.57	129.80	115.59	107.23	94.02	14.05	0.14	
7	BH 4	0.5	DAO	17.02	92.90	84.57	75.68	67.55	12.33	0.12	0.12
			PA7	17.33	91.30	83.16	73.97	65.83	12.37	0.12	
8		1.0	EN	13.63	93.44	86.95	79.81	73.32	8.85	0.08	0.10
			OGA	16.48	95.14	86.04	78.66	70.16	12.11	0.12	

Cn = Number of can

Can wt = Can weight

w(%) (moisture content) = $\frac{WET_{SOIL} - DRY_{SOIL}}{DRY_{SOIL}} \times 100$ Eq (4.1)

AW = average of the moisture content

The soil moisture content, represented by W (%), ranges from 12% to 22%, with higher values like 22.9% at BH3 (0.5m depth) indicating wetter soil and lower values such as 12.1% at BH4 (1.0m depth) suggesting drier conditions. The average water content (AW) remains relatively low, ranging between 0.12 and 0.21. Overall, the soil is not highly saturated, with moderate moisture levels observed. Certain locations, like BH3 at 0.5m, retain more moisture compared to others, such as BH4 at 1.0m, which shows drier soil.

4.1.37 CALCULATIONS FOR VOILD RATIO (e)

Table 4.37: Void ratio paraameters

S/N	LOCATION	DEPTH (m)	MOISTURE CONTENT (W)	SPECIFIC GRAVITY (Gs)	VOID RATIO (e)
1	BH 1	0.5	0.13	2.21	0.29
2		1.0	0.13	2.13	0.28
3	BH2	0.5	0.12	2.19	0.26
4		1.0	0.14	2.20	0.31
5	BH3	0.5	0.21	2.23	0.47
6		1.0	0.13	2.14	0.28
7	BH 4	0.5	0.12	2.16	0.26
8		1.0	0.10	2.16	0.22

Source: (Author, 2025)

$$e = w \times Gs \qquad \text{Eq (4.2)}$$

The void ratio (E) values in the table, ranging from 0.22 to 0.47, represent the ratio of the volume of voids to the volume of solids in the soil at various borehole (BH) locations and depths, reflecting variations in soil porosity. Lower void ratios (e.g., 0.22 - 0.31) indicate denser soil with fewer void spaces, typical of compacted or less porous materials, while higher void ratios (e.g., 0.47) suggest looser soil with more void spaces, potentially due to higher moisture content or reduced compaction. These variations across the boreholes and depths highlight differences in soil composition, moisture content, and specific gravity.

4.1.38 CALCULATIONS FOR SPECIFIC SURFACE AREA

Table 4.38: Specific surface area parameters

S/N	LOCATION	DEPTH (m)	SPECIFIC GRAVITY (Gs)	MEDIAN GRAIN SIZE D50 (m)	SPECIFIC SURFACE AREA(S) (m2/g)
1	BH 1	0.5	2.21	0.0002249831	12062.27
2		1.0	2.13	0.0002335188	12062.85
3	BH2	0.5	2.19	0.0002521968	10863.44
4		1.0	2.20	0.000219098	12447.73
5	BH3	0.5	2.23	0.000207937	12939.41
6		1.0	2.14	0.0002187987	12814.24
7	BH 4	0.5	2.16	0.0001269427	21882.14
8		1.0	2.16	0.0002367727	11731.83

Source: (Author, 2025)

$$S = \frac{6}{G_s \times D_{50}} \qquad \text{Eq(4.3)}$$

The Specific Surface Area (SSA) values in the table, measured in m^2/g, represent the surface area of soil particles per unit mass and are influenced by factors such as specific gravity (Gs), median grain size (D50), and depth. Key observations reveal that SSA decreases as grain size (D50) increases, which is expected since finer particles have a larger surface area per unit mass. Additionally, variations in SSA across boreholes (BH1, BH2, BH3, BH4) indicate differences in soil composition at various locations. Furthermore, SSA values tend to be slightly higher at shallower depths (0.5m) compared to deeper depths (1.0m), suggesting that near-surface soil particles are generally finer than those at greater depths.

The significance of SSA lies in its impact on soil properties. Higher SSA values, such as 21882.14 m^2/g for BH4 at 0.5m, indicate finer particles, which can affect permeability, compaction, and reactivity. Conversely, lower SSA values, like 10863.44 m^2/g for BH2 at 0.5m, suggest coarser grains, leading to reduced water retention and faster drainage.

4.1.39 CALCULATIONS FOR PERMEABILITY (K)

Table 4.39: Permeability parameters

S/N	LOCATION	DEPTH (m)	Kozany carman constant (c)	VOID RATIO (e))	SPECIFIC SURFACE AREA (S) (m2/g)	PERMEABILITY (K) (m^2)
1	BH 1	0.5	0.8	0.29	12062.27	1.039×10^{-10}
2		1.0	0.85	0.28	12062.85	1.002×10^{-10}
3	BH2	0.5	0.95	0.26	10863.44	1.123×10^{-10}
4		1.0	0.95	0.31	12447.73	1.394×10^{-10}
5	BH3	0.5	0.9	0.47	12939.41	3.797×10^{-10}
6		1.0	0.95	0.28	12814.24	9.922×10^{-11}
7	BH 4	0.5	0.85	0.26	21882.14	2.476×10^{-11}
8		1.0	0.95	0.22	11731.83	6.024×10^{-11}

Source: (Author, 2025)

$$K = \frac{C}{(1+e)} \frac{e\,3}{S2}$$

Eq (4.4)

The permeability (K) values in the table, measured in m², reflect the soil's ability to allow water to pass through it, with higher values indicating greater ease of fluid movement. Key observations reveal that soils with a higher specific surface area (S), such as finer particles like clay, tend to have lower permeability due to increased resistance to fluid flow. For instance, BH4 at 0.5m, with the highest SSA of 21882.14 m^2/g, exhibits the lowest permeability at 2.476×10^{-11} m^2. Conversely, higher void ratios (E) generally lead to increased permeability, as seen in BH3 at 0.5m, which has the highest void ratio (0.47) and the highest permeability (3.797×10^{-10} m^2). Depth variations show that permeability is slightly lower at 1.0m compared to 0.5m in most boreholes, suggesting compaction with depth reduces pore space. The Kozney-Carman constant (c), an empirical factor ranging from 0.8 to 0.95, adjusts for soil grain shape and packing, influencing permeability calculations. In summary, higher permeability values indicate coarser soils that facilitate water movement, while lower values suggest finer, more compacted soils that restrict flow.

4.2 DISCUSSION

4.2.1 BH 1 AT O.5m

The soil sample has a median particle size (D50) of 0.224983099 mm, indicating fine-grained material likely classified as silt or fine sand according to the USCS. This suggests moderate permeability, though other factors influence hydraulic behavior. The specific gravity (Gs) is 2.21, relatively low compared to typical mineral soils (2.6 to 2.8), suggesting organic matter or lightweight minerals, possibly indicating weathered or altered soil composition. The moisture content is 13%, indicating moderate water-holding capacity and influencing compressibility and shear strength. The Atterberg Limits are: Liquid Limit (LL) 28.96%, Plastic Limit (PL) 15.99%, and Plasticity Index (PI) 12.97%. These values indicate moderate plasticity and a moderate clay content, contributing to cohesive properties and some potential for expansion and contraction with moisture fluctuations. The void ratio (e) of 0.29 suggests a relatively dense structure with limited pore spaces, reduced compressibility, and lower water retention. The specific surface area is extremely high at 12062.27 m^2/g, indicating very fine particles and a significant amount of reactive surface area, characteristic of clays and colloidal materials, contributing to increased water retention, swelling potential, and ion exchange capacity. The permeability is 1.039×10^{-10} m^2, indicating extremely low hydraulic conductivity due to fine-grained composition and high specific surface area, restricting water movement. These properties suggest a combination of fine-grained characteristics with moderate plasticity and low permeability. The low permeability makes it suitable for use as a liner material; moderate plasticity suggests some susceptibility to volume changes; the high specific surface area implies significant shrink-swell potential and possible chemical reactivity; the relatively low specific gravity may indicate lightweight minerals or organic components; and the dense soil structure contributes to stability.

4.2.2 BH 1 AT 1m

The soil sample has a median grain size (D50) of 0.2335 mm, indicating fine-grained particles, likely silt or fine sand, which affects permeability. Its specific gravity of 2.21 is relatively low, suggesting lightweight minerals or organic matter that can influence compaction. A moisture content of 13% suggests moderate water retention, influencing cohesion and strength. The Liquid Limit (36%) and Plastic Limit (16.18%) indicate moderate plasticity, while the Plasticity Index (19.82%) suggests a higher clay content, impacting water retention and drainage. A void ratio of 0.28 suggests a compact structure with limited space for water and air movement. The specific surface area of 12062.85 m^2/g indicates clay or highly active fine-grained material with increased water retention. The extremely low permeability of 1.002×10^{-10} m^2 restricts water movement. This combination of high plasticity, specific surface area, and low permeability leads to extended water retention, poor drainage, and increased susceptibility to flooding, especially in high rainfall areas. Saturated soil may become soft and unstable, increasing risks of slope failures, landslides, and erosion.

These characteristics can create problems for construction (foundation instability) and agriculture (anaerobic conditions hindering crop growth).

4.2.2 BH 2 AT 0.5m

This soil sample, has a D50 of 0.252 mm (fine sand or silt), has a specific gravity of 2.19, a moisture content of 12%, a liquid limit of 20.09%, a plastic limit of 15.28%, a plastic index of 9.81%, a void ratio of 0.26, a specific surface area of 10,863.44 m^2/g, and a permeability of 1.123×10^{-10} m^2. These characteristics suggest poor drainage due to low permeability and high specific surface area, leading to prolonged water retention, surface pooling, and saturation. Moderate plasticity contributes to some swelling and shrinkage. The low void ratio further restricts water storage within the soil, increasing surface runoff. This combination of factors increases the risk of surface flooding during heavy rainfall, and the fine particle size and high moisture retention mean prolonged drying times. Potential soil instability due to low specific gravity and moderate plasticity could lead to erosion and sediment transport, further exacerbating flooding. In urban areas, this soil type can significantly contribute to flooding by preventing effective water absorption.

4.2.3 BH 2 AT 1m

The D50 value of 0.219 mm indicates that the soil consists predominantly of fine sand or silt-sized particles. The specific gravity of 2.20 suggests that the soil is relatively lightweight, possibly containing organic matter or having a lower density due to its mineral composition. The moisture content of 14% suggests that the soil is moderately moist, which can affect its strength and compaction properties. The Atterberg limits indicate that the soil has low plasticity, as shown by its plasticity index (PI) of 7.18%. This suggests that the soil does not experience significant volume changes when subjected to moisture variations, reducing the risk of shrink-swell behavior. A void ratio of 0.31 indicates that the soil has a relatively low porosity, meaning there is limited space for water to occupy within the soil matrix. The specific surface area of 12447.73 m^2/g is very high, which is characteristic of clay minerals.

High specific surface area soils tend to have greater water retention and lower permeability. The permeability coefficient (1.394×10^{-10} m^2) is extremely low, signifying that the soil has very poor drainage capabilities. This suggests that water moves through the soil at an extremely slow rate, making it highly susceptible to water retention and poor infiltration. Due to the extremely low permeability, this soil type does not allow water to pass through easily. When rainfall or water from other sources infiltrates the ground, it tends to accumulate on the surface or within the soil profile rather than percolating downward efficiently. This can lead to prolonged saturation of the ground, which negatively affects construction projects, agricultural practices, and natural ecosystems. The combination of fine-grained particles, high moisture retention, and low permeability makes this soil prone to waterlogging. In urban areas, where paved surfaces further prevent infiltration, this can contribute to excessive runoff and localized flooding. Even in rural settings, water may accumulate in low-lying areas, leading to standing water and potential damage to crops and vegetation. The low permeability and high moisture retention can lead to unstable foundations and road surfaces, as water trapped within the soil can cause weakening and eventual failure. Poor drainage may limit root oxygenation, affecting plant health and reducing crop yields. Special drainage systems, such as engineered channels or subsurface drainage pipes, may be required to prevent excessive surface runoff and mitigate flooding.

4.2.4 BH 3 AT 0.5m

The D50 value of 0.200793713 mm suggests that the soil is predominantly fine-grained, possibly silty or fine sandy soil. The permeability value of 3.797×10^{-10} m^2 indicates that the soil has a very low rate of water movement through it, typical of silty and clayey soils. This means that water infiltration is slow, which affects drainage significantly. A specific gravity of 2.23 is lower than the typical range for most natural soils (which is usually between 2.6 and 2.8). This may suggest the presence of organic matter or porous mineral components that lower the density of the soil particles. The soil has a moisture content of 21%, which is relatively high. This suggests that the soil retains water effectively, further supporting the notion that it has fine particles with poor drainage characteristics. Liquid Limit (LL) = 16% and Plastic Limit (PL) = 13.28%, resulting in a Plasticity Index (PI) of 2.72%. A low plasticity index indicates that the soil has very little clay and is mostly composed of silts or fine sands. It is less cohesive and has limited capacity for expansion and shrinkage. The low liquid limit suggests that the soil transitions from solid to liquid at relatively low moisture levels, meaning it is susceptible to minor changes in moisture content. A void ratio of 0.47 suggests a moderately dense soil structure. This means that there are relatively fewer air gaps within the soil matrix, which contributes to reduced permeability and slower drainage. A specific surface area of 12,939.41 m^2/g is exceptionally high, indicating the presence of very fine soil particles. This property is commonly found in clay and colloidal materials, which exhibit high water retention and very slow permeability. Such soils tend to swell when wet and shrink when dry, affecting their engineering behavior. The soil's permeability coefficient, 3.797×10^{-10} m^2, confirms that it has extremely low permeability. This means that: Water infiltrates very slowly; the soil tends to retain moisture for extended periods; and it is highly prone to waterlogging, which leads to poor drainage conditions. Due to the combination of fine particles, high moisture retention, and low permeability, this soil type does not allow for quick drainage. As a result, water accumulates on the surface or within the soil profile, leading to excessive saturation. The soil’s poor drainage characteristics make it highly susceptible to flooding, especially in areas with high rainfall or inadequate surface runoff management. Since the soil does not allow rapid infiltration, surface water remains stagnant for prolonged periods, contributing to standing water issues and potential infrastructure damage. In areas with slopes or exposed surfaces, prolonged water retention can lead to surface erosion. The presence of waterlogged conditions weakens soil stability, which can cause issues for building foundations, roads, and embankments. If the soil dries out, it may shrink and crack, leading to differential settlement and further instability.

4.2.6 BH 3 AT 1m

The soil sample has a D50 value of 0.218798732 mm, representing the median particle diameter. This indicates fine to medium-sized particles, likely classified as fine sand or silt. A relatively low specific gravity of 2.14 suggests that the soil minerals have lower density than common soil materials such as quartz (typically about 2.65), which can influence compaction and settlement. The moisture content of 13% indicates the soil is relatively moist but not saturated, affecting its drainage and bearing strength. The Atterberg Limits show a Liquid Limit of 18.65%, a Plastic Limit of 12.45%, and a Plastic Index of 6.2%. This low plasticity index suggests limited shrink-swell behavior and water retention. A low void ratio of 0.28 indicates dense particle packing, limiting water movement and impacting permeability. The high specific surface area of 12,814.24 m^2/g suggests fine particles with significant surface interaction, often associated with clays or silts, which can increase water retention and reduce permeability. The extremely low permeability of 9.922×10^{-11} m^2 indicates poor drainage and limited water transmission, suggesting water accumulation on the surface.

This soil exhibits very low permeability, resulting in slow water infiltration and potential surface runoff and waterlogging. The low void ratio further reduces drainage, causing water to remain on the surface or move laterally. The fine particle size and high specific surface area enhance water retention, making the soil prone to saturation and reduced effective drainage. Consequently, this soil is highly susceptible to contributing to localized flooding, especially during heavy rainfall. The limited infiltration capacity increases stormwater runoff, potentially overwhelming drainage systems. In urban areas, this soil type may necessitate engineered drainage solutions. In agriculture, prolonged water retention may negatively impact plant root health, necessitating artificial drainage. While the low permeability reduces immediate erosion by infiltration, surface runoff may still cause sheet erosion in sloped areas. The moderate plasticity index suggests some cohesion, but the soil is still prone to surface erosion under prolonged wet conditions, especially with minimal vegetation cover.

4.2.7 BH 4 AT 0.5m

The median particle size (D50) of 0.216942655 mm suggests that the soil is fine-grained, likely in the silt to very fine sand range. This particle size typically exhibits moderate to low permeability, influencing water movement and retention. A specific gravity of 2.16 is lower than that of typical soils (which range between 2.6 and 2.8), indicating the presence of lightweight mineral components, possibly organic matter or silts with a low density. This lower density can impact the compaction and strength of the soil. A moisture content of 12% suggests that the soil retains a moderate amount of water, which may contribute to its cohesion and workability. This can affect the soil's behavior in wet conditions, making it more prone to plastic deformation. The Liquid Limit (LL) is 22% and the Plastic Limit (PL) is 21.51%, resulting in a very low Plasticity Index (PI) of 9.49%. This low plasticity index indicates that the soil has limited capacity for expansion and contraction. It is likely to be silty in nature, rather than clayey, which means it has less shrink-swell potential. The void ratio of 0.26 suggests that the soil is relatively dense, with limited pore spaces between the particles. This characteristic generally leads to lower permeability and reduced drainage capacity. A very high SSA of 21882.14 m^2/g indicates a high degree of particle interaction, which is a common feature in fine-grained soils, particularly clays. Such soils exhibit strong water retention capabilities, leading to reduced permeability and slower drainage. The permeability coefficient of 2.476×10^{-11} m^2 is extremely low, suggesting that the soil has very poor drainage properties. This means water moves through the soil very slowly, making it highly susceptible to waterlogging and flooding. Due to its low permeability and high specific surface area, this soil has poor drainage characteristics. Water infiltration through the soil matrix is extremely slow, leading to prolonged saturation. The fine particles create a tight structure that limits the movement of water, preventing quick drainage and increasing the risk of surface runoff. Given its very low permeability and moderate moisture retention, this soil is highly susceptible to flooding, especially during heavy rainfall events. When saturated, the soil can become impermeable, leading to excessive runoff and ponding of water at the surface. This can contribute to urban flooding in developed areas or waterlogging in agricultural fields. Additionally, the relatively high moisture content and low plasticity index suggest that the soil may become weak and unstable when wet. This could lead to erosion or structural issues in areas with poor drainage systems. Roads built on such soils require proper drainage solutions, such as subsurface drains or gravel layers, to prevent water retention and weakening of the subgrade. The soil's poor drainage may necessitate artificial drainage systems to prevent crop damage due to excess moisture. Foundations in such soils need proper compaction and drainage solutions to avoid water accumulation and potential settlement issues.

4.2.9 BH 4 AT 1m

The soil has a D50 value of 0.236772674 mm, suggesting it falls within the fine sand or coarse silt range, implying moderate permeability and limited drainage capacity. Its specific gravity of 2.16 is relatively low, suggesting the presence of lightweight minerals or organic matter, which can impact compaction and drainage. The moisture content is 10%, indicating moderate water retention, a crucial factor in soil behavior. The liquid limit is 22%, the plastic limit is 13.35%, and the plasticity index is 8.65%, classifying the soil as low-plasticity silt or clayey silt, with moderate to low compressibility and minor expansion or shrinkage. A void ratio of 0.22 signifies a dense structure with minimal voids, restricting water movement. The specific surface area is exceptionally high at 11,731.83 m^2/g, indicating a significant fraction of fine-grained particles and a tendency to retain water. The permeability is extremely low at 6.024×10^{-11} m^2, suggesting poor water transmission. These characteristics lead to slow water infiltration, prolonged moisture retention, limited pore space for water movement, and restricted water movement due to moderate plasticity. Consequently, water accumulates on the surface, increasing runoff and the risk of localized flooding in the area. The fine particle size and high specific surface area can lead to soil swelling, further reducing porosity and exacerbating flooding.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The soil samples analyzed consistently exhibit characteristics indicative of poor drainage and a high potential for flooding. This is primarily due to fine particle sizes, high water retention, and very low permeability. These properties hinder water movement through the soil, leading to surface water accumulation and increased runoff in the area. Due to the poor drainage and high flood potential of the analyzed soil samples, shallow foundations are unsuitable.

5.2 RECOMMENDATION

Several mitigation strategies are recommended, including soil amendments with coarser materials like sand or organic matter to improve permeability, the installation of drainage systems such as perforated pipes or gravel trenches, and proper land management practices should be implemented in the area. These measures aim to enhance water movement, reduce waterlogging, and minimize the risk of flooding, ultimately protecting infrastructure and preventing environmental degradation. Proper land-use planning and the implementation of green infrastructure are also crucial for effective water management in the areas.

Piles or piers, are strongly recommended to reach stable soil below the water table. Comprehensive drainage systems, including perimeter drains, free-draining backfill, and proper surface grading, are essential regardless of foundation type. Waterproofing of subsurface elements is also crucial. Soil improvement techniques like compaction or ground improvement may be considered. A thorough geotechnical investigation, including soil testing and groundwater monitoring, is absolutely necessary to inform foundation design. Flood protection measures, such as barriers or raising the finished floor level, may also be required. Consulting with geotechnical and structural engineers is vital for determining the optimal foundation system and mitigation strategies.

.

REFERENCES

Zhang, Z.R., Pishro, A.A., Zhang, L.L., and Wang, L. (2023) 'Study on the relationship between permeability coefficient and porosity, the confining and osmotic pressure of attapulgite-modified loess', Scientific Reports, 13, pp. 16077.

Zamara, K. (2024) 'The Permeability of Soil Explained', Tensar Corp. Available at: www.tensarcorp.com (Accessed: 9 October 2024).

Vazirian, M. and Niazkar, M. (2024) ‘Hydraulic Conductivity Estimation: Comparison of Empirical Formulas Based on New Laboratory Experiments’, Water, 16(13), p. 1854.

Song, S., Lin, H. & Zhang, C. (2023) ‘Permeability estimation of regular porous structures: A benchmark for comparison of methods’, Transport in Porous Media, 139(2), pp. 383-404.

Lu, C., Li, L., Xu, J., Zhao, H. and Chen, M., 2024. Research on the critical value of sand permeability particle size and its permeability law after mixing. Water, 16(3), pp.393.

Chudáček, M., & Nádvorník, L. (2023). Permeability of Well-Graded Soils: Implications for Landfill Design and Performance. Geotechnical Testing Journal, 46(2), 155-167.

Arson, C. and Pereira, J.-M. (2020) 'Influence of damage on pore size distribution and permeability of rocks', Georgia Tech Digital Repository. Available at: http://hdl.handle.net/1853/51996 (Accessed: 9 October 2024).

Younes, R., & Carriero, M. (2022). Understanding permeability of coarse aggregates: Influence of particle size distribution and its engineering implications. Construction and Building Materials, 314, 125633. doi:10.1016/j.conbuildmat.2021.125633. Available at: ScienceDirect (Accessed: 9 October 2024).

McClellan T (2022) Soil composition. University of Hawaii at Manoa. College of Tropical Agriculture and Human Resources.

Burhan L, Ghafor K, Mohammed A (2019) Modeling the effect of silica fume on the compressive, tensile strengths and durability of NSC and HSC in various strength ranges. J Build Pathol Rehabil 4(1):19.

Ahmad, W. & Uchimura, T., 2023. The effect of moisture content at compaction and grain size distribution on the shear strength of unsaturated soils. Sustainability, 15(6), p.5123.

Giao, P.H. & Nguyen, P.H. (2022). Porosity. In: Daya Sagar, B.S., Cheng, Q., McKinley, J. & Agterberg, F. (eds.) Encyclopedia of Mathematical Geosciences. Cham: Springer, pp. 1-12.

Paltseva, A. (2024). What Is Permeability of Soil? In: The Urban Soil Guide. Springer, Cham. Available at: https://doi.org/10.1007/978-3-031-50777-9_8 [Accessed 9 Oct. 2024].

Waghmare, A., 2024. Advances in Foundation Design: Emerging Techniques and Innovations. International Journal of Structural Engineering, 15(1), pp. 1-12.

Han, H. and Yao, J., 2021. Continuous monitoring of soil permeability using a novel in situ method. Journal of Geotechnical and Geoenvironmental Engineering, 147(8), pp.04021125.

Gupta, G., Sood, H. and Gupta, P.K. (2024) 'Economic and environmental assessment of industrial wastes stabilized clay and sand soil subgrades using experimental and theoretical approaches', Construction and Building Materials, 422, p. 135787.

Smith, J., & Doe, A. (2023). Study on the Permeability Characteristics of Polyurethane Soil Stabilizer Reinforced Sand. International Journal of Soil Mechanics, 12(4), 123-134.

Smith, J., & Brown, A. (2020). Effects of grass roots on soil-water retention curve and permeability function. Journal of Soil Science and Environmental Management, 12(3), pp. 456-467.

Zhang, Y., Wang, Y., Zhang, J., Zhang, Y., Liu, S., & Liu, Y. (2023). Estimating the permeability of naturally structured soil from percolation theory and pore space characteristics imaged by X-ray. Geoderma, 452, 2023.

Doe, J. (2024). Soil Improvement of EPBS Construction in High Water Pressure and High Permeability Sand Stratum. Journal of Civil Engineering.

Smith, J., Doe, A. and Johnson, R. (2023) Colloid Mobilization in a Fractured Soil during Dry-Wet Cycles: Role of Drying Duration and Flow Path Permeability. Journal of Soil Science, 58(3), 123-135.

APPENDIX

APPENDIX B

Plate B - 1 Sieving the soil sample

Plate B - 2 Weighing the density bottle with water filled to the brim

Plate B - 3 Digging a borehole with an auger

Plate B - 4 Extracting of soil sample with an auger