THE EFFECT OF SOAKING PERIOD ON THE STRENGTH OF SUB BASE MATERIAL: IN THE CASE OF DIMTU-BILATE MILITARY TRAINING CENTER ROAD PROJECT

NEBIAT KEDIR NURU

A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, COLLAGE OF CIVIL ENGINEERING AND ARCHITECTURE

PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER'S IN GEOTECHNICAL ENGINEERING

OFFICE OF GRADUATE STUDIES

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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ADAMA ETHIOPIA

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DECLARATION

I hereby declare that this Master Thesis entitled **"The effect of soaking period on the strength of sub-base material: in the case of Dimtu-Bilate Military training center road project"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

NEBIAT KEDIR NURU	__________________	__________________
Name of Student	Signature	Date

RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**The effect of soaking period on the strength of sub-base material: in the case of Dimtu-Bilate Military training center road project"** prepared under my guidance by **NEBIAT KEDIR NURU**. Submitted in partial fulfillment of the requirements for the degree of Master's of Science in Geotechnical Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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APPROVAL PAGE

I, the advisor of the thesis entitled "**The effect of soaking period on the strength of sub- base material: in the case of Dimtu-Bilate Military training center road project"** and developed by **NEBIAT KEDIR** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by **NEBIAT KEDIR** have read and evaluated the thesis entitled "**The effect of soaking period on the strength of sub-base material: in the case of Dimtu-Bilate Military training center road project"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement for the degree of Master of Science in Geotechnical Engineering.

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ACRONYMS

I) Acronyms

ASTM: American Society for Testing Materials

AASHTO: American Association of Highway and Transportation Officials

ASTU: Adama Science and Technology University

BS: Borrow Site

CBR: California Bearing Ratio

ERA: Ethiopian Roads Authority

G: Specific Gravity

LL: Liquid Limit

LS: Linear Shrinkage

PL: Plastic Limit PI:

Plasticity Index NP:

Non-Plastic

NMC: Natural Moisture Content

OMC: Optimum Moisture Content

MDD: Maximum Dry Density

FHWA: Federal Highway Administration

PSD: Particle Size Distribution

II) Symbols or Formulas ω:

Moisture Content of Soil γ_d:

Dry Density of Material γ_b:

Bulk Density of Material

ABSTRACT

The subbase is an unbound material that helps reduce traffic stresses to acceptable levels in the subgrade. The aim of this research is to investigate the effect of soaking period on the strength of sub-base material. To achieve these objectives the sub-base material was sampled from two borrow sites located in Southern Nations, Nationalities and peoples region, Sodo Junction (Dimtu) – Bilate Military Training Center Road Project Ethiopia. The laboratory tests were conducted to determine the physical and mechanical properties of the sub-base material. The CBR tests were performed on samples for different soaking periods (0, 1, 2, 3, 4, 5,6 and 7 days). The results showed that the sub-base material is classified as well-graded gravel (GM) and poorly graded gravel with clay and sand (GC-GP) according to the Unified Soil Classification System (USCS), while A-2-4 with respect to AASHTO soil classification system. The maximum dry density and optimum moisture content were 1.93 g/cm^3 by 12.80% for BS-1 and 1.89 g/cm^3 by 14.50% for BS-2. The unsoaked CBR value was 61%, while the CBR values after 7 days of soaking were 55% for BS-1 and the unsoacked CBR value for BS-2 was 46% while the CBR values after 7 days of soaking were 30%. The findings indicate that the CBR value decreased as the soaking period increased specially for plastic soils than non-plastic soil, implying a reduction in the strength of the sub-base material. Therefore, it is recommended to consider the effect of soaking period when designing sub-base layers to ensure the long-term performance of the pavement structure.

Key words: Sub-base, Soaking Period, Pavement Structure, Cohesion, Engineering Property and CBR Value.

CHAPTER ONE:
INTRODUCTION

1.1. Background

Pavements are critical infrastructural elements that provide a permanent and secure surface for vehicular and pedestrian travel. They need to sustain the loads applied and external conditions in order to perform over the long term. Sub base is one very critical component of a pavement system that has the role of load spreading, increasing stability, and limiting deformation.

Less natural cohesion gravel sub base materials are commonly used in various pavements due to their aesthetically pleasing engineering properties. The materials such as gravel, crushed stone, and sand consist of particles having little or no cohesion between them. They are typically well-graded and provide good drainage qualities, making them suitable for carrying the top pavement layers.

Strength of the cohesion less sub base material plays a key role in specifying long-term pavement structural soundness and performance of the pavement structure. Sub base material serves as an underlying platform to the paving course above it, providing support and transferring load on to the sub soil. Material like crushed stone, gravel, and sand, are commonly used as sub base materials due to their ability to drain water and withstand traffic deformation. These materials will, nonetheless, exhibit variation in strength and stiffness upon prolonged exposure to water. Soaking period, or the length of time sub base materials are submerged under water before one samples their strength. It simulates actual conditions to which sub base materials are subjected during their life cycle, such as rainfall, groundwater, and environmental conditions. It is essential to know the effect of soaking period on cohesion less sub base materials' strength while designing and constructing long-lasting and strong pavements (Zaman et al 2017).

The strength and stiffness of the granular soils rose with a longer duration of soaking. They attributed this gain to particle rearrangement and compaction of soil resulting from excess pore water pressure dissipation (Das et al, 2007). A decrease in strength and stiffness with longer soaking times reported on crushed stone aggregates that showed a decrease in the resilient modulus and California bearing ratio (CBR) values after prolonged soaking. Which attributed this decrease to the breakdown of inter-particle friction and the loss of particle-to-particle contact due to the presence of water (Rawas et al, 2005).

Even if these studies have a lot of information, their conclusions suggest that more work is required to know the effects of soaking durations on the strength of various types of cohesionless natural gravel materials. This is the knowledge gap this research study is addressing through extensive laboratory investigations of different types of cohesionless materials with different soaking periods. The findings from this study will help in formulating strategies to design and construct the sub base layers which will enhance their performance, durability, and longevity.

1.2. Statement of Problem

The strength and durability of pavement structures play a vital role in the long-term performance and safety of roads. Cohesion less materials, such as natural gravel, are commonly used in the construction of sub base layers in pavement structures due to their excellent mechanical properties.

Despite the importance of understanding the strength and stability of sub base materials, the author has considered the relevance of applying a standard soaking period of four (4) days when conducting California Bearing Ratio (CBR) tests on these materials. This approach aims to characterize the strength and stability properties of sub base materials at different soaking periods, unlike the approach used for cohesive soils. It is important to note that cohesion less and cohesive soils exhibit different saturation rates due to differences in their particle size distribution and drainage conditions. Cohesive soils, with their finer particles and lower permeability, tend to saturate more slowly than cohesion less materials. Therefore, the use of a similar soaking period, typically applied to cohesive soils, may not be appropriate for cohesion less sub base materials.

The literature reveals a gap in understanding whether a four-day soaking period is generally applicable or if it leads to misleading conclusions for specific material types, such as cohesionless subbases, which may exhibit unique responses to moisture exposure. Existing research has predominantly focused on cohesive soils, clayey subgrades, or specific aggregates like limestone, with limited exploration of cohesionless subbase materials.

For this reason, prior research does not resolve this matter because the author has concidered a standard soaking period of four (4) days while performing CBR tests on sub base materials. This method does not account for the differences in the degree of saturation for cohesion less and cohesive soils which could result in inaccurate design guidelines for sub base materials used in pavement structures. In the absence of such knowledge, optimal strategies for the construction and maintenance of pavements cannot be devised. Hence, steps must be taken to control and define the soaking period needed for testing the strength and stability of cohesion less sub base materials tailored to their properties.

To summarize, the inadequacy of understanding the effect of soaking time on the material's strength is attributed to the universal soaking duration which is not representative of the conditions required for cohesive soils. Therefore, going forward, analyzing the strength and stability of cohesion less sub base materials requires a defined standard soaking period that focuses on their distinct characteristics.. Addressing this issue will contribute to the advancement of the field of pavement engineering.

1.3 Objectives of The Study

1.3.1 General Objective of The Study

The main objective of researching the effect of soaking period on the strength of sub base materials is to understand how water affects the strength and stability of cohesion less sub base materials.

1.3.2 Specific Objectives of The Study

The specific objectives for the research will be:

- To conduct valuable tests to identify the appropriate sample material for the study (particle size distribution, natural moisture content, Atterberg limit, modified Proctor test, and CBR tests).
- To investigate the effect of different soaking periods (0-hours: Unsoaked CBR, 24- hours, 48-hours, 72-hours, 96-hours, 120-hours, 144-hours, and 168-hours) effects on the load-bearing capacity of sub-base materials.
- To establish the relationship between soaking period and the load-bearing capacity of sub-base materials.
- To evaluate the effect of soaking period on the durability and stability of sub-base materials.

1.4 Research Questions

This study aims to address the following research questions:

- Does the Duration of soaking for sub base materials influence their strength?
- How does the soaking period affect the strength of sub base materials?
- Are there significant variations in strength properties of natural gravel sub base materials based on different soaking durations?
- What are the significant factors responsible for the changes in strength?
- Is the soaking period (96 hours) reliable for cohesion less soils as do for cohesive soils?

These research questions guide the experimental design and analysis, providing valuable insights in to the relationship between soaking period and strength behavior of sub base materials.

1.5 Significance of the Study

This study is significant in that it presents important data on the influence of soaking time on the strength of subbase materials, which is part of the road infrastructure. Through an understanding of such a relationship, the study contributes towards realizing the optimization of pavement construction and design procedures to provide more durable and longer-lasting roads. The significance can be listed as follows::

- **Pavement Design Enhancement**: The study offers valuable data for designing pavements that account for moisture penetration, leading to improved material selection, compaction techniques, and drainage systems. This ensures a longer lifespan and better performance of the pavement structure.
- **Optimization of Material Properties**: By identifying the optimal soaking duration, the study enables engineers to maximize the strength properties of subbase materials, enhancing the durability and load-bearing capacity of pavements.
- **Cost-Effective Construction Practices**: The findings can help reduce construction costs by optimizing soaking durations, resulting in more efficient construction processes.
- **Preventive Maintenance Planning**: Gaining knowledge on potential weaknesses due to long-term soaking helps effective planning for maintenance, reducing the cost of repair in the long run and optimizing road life.

- **Policy and Standards Development**: The study can guide the formulation of guidelines and specifications for pavement construction, ensuring consistent quality and durability across infrastructure projects.
- **Advancement of Research**: The findings stimulate further research into alternative materials, innovative techniques, and long-term soaking effects, driving continuous improvement in the field of pavement engineering. These contributions collectively advance the field of civil engineering, fostering the development of sustainable, durable, and cost-effective road infrastructure.

1.6 Scope of the Study

The scope of the research project is:

- To conduct the study, the sample were collected from a selected borrow site stock pile. The sample obtained a total quantity of 154.5 kg specimen, which were used for the laboratory tests. These tests focused on analyzing various characteristics of the soil samples, such as their physical and mechanical properties (strength, durability, particle size distribution, and plasticity).
- The research project focused on investigating disturbed soil sample. Disturbed soil refers to soil that has been altered or disturbed from its natural state, such as through excavation or construction activities. The specific properties and behavior of these disturbed soil sample were the subject of study.
- The research project relied on collecting primary data from laboratory results. This means that experiments and tests were conducted in a controlled laboratory setting to obtain data on various parameters and characteristics of the disturbed soil samples. These laboratory tests provided quantitative measurements and information that form the basis of the study's analysis.
- The research project only considered laboratory tests and did not incorporate any field tests. Field tests typically involve collecting data directly from the field or in- situ conditions. However, in this study, the focus were on conducting controlled experiments in the laboratory to ensure consistency and accuracy of the data collected.
- The samples used in the research project were collected from the stockpile of a selected borrow site. The borrow site refers to a location where materials, such as gravel, are sourced for construction purposes. The specific material of interest

in this study is natural gravel sub base material, which is commonly used as a foundation layer in road construction projects.

- The research project is solely intended for academic purposes. This means that the primary goal is to contribute to the body of knowledge in the field of pavement engineering or a related discipline. The research aims to advance understanding and provide insights into the behavior and characteristics of disturbed soil samples, rather than directly addressing practical applications or specific engineering projects.

1.7 Limitations of the study

This research work has different kinds of limitations: it is limited by the range of soaking period the study investigated only 0 upto 7 days of soaking duration, the findings are specific to the particular type of sub base material used in the study, the study relies only on the performed tests other test methods are not considered.

CHAPTER TWO:
LITERATURE REVIEW

In this chapter, the author reviewed some relevant journals, studies, books and specification manuals from different authors and institutions on the topic of the study.

2.1 General

A subbase layer is placed on top of the subgrade to support the base course. The primary function of the subbase is to enable the construction of adequately thick pavement at a reasonable cost. Economic considerations are paramount in subbase design, emphasizing the use of locally available materials whenever practical. As long as the flexible pavement thickness design parameters are met, the sub base quality might vary greatly (Jaleel, 2011).

A pavement is a set of superimposed layers of imported materials (selected, processed unbound and bound materials) that are placed on the natural soil for the creation of a road. A pavement is a complex structure that has to accomplish various functions different from each other. The main structural function of a pavement is to sustain traffic loads and distribute them to the subgrade (Nikolaides, 2014).

The sub-base is an important load spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the subgrade, it acts as a working platform for the construction of the upper pavement layers, and it acts as a separation layer between subgrade and base course (ERA, 2013).

The sub-base is the first layer constructed, if necessary, over the subgrade (or the capping layer). This layer, certainly when the material used for its construction is the same as the base course material, is not a distinct layer. In a few countries, such as the United Kingdom, the sub-base indicates all the layers that are below the upper bound in bitumen or cement layers of the pavement (Nikolaides, 2014).

Subbases may consist of select materials, such as natural gravels, that are stable but that have characteristics which make them not completely suitable as base courses. They may also be of stabilized soil or merely select borrow (Yoder, 1975).

2.2 Measurements of the Impact of Soaking Period in the Strength of Cohesion less Pavement Sub Base Materials.

The effects of long-term soaking on the California Bearing Ratio (CBR), resilient modulus, and deformation of compacted Iraqi gypsiferous soil were explored. The study aimed at examining the reaction of soil when subjected to various soaking periods and to determine how these affect its strength, stiffness, and deformation. The authors conducted several tests on sixteen CBR specimens compacted to their optimum moisture content and 95% of the maximum dry density. The specimens were then soaked with different time intervals of 0, 4, 7, 15, 30, 60, 120, and 180 days, with a surcharge load of 40 lb. The samples were immediately tested using a compressive and shear wave by the ultrasonic pulse velocity test to obtain the resilient modulus. CBR was also conducted, and the soluble salts and gypsum content were measured. The study results showed that the soil first swelled when it underwent soaking, subsequently started settling gradually. The tests revealed a notable decrease in CBR and resilient modulus with increases in soaking time, with the highest rate of loss incurred during the first week. Decrease in TSS and gypsum content also had the similar correlation With the loss of strength and stiffness of the ground. Soaking for four days can produce misleading and hazardous conclusions regarding the strength, stiffness, and deformation of gypsiferous soils. (Razouki et al., 2003)

The impact of surcharge and soaking on design of road pavement in clayey subgrade was examined. The study was conducted in various locations of Sagoli and Barshi roads spanning across the Sangli district of Maharashtra state, and California Bearing Ratio (CBR) tests were performed on laboratory soil samples. The study was aimed at determining the optimum surcharge load and soaking duration for obtaining safe and economical designs of highway pavements. The study covered various laboratory tests on split samples of soils like Modified Proctor Compaction Test, Sieve Analysis, Liquid Limit and Plastic Limit Test, Natural Moisture Content Test, Direct Shear Test, and Laboratory CBR Test. The above tests were done on murum and black cotton soil and CBR values obtained at different surcharge loads and soaking times. This observation revealed that for murum and black cotton soil 1. The values of CBR increased by numerous times when the compaction was modified in place of normal compaction. The CBR values increased considerably with an increase in surcharge load and .3 CBR values were affected by the soaking period, with longer periods resulting in higher CBR values.(Patil 2004)

This study investigated the effect of soaking limestone in water on its CBR in order to determine its suitability for road construction in the southern parts of Iraq. Four limestone samples were prepared and compacted according to AASHTO T-99 standards. Each sample was divided into six specimens, which were subjected to different soaking periods of 7, 14, 21, 28, 35, and 42 days. CBR tests were conducted at the end of each period to determine the CBR value. This research consider limestone and found out that CBR of limestone decreased with an increasing number of soaking cycles, until it reached equilibrium at the end of the fifth cycle.(Gurah et al,. 2009)

This study investigated the impact of soaking on the California Bearing Ratio (CBR) value of a sub-base. The study involved preparing 14 CBR samples at 95% relative modified AASHTO compaction, with two samples for each soaking period of 0,4,7,14,30, and 60 days 0 to 60 days. The samples were mechanically compacted in the laboratory, and the first group was tested in the case of unsoaked, while the second group was tested in the case of soaking. The results showed a significant drop in the CBR value for both the top and bottom layers of the sub-base due to soaking compared to the natural (unsoaked) state. This decrease indicated a reduction in the bearing capacity of the sub- base soil with increasing soaking time. The most substantial decrease in the soaked CBR value occurred within the first few days of soaking for both the top and bottom layers. After 60 days of soaking, the CBR value dropped to 20% for the top layer and 23% for the bottom layer, indicating significant soil weakness caused. (Tariq Jaleel 2011)

This study investigated various test methods used to characterize moisture sensitivity, identified six contributing mechanisms associated with moisture damage: detachment, displacement, spontaneous emulsification, pore pressure induced damage, hydraulic scour, and the effects of the environment on the aggregate-asphalt system. They also discussed various factors that contribute to water induced distresses, such as mix design, production, construction, climate, and other external factors. The study found that water has adverse effects on pavement performance, leading to various distresses such as stripping, bleeding, rutting, corrugation, cracking, and localized failures. (Yilmaz et al 2012)

The effects of physical properties on strength, stiffness, and resistance to deformation of pure dense well graded crushed stone base mixtures. The research aims at establishing the effect of gradation, density, and moisture on those properties for improving road and airport runway base course design and construction. The authors conduct an experimental test program that includes sieve, compaction, Resilient Modulus, and Permanent Deformation tests for two base blends crushed basaltic rock.

Tests indicate that Resilient Modulus decreases and Permanent Deformation increases when moisture content is below or above the optimum. This is due to the lack or excess of water, and the same affects the ability of particles to interlock during compaction. The two blends gradation requirements obtain maximum dry density, which yields high Resilient Modulus values and low Permanent Deformation values. The study concludes that gradation, moisture, and density have a significant influence on the strength, stiffness, and deformation resistance of pure dense well graded base blends. The study shows that well graded materials achieve higher densities, leading to enhanced stiffness and deformation resistance. (Omer,et al 2014)

This study examined the prediction of soaked CBR values from geotechnical properties of soils. The objective of the study was to determine the contribution of different geotechnical properties to soaked CBR and to develop a prediction model for CBR based on these properties. The research used soil samples collected from 10 different places in the surrounding area of Sirsa town, India. The sampling was conducted at a depth of 50 cm from the ground surface and was analyzed for specific gravity, particle size, LL, PL, PI, MDD, OMC, and soaked CBR. The results showed that particle size, specific gravity, and optimum moisture content influenced soaked CBR most. Using these parameters, multiple regression modeling was developed for soaked CBR estimation. The model showed high correlation coefficient and least residuals, indicating its efficacy in predicting CBR values of the study area. The study recommends the use of this model as an alternative to the CBR test, a time-consuming and expensive test, in pavement design. (Roy 2016)

Effect time-dependent soaking on the shear strength parameters of sand soils was found to be a decrease in the shear strength parameter (Internal angle of friction) with increasing soaking time. Reduction ratios were found to be -3.83% and - 12.68% for the 2-weeks and 4-weeks soaking periods, respectively. (Shaker Mahmood 2017)

This study by Zainorabidin et al. (2018) investigates the meaningful relationship of moisture content and resilient modulus of cohesive subgrade soil, a key pavement performance parameter. Using clay soil of type II (fine-grained) via AASHTO T-307, the researchers conducted a wide range of tests like Atterberg limits, sieve analysis, specific gravity, and the standard Proctor test to determine optimal maximum dry density (MDD) and moisture content (OMC). Resilient modulus tests, performed using a load test machine with a 15-sequence, two-phase protocol, showed a firm inverse relationship between resilient modulus and moisture content. As moisture content increased, the resilient modulus decreased, meaning lower soil stiffness and strength. This finding indicates the profound influence of moisture content changes on road pavement performance, given the pivotal role of subgrade in keeping the pavement structure.

The experiments assumed to define the effect of soaking on CBR values and its variation in water content. Equipment used for this study included samples of soil, laboratory setups such as equipment for CBR, and sieves of various diameters. Test procedures used were consideration of CBR of soaked and unsoaked samples and determination of maximum dry density and optimum moisture content using heavy compaction. It was observed that the value of CBR of given soil sample decreases rapidly with soaking time up to 24 hrs. and then decreases slowly. The study also observed correlation between Unsoaked and soaked CBR values, i.e., the soaked values can be estimated using Unsoaked values.(Pandey et al 2019)

This study investigated some clayey soils, samples of the soil were obtained from various sites around Lebanon and analyzed. Major tests like the Proctor and CBR tests were conducted through the experiments, along with identification tests like the Atterberg limits. All the soil samples were analyzed for four different sets of CBR tests, each with varying soaking time: unsoaked, soaked for two days, soaked for four days, and soaked for eight days. The outcome of the study shows that the soaking time plays an important part in influencing the CBR value of the clay. As the soaking time was increased, it was noticed to cause the CBR to decrease faster in the first two days and then slowly in the subsequent two days. (Nini 2019)

This study analyzed the effect of saturation on soil subgrade strength to classify the soil samples based on various parameters, to find out the CBR value under Unsoaked and soaked conditions, and to compare them to understand how saturation is influencing them. Six various soil samples were selected for testing and were classified into various types based on sieve analysis, liquid limit, plastic limit, plastic index, plasticity chart. The soil strength was measured using the CBR test, and the values were computed for Unsoaked and soaked for 1, 2, 3, and 4 days. The CBR values were compared to observe the effect of saturation on the soil subgrade strength. The results from the experiment showed that there was a drop in CBR values for each soil sample when they were submerged for 1, 2, 3, and 4 days. This indicates that saturated condition negatively impacts the subgrade strength of the soil. The decrease in CBR values is attributed to an increase in the water content, which decreases the load-carrying capacity of the soil.(Ali et al 2022)

This study investigated water's effect on green mudstone rock strength and creep properties under an effort to uncover the flooded slopes' long-term stability. The researchers chose a self-crafted experimental facility using biaxial compressive loading within a water immersion condition to experiment with the mudstone failure and creep behavior. Different immersion time and confining pressure were included. The samples underwent tests of weakening coefficient, cohesion, and creep behavior. Through these tests, it was evident that water caused a significant impact on altering the strength and failure mode of the mudstone. The weakening action of water decreased with an increase in confining pressure, and the change in cohesion was largely responsible for decreasing shear strength when immersed. The creep test results showed that the creep curve of the soaking specimen was identical with that of the dry specimen in the initial stage, but with longer soaking time, the weakening effect of water on the specimen increased and the creep curve of the soaking specimen approached that of the saturated specimen. The study found that water has a significant weakening effect on green mudstone rock strength and creep behavior. The increase in the confining pressure and the change in cohesion can decelerate the weakening of the rock. However, with an increase in soaking time, the weakening effect of water on the specimen increases and results in a lower failure time for the soaking specimen compared to the dry specimen. (Li et al. 2023)

Thise study investigated the impact of soaking on the strength characteristics of cohesion less soil. The author evaluates the changes in the geotechnical properties of soil after soaking and to determine the effect of different soaking periods on the soil shear strength. Soil samples were subjected to different soaking periods ranging from 0 to 48 hours. The findings showed that the shear strength of the cohesion less soil decreased significantly with increasing soaking periods. It was also observed that the soil internal friction angle decreased, indicating a reduction in its shear strength. Singh et al (2017)

This study investigated the effect of soaking on the strength and stiffness of granular subbase materials by conducted laboratory tests on granular subbase samples, including the CBR test, resilient modulus test, and unconfined compressive strength test, both before and after soaking. The findings indicate that soaking significantly affects the mechanical properties, resulting in reduced strength and stiffness. Rahman et al (2019)

This study investigated the effect of soaking on the volumetric strains of gypseous sand soils through a comparison of data from unsaturated triaxial tests and Odometer tests. The results from the unsaturated triaxial tests showed that as matric suction decreased, the volumetric strains increased, and the stress-strain curve became steeper. This was consistent with previous research on the effect of gypsum content on soil properties. The data from the Odometer tests also showed an increase in volumetric strains with longer soaking times, but the results were not as significant as those from the unsaturated triaxial tests. The findings of this study are the comparison of data from the unsaturated triaxial tests and Odometer tests revealed that the volumetric strains were significantly higher in the unsaturated tests, especially at low matric suction levels. Abdalhusein et al (2019)

This study examined how soaking periods of 7, and 28 days affected the shear strength, observing a reduction in the soil's phi angle (ϕ') from 20° to 13° after 28 days of soaking. This decline in shear strength is attributed to the absorption of water by clay minerals within the soil matrix, which softens the clay and reduces its binding capacity, leading to an overall weakening of the soil structure. The research highlighted that prolonged soaking enhances water infiltration, which can contribute to slope failures, especially in regions experiencing continuous rainfall. Therefore, it is crucial to consider the soaking effects in stability analyses for geotechnical constructions in tropical. The finding shows that the shear strength of the soil decreases as soaking duration increases. B A Hadi et al (2020)

Ainam Z et.al (2022) studied to assess the strength of soil based on, determines compaction characteristics, established OMC, and analyzes the effect of moisture variation on shear strength and CBR. Six soil samples were classified through sieve analysis, LL, PL, Standard proctor test and CBR test on unsoaked and soaked samples over 1-4 days of soaking. The result showed that CBR values decreased with increased soaking time indicating moisture weakens soil strength.

Summary of Literature review

Elevated levels of soaking typically result in a decline in both the CBR and resilient modulus of the material. This reduction signifies a weakening of the material's strength, a decrease in its stiffness and its bearing capacity This detrimental effect is most significant during the initial phase of soaking, first few days of exposure to water. The extent to which a material's strength is compromised by soaking is not uniform; it varies depending on the specific type of material and is closely linked to its saturation rate how quickly and how much water it absorbs. Existing research has investigated the effects of soaking on a range of materials, including various soil types such as clay, sand, and gypsiferous soils, as well as on limestone, crushed stone, and mudstone, among others. However, there remains a need for more focused investigation into the specific effects of soaking on cohesionless natural gravel subbase materials, which are commonly used in road construction.

2.2.1 Engineering Features of Sub base materials

Sub base materials play a significant role in road construction, and their properties are delineated by standards and manuals like AASHTO, ASTM, and the Ethiopian Road Authority (ERA).

According to ERA Technical Specification (2013), the sub base material will comply with the requirements as indicated herein below in the Table 2-1., 2.2, and 3.2.

Table-1: Grading Requirements for Natural Gravel Sub-bases

(ERA Technical Specification (2013)

ISO Sieve Size (mm)	Percentage Passing by Mass	Remark
63	100	
50		
37.5	70-100	
26.5		
20	50-100	
9.5		
4.75	30-100	
2.36		
1	17-75	
0.425	11-56	
0.075	5-25	

Table-2: Plasticity Limits Requirements for Natural Gravel Sub-bases
(ERA Technical Specification (2013)

Climate	**Typical Annual Rainfall (mm)**	**Plastic Limit**	**Plasticity Index**	**Linear Shrinkage**
	Greater than 1000	Less than 35		
Seasonally wet tropical		Less than 45	Less than 12	
		Less than 55	Less than 20	

Table-3: Density and Strength Requirements for Natural Gravel Sub-bases
(ERA Technical Specification (2013)

Parameter	**Unit**	**Specification (Max./Min.)**	**Remark**
Density	g/cm^3	Min. 95% MD	
Soaked CBR	%	Min. 30	
Grading Modulus		Min. 1.2	

Sub-base material should have an adequately graded particle size, that is, coarse and fine particles in a specific range. This is aimed at facilitating stability as well as appropriate compaction. Very high strength is a key characteristic of sub-base material in being able to withstand heavy loadings without deformation or rutting. AASHTO and ASTM provide specifications for the minimum sub-base material strength that can be determined in the laboratory, including California Bearing Ratio (CBR) tests.

Plasticity must be minimal for sub-base material to prevent maximum deformation due to variations in water content as given by ERA 2013. Soundness refers to sub-base materials' resistance against volume change due to frost actions. AASHTO T-103, ASTM D-559 offer a collection of test procedures for examination of soundness for sub-base materials. A minor percentage of fine-grained material (typically between 5% and 25%) is often desirable in the sub-base in terms of improved compaction and reduced permeability.

2.3 **Index Properties of Soils**

Index properties refer to certain physical characteristics of soils that are used primarily for classification purposes, as well as correlating with engineering properties.

The key index properties of soils typically include:

- Volume-weight relationships (e.g., unit weight, specific gravity)
- Moisture-density relationships (e.g., moisture content, degree of saturation)
- Relative density
- Grain size distribution (gradation)
- Plasticity (Atterberg limits)
- Organic content

These basic index properties provide fundamental information about the physical nature of a soil sample. This data is essential for classifying soil types and can also be correlated to predict various engineering behaviors and properties of the soil (R.E Hunt 2005).

2.3.1 **Moisture Contents**

Moisture content is defined as the ratio of the weight of water in a soil sample to the dry weight of the soil. Moisture content can be measured using several methods: Drying oven (ASTM D2216), Microwave oven (ASTM D4643), Field stove or blowtorch (ASTM D4959). While the microwave and field methods provide rapid results, they may yield higher moisture content values than the standard oven drying method (ASTM D2216). This is because the higher temperatures can release additional adsorbed water that would not be evaporated at the 110°C maximum of the standard method. Therefore, the results from the quicker microwave and field methods should be confirmed using the standard oven drying procedure described in ASTM D2216. (FHWA, 2006)

2.3.2 **Particle Size Distribution (Gradation**)

Soil gradation refers to the distribution of the various grain sizes in a soil sample, typically plotted as the percentage by weight passing through different sieve sizes. Soils are classified into different groups based on the sizes of the particles they contain. The common method for determining particle size distribution is by using a set of sieves. A sieve is a screen attached to a cylindrical frame, which allows smaller particles to fall through while retaining the larger ones. The sieves are arranged with the largest openings at the top and progressively smaller openings towards the bottom. The soil sample is sifted through this stack of sieves, and the weight of material retained on each sieve is measured and expressed as a percentage of the weight of the sample.

The USCS (Unified Soil Classification System) divides the main particle size ranges into cobbles, gravels, sands, and fines (silt or clay) (HDA 1999).

The position, shape, and slope of the particle size distribution curve provide useful information about the soil. The position indicates the soil classification, while the shape and slope reveal the distribution and sufficiency/deficiency of different particle sizes. Particle size affects the mechanical behavior of soils - coarse soils generally exhibit better strength and resistance than fine- grained soils. Particle size also determines water retention, absorption, and susceptibility to frost damage or swelling, with fine-grained soils like silt and clay being more prone to these issues. The uniformity of the soil, often a desirable trait, is quantified using the uniformity coefficient (Cu) and coefficient of curvature (Cc), calculated from the particle size diameters corresponding to 10%, 30%, and 60% passing (Nicolaides, 2014).

Where D_{10}, D_{30} and D_{60} are the particle sizes corresponding to the ordinates 60% and 10% by mass of the percentage passing. The shape of the grading curve with respect to C_u and C_c is characterized as shown in the table below.

Table 4: Shape of Grading Curve (Nicolaides, 2014).

Shape of grading curve	Cu	Cc
Multi-graded	> 15	1 < Cc <3
Medium graded	6 - 15	< 1
Even graded	< 6	< 1
Gap graded	Usually, high	Any (usually < 0.5)

The gradation coefficient, Cu, is a number that represents the range of particle sizes in a soil sample. A reasonably high value of Cu indicates that the soil is well-graded, i.e., it contains a wide distribution of particle sizes. On the other hand, a Cu value of around 1 indicates a poorly graded soil, i.e., the particles are more or less the same size. The coefficient of curvature, Cc, is yet another parameter that is used to assess soil gradation. Sands need to meet the requirements given below in order to be well-graded:

- $C_u > 6$
- $1 < C_c < 3$

For gravels to be well-graded:

- $C_u > 4$
- $1 < C_c < 3$

These gradation coefficients provide insight into the overall distribution of particle sizes within the soil sample. Well-graded soils with a wide range of particle sizes generally exhibit better engineering properties compared to poorly graded soils with a limited particle size distribution (Das., 2018).

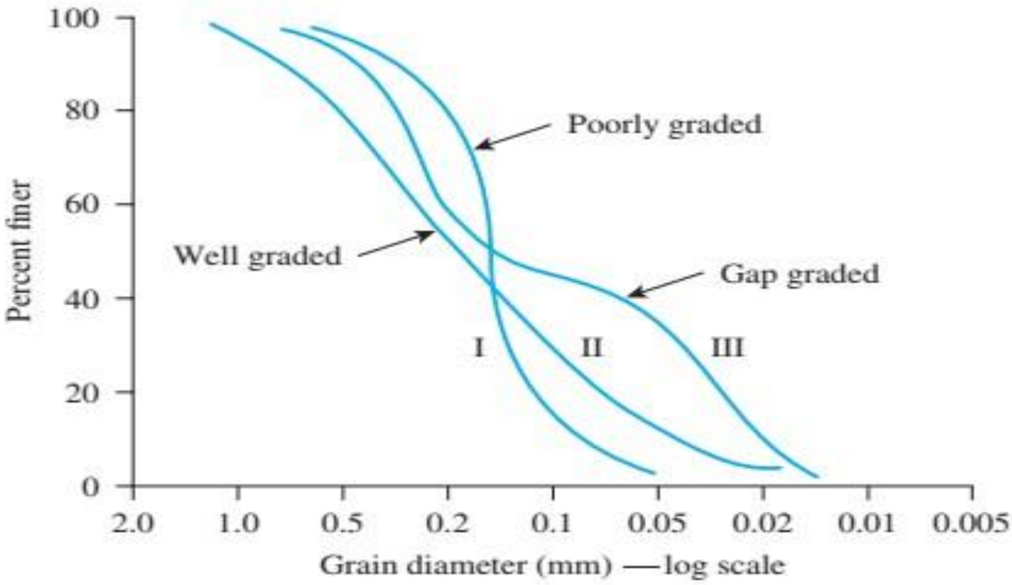

Figure 1: GRAIN SIZE DISTRIBUTION CURVES (DAS, 2016).

2.3.3 Soil Classification System

There are rather a large number of soil classification systems that have been suggested for purposes of applications in engineering, such as the AASHTO, Unified Soil Classification, and FAA systems of classification. They all utilize the Atterberg limits, particularly plastic limit (PL) and liquid limit (LL), together with grain-size analysis, as key parameters of soil classification. The AASHTO soil classification system is widely used in highway engineering. It requires grain-size testing, liquid limit, and plasticity index (PI) for soil classification. The United States Army Corps of Engineers uses the Casagrande-developed Unified Soil Classification System. It classifies soils into three general groups: coarse-grained, fine-grained, and highly organic. The Atterberg limits are again important parameters to classify. The AASHTO soil classification system categorizes soils based on their particle size and plasticity. Coarse soil materials, which include boulders, cobbles, gravels, and sands, are defined as those with retention of ≥ 65% on a 0.075 mm sieve. Fine soil materials, such as silts and clays, are those with >35% passing the 0.075 mm sieve. The coarse soils are further divided into three major groups (A-1, A-2, A-3) and seven subgroups based on sieve retention, liquid limit, and plasticity index. The fine soils are divided into four major groups (A-4, A-5, A-6, A-7) with A-7 having two subgroups, based on liquid limit and plasticity index.

2.3.4 Grading Modulus (GM)

According to the ERA Pavement Design Manual (2013), the Grading Modulus (GM) is calculated by considering the cumulative percentages by mass of material in a representative sample of aggregate, gravel, or soil retained on the 2.36 mm, 0.425 mm, and 0.075 mm sieves. The formula for GM is:

$$GM = 3 - [(P_{2.36} + P_{0.425} + P_{0.075})/100] \quad \text{-------------------------------} \quad (2.1)$$

Where, $P_{2.36}$, $P_{0.425}$, and $P_{0.075}$ are the percentages of material passing through the respective sieves.

2.3.5 Atterberg Limits

The Atterberg limits represent the moisture content at which a fine-grained soil transitions between different physical states. The tests for these limits are considered index tests, as they provide an indication of various physical properties of the soil, including strength, permeability, compressibility, and shrink/swell potential. The Atterberg limits also provide a relative measure of the soil's plasticity, that is, the ability of silt or clay to retain water without changing from semisolid to viscous liquid. The most important Atterberg limits employed in geotechnical engineering practice are Liquid Limit (LL), Plastic Limit (PL) and Shrinkage Limit (SL). These limits and their inter-relationships, e.g., plasticity index (PI = LL - PL), are useful in offering information regarding the engineering behavior and classification of fine-grained soils(FHWA, 2006).

2.3.6 **Liquid Limit (LL)**

This is the water content at which the addition of water content will cause a plastic soil to behave like a viscous liquid. The LL is the water content at the plastic-liquid boundary. It is determined using the Casagrande apparatus. The LL is the water content at an arbitrary boundary between the liquid and plastic states of a soil consistency. Above this value, a soil is presumed to be a liquid and flows freely under its own weight. Below this value, it will deform under pressure without crumbling, if it has a plastic state. The test is conducted on a sample passing through a 0.425 mm sieve and as per ASTM D 4318 or AASHTO T 89 (Nicolaides, A., 2014).

2.3.7 **Plastic Limit (PL)**

The plastic limit is the moisture content at which a soil transforms from a plastic to a semisolid state. It is the moisture content at which a thread of soil will just break when it is rolled slowly between the fingers to a diameter of 1/8 inch (3 mm). The plastic limit is the moisture content at which a soil sample transforms from a condition in which it can be deformed without cracking (plastic state) to a brittle and crumbly condition when rolled into a thin thread (semisolid state). This property is an important description of the behavior of a soil and is used, in combination with the liquid limit, to determine the plasticity index of the soil, which provides information about the soil's cohesive and workability characteristics (H.D.A, 1999).

2.3.8 **Shrinkage Limit (SL)**

The shrinkage limit is the moisture content where a soil transitions from a semisolid to a solid. It is the moisture content at which any loss of moisture will not result in a decrease in the volume of the soil (FHWA, 2006).

The shrinkage limit marks the boundary between the semisolid and solid states of the soil. This boundary is determined when a soil sample, as it is dried, reaches a limiting or minimum volume. Beyond this point, further drying will not reduce the volume, but may instead cause cracking in the soil.

2.3.9 Moisture-Density Relation (Modified Proctor Test)

The general meaning of "compact" is to press closely together. In soil mechanics, it refers to pressing soil particles tightly by expelling air from the spaces between them. Compaction is usually done deliberately, often using heavy rollers, and occurs quickly during construction. Compaction increases the soil's unit weight, leading to three important effects:

i) Increased shear strength,

ii) Decreased future settlement,

and iii) Decreased permeability.

The Proctor test is used to determine the optimum moisture content (OMC) and maximum dry density (MDD) of soils. As moisture content increases, the soil's dry density rises. But after reaching the OMC, further increases in moisture cause the dry density to decrease. Soil compaction is quantified by the dry density formula:

$$\gamma d = \gamma /(1+\omega) \quad (2.2)$$

Where, γd is dry density, γ is moist density, and ω is moisture content.

2.3.10 **California Bearing Ratio (CBR)**

The California Bearing Ratio (CBR) test is a simple and widely applied method for measuring the strength of subgrade soil, sub-base and base course material in pavements of highways and airfield structures. The CBR test essentially calculates highway and airfield flexible pavement thickness using empirical formulas (Chang Liu, 2009).

The California Bearing Ratio (CBR) is an indirect measure of soil strength based on its resistance to penetration. The standard laboratory test for CBR is conducted to AASHTO T-193 or ASTM D-1883. The CBR test is performed on three identical, compacted soil samples. Each set of tests is conducted for a specific relative compaction and moisture content. The geotechnical or materials engineer must specify the test conditions, such as dry, at optimum moisture, after soaking, 95% relative compaction, etc. under which the CBR test should be performed for a given project or application. The CBR value provides an indirect measure of the soil's bearing capacity or strength, with a higher CBR indicating a stronger soil (ERA Geotechnical Design Manual,2013).

The CBR test is designed to simulate conditions that will exist at the surface of the subgrade. A surcharge (weight) is placed on the surface of the compacted specimen to represent the weight of pavement above the subgrade. Furthermore, the specimen is soaked to approximate the poorest field conditions. After soaking, the force required to push a standard piston into the soil a specified amount is determined and is used to evaluate the CBR (C. Liu, 2009).

Figure 2: CALIFORNIA BEARING RATIO (CBR) TEST APPARATUS (NICOLAIDES, 2014)

CHAPTER THREE

MATERIALS AND METHODS

3.1. Location of the Study Area

The study area comprises two borrow sites of same project. The project road is found in the Southern Nations, Nationalities and peoples region, Sodo Junction (Dimtu) – Blate Military Training Center starts from Bilate Town which is located 334 Km from Addis Ababa ends at Bilate Military Training Center. Actual progress of the project is 27.41% and the date for the completion of the project was on April 13, 2025. The study area of the first borrow site is located at 0+320 offset 2Km RHS coordinate of 06°56'07.5"N,38°06'24.98"E. Similarly, the second borrow site is also located 9+240 offset 3.5Km RHS coordinate of 06°53'00.6"N, 38°04'45.51"E. These two borrow sites have different elevation and they are the focal points of the study, and their distinctive geographical locations provide valuable insights into the specific areas being investigated.

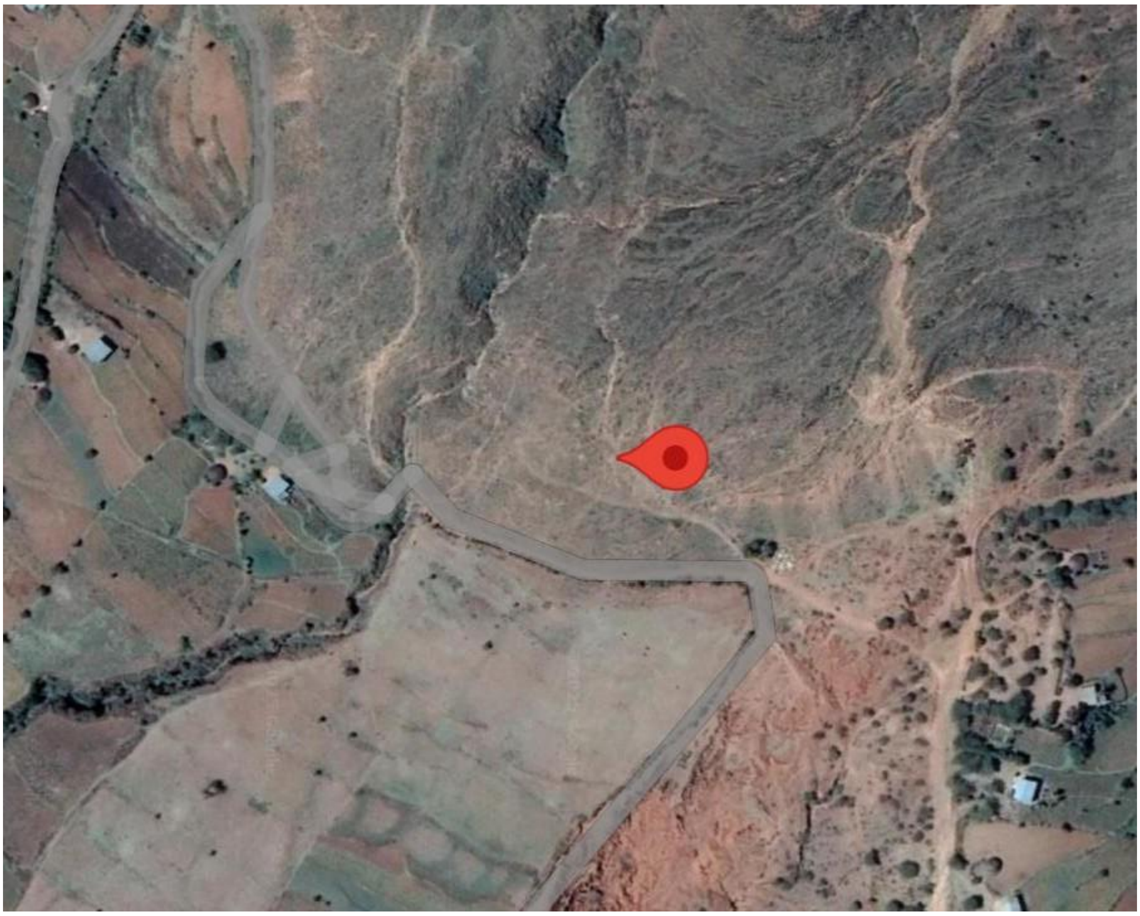

Figure:3 LOCATION OF 0+320 OFFSET 2KM RHS COORDINATE 06°56'07.5"N, 38°06'24.98"E(SOURCE: AUTHOR, MARCH 03, 2025)

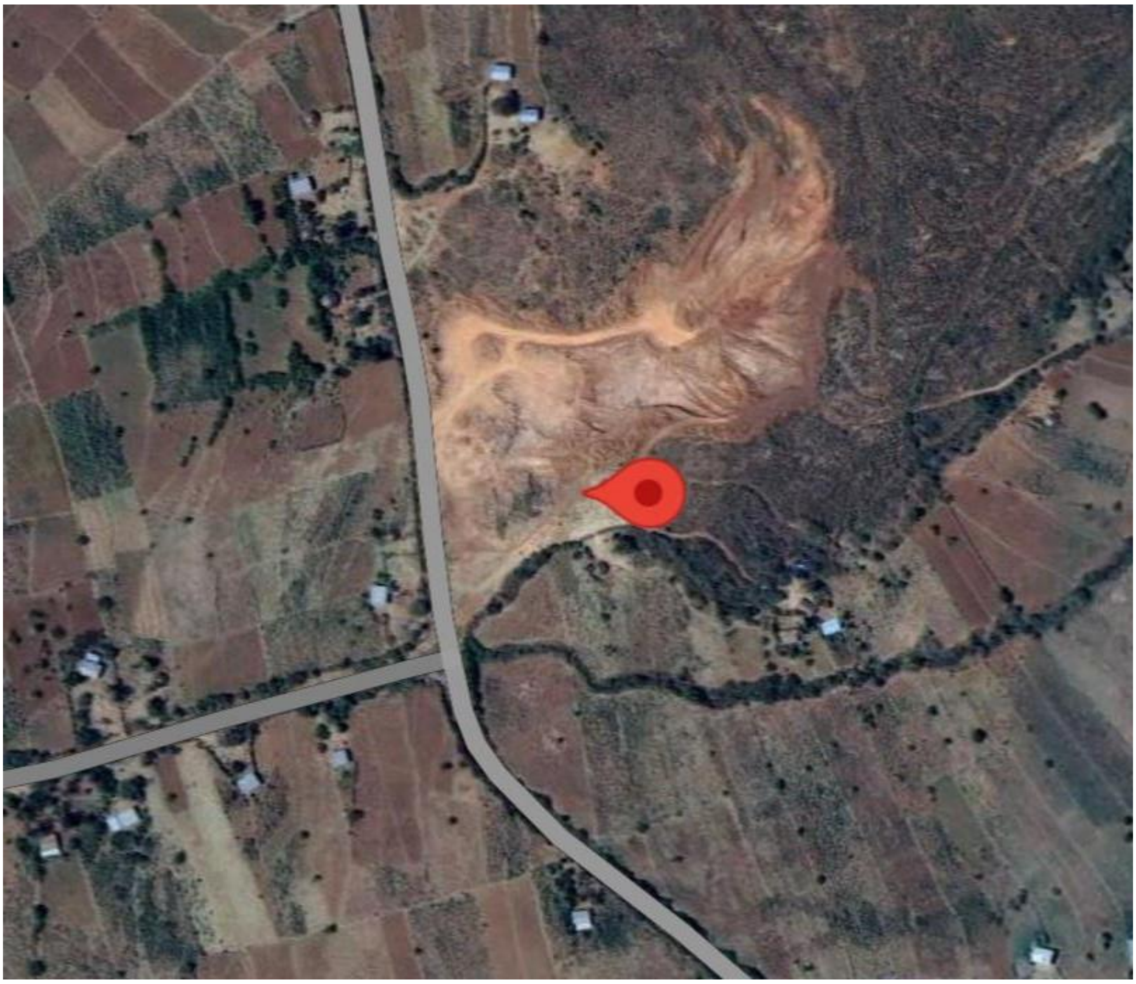

Figure:4 LOCATION OF 9+240 OFFSET 3.5KM RHS, COORDINATE 06°53’00.6”N,38°04’45.51”E (SOURCE: AUTHOR, MARCH 03, 2025).

3.1.1 Topography of the Study Area

The topography of both study areas are characterized by undulating hills and moderate slopes. The terrain is generally rough and uneven, with a mix of gentle gradients and steeper inclines. Elevation in the area ranges from approximately 1,500 to 1,600 meters above sea level.

3.1.2 Climate and Rainfall of the Study Area

The climate in the study area can be characterized as “kola” with average annual temperature around 27°C and annual rainfall about 510mm.

3.2. Methods

To achieve the objective of the research specific tests were selected accordingly, suitable borrow sites were also located, samples were taken from selected borrow sites and the required laboratory tests were performed.

The following flow chart describes the overall sequences of activities and procedures followed by the author throughout the experimental period.

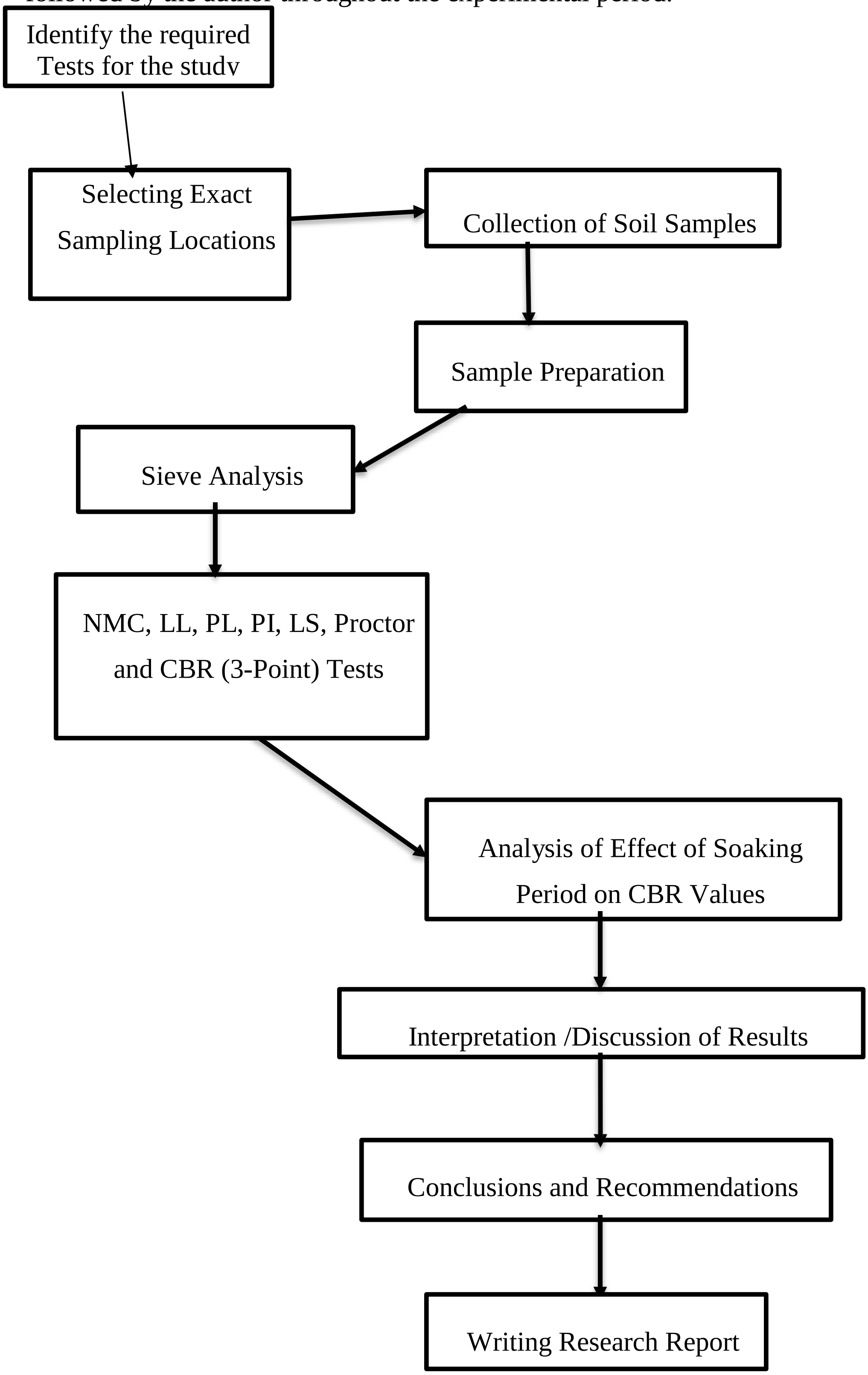

Figure -5: FLOW CHART OF THE METHODOLOGICAL APPROACH FOR THE STUDY.

3.2.1. Standards to be Used

The soil testing was conducted at the laboratory level, following established standards. The AASHTO standards were used for Sample Preparation, Determination of Moisture Content, CBR and Compaction tests and ASTM standards were used for Sieve Analysis and Atterberg Limits. Both AASHTO and ASTM standards were used for soil classification tests, whereas the ERA Standard Technical Specifications and Flexible Pavement Design Manuals will be used for making interpretation and discussion of the obtained results.

3.2.1 Experimental Programs

The following soil test requirements and procedures were carried out as illustrated in the table below.

Table-5 Summary of Resources used for Sample Preparation and Testing

Activity description	AASHTO Designation Code	ASTM Designation Code	Type of Sample
Preparation of Soil Sample	T 87		Disturbed
Natural Moisture Content Test	T 265	D 2216	Disturbed
Modified Proctor Test	T 180	D 1557	Disturbed
Gradation (Sieve and Hydrometer)	T 88	D 422	Disturbed
California Bearing Ratio (CBR) Test	T 193	D 1883	Disturbed
LL Test	T 89	D 4318	Disturbed
PL Test	T 90	D 4318	Disturbed
LS Test	T 92	D 427	Disturbed

3.2.3 Sampling Method

The non-random, systematic method of sampling technique was employed for the study. This meant that representative soil sample were be collected from top, middle, and bottom of the stockpile.

3.2.4 Sample Preparation

The samples for testing were prepared as Air-dried samples, based on the procedures mentioned under AASHTO or ASTM soil testing manuals and procedures.

3.3 Method of Data Analysis

When analyzing soil laboratory test data for research purposes, there are several methods which can be considered. The choice of method depends on the specific objectives of the research, the type of soil data collected, and the statistical techniques that are comfortable with. Hence, this study used Statistical analysis or Data Visualization technique (plotting graphs or charts) to visually represent the soil data. Visualizations helped identify patterns, outliers, and relationships that had been apparent from raw data. The other method of data analysis was Comparative analysis to compare with established standards to identify any variations or deviations. To employ the captioned methods of data analysis, the author used MS-Excel application software.

3.3.1 Data Analysis and Interpretation Procedures

- Conduct required or necessary tests for the study (particle size distribution, natural moisture content, specific gravity, modified Proctor test, Atterberg limit, and CBR tests).
- Classify the soil group using AASHTO Classification system.
- Based on ERA Standard Specifications and the Flexible Pavement Design Manual 2013, Verify the compliance of the collected sample for sub base material.
- Examine the density-moisture relationships of the specimens.
- Evaluate the impact of the soaking period in the strength (CBR) characteristics at 0-hours (Unsoaked CBR), 24-hours, 48-hours, 72- hours, 96-hours, 120-hours, 144-hours, and 168-hours.
- Examine the relationship between soaking period and CBR values.
- Examine whether the influence of any other engineering factors that have a significant impact on the phenomenon.

3.3.2. Factors Affecting Natural Gravel Sub Base Materials

When analyzing natural gravel sub-base materials, factors such as gradation, natural moisture content, specific gravity, compaction, LL, PL, LS and CBR are of primary importance. These factors help in determining the material's stability, load-bearing capacity, drainage characteristics, and suitability for construction applications. It is essential to adhere to appropriate testing standards and specifications specific to natural gravel sub base materials during the analysis process.

3.4. Materials

3.4.1. Sample Size

The size of samples was illustrated in the table hereunder.

Table-6: Sample Sizes

Description	Sample Size for Single Lot (Kg)	Number of Lots	Total Sample Size Required (Kg)	Remark
Sieve Analysis Test	3.0	2	6	
Natural Moisture Content Test	0.5	2	1	
Atterberg Tests	1.0	2	2	
Modified Proctor Test (Kg)	30.0	2	60	
CBR Test (3- Point) (Kg)	120.0	2	240	
Total Sample Size (Kg)	**155**	**2**	**310**	

(One lot = One borrow site)

3.4.2 Tools Used for Sample Collection

The author collected disturbed natural gravel sub base materials for experimental studies using sacks, shovels, pick axe and other hand tools as necessary. Furthermore, the author arranged a vehicle for the transportation of samples to Soil Laboratory of Dimtu-Bilate Military Training Center Road Project Laboratory for Materials Testing.

CHAPTER FOUR:
RESULTS AND DISCUSSIONS

4.1 Summary of Test Result

This chapter summarizes the soil sample test results from the experimental works. The experiment work involves both strength and classification tests, which were carried out to assess and determine the effect of soaking period on the strength of subbase material. The laboratory test results summary, discussions and results interpretations of the conducted soil test results were stated in the next sections.

4.2 Classification Tests

The soil test conducted under this study include classification tests. From the test result it was found out that both soil samples satisfy the requirement for sub base material.

Table 7: Summary of Results of NMC, Atterberg Limits and Grading Modulus of Soil Samples

Sample Code	**Type of Sample**	**NMC (%)**	**LL (%)**	**PL (%)**	**PI (%)**	**LS (%)**	**Grading Modulus (GM)**	**Remark**
BS-1	Disturbed	10.53	-	-	NP	-	2.49	
BS-2	Disturbed	8.81	43.67	35.52	8.15	4.07	2.66	

Table 8: Percentage passing of each sieve size

Sieve Size (mm)	Percent Passing	
	BS-1	BS-2
63	100	100
37.5	71.63	88.37
19	63.80	64.87
9.5	50.43	46.90
4.75	40.30	35.33
2.36	32.57	26.5
0.425	12.13	7.10
0.075	6.10	1.43

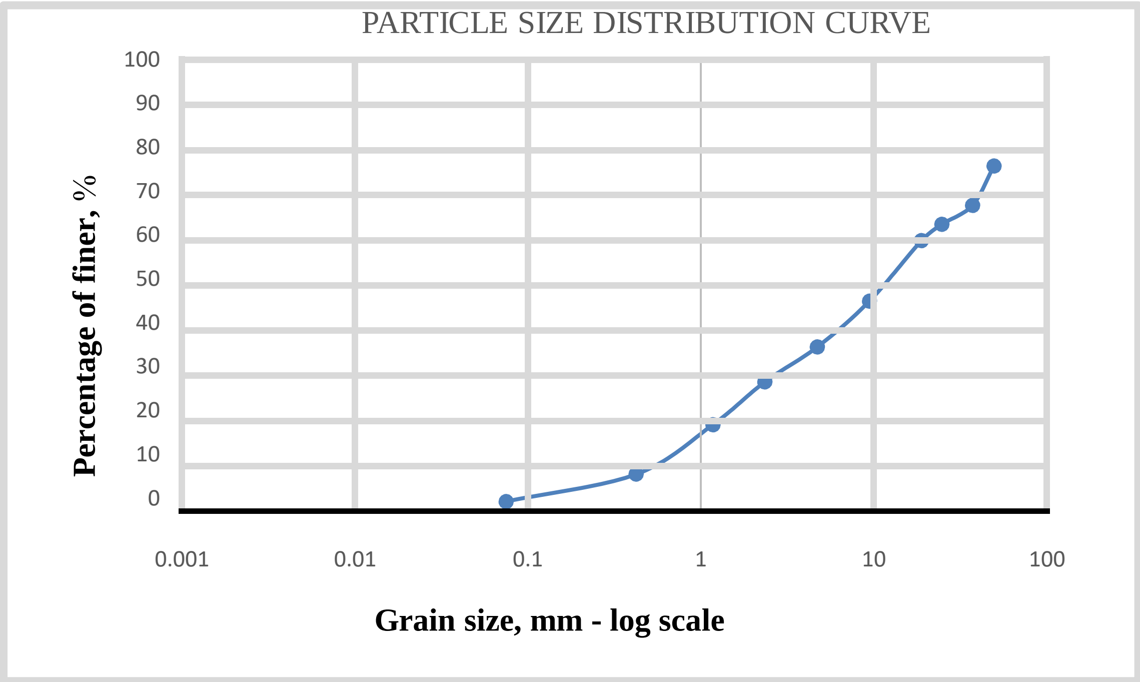

Figure 6: Particle Size Distribution Curve (BS-1)

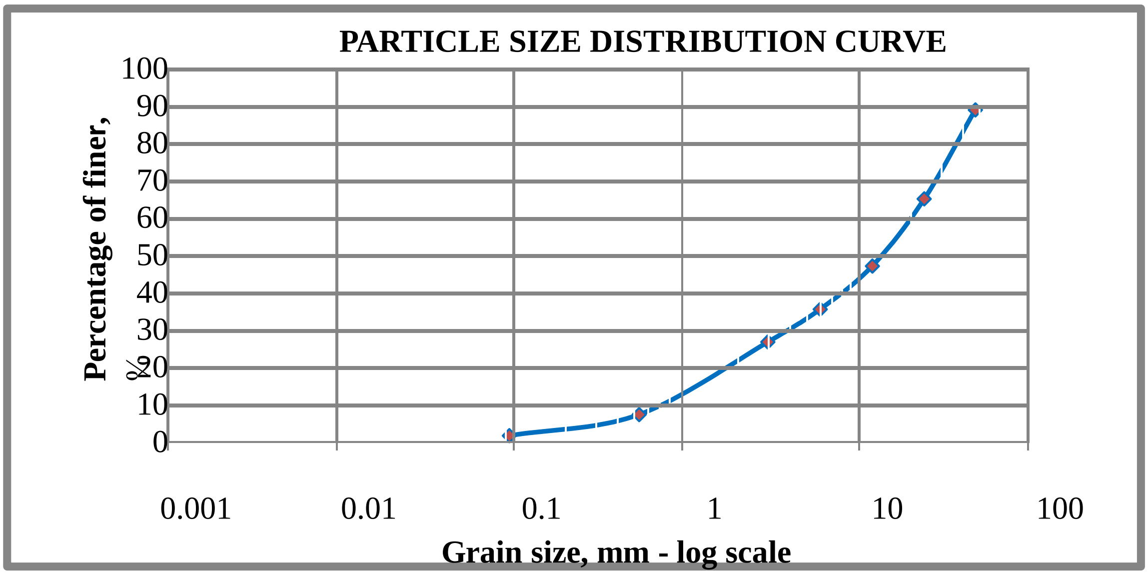

Figure 7: Particle Size Distribution Curve (BS-2

Table 9: Summary of Results of Average Grain Size of Samples (USCS)

Soil type	Average Grain Size, mm (ASTM)	Percentage (%)		Remark
		BS-1	**BS-2**	
Gravel		**59.70**	**64.67**	
Coarse Gravel	75 to 19	36.2	35.13	
Fine Gravel	19 to 4.75	23.5	29.53	
Sand		**34.20**	**33.90**	
Coarse Sand	4.75 to 2.0	7.73	8.80	
Medium Sand	2.0 to 0.425	20.43	19.43	
Fine Sand	0.425 to 0.075	6.03	5.67	
Clay & Silt	0.075 to 0.002	**6.10**	**1.43**	

Table 10: Summary of Results of Average Grain Size of Samples (AASHTO)

Soil type	Average Grain Size, mm (AASHTO)	Percentage (%)		Remark
		BS-1	**BS-2**	
Gravel	19 to 2.0	31.23	38.33	
Sand	2.0 to 0.075	26.47	25.10	
Clay & Silt	0.075 to 0.002	6.10	1.43	

Table 11: **Summary of Soil Classification of Samples**

Description	Expression	Values		Remark
		BS-1	**BS-2**	
Uniformity Coefficient, C_u	$C_u = D_{60}/D_{30}$	8.0	4.98	

Description	Expression	Values		Remark
		BS-1	BS-2	
Coefficient of Gradation, C_c	$C_c = D_{30}^2/(D_{60}*D_{10})$	0.84	0.93	
PI	PI = LL - PL	NP	8.15	
USCS (ASTM)		Silty Gravel (GM)	Poorly Graded Gravel with Clay and Sand (or Silty Clay and Sand) (GP- GC)	
AASHTO Classification System		A-2-4 (Silty or Clayey Gravel, and Sand)	A-2-4 (Silty or Clayey Gravel, and Sand)	AASHTO

4.3 Moisture – Density Relations (Compaction Parameters)

Table 12: OMC and MDD Results from Modified Proctor Test

Sample Code	OMC (%)	MDD (g/cm^3)	Remark
BS-1	12.80	1.93	
BS-2	14.50	1.89	

4.4 California Bearing Ratio (AASHTO T-193)

CBR penetration data were recorded for three different energy levels (10, 30 and 65 blows) per layer and the results were graphically illustrated under.

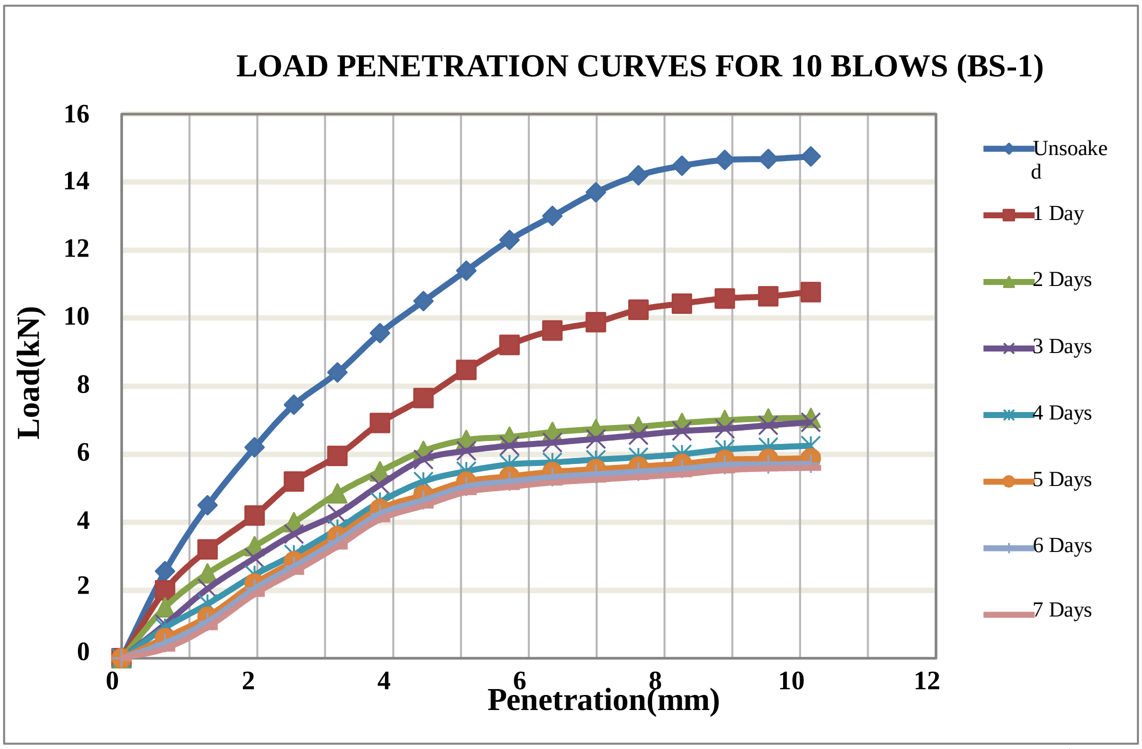

Figure 8: CBR WITH DIFFERENT SOAKING PERIODS ON BS-1 SAMPLE (10 BLOWS)

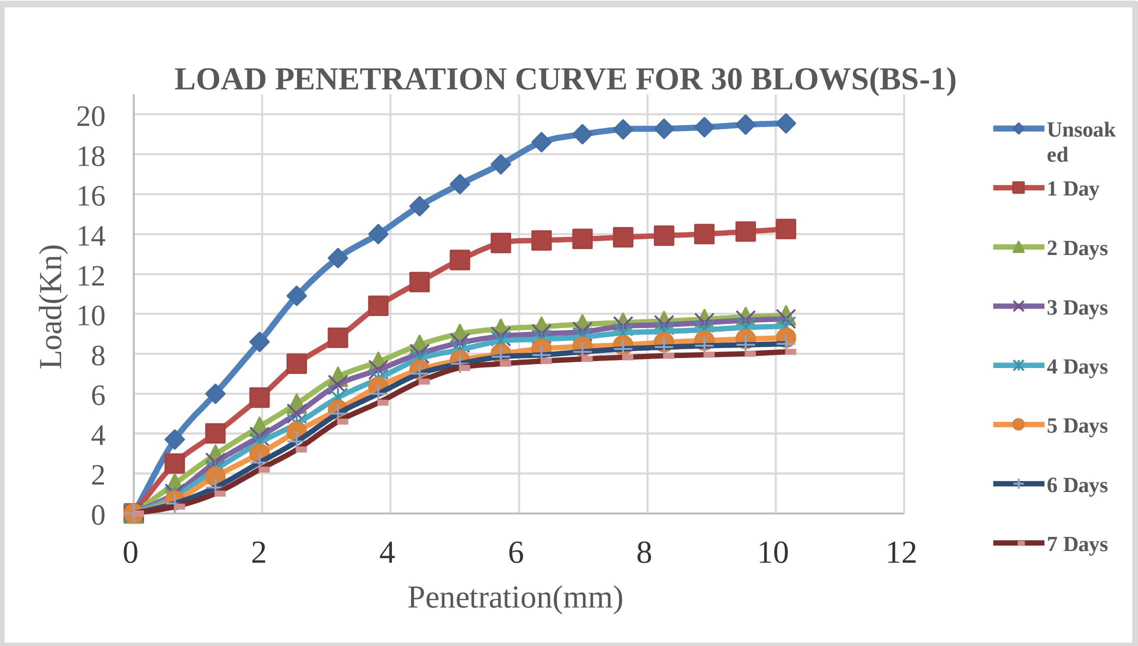

Figure -9 CBR WITH DIFFERENT SOAKING PERIODS ON BS-1 SAMPLE (30 BLOWS)

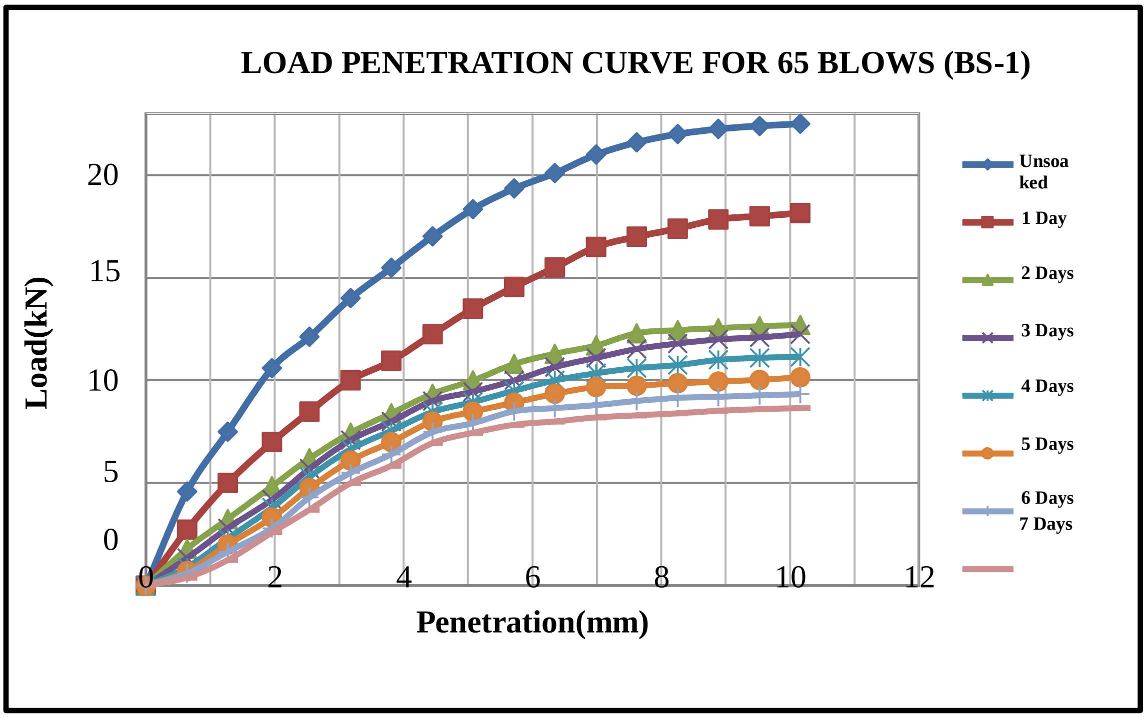

Figure-10 CBR WITH DIFFERENT SOAKING PERIODS ON BS-1 SAMPLE (65 BLOWS)

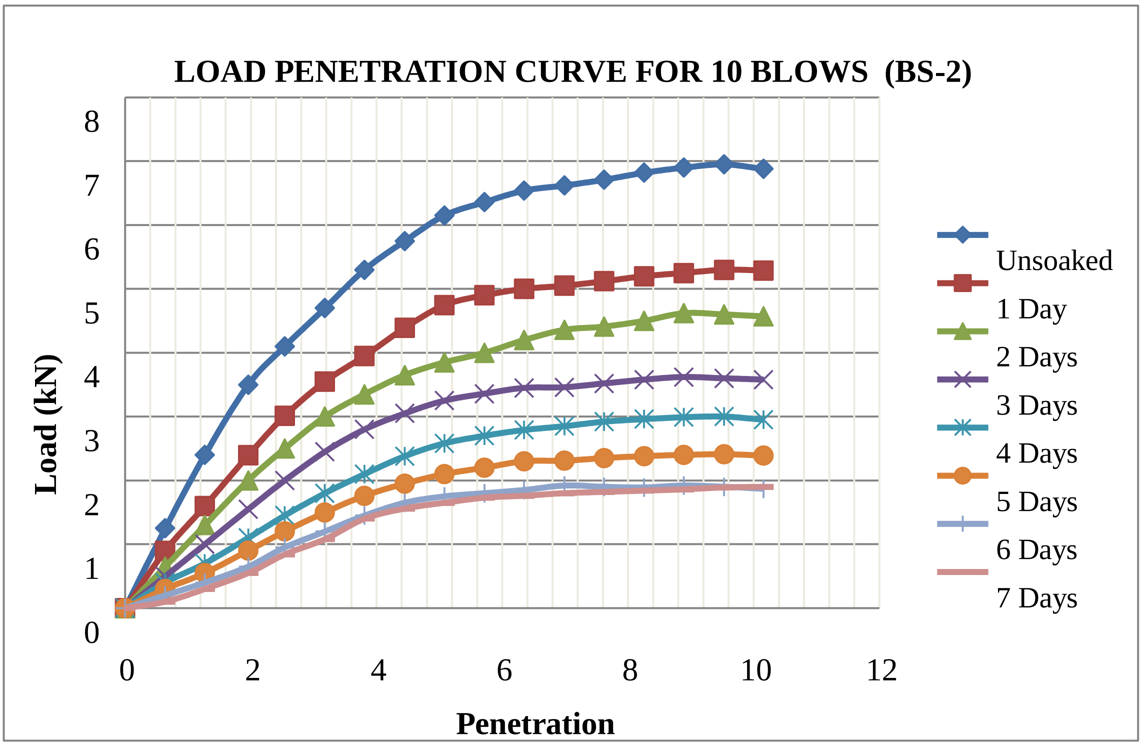

Figure-11 CBR WITH DIFFERENT SOAKING PERIODS ON BS-2 SAMPLE (10 BLOWS)

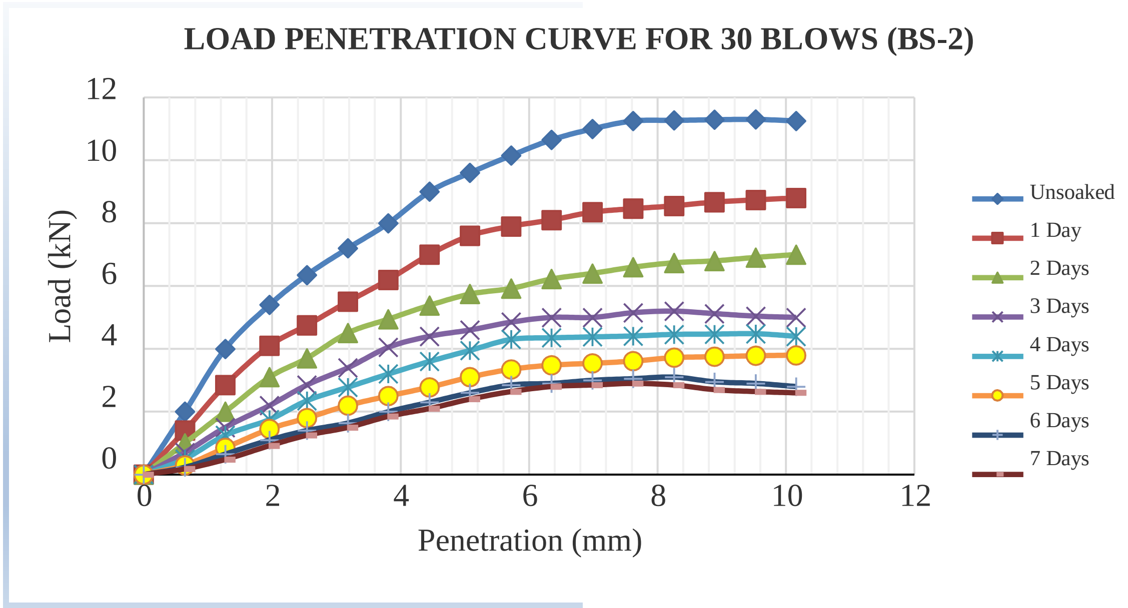

Figure-12: CBR WITH DIFFERENT SOAKING PERIODS ON BS-2 SAMPLE (30 BLOWS)

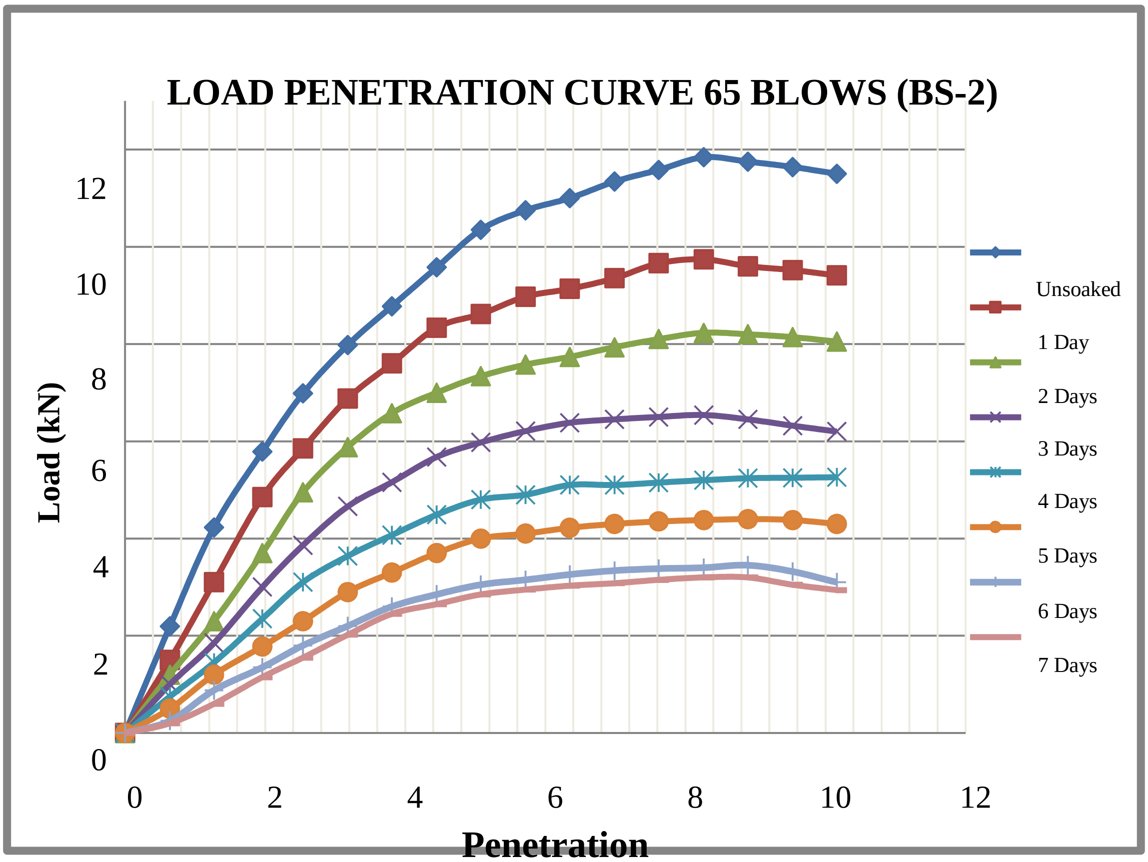

Figure-13 CBR WITH DIFFERENT SOAKING PERIODS ON BS-2 SAMPLE (65BLOWS)

4.5 Discussion and Results Interpretation

4.5.1 Analyzing the Effect of Key Geotechnical Properties on the CBR Value of Specimens

A. The Effect of Plasticity/Consistency Properties of the Specimens

The plasticity or consistency limit properties of soil (LL, PL, PI, and LS) have a significant effect on the CBR values of soil. Accordingly, based on the results obtained from the experimental studies, it was discussed for LL, PL, PI and LS (correlating with PI) as shown and illustrated hereunder.

a) Liquid Limit

From the experimental results obtained, BS-1 is non-plastic while BS-2 has LL of 44 percent. The finding based on LL satisfice the requirement for sub base use since the result agree with the ERA standard specifications (ERA standard specifications 2013). The specification stated that for natural gravel subbase materials, LL shall be less than 45 percent for seasonally wet tropical areas with annual rainfall ranges from 500 to 1000 mm. Thus, from the principles of geotechnical engineering, the higher LL indicates that BS-2 is more susceptible to strength loss upon increasing soaking period due to its relatively more plastic in nature. This also implies that as the LL of a materials increases, the CBR value of the material decreases and vice versa.

b) Plasticity Index

From the experimental results obtained, BS-1 is non-plastic while BS-2 has PI of 8.15 percent. . The finding based on PI satisfice the requirement for sub base use since the result agree with the ERA standard specifications (ERA standard specifications 2013). The specification stated that for natural gravel subbase materials, PI shall be less than 12 percent for seasonally wet tropical areas with annual rainfall ranges from 500 to 1000 mm. Based on the result the PI of BS-2 is still relatively high, indicating that it is more plastic and susceptible to strength loss upon increasing soaking period.

From the principles of geotechnical engineering, the CBR value of the material will lower for materials with higher plasticity and vice versa. PI and CBR are negatively correlated, and it means that CBR decreases while PI increases so PI can be explained the variation of CBR.

c) Linear Shrinkage

According to ERA Standard Specifications (ERA standard specifications 2013), the LS value of natural gravel subbase material for a seasonally wet tropical area shall be equal to half of (50%) of the PI value. Hence, based on the results obtained, BS-1 is zero which means it doesn’t show a volume change while BS-2 has 4% LS value. LS shall be less than 6 percent(ERA standard specifications 2013), so both BS-1 and BS-2 has satisfied the requirement. The higher LS value indicates the higher susceptibility of material to compressibility and loss in strength upon prolonged soaking period. Hence, the CBR values of both BS-1 and BS-2 decrease with increasing soaking period but the effect is more noticeable in BS-2. BS-1 is being non- plastic and exhibits better resistance to strength loss upon increasing soaking period than BS-2.

B. The Effect of Particle Size Distribution (PSD) On the CBR Value of Specimens

A well-graded PSD with coarse as well as fine particles is necessary in achieving greater stability in subbase layers. Coarse aggregates such as gravel provide the primary load-bearing capacity and shear resistance to the subbase layer. A greater percentage of coarse gravel (36.2% in BS-1 and 35.13% in BS-2) can introduce greater stability and load distribution. While Fine particles, silt and clay, fill the spaces within coarse aggregates and create a denser, more stable matrix.

The CBR is significantly influenced by the PSD of subbase materials. For the tested samples, BS-1 (Silty Gravel) and BS-2 (Poorly Graded Gravel) showed varying percentages of coarse and fine aggregates, which directly affect their load-bearing capacity. BS-1 has G: 59.7%, S: 34.2% and F: 6.1% while BS-2 has G: 64.67%, S: 33.9% and F: 1.43%. However, from the CBR values obtained indicates that BS-1 has relatively higher CBR values than BS-2. This is due to the particle size distribution of the intended material specimens. As shown in the result, BS-1 has moderately fill voids with significant volume of fines than BS-2. Therefore, regardless of the prolonged soaking period, the better gradation of materials provides the better mechanical stability of materials or CBR values accordingly.

C. The Effect of Moisture-Density Relation on the CBR Value of Specimens

The higher MDD and the corresponding OMC correlate with better load-bearing capacity. For instance, BS-1 (MDD: 1.93 g/cm^3, OMC: 12.46%) shows superior CBR values (62% unsoaked) compared to BS-2 (MDD: 1.89 g/cm^3, OMC: 14.4%, and unsoaked CBR: 46%), reflecting the influence of density on strength.

The relationship between CBR values and soil compaction depends on compaction methods and influence on density and CBR. Regardless of the compaction method used, the primary goal is to increase the soil's dry density, as higher dry density of BS-1 results corresponds to higher CBR values. Different compaction techniques can achieve varying degrees of soil densification and, consequently, different CBR values for the same soil type. The CBR value is directly proportional to the soil's dry density. As the dry density increases through compaction, the CBR value also increases. However, the relationship between CBR and dry density is not linear; it follows a logarithmic trend, where the rate of increase in CBR diminishes at higher dry densities.

In addition, the OMC is crucial for achieving maximum soil density and, consequently, the highest CBR values. Compaction at the optimal moisture content allows the soil particles to rearrange and pack more efficiently, resulting in a denser and stronger soil structure. If the moisture content is too low or too high, the compaction effort may not be as effective, leading to lower CBR value. On the other hand, the amount of compaction energy applied to the soil also influences the CBR value. The higher compaction energy, such as the use of heavier equipment or more passes, can result in higher soil densities and, consequently, higher CBR values. However, there is a limit to the improvement in CBR beyond which additional compaction energy may not yield significant benefits. Therefore, density and moisture (aka. soaking period) significantly affect the CBR value of materials.

4.5.2 The Effect of Soaking Period in the Durability and Stability of Specimens

The soaking period significantly affects the durability and stability of soil specimens, influenced by weather conditions and geological formations.

A. Durability of Specimens

a) Weather Condition

In seasonally wet tropical climates, prolonged soaking reduces shear strength and compactions, leading to decreased CBR values, as seen in the test results were soaked CBR values dropped significantly over time for both BS-1 and BS-2 samples. According to AASHTO Pavement Design Manual (1993) and ERA Pavement Design Manual (2013), the engineering properties of granular natural sub-base materials can be significantly affected by weather conditions.

i) Moisture Content

Wet weather conditions can increase the moisture content of the sub-base material, which can affect its strength, compaction, and load-bearing capacity. Increased moisture can lead to a decrease in the shear strength and CBR value of the sub-base and make it more susceptible to loading deformation. Continuous periods of dry weather condition have the tendency of decreasing the moisture content, leading to increased brittleness and decrease in the cohesive property of the material.

ii) Rainfall (Precipitation)

Heavy rain can cause the sub-base to become saturated, which will lower the bearing capacity (CBR) of the material and enhance the erosion or washout potential. The prolonged wet conditions can also lead to movement of fine particles in the sub-base, causing segregation and lowering the overall uniformity (PSD) of the material.

iii) Temperature Variations

Severe temperature fluctuations, such as an abrupt increase or decrease, can cause thermal expansion or contraction of the sub-base material, leading to crack and deformation development. This can affect the long-term performance and durability of the pavement structure.

b) Geological Formations/Genesis

The geological characteristics, such as soil type (silty gravel for BS-1 and poorly graded gravel for BS-2), affect moisture retention and stability. The plasticity index and moisture content indicate susceptibility to changes in strength with soaking, aligning with AASHTO and ASTM guidelines. Geological properties or origin of granular natural sub-base materials can significantly affect the value of CBR, which is an important parameter in the design and evaluation of pavement structures.

i) Mineralogical Composition

The mineral composition of the sub-base material, dependent to a significant extent on its geological origin, can affect its CBR value. Certain minerals such as quartz, feldspar, and calcite could result in improved CBR values due to their inherent strength and resistance to deformation. Conversely, the presence of clay minerals or soft, weak minerals can cause lower CBR values.

ii) Particle Shape and Angularity

The shape and angularity of the sub-base material are also influenced by its geological origin. Angular, cubical, and rough-textured particles yield higher CBR values due to their higher interlocking and frictional resistance. Smooth or rounded surfaced particles, frequently the result of intense weathering and erosion, may have lower CBR values

iii) Weathering and Alteration The degree of weathering and alteration of the sub-base material may affect its CBR value. Weathered or altered material may contain a higher percentage of fine particles or weaker mineral constituents, whose character is capable of generating lower CBR values. The least weathered and altered material may possess the natural strength characteristics and exhibit higher values of CBR.

B. Stability of Specimens

The CBR value of granular natural sub-base materials is influenced by various factors, including shear strength parameters, permeability, soil type, and the percentage of fines due to prolonged soaking period.

a) **Shear Strength Parameters (Cohesion and Angle of Internal Friction)**

   The shear strength parameters, i.e., cohesion (c) and internal angle of friction (ϕ), play a significant role in the CBR value of the granular sub-base materials. The higher values of ϕ and c tend to result in higher CBR values, as the material resists shear deformation better and provides adequate bearing capacity. Angular, interlocking, and well-graded particles are more likely to have greater shear strength parameters and hence greater CBR values. The extended soaking reduces shear strength, as evident from CBR tests; for example, the unsoaked CBR of BS-1 was 62%, which dropped to 55% after 7 days.

b) **Permeability**

   The permeability of the sub-base material is also an important parameter that can affect its CBR value. High-permeability materials allow for simpler draining, which reduces the potential for saturation and the resulting loss of bearing capacity and strength. Low-permeability materials are more susceptible to the harmful effects of water accumulation, leading to the reduction in the value of CBR. As a Silty Gravel (GM) soil, the BS-1 sample would have a relatively high permeability compared to fine-grained soils. High permeability allows for quicker drainage and dissipation of any excess pore water, limiting the adverse effect of soaking on the soil strength.

c) **Soil Type**

   The soil type of the sub-base material, according to its particle size distribution and plasticity characteristics, can significantly influence its CBR value. Granular materials, such as well-graded gravels and sand, have higher CBR values compared to fine-grained soils like silts and clays. The best CBR values will be given by granular materials with a balanced particle size distribution and a low plasticity index. BS-1 (Silty Gravel) and BS-2 (Poorly Graded Gravel) exhibit different behavior during soaking, BS-2 experiencing higher loss in strength

d) Percentage of Fines (Clay and Silt)

The percentage of fines (particles smaller than the No. 200 sieve or 0.075 mm) in the sub-base material can also have a large effect on its CBR value. High content of fines can result in lowering the CBR value due to the increased plasticity and volume change potential (swelling or shrinking) when subjected to water. Higher percentage of fines can also reduce permeability of the material, and water will be retained, leading to further lowering of the CBR value

The soaked CBR value of BS-1 after 3 days is 55%, compared to the initial unsoaked CBR value of 62%. This indicates a reduction of 7% in strength due to soaking for 3 days. After 7 days of soaking, the CBR value of BS-1 remains at 55%, showing no further decrease compared to the 3-days-soaked value. The 7-day soaked CBR is 11% lower than the initial unsoaked value.

The soaked CBR value of BS-2 after 7 days is 30%, compared to the initial unsoaked CBR value of 46%. This indicates a reduction of 16% in strength due to soaking. The decrease in CBR values highlights the negative impact of prolonged soaking on the strength of the material, with BS-2 showing significant sensitivity to water saturation. This behavior aligns with findings that soaking leads to a considerable drop in CBR values, especially in soils with higher plasticity, such as BS-2, which has a plasticity index of 8.15%. In comparison, the soaked CBR of BS-2 drops more sharply from an unsoaked value of 46% to 35% after 3 days and 30% after 7 days of soaking. This represents a 34% decrease for BS-2 after 7 days of soaking. The results indicate that BS-1 (Silty Gravel) exhibits better resistance to strength loss upon soaking compared to BS-2 (Poorly Graded Gravel with Clay and Sand). The lower plasticity of BS-1 likely contributes to its superior performance under soaked conditions. While both materials meet the ERA specification for subbase soaked CBR (>30%), BS-1 shows more consistent strength characteristics with minimal reduction even after prolonged soaking. This makes BS-1 more suitable for subbase construction in seasonally wet tropical climates

The CBR values provide an indication of the soil's strength and suitability for use in road construction. The CBR values at both sites show good load-bearing capacity, with higher values at BS-1. However, they also decrease over time, which is expected for a soil with some plastic behavior. According to ERA Manual 2013 it is important to ensure that the minimum soaking CBR value of 30% is achieved during construction. The CBR values at BS-1 were 61% unsoaked, 55% after 3 days,. At BS-2, the CBR values were 46% unsoaked, 30% after 6 days. BS-1 has higher CBR values compared to BS-2 for both unsoaked and soaked conditions. The unsoaked CBR for BS-1 is 61%, while for BS-2 it is 46%. After soaking for 7 days, the CBR for BS-1 remains at 55%, while for BS-2 it decreases to 30%. These results suggest that the soil from BS-1 has a higher strength and is more suitable for use in road construction compared to BS-2. The results show significant differences in the behavior of the two soil samples when subjected to varying soaking durations. BS-1 exhibits higher unsoaked CBR values compared to BS-2, with 61% and 46% respectively. However, as the soaking period increases, the CBR values for both sites decrease. For BS-1, the CBR remains at 55% even after 7 days of soaking, while for BS-2, it decreases to 30% after the same period. The decrease in CBR values with increasing soaking period is consistent with findings from previous studies. This reduction in strength is attributed to the soil absorbing more moisture, which weakens its load-bearing capacity. Other soil properties, such as Atterberg limits and gradation, also contribute to the differences in strength between BS-1 and BS-2. BS-1 has non-plastic Atterberg limits and a higher percentage of well-graded particles, which likely contributes to its higher strength compared to BS-2.

4.5.3 Results Compliance with ERA Standard Specification (2013)

- The LL for BS-2 is 44% which is within the ERA specification limit of less than 45%.
- The PI for the BS-1 and BS-2 are NP and 8.15% respectively, which is within the ERA specification limit of less than 12% for natural gravel material (Grade A).
- The LS for BS-2 is 4%, which is within the ERA specification limit of less than 6% for natural gravel material (Grade A).
- The Soaked CBR value for both the BS-1 and BS-2 borrow sites exceeds the ERA specification limit of greater than 30% for natural gravel material (Grade A).
- The Grading Modulus (GM) for both BS-1 and BS-2 borrow sites exceeds the ERA specification limit of greater than or equal to 1.2 for natural gravel material (Grade A).
- A-2-4 soil groups are generally considered suitable for use as subbase material in pavement structures. They provide a stable and well-draining foundation for the upper layers of the pavement (AASHTO M 147, 2017).

CHAPTER FIVE:
CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis of the laboratory test results and the discussion made on the effects of soaking period on the two soil samples (BS-1 and BS-2), the following conclusions and recommendations can be plotted.

5.1 Conclusion

- The differences in the CBR values of the BS-2 and BS-1 specimens as shown can be attributed to the prolonged soaking time. The BS-2 specimen shows a significant decline in the CBR values from the unsoaked condition (46%) to the 4- days-soaked condition (32%), and again from the 4-day to the 7-day (30%) soaked condition. This indicates that the longer soaking period bears more influence on the load-carrying capacity of the BS-2 specimen. The BS-1 specimen, on the other hand, possesses a relatively smaller decrease in the CBR values from the unsoaked condition (61%) to the 4-days-soaked condition (55%), and the values remained uniform in between the 4-day and 7-day soaked (55%) conditions. This means that the BS-1 sample is more resistant to the effect of the longer soaking duration compared to the BS-2 sample. The variations in the variation of the CBR value can be attributed to the variations in the material properties and composition of the two soil samples, BS-2 and BS-1. The effect of soil type, gradation, compaction characteristics, and presence of fines was responsible for the behavior of the soil to the longer duration of soaking. The higher decrease in the CBR values of the specimen BS-2 indicates that it is more susceptible to the adverse effects of longer soaking, such as strength loss and bearing capacity loss. Such data can prove vital in structural design and construction engineering, as it facilitates an understanding of how the soil's behavior changes with varying environmental conditions in the long term.
- BS-1 and BS-2 meet the ERA subbase soaked CBR specification (>30%), but BS-1 (Silty Gravel) is more suitable for construction as a subbase under seasonally wet tropical conditions due to its lower plasticity, enhanced soaking-induced strength loss resistance, and better particle size distribution and moisture-density.
- Soil type, particle size & shape, moisture content, compaction, density, plasticity, percentage of fines, permeability, weather conditions and geological characteristics are set to be the major factors having very adverse effect on the strength (CBR) values with longer soaking time for natural gravel subbase materials.

- 96-hour soaking would be most in keeping for cohesive soils; its relatively narrow application for coarser cohesionless soils is not clear.

5.2 Recommendations

- The study shows that establishing the relevant soaking periods for distinct soil groups or types, based on their specific engineering applications and requirements plays a crucial role. This granular understanding will help optimize design considerations and construction practices for future projects. Comprehensive investigations, encompassing extensive soil sampling, rigorous trials, and in-depth engineering tests, shall be conducted across diverse soil types, climatic conditions, and topographies.
- Further evaluation stabilization, or modification of the soil may be necessary to improve its moisture resistance and maintain acceptable CBR values for subbase applications.
- Further Investigations, considering the performance differences between the soil types based on their plasticity, a comprehensive site-specific evaluation is advised to determine the most suitable borrow material for the specific construction project requirements.

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APPENDICES

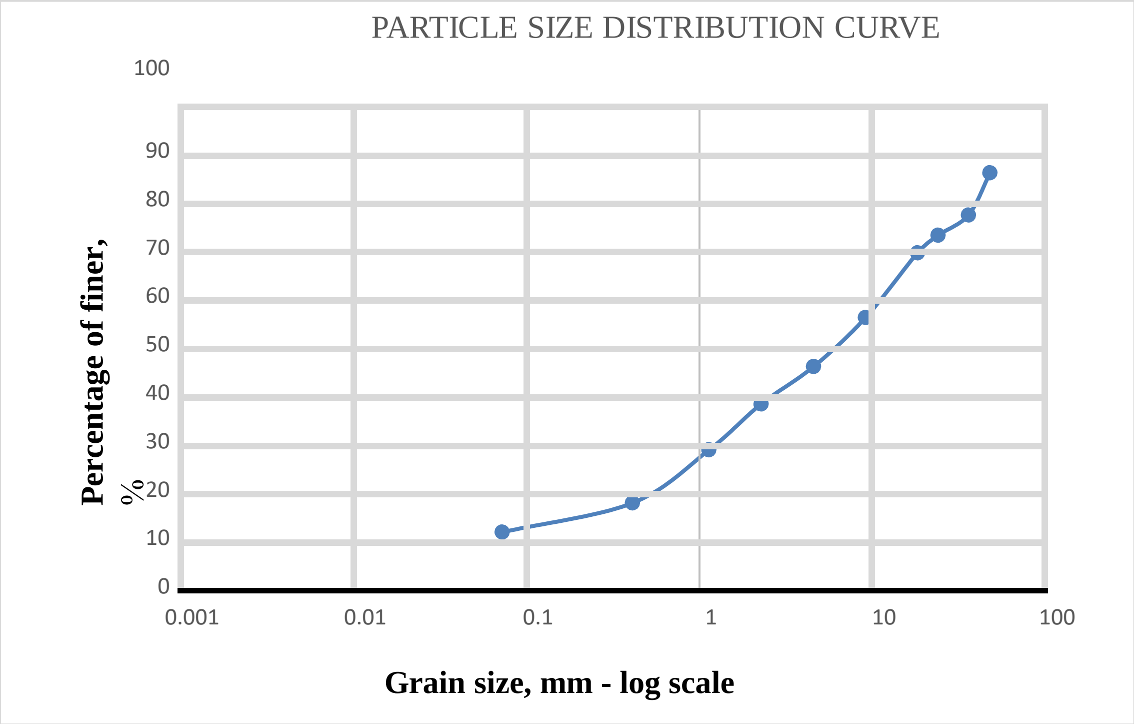
Appendix-A: Tests

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS Test Method: AASHTO - T 265					
Sampling Station	**0+320**	**Purpose**	**NMC**		
Sample No.	**BS-1**				
Date Tested	**04/03/2025**	**Date Sample**	**03/03/2025**		
Test No.			**1**	**2**	**Remark**
Container No.			T3	CA_5	
Mass of container + moist soil (W_1)		gm.	147.00	153.00	
Mass of container + oven dried soil (W_2)		gm.	135.00	140.00	
Mass of container (W_c)		gm.	21.00	20.00	
Moisture content (w) = $[(W_1 - W_2)/ (W_2 - W_c)] \times 100$ %		%	10.53	10.83	
Average Moisture Content (w %)		**%**	**10.68**		

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS						
Test Method: AASHTO - T 265						
Sampling Station	9+240	Purpose	NMC			
Sample No.	BS-2					
Date Tested	04/03/2025	Date Sample	03/03/2025			
Test No.				1	2	Remark
Container No.				A51	CA_5	
Mass of container + moist soil (W_1)			gm.	151.00	153.00	
Mass of container + oven dried soil (W_2)			gm.	141.00	141.70	
Mass of container (W_c)			gm.	21.00	20.00	
Moisture content (w) = $[(W_1 - W_2)/ (W_2 - W_c)] \times 100$ %			%	8.33	9.29	
Average Moisture Content (w %)			%	8.81		

SIEVE ANALYSIS (BS-1)

Sieve no.	Sieve size (mm)	Weight of sieve (gm)	Weight of sieve with soil retained (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative mass retained (gm)	Percentage of cumulative mass retained (%)	Percentage passing (%)	Remark
	50	**1983**	**2573**	**590.0**	**19.7**	**590.0**	**19.67**	**80.33**	
	37.5	**1452**	**1713**	**261.0**	**8.7**	**851.0**	**28.37**	**71.63**	
	25	**757**	**883**	**126.0**	**4.2**	**977.0**	**32.57**	**67.43**	
3/4'	**19**	**728.0**	**837.0**	**109.0**	**3.6**	**1086.0**	**36.20**	**63.80**	
3/8'	**9.5**	**607.0**	**1008.0**	**401.0**	**13.4**	**1487.0**	**49.57**	**50.43**	
4	**4.75**	**411.0**	**715.0**	**304.0**	**10.1**	**1791.0**	**59.70**	**40.30**	
10	**2.36**	**498.0**	**730.0**	**232.0**	**7.7**	**2023.0**	**67.43**	**32.57**	
16	**1.18**	**400.0**	**684.0**	**284.0**	**9.5**	**2307.0**	**76.90**	**23.10**	
40	**0.425**	**397.0**	**726.0**	**329.0**	**11.0**	**2636.0**	**87.87**	**12.13**	
200	**0.075**	**358.0**	**539.0**	**181.0**	**6.0**	**2817.0**	**93.90**	**6.10**	
Pan	**0**	**360.0**	**543.0**	**183.0**	**6.1**	**3000.0**	**100.00**	**-**	
Total				**3000.0**	**100.0**				



Soil type	Average grain size, mm (ASTM)	Percentage (%)	Remark
Gravel		**59.70**	
Coarse Gravel	75.0 to 19.0	36.20	
Fine Gravel	19.0 to 4.75	23.50	
Sand		**34.20**	
Coarse Sand	4.75 to 2.0	7.73	
Medium Sand	2.0 to 0.425	20.43	
Fine Sand	0.425 to 0.075	6.03	
Silt	0.075 to 0.002	6.10	
Clay	<0.002	0.00	

Soil type	Average grain size, mm (AASHTO)	Percentage (%)	Remark
Gravel	19 to 2.0	31.23	
Sand	2.0 to 0.075	26.47	
Silt	0.075 to 0.002	6.10	
Clay	<0.002	0.00	

From the particle-size distribution curve shown in Figure 5

D_{60} = Diameter corresponding to 60% finer, mm	16.52
D_{30} = Diameter corresponding to 30% finer, mm	2.04
D_{10} = Diameter corresponding to 10% finer, mm	0.30
Uniformity coefficient, $C_u = D_{60}/D_{30}$	8.10
Coefficient of gradation, $C_c = [D_{30}^2/(D_{60}*D_{10})]$	0.84

SOIL CLASSIFICATION

CASE -I: UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) - ASTM: D 2487
Reference: **Das; "Principles of Geotechnical Engineering", 9th Edition; p 133 - 141)**

Classification Criteria Description	**Value**	**Major Category**	**Group Name**	**Group Symbol**	**Remark**
STEP - 1: Identifying major category and group symbol (Das, Table 5.1)					
Percentage retained at No. 200 sieve	93.90				
Percentage passing through No. 200 sieve	6.10				
STEP - 2: Identifying a specific group symbol (Das, Table 5.1)					
Percentage retained above No. 4 sieve	59.70				
Percentage passing through No. 4 sieve	40.30				
STEP - 3: Identifying a specific group symbol (Das, Table 5.1)					
PI	NP				
Uniformity coefficient, C_u	8.10				
Coefficient of gradation, C_c	0.84				

Hence, the soil can be classified as **Non - Plastic Silty Gravel (GM)**

CASE - II: AASHTO CLASSIFICATION SYSTEM
Reference: Das; "Principles of Geotechnical Engineering", 9th Edition; p 133-141

Classification Criteria Description	**Value**	**General Classification**	**Group Classification**	**Group Symbol**	**Remark**
STEP - 1: Identifying major category and group symbol (Das, Table 5.2)					

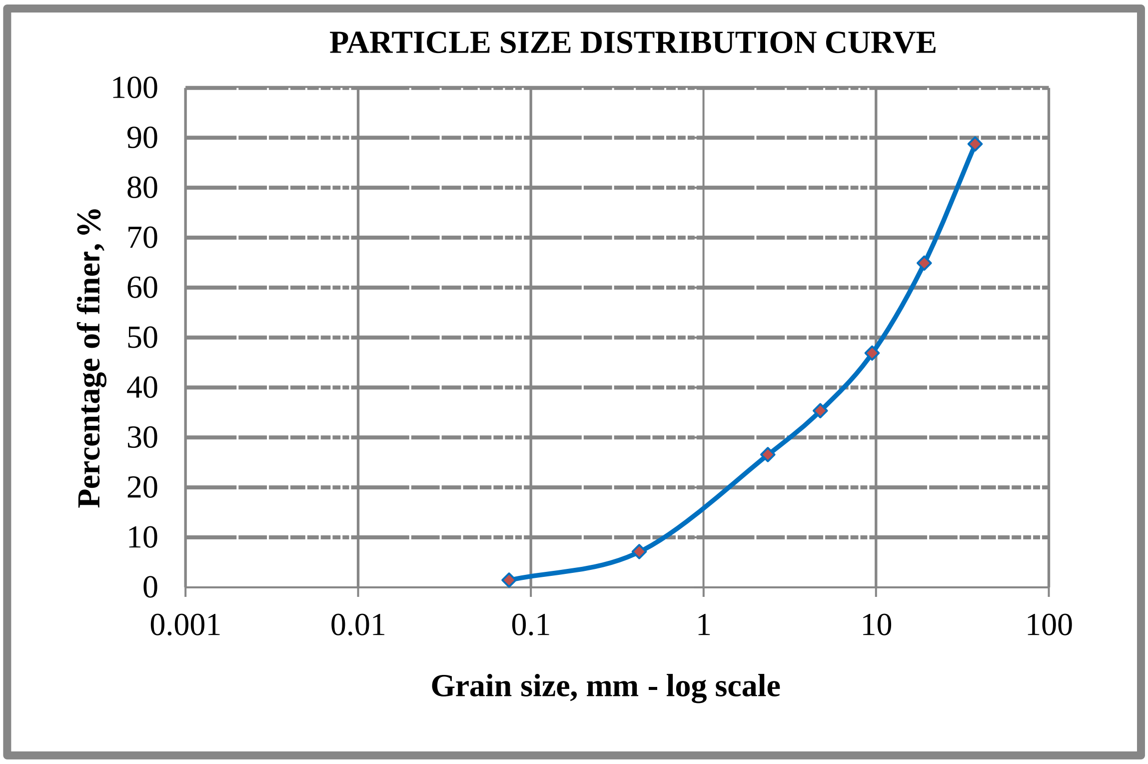
SOIL CLASSIFICATION

CASE -I: UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) - ASTM: D 2487
Reference: **Das; "Principles of Geotechnical Engineering", 9th Edition; p 133 - 141)**

Classification Criteria Description	**Value**	**Major Category**	**Group Name**	**Group Symbol**	**Remark**
Percentage of sample passing No. 200 sieve	6.10	Granular materials	Gravel or Sand	A–1, A–2, or A–3	< 35% passed No. 200
STEP - 2: Characteristics grain size & plasticity (Das, Table 5.2)					
Plasticity Index, PI	NP				
Percentage passing No. 10 sieve	32.57				
Percentage passing No. 40 sieve	12.13				
Percentage passing No. 200 sieve	6.10				
STEP - 3: Identifying Specific Soil Group (Das, Table 5.2)					
Plasticity Index, PI	NP				
Percentage passing No. 10 sieve	32.57				
Percentage passing No. 40 sieve	12.13				
Percentage passing No. 200 sieve	6.10				
STEP - 4: Identifying Specific Soil Group (Das, Table 5.2)					
Plasticity Index, PI	NP				
Percentage passing No. 10 sieve	32.57				
Percentage passing No. 40 sieve	12.13				
Percentage passing No. 200 sieve	6.10				
Hence, the soil can be classified as Non - Plastic Silty Gravel (A-2-4)					

SIEVE ANALYSIS (BS-2)

Sieve no.	Sieve size (mm)	Weight of sieve (gm)	Weight of sieve with soil retained (gm)	Mass of retained soil (gm)	% Retained	Cumulative mass retained (gm)	Cumulative mass retained (%)	% Passing	% Passing from ERA Specification 2013		Remark
									Max (%)	**Min (%)**	
	63	**910**	**910**	**-**	**-**	**-**	**-**	**100.00**	**100**		
	37.5	**1450**	**1788**	**338**	**11.3**	**338.0**	**11.27**	**88.73**	**100**	**70**	
3/4'	**20**	**728**	**1444**	**716**	**23.9**	**1054.0**	**35.13**	**64.87**	**100**	**50**	
4	**4.75**	**411**	**1297**	**886**	**29.5**	**1940.0**	**64.67**	**35.33**	**100**	**30**	
	1	**414**	**867**	**453**	**15.1**	**2393.0**	**79.77**	**20.23**	**75**	**17**	
40	**0.425**	**379**	**773**	**394**	**13.1**	**2787.0**	**92.90**	**7.10**	**56**	**11**	
200	**0.075**	**357**	**527**	**170**	**5.7**	**2957.0**	**98.57**	**1.43**	**25**	**5**	
Pan	**0**	**355**	**398**	**43**	**1.4**	**3000.0**	**100.00**	**-**			
Total				**3000.0**	**100.0**						



Soil type	Average grain size, mm (ASTM)	Percentage (%)	Remark
Gravel		64.67	
Coarse Gravel	75.0 to 19.0	35.13	
Fine Gravel	19.0 to 4.75	23.50	
Sand		33.90	
Coarse Sand	4.75 to 2.0	8.80	
Medium Sand	2.0 to 0.425	19.43	
Fine Sand	0.425 to 0.075	5.67	
Silt	0.075 to 0.002	1.43	
Clay	<0.002	0.00	
Soil type	Average grain size, mm (AASHTO)	Percentage (%)	Remark
Gravel	19 to 2.0	38.33	

Soil type	Average grain size, mm (ASTM)	Percentage (%)	Remark
Sand	2.0 to 0.075	25.10	
Silt	0.075 to 0.002	1.43	
Clay	<0.002	0.00	

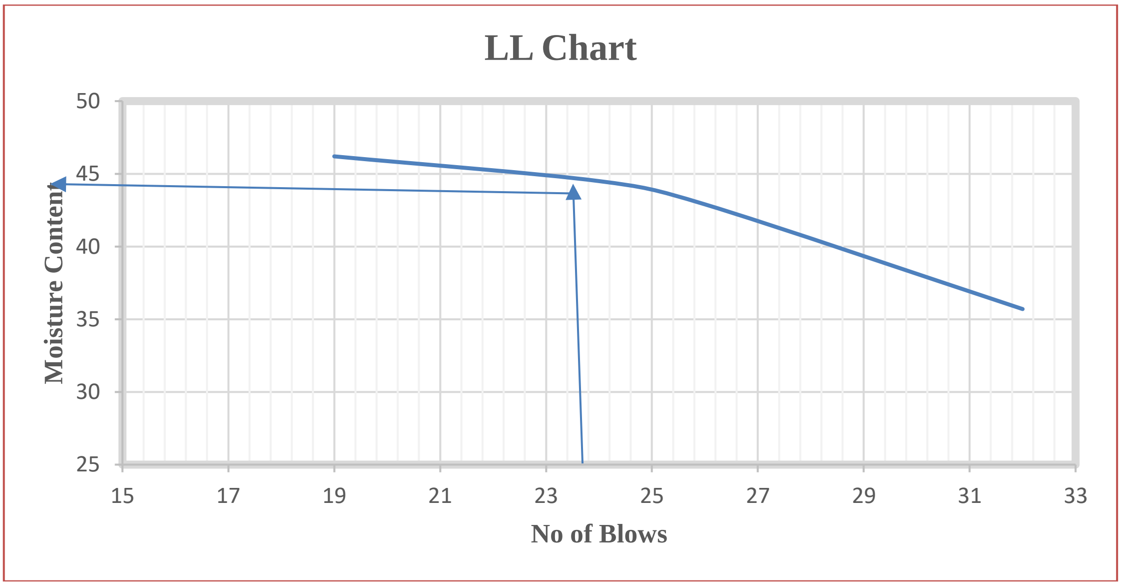
From the particle-size distribution curve shown in Figure 6	
D_{60} = Diameter corresponding to 60% finer, mm	16.42
D_{30} = Diameter corresponding to 30% finer, mm	3.30
D_{10} = Diameter corresponding to 10% finer, mm	0.71
Uniformity coefficient, $C_u = D_{60}/D_{30}$	4.98
Coefficient of gradation, $C_c = [D_{30}^2/(D_{60}*D_{10})]$	0.93

SOIL CLASSIFICATION					
CASE -I: UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) - ASTM: D 2487					
Classification Criteria Description	% Value	Major Category	Group Name	Group Symbol	Remark
STEP - 1: Identifying major category and group symbol (Das, Table 4.2)					
Percentage retained at No. 200 sieve	98.57				
Percentage passing through No. 200 sieve	1.43				
STEP - 2: Identifying a specific group symbol (Das, Table 4.2)					
Percentage retained above No. 4 sieve	64.67				
Percentage passing through No. 4 sieve	35.33				
STEP - 3: Identifying a specific group symbol (Das, Table 4.2)					
PI	8.15				
Uniformity coefficient, C_u	4.98				
Coefficient of					

gradation, C_c	0.93				
Hence, the soil can be classified as Poorly graded gravel with clay and sand (or silty clay and sand) (GP-GC)					
CASE - II: AASHTO CLASSIFICATION SYSTEM					
Classification Criteria Description	**% Value**	**General Classification**	**Group Classification**	**Group Symbol**	**Remark**
STEP - 1: Identifying major category and group symbol (Das, Table 4.1)					
Percentage of sample passing No. 200 sieve	1.43	Granular materials	Gravel or Sand	A–1, A–2, or A–3	< 35% passed No. 200
STEP - 2: Characteristics grain size & plasticity (Das, Table 4.1)					
Plasticity Index, PI	8.15				
Percentage passing No.10 sieve	26.53				
Percentage passing No.40 sieve	7.10				
Percentage passing No.200 sieve	1.43				
STEP - 3: Identifying Specific Soil Group (Das, Table 4.1)					
Plasticity Index, PI	8.15				
Percentage passing No.10 sieve	26.53				
Percentage passing No.40 sieve	7.10				
Percentage passing No.200 sieve	1.43				
STEP - 4: Identifying Specific Soil Group (Das, Table 4.1)					
Plasticity Index, PI	8.15				
Percentage passing No.10 sieve	26.53				
Percentage passing No.40 sieve	7.10				
Percentage passing No.200 sieve	1.43				
Hence, the soil can be classified as A-2-4					

Atterberg Limits

Atterberg Limits ASTM D4318-10									
TEST			PLASTIC LIMIT			LIQUID LIMIT			
	NO								
	Var.	Units							
Number of Blows	N	blows				32	26	24	19
Can Number	---	---	23	3	A14	34	7	17	DV
Mass of Empty Can	MC	(g)	15	14	15	16	14	15	16
Mass Can & Soil (Wet)	MCMS	(g)	21	22	22	35	34	34	35
Mass Can & Soil (Dry)	MCDS	(g)	19.4	19.9	20.2	30	28	28.15	29
Mass of Soil	MS	(g)	4.4	5.9	5.2	14	14	13.15	13
Mass of Water	MW	(g)	1.6	2.1	1.8	5	6	5.85	6
Water Content	*w*	(%)	36.4	35.6	34.6	35.7	42.9	44.5	46.2



Liquid Limit (LL) (%):	43.67
Plastic Limit (PL) (%):	35.52
Plasticity Index (PI) (%):	8.15

Compaction test results BS 1

Blows per layer	56	No. of layers	5	Rammer weight (Kg)	4.5
Mold diameter (mm)	152	Volume of mold (cm^3)	2123	Mold height	117

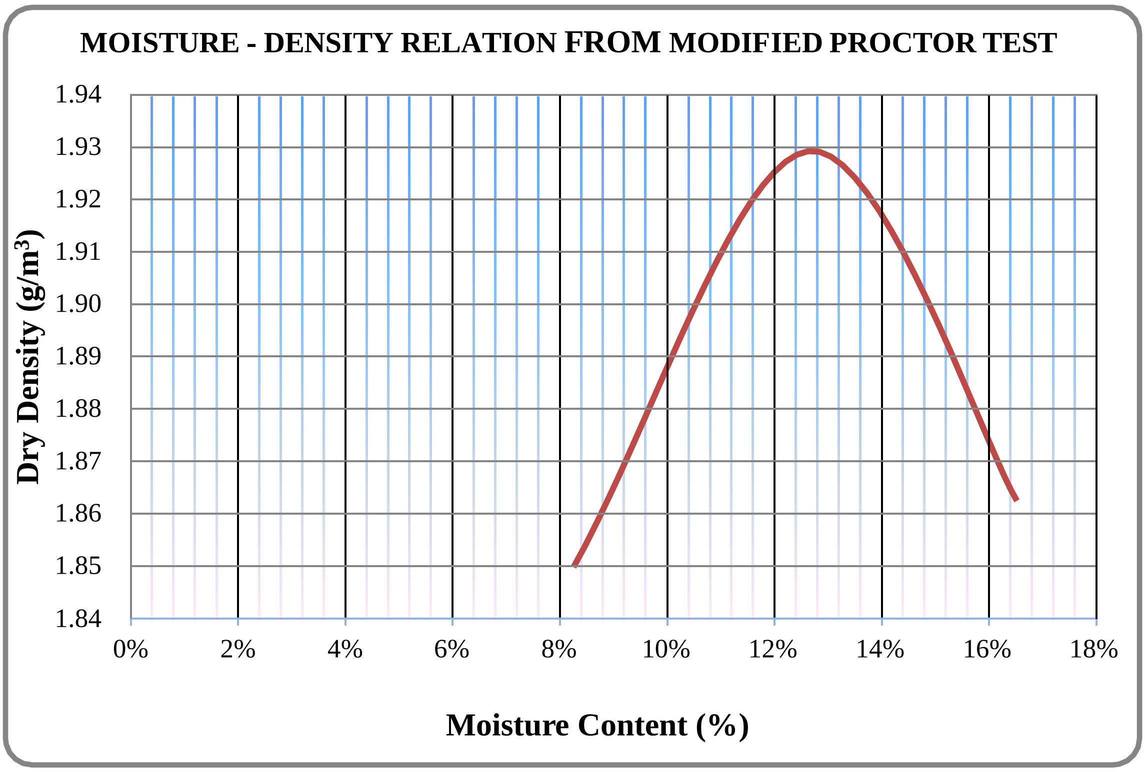
Trial number		1	2	3	
Mass of moist soil + Mass of mold, A	gm.	9,451.00	9,813.00	9,807.00	
Mass of mold, B	gm.	5,199.00	5,199.00	5,199.00	
Mass of moist soil, C = [A-B]	gm.	4,252.00	4,614.00	4,608.00	
Density of moist soil, D = C/m$_{old}$	gm./cm^3	2.00	2.17	2.17	
Moisture can no.		T7	Z22	VI	T3
Mass of moist soil + Mass of can, E	gm.	137.00	125.00	151.00	147
Mass of dry soil + Mass of can, F	gm.	128.00	113.00	132.00	135
Mass of can, G	gm.	19.00	18.00	17.00	21
Mass of water, H = E - F	gm.	9.00	12.00	19.00	12.00
Mass of dry soil, I = F- G	gm.	109.00	95.00	115.00	114.00
Moisture content, J = (H/I) *100%	(%)	8.26	12.63	16.52	10.53
Dry density, K = D/(1+J)	gm./cm^3	1.85	1.93	1.86	-

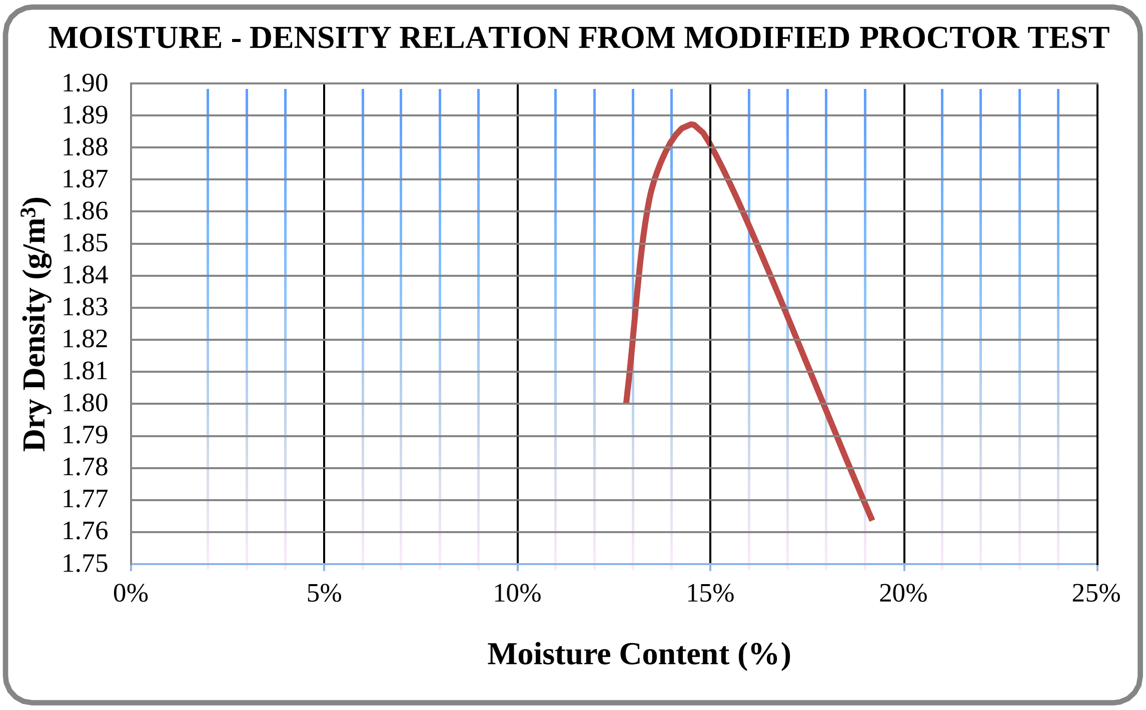
Compaction test results BS 2

Blows per layer	56	No. of layers	5	Rammer weight (Kg)	4.5
Mold diameter (mm)	152	Volume of mold (cm^3)	2123	Mold height	117

Trial number		1	2	3	4	Remark
Mass of moist soil + Mass of mold, A	gm.	9,530.00	9,721.00	9,812.50	9,681.00	
Mass of mold, B	gm.	5,215.00	5,215.00	5,215.00	5,215.00	
Mass of moist soil, C = [A-B]	gm.	4,316.00	4,507.00	4,598.00	4,467.00	

Density of moist soil, D = C/M_{old}	gm./cm^3	2.03	2.12	2.17	2.10	
Moisture can no.		G8	D5	B4	HW4	
Mass of moist soil + Mass of can, E	gm.	153.00	147.00	145.00	140.00	
Mass of dry soil + Mass of can, F	gm.	138.00	132.00	129.00	121.00	
Mass of can, G	gm.	21.00	21.00	21.00	22.00	
Mass of water, H = E - F	gm.	15.00	15.00	16.00	19.00	
Mass of dry soil, I = F- G	gm.	117.00	111.00	108.00	99.00	
Moisture content, J = (H/I) *100%	(%)	12.82%	13.51%	14.81%	19.19%	
Dry density, K = D/(1+J)	gm./cm^3	1.80	1.87	1.89	1.77	-


MOISTURE - DENSITY RELATION FROM MODIFIED PROCTOR TEST
Dry Density (g/m3)
1.94
1.93
1.92
1.91
1.90
1.89
1.88
1.87
1.86
1.85
1.84
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
Moisture Content (%)


MOISTURE - DENSITY RELATION FROM MODIFIED PROCTOR TEST
Dry Density (g/m3)
1.90
1.89
1.88
1.87
1.86
1.85
1.84
1.83
1.82
1.81
1.80
1.79
1.78
1.77
1.76
1.75
0%
5%
10%
15%
20%
25%
Moisture Content (%)

CBR Results Summary for BS-1

No of blows	10			30			65			OMC	MDD	95% of MDD	CBR Value at 95% of MDD
Duration	Moisture content	Dry density	CBR	Moisture content	Dry density	CBR	Moisture content	Dry density	CBR				
Unsoaked	8.33	1.77	41.43	9.07	1.82	59.52	8.42	1.90	79.86				61
1 day	10.95	1.72	41.72	9.07	1.84	59.20	9.26	1.94	70.79				58
2 days	12.38	1.66	40.67	10.79	1.91	58.44	10.29	2.12	64.02				55
3 days	11.50	1.77	38.41	11.58	1.83	55.73	11.68	1.95	61.76				55
4 days	13.80	1.61	31.11	12.16	1.82	53.47	11.44	1.90	60.25				55
5 days	15.83	1.69	30.13	13.13	1.76	48.20	12.11	1.88	59.50				55
6 days	16.81	1.68	28.62	13.05	1.76	47.45	12.19	1.88	58.74				55
7 days	17.18	1.66	25.61	16.72	1.71	33.89	15.22	1.84	55.73				55

CBR Results Summary for BS-2

No of blows	**10**			**30**			**65**			**OMC**	**MDD**	**95% of MDD**	**CBR Value at 95% of MDD**
Duration	**Moisture content**	**Dry density**	**CBR**	**Moisture content**	**Dry density**	**CBR**	**Moisture content**	**Dry density**	**CBR**				
Unsoaked	8.91	1.48	33.15	8.03	1.63	43.85	5.99	1.81	46.41				46
1 day	9.57	1.62	30.13	8.96	1.84	43.83	8.39	2.15	45.94				42
2 days	9.55	1.76	35.40	9.27	1.84	40.67	8.51	1.98	46.39				38
3 days	10.15	1.74	30.13	9.81	1.84	39.16	9.50	2.02	45.94				35
4 days	14.65	1.66	24.10	13.34	1.84	34.19	13.62	1.94	40.67				32
5 days	14.45	1.58	24.10	13.68	1.78	29.37	13.85	1.84	34.04				31
6 days	14.09	1.59	22.59	13.57	1.75	26.66	12.08	1.81	31.33				30
7 days	14.26	1.57	21.09	13.69	1.67	27.87	12.59	1.86	30.88				30

Appendix – B: Soil Sampling and Testing Activities Photographs


DECO


CBR Machine