JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Engineering Properties of Expansive Soil Stabilized with Barley Husk Ash and Lime for Subgrade Soil Formation (A Case Study in Jimma Town).

A Final Thesis Submitted To the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for Master of Science in Civil Engineering (Highway Engineering)

By

Alemu Balcha

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Alemu Balcha

Main Advisor: Anteneh Geremew (Assi. Prof.)

Co-Advisor: Mohammed Hassen (MSc)

March, 2024

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that this final thesis entitled: "Engineering Properties of Expansive Soil Stabilized with Barley Husk Ash and Lime for Subgrade Soil Formation (A Case Study in Jimma Town)." is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have been duly acknowledged.

Mr. Alemu Balcha	_______________	____________
Name	Signature	Date

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Finally, I would like to express my gratitude to all participants of my study. Their experience and patience had valuable contributions to the success of my study.

ABSTRACT

In road construction, expansive soils are the most common problem encountered in the world, as well as in Ethiopia. To overcome these problems, the expansive soil needs to be stabilized by using different techniques and materials or removed and replaced by better materials for subgrade formation. Cement and lime are common materials used for the stabilization of weak soil for subgrade formation. Nowadays, in addition to common stabilizing materials, locally available materials are also used for soil stabilization. Barley is highly produced in Ethiopia, especially in the Oromia region in the Arsi and Bale zones. The beverage industries are growing fast and consume barley for the production of different alcohol and non-alcohol drinks. Hence barley husk ash from Assela Malt Factory was studied and used for the stabilization of expansive soils for subgrade soil formation with lime. The sampling and test methods used in this research are according to ASTM and AASHTO test methods. The results were analyzed according to the guidelines of the ERA pavement design manual. In this study, the expansive soil was sampled from three different locations of Jimma Town and tested with 0%, 10%, 15%, and 20% of lime to obtain an optimum percentage of lime. The optimum amount of lime used was 10% and the PI, LL, PL, SG, OMC, MDD, CBR, Free swell and UCS values obtained at optimum lime content are; 22%, 52%, 30%, 2.59, 22.8%, 1.423g/cm^3, 9.72%, 42%, and 137kpa respectively. The microstructure of the soil treated with 10% lime had less void showing denser compared to untreated soil. A varying amount of BHA was added to check its effect on the results obtained using optimum lime content. The optimum amount of BHA used with lime is also obtained at 10%. Hence lime and BHA used for this study percentage by weight are 10% lime and 10% BHA. Test result values obtained at 10% lime and 10% BHA for PI, LL, PL, SG, OMC, MDD, CBR, Free swell, and UCS values are; 18%, 49%, 31%, 2.25, 27.2%, 1.315g/cm^3, 18.42%, 33%, and 101kpa respectively. The microstructure of the soil shows that the particles are closely spaced which is the indication for the tendency of blended materials to form a better material. BHA improved most of the engineering properties of the soil and satisfies ERA pavement design manual requirement hence, it can be used as a partial replacement with lime for subgrade soil stabilization.

Keywords: Expansive Soil, Stabilization, Barley Husk Ash, Standard specification, Percentage by weight.

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List of Acronyms

AASHTO	American Association of State Highway and Transport Official
ASTM	American Society for Testing and Materials
BHA	Barley Husk Ash
BS	British Standard
CBR	California Bearing Ratio
CTGA	Common Thatching Grass Ash
ES	Expansive Soil
ERA	Ethiopian Roads Authority
FSI	Free Swell Index
LCF	Lime-Cement-Fly Ash
LL	Liquid Limit
MDD	Maximum Dry Density
MT	Million Tone
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
PGSS	Powdered Ground Steel Slag
RHA	Rice Husk Ash
SEM	Scanning Electron Microscope
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System

CHAPTER ONE

INTRODUCTION

1.1 Background

Subgrade is the term for the material that is in place and on top of which the pavement structure is built. When studying pavement performance, there is a tendency to focus primarily on pavement structures and mix design; nevertheless, subgrade soils are often the most important factor. Utilizing inexpensive, locally accessible materials to build the bottom layers of pavement, such as subbase and subgrade, will significantly reduce the overall cost of pavement construction. If the local soil's stability is insufficient to support the loads, appropriate techniques for improving the soil's qualities must be used. Among these is soil stabilization. Typical stabilizing elements are lime and cement. Nowadays, in addition to cement and lime, locally available materials are also used in soil stabilization. Soil stabilization can be done with many materials, out of which locally available materials can be used with cement and lime [1].

Resource depletion and waste production are major concerns on a global level. To attain environmental sustainability, road networks and transportation are necessary. Any economy is built on its transportation infrastructure, which is why developing nations like Ethiopia depend heavily on it. Finding a useful method to attain financial effectiveness for sustainable transportation infrastructure has thus far involved using waste materials to enhance the strength and performance of road pavements. Flexible pavements collapse earlier than expected due to common problems that highway engineers have recently seen, like rutting, raveling, stripping, and cracking. The highway's subgrade layer primarily determines its strength and operating life [2].

The goal of soil stabilization is to improve the engineering properties of soils by chemically modifying the soil and boosting or preserving its stability. Expansive clays and granular materials are just two examples of the many sub-grade materials that can be treated with stabilization. Increased resistance values, less permeability, less plasticity, thinner pavement, and no need to transport or handle excavation material are some advantages of the stabilizing process. Expansive soils can be stabilized with admixtures to increase their strength and reduce their potential for volume changes [3].

The proportion of moisture content in expansive soil affects its tendency to swell and shrink. As a result, the expansive soil experiences volumetric variations as a result of fluctuating water content. The expansive soil's finer particles are what contribute to its capacity to hold water. The seasonal change affects the expansive soil's moisture content. The expansive soil's properties of swelling and shrinkage generate differential settlement, which severely damages the foundations of buildings, roadways, retaining walls, canal linings, and other structures. It is common practice to stabilize these soils to increase their strength [4].

Certain measures must be taken during construction to minimize the damage caused by expansive soil. Expansive soil can be stabilized using a variety of techniques, including soil replacement, chemical modification, humidity management, and special foundation systems [5]. The main problem with expansive soil is that it changes a lot in volume as the amount of moisture in the soil varies. When lightweight constructions, highways, and other civil structures are built directly on this kind of problematic soil, the volume change can cause cracks and other damage. Because they are quite lightweight, pavements are also very prone to deterioration. In geotechnical engineering, the chemical stabilization of clay soil with fly ash, cement, or lime has been used to improve the soil's mechanical properties and workability [6].

Because of its flexible and cohesive properties when wet, clay is one type of soil that frequently undergoes volume changes. The soil swells and shrinks quickly which results in volume changing because of the water content variation. To reduce this effect and raise bearing capacity, stabilization plays a great role. Soil stabilization is the process of combining soil with lime and water on the construction site to change the qualities of the soil and make it a better building material as specified in the planning. Lime changes the properties of the soil and reduces its cohesiveness and softness when it interacts with soil and water. Lime and clay minerals react to generate calcium silicate, a stiff gel that adheres to soil fine-grains or particles. Clay particles are coated, bound, and covered with silica gel, which lowers the soil's plasticity index [7].

Because they are effective at reducing expansive characteristics, increasing strength, decreasing the plasticity index, swell and shrinkage potential, and controlling volume change, lime, and cement are frequently used to treat cohesive soils with expansive properties. However, because lime increases the soils' friability and reduces their plasticity, making them easier to deal with, it has been thought that lime is a better suitable stabilizing agent for clay soils with fine amounts over 25%. Strengthening results from lime's interactions with soils. The primary source of the strength enhancement is the chemical interaction between the soil's amorphous component, clay minerals, and lime [8].

To improve the engineering properties of soil, soil stabilization entails changing its properties using chemical or physical methods. The primary goals of soil stabilization are to increase the soil's bearing capacity, weathering resistance, and permeability [9]. Any construction project's long-term performance depends on the stability of the underlying soils. Soil stabilization techniques are necessary to ensure the good stability of soil so that it can successfully support the load of the superstructure, especially in cases where the soil is highly active. It also saves a significant amount of time and millions of dollars when compared to the method of removing and replacing unstable soil [10].

The two types of soil stabilization techniques are chemical stabilization and mechanical stabilization. Almost all road and other civil engineering construction processes use one or both of these techniques. Changing the physical characteristics of unprocessed soil particles through techniques like compaction, dewatering, soil reinforcing (soil nailing), and the addition of graded aggregates, are the mechanical methods of soil stabilization. Reducing volume fluctuations and improving soil stability and drain ability are the primary goals. Through chemical reactions between additives (cementitious compounds) and soil minerals, the soil is stabilized using chemical processes. At the moment, cement and lime are frequently utilized as binders in soil stabilization. Because they are entirely dependent on natural resources, these materials cannot be considered environmentally sustainable [11].

The need to bring down the cost of waste disposal and the escalating cost of conventional soil stabilizers have led to intense global research on the economic utilization of wastes and locally available materials for engineering purposes in road construction. The safe disposal of industrial, agricultural, and other wastes demands urgent and cost-effective solutions because of the debilitating effect of these materials on the environment and the health hazards that these wastes contribute [12].

Soil problems are exclusively associated with its geotechnical characteristics. These problems may be a factor in a poorly constructed structure. Any construction that is to be built, whether it is a building, an airport, a highway, or a dam, is impacted by the geotechnical characteristics of the soil; which include particle size, moisture content, specific gravity, and maximum dry density. It is possible to prevent damage by taking appropriate corrective measures. These are adding materials to the soil to fill up the voids between the soil particles or moistening the soil [13].

1.2 Statement of the Problem

Expansive clays are a problem for subgrade foundations in Ethiopia as well as worldwide. Expansive soils are those that, as a result of changes in their moisture content, show unusually substantial volumetric changes, including shrinking and swelling, and have a low bearing capacity [14]. Buildings, bridges, highways, tunnels, dams, towers, and other structures used in civil engineering are built either below or on top of the soil. Appropriate foundation soil is necessary for their stability. It is necessary to evaluate the qualities of soil to determine whether it is suitable for use as a foundation or as a construction material [15].

Poor subgrade soil is a prevalent issue in the building of new roads. Pavements, railroads, highway embankments, roads, building foundations, slab-on-grade members, irrigation systems, water and sewer lines, and channel and reservoir linings have all shown signs of cracking and breaking due to expansive soils. Before beginning building, the underlying soil must be treated to solve these issues. Two common methods for stabilizing soil are lime and cement. However, these materials can occasionally be costly [16].

Expansive soil causes challenges in building due to its low strength and cyclic swell-shrink characteristics. These soils cause serious damage to lightly loaded structures because they expand greatly when exposed to water and shrink when the water evaporates. Among the several methods for building on expansive soils, stabilization with industrial wastes is one of the most effective, well-liked, and economical methods. The technique of adding certain materials to the soil to enhance its engineering properties is known as soil stabilization. These materials can be classified as pozzolanic (fly ash, rice husk ash, etc.), binder (lime, cement, cement kiln dust, lime sludge, etc.), and inert (sand, quarry dust, ceramic dust, etc.) [17].

The greatest option for enhancing the soil qualities of black cotton soil is stabilization. Lime, cement, fly ash, rice husk, ground nut shell, crushed seashell, geotextile materials, etc are utilized to improve the soil engineering property. However, from an economic standpoint, locally available materials such as grit, stone dust, and sand can be utilized. These materials work well as stabilizers and enhance the quality of the soil. The combination of these components raises the soil's soaking CBR value by three to five percent. It is more cost-effective than the alternative [18].

Currently, agricultural waste is receiving a lot of attention from geotechnical engineers and researchers as an alternate material for improving soil. According to the experts' assessment, additives made from agricultural waste have been employed to strengthen the subgrade soil's weak points. Furthermore, because agricultural waste is widely available, it is inexpensive, sustainable, and might be regarded as a viable substitute material for soil stabilization. For these reasons among others, enhancing the soil's carrying capacity, raising its shear strength, and decreasing its permeability using waste materials for soil stabilization is seen favorably. People who live in rural parts of various countries seldom have access to all-weather roads for their everyday needs in transportation [19].

To satisfy the growing demand for processed malt barley from the brewing industries, Assela Malt Factory doubled its processing capacity from 22,000 to 36,000 tons in 2012. 500,000 quintals (50,000 tonnes) of premium raw malt barley are needed for the factory to produce 360,000 quintals (36,000 tonnes) of malt yearly [20]. A large amount of barley husk will be produced as an industrial waste material from the malt barley needed to produce malt. This makes it easy to obtain Barley Husk Ash in tremendous amounts.

Hence it is important to use locally available materials for subgrade soil stabilization. Researches were conducted using BHA for soil stabilization. Previously conducted researches were conducted using BHA alone to study its effect on stabilization. In this Thesis, BHA is used with lime to study its effect with optimum lime used in stabilization, for further improvement and partial replacement the effectiveness of BHA was studied for subgrade soil stabilization with lime and its result was analyzed according to ERA pavement design manual.

1.3 Research Questions

The researcher formulated the following questions to conduct the study

i. What are the engineering properties of expansive soil?
ii. What are the engineering properties of the soil stabilized with lime and BHA?
iii. What will be the optimum percentage of lime and BHA used for stabilization?
iv. What will be the laboratory test result when compared to standard specifications?

1.4 Objective

1.4.1 General Objective

The General objective of this study was to examine the Engineering property of Expansive soil stabilized with Barley Husk Ash and lime for subgrade soil formation.

1.4.2 Specific Objective

1. To identify the engineering properties of expansive soil
2. To evaluate the engineering properties of the soil stabilized with lime and BHA
3. To identify the optimum percentage of lime and BHA for stabilizing expansive soil
4. To compare the laboratory results with ERA pavement design manual standard specification and recommendation on the results.

1.5 Significance of the Study

The purpose of adding BHA to expansive soil is to use locally available material to improve engineering properties and to get better material for subgrade construction. This study provides the following significances. Firstly it provides knowledge on the use of locally available materials with common stabilizing materials. Secondly, it provides the potential of barley husk ash for stabilization of weak subgrade. Thirdly it provides a reference for further detailed studies on the barley husk ash in subgrade soil stabilization. Owners, contractors, and consultants can get some benefit from the study as a source of information for constructing road projects, in the case of Jimma town. The study provided lessons that can help the concerned body come up with appropriate measures to address problems caused by expansive soil.

1.6 Scope of the Study

The scope of this study was to evaluate the suitability of barley husk ash with lime for subgrade soil stabilization. This study was done by using barley husk ash from potentially known areas in barley crop production and lime from nearby suppliers. The Engineering properties of stabilized soil with a combination of barley husk ash and lime was studied and evaluated for using locally available materials from economic consideration. Three soil samples were taken from different locations in Jimma town. Tests that had been conducted for evaluation of strength are; Atterberg limit, gradation, specific gravity, free swell, unconfined compressive strength (UCS), compaction, and CBR tests. The results were compared to the ERA pavement design manual. The sampling area was limited to 3 selected areas and the soil sample which showed a lower strength parameter was selected for stabilization for further analysis.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In the construction industry, the main problem encountered is expansive soils. The effect of expansive soil on the highway can be visible by different cracks on the pavement. Construction on expansive soil needs either removing the soil & replacing it with better material or stabilization of the existing soil for subgrade formation [21]. To improve the engineering properties of the soil, soil stabilization entails changing its properties using chemical or physical methods. Increasing the soil's bearing capacity, resistance to weathering, and permeability are the major goals of soil stabilization. Any building project's long-term performance is reliant on the stability of the underlying soils [22].

The adjustment or improvement of one or more soil properties to enhance a soil's engineering properties and performance is known as soil stabilization. In a broad sense, stabilization includes any techniques used to change the characteristics of the soil to enhance its engineering properties. [10]. When building roads, soil stabilization frequently involves the use of cement and lime. However, using these materials for production, shipping, and stabilization results in the release of a sizable amount of carbon dioxide (CO_2) and other greenhouse gases (GHGs). The extensive agricultural land cultivation and the active expansion of agro-based industries may make it economical and environmentally friendly to use locally accessible materials in addition to these products [1]. In Ethiopia and other developing countries, agriculture accounts for the majority of economic activity. Unfortunately, the vast amounts of agricultural waste that emerge from this are not always properly managed or utilized. When discarding leaves and hulls/husks, for example, it is possible to save the ashes [12].

2.2 Occurrence of Expansive Soil

The clay mineral is crucial in revealing the swelling characteristics of any ordinary, non-swelling soil. Montmorillonite has the highest swelling potential among the numerous clay mineral kinds. Since the primary clay minerals must grow in-situ under alkaline conditions, this type of expansive soil can be traced back to the subaqueous breakdown of blast rocks. These types of soil can also be created by weathering in alkaline conditions with sufficient magnesium, ferric, or ferrous oxide availability. Montmorillonite formation is encouraged where alumina and silica are both readily available.

2.3 Nature of Expansive Soil

Clay-related swelling can be divided into two categories: water-sensitive clays that expand as a result of imbibing water, and elastic rebound in the compressed soil mass caused by a decrease in compressive force. Clays that exhibit the first type of swelling, characterized by the presence of clay minerals with a significantly expanding lattice, are referred to as swelling clays. Cohesion and strength are modest on damp, clayey soil on top, but they solidify into their distinctive shape after the water is drained. Still, after soaking, none of them swell. Considerable differential settling is caused by a reduced ultimate bearing capacity at saturation. Therefore, clayey soils can cause foundation problems [23].

2.4 Clay Mineralogy

Clay has 3 most common minerals. These are: Montmorillonite, Illite, and Kaolinite.

2.4.1 Montmorillonite

The most prevalent clay mineral is montmorillonite, which is widely known for its swelling characteristics. Two silica sheets and an alumina sheet form its fundamental structure. The fundamental montmorillonite units are piled one on top of the other, but because of the weak link between the individual units, water may easily pass between the sheets, causing them to separate and swell. Montmorillonite has a very high degree of expansiveness as a result.

2.4.2 Illite

The fundamental structure of illite is comparable to that of montmorillonite. Nonetheless, potassium ions which are non-exchangeable bind the fundamental illite units together. As a result, the illite units inflate considerably less than montmorillonite because they are very stable. Illite possesses a moderate degree of expansiveness.

2.4.3 Kaolinite

The structural unit of kaolinite is composed of silica and alumina sheets connected. These layers are piled one on top of the other to form kaolinite. Because of the strong link between the layers, it is challenging to separate them. Because of this, the kaolinite is comparatively stable and the layers prevent water from passing through. Kaolinite has a low degree of expansiveness as a result.

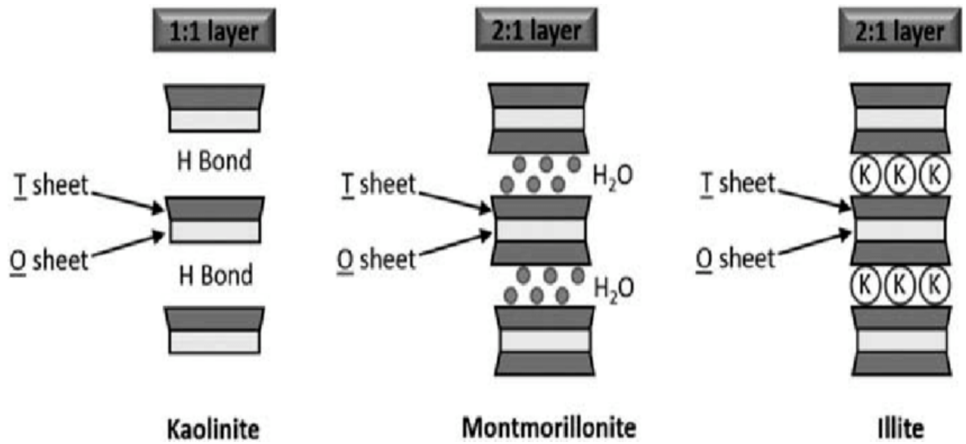


Figure 2.1: A schematic diagram of clay minerals (Zhang 2016)

2.5 Soil Stabilization

Increasing the soil's bearing capacity, resistance to weathering, and permeability are the main objectives of soil stabilization. The process of "soil stabilization" entails using chemical or physical means to improve the engineering properties of soil [10]. The stabilizing process has several benefits, including higher resistance values, decreased permeability, permeability reduction, pavement thickness reduction, and elimination of hauling or managing excavation debris. Soil stabilization is the process of enhancing one or more of a natural soil's properties by incorporating a particular soil, cement, or other chemical elements [24].

2.6 Methods of Soil Stabilization

There are two general categories for soil stabilization. These are Mechanical stabilization and chemical stabilization by the use of various admixtures. Mechanical stabilization entails combining the soil with better materials to create homogeneity and enhance the engineering properties of the soil [24]. Lime stabilization, cement stabilization, bituminous stabilization, and fly ash stabilization are the most popular types of chemical stabilization [25].

2.6.1 Mechanical Stabilization

By altering the gradation of the soil, mechanical stabilization improves its qualities. It is performed by combining or blending two or more different kinds of materials. These components might be put together at a central plant, a borrow location, or the construction site. The combined material is then spread out and conventionally compacted to produce the required densities [22]. Using rollers, rammers, vibrational techniques, and sometimes blasting, this procedure applies mechanical energy to the soil to compact and densify it. The soil is stable in this way because of the natural characteristics of the soil composition. A composite material that is better than any of its parts is created by blending two or more different types of natural soil. To create a material that meets the necessary specifications, soils with two or more gradations are mixed. If these elements are mixed and the mixture doesn't fulfill the requirements, stabilization with admixture can be required [24].

2.6.2 Chemical Stabilization

Chemical stabilization entails mixing one or more additives into the soil, such as cement, lime, bituminous material, etc. Increased soil strength results from a chemical reaction between the stabilizer and the minerals in the soil through chemical reaction [26]. The term "additives" describes a produced, commercial product that, when added to the soil in the right amounts, will enhance the soil's quality. By adding the right proportions of Portland cement, lime, lime-cement-fly ash (LCF), or mixtures of these ingredients to the soil, chemical stabilization is accomplished. Bituminous stabilization can be achieved by adding the appropriate amounts of bituminous material to the soil. Choosing and calculating the proportion of additives based on the desired level of soil quality improvement and the classification of the soil is essential. In most cases, less additive is needed to change the qualities of the soil (gradation, workability, plasticity) than to increase the strength and durability to the point where a thickness-reduction design is possible. Conventional methods are used for spreading and compacting the soil after the addition has been combined with it [24].

2.7 Common Types of Stabilizers Used

2.7.1 Cement

Use the instructions to conduct an Atterberg-limits test and a sieve analysis test to choose the right stabilizer type for a certain soil. Portland cement can be used to either alter or enhance the soil's quality or to transform the soil into a mass that is cemented and has higher strength and durability. A wide variety of materials can be stabilized with cement, however the soil needs to have a PI of less than 30. The percentage of coarse-grained soils that pass through a No. 4 sieve should be more than 45%. Whether the soil needs to be stabilized or amended determines how much cement is required. To generate the cementing components calcium-silicate-hydrate and calcium-aluminate-hydrate, as well as extra calcium hydroxide, calcium-silicates, and calcium-aluminates must be mixed with water to form cement. Cement may be effective in stabilizing both granular and fine-grained soils due to the cementitious material and the calcium hydroxide formed [16].

The cement-treated aggregate basis or cement-stabilized base is produced by combining the soil and the hydrated cement product. The strength of stabilized soil will be most influenced by the amount of cement put into the soil. The quantity of cement required in the soil depends on the kind of soil. Portland cement is often used as a soil stabilizer because it is simple to handle and has high-quality control capabilities. With an increase in cement volume, the soil that the cement has stabilized becomes stronger. For granular soil and low PI clay soil, stabilization using cement is preferred, according to various research [27]. The type of soil affects how well cement stabilization works. Cement was used to stabilize two soil samples. The rise in CBR values is correlated with the increase in cement content. For both Samples, the CBR values multiply when cement is added to the soil, and the highest CBR was discovered at 8% cement addition with CBR results of 86.52% and 63.55% for Sample-1 and Sample-2, respectively [28].

2.7.2 Lime

Soil stabilization using lime is affordable. The process of "lime stabilization" involves adding lime to the soil to improve it. The several types of lime used in the soil include hydrated high-calcium lime, monohydrated dolomite lime, calcite quick lime, and dolomite lime. Most soil stabilizers contain 5% to 10% lime by weight. The term "lime modification" describes a rise in strength brought on by cat-ion exchange capacity, as opposed to the cementing effect brought on by the pozzolanic reaction [24]. For the stabilization of soil, lime stabilization refers to the use of quick lime (CaO) or hydrated lime ($Ca(OH)_2$) as a stabilizing agent. This method works best with fine-grained soils that contain a significant amount of clay. Because of its efficacy and greater development of strength, quick lime is more frequently preferred. The process of calcium ions replacing monovalent ions like Na^+, Li^+, etc. that are adsorbed to the clay mineral surface is known as a cation exchange process and occurs when water and lime are added to a clayey soil. Lime dissociates into Ca^{2+} and OH^- during this process [29].

The calcium ion (Ca^{++}), which migrates to the surface of the clay particle when lime is combined with soil and clay, dispenses water to create granular materials that are simple to compact. Lime produces hydrated calcium aluminates and calcium silicates when it comes into contact with a substance that contains soluble silicates and aluminates, such as clay and silt. Similar to cement, when this crystallizes, a real link is created. This bonding mechanism, known as a pozzolanic reaction, increases the soil's compressive strength and CBR and improves its resistance to frost. The soil typically becomes strong enough in non-winter circumstances after three to six months. The ability to work with the treated soil more freely is a clear benefit of a slow curing process during road construction. Designing the bases for industrial platforms is made easier by the long-term hardness. The stabilizing action gives the treated soil the ability to support loads [10].

Improved strength, increased resistance to fracture, fatigue, and permanent deformation, decreased swelling, and resistance to the destructive effects of moisture are only a few of the essential engineering features that lime stabilization gives soils. The soils with moderate to high flexibility, like heavy clays, exhibit the greatest improvements in the attributes mentioned above. The addition of lime to a reactive soil to produce a pozzolanic reaction that results in long-term strength gain is when soil stabilization happens. While the calcium from the lime combines with the aluminates and silicates dissolved from the clay, stable calcium silicate hydrates and calcium aluminate hydrates are produced. As long as there is enough lime available and the PH is high (over 10), this pozzolanic process can last for decades or longer. Lime treatment can therefore result in strong and durable strength. The soils can be treated with lime in the form of quicklime (calcium oxide, or CaO), hydrated lime (calcium hydroxide, or $Ca[OH]_2$), or lime slurry. When quicklime and water interact chemically, hydrated lime is produced. The clay particles react with hydrated lime, which permanently changes them into a robust cementitious matrix [10].

The highest reduction in PI was observed for 6% lime treatment cured for 3 days with a 78.26% reduction in PI compared to native soil. An increased reduction in PI associated with the increased amount of lime is expected as more calcium is available for action exchange to take place [30]. In many medium, moderately fine, and fine-grained soils, lime will react to create lower flexibility, enhanced workability, reduced swell, and increased strength, according to experience. Lime stabilization should be regarded as a possibility for soils categorized by the USCS as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GWGC, GP-GC, ML-CL, and GM-

GC. All soils with a PI greater than 10 and more than 25% of the soil passing the No. 200 sieve should be given lime consideration.

Economic Benefits of Lime Stabilization

- Reduce materials needed for embankment
- Reduction of transport movements near the construction site.
- It is significantly easier for machines to move around. There are fewer weather-related delays, which boosts output. Thus, it is possible to substantially decrease both the overall building time and expense.
- Structures (such as capping layers and embankments) require less maintenance and have a longer service life.

2.7.3 Bituminous

Bitumen soil stabilization can be accomplished with one of two additions. The option between employing an asphalt emulsion or foamed bitumen as the additive depends on the specifics of the project. To account for the high field moisture content, extremely wet soil conditions might need the use of foamed bitumen rather than a typical asphalt emulsion. For projects where high-performance emulsions are easily accessible, emulsion might be chosen. The California Bearing Ratio value in this particular experimental investigation has increased by up to 50% compared to the California Bearing Ratio of unmodified soil. This method of stabilization may be appropriate in gravel soil when considering its financial cost and stabilization quality enhancement. The soil's California Bearing Ratio value rises as the mixture's volume is increased [31].

Asphalt cement, cutback asphalt, and asphalt emulsions have been used most often for bituminous soil stabilization. A PI of less than 10 and less than 30% passing the No. 200 sieve is typical for soils that can be efficiently stabilized using bituminous materials. If the gradation and plasticity requirements are met, bituminous materials can successfully stabilize soils defined by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC.

2.7.4 Combinations

The terms lime-cement, lime-asphalt, and LCF stabilization are specifically used to describe combination stabilization. Combinations of lime and cement are often acceptable expedient stabilizers. Lime can be added to the soil to increase the soil's workability and mixing characteristics as well as to reduce its plasticity. Cement can then be mixed into the soil to provide rapid strength gain. Combinations of lime and asphalt are often acceptable stabilizers. The lime addition may prevent stripping at the asphalt-aggregate interface and increase the mixture's stability [32].

The change in microstructure and fabric of expansive soil due to the addition of fly ash and lime sludge from SEM photograph and found changes in microstructure and fabric when 16% fly ash and 16% lime sludge were added to expansive soil. The results of studies conducted to examine the consolidation and swelling behavior of expansive soil stabilized with lime sludge and fly ash were similarly described. The best stabilizing effect was obtained with 16% of fly ash and 16% of lime sludge [33].

2.7.5 Fly Ash

Thermal power stations that use coal as a fuel produce fly ash as a waste byproduct. Fly ash is often divided into two categories: Class-C fly ash and Class-F fly ash. The amount of calcium oxide present in fly ash is the basis for this classification. A series of studies were conducted with fly ash levels varying from 10% to 25% in expansive soils to assess its effectiveness as a stabilizing addition. At 25% fly ash by weight, the soil-gypsum mixture gains 90% more compressive strength after the addition of fly ash. To improve soil quality, fly ash-gypsum mix may be utilized [34].

After analyzing how F-class Catalagzi fly ash and C-class Soma fly ash affected the characteristics of consistency, swell, and strength of two different soil types with high and low plasticity, the following results were found: The plasticity index values increased as the fly ash content reached 20% and declined in almost all fly ash-clay combinations below this threshold. It was determined that the optimum fly ash content for this application was 20%. Furthermore, due to its higher CaO content than Catalagzi fly ash, Soma fly ash had a far bigger impact on the consistency limitations [35].

The percentage of binder material grows in tandem with the OMC value. The highest OMC value is recorded for natural soil, at 24.09 percent. As the proportion of binder material rises, the MDD value decreases. The MDD value falls with an increase in the mix's OMC. The UCS value falls during the first 0 days of curing when the percentage of binder material rises. This might occur from a declining MDD value. It can be seen that as the curing time increases, the UCS value rises. This is because the binders that were applied to the soil had a delayed pozzolanic response. Furthermore, it can be demonstrated that for all combinations, the UCS values increase in tandem with the growth of the binder content [36].

Fly ash's impact on the swelling of highly plastic expansive clay and the compressibility of another non-expansive high plasticity clay was investigated by Phani Kumar and Sharma (2007). At 20% fly ash concentration, the swell potential and swelling pressure of both clays reduced by 40%, while the compression index and coefficient of secondary consolidation decreased by nearly 50% when measured at a constant dry unit weight of the sample (mixture) [37].

Fly ash's contents can vary widely depending on the origin and nature of the coal being burned, but they invariably contain sizable levels of silicon dioxide (SiO_2) and calcium oxide (CaO), two elements that are endemic to many coal-containing geological strata. Using different ratios—such as 10%, 20%, 30%, 40%, and 50%—is necessary to stabilize expansive soils. Based on compaction qualities and UCS value, a fly ash content of 20% was determined to be the optimal amount to use. The value of the free swell ratio was found to decrease when the soil-fly ash mixture's fly ash percentage rose. As fly ash content increased, the plasticity index increased as well. [37].

The addition of fly ash and PGSS into expansive soil improved the engineering properties of the soil. With 20% fly ash and 10% PGSS, the unsoaked CBR value increased from 2.46% for unsoaked natural soil to 16.21%. According to the SEM results, blended soils treated with 20% fly ash and 10% PGSS had microstructures that were thicker, more compact, and more uniform than expansive soils. This indicates how much thicker and fewer holes the treated soil had [38].

2.8 Barley Husk Ash

Ethiopia produces a lot of barley, among other crops. Since barley grows at all elevations, smallholders cultivate it throughout Ethiopia, albeit the northern and central regions of the nation are best suited for higher elevations. In Ethiopia's highlands, barley is a significant staple crop.

Many traditional foods, including Kita, Kolo, Beso, Enjera, Giat, cuko (shakeka), and many more, are made using this crop. Malt barley's market potential is strongly correlated with the beer market, so the best way to evaluate it is to examine how Ethiopia's expanding brewery industry is changing over time [39]. The Ethiopian Agricultural Research Institute investigated the production of many barley varieties throughout the nation. It is primarily grown in the Oromia Region's mountains around Arsi and Bale.

Burning barley husk produces barley husk ash. The burning environment has a significant impact on the BHA's physical characteristics. Incomplete combustion results in a significant proportion of unburned carbon being present in the ash. Grey to whitish ash is produced after combustion is complete. The burning temperature and retention duration affect the amorphous content. Barley husks can be burned at temperatures between 500 and 700 °C for a short time to achieve the best qualities. This temperature is lower than that needed to generate clinker during the manufacturing process for cement [12].

The MDD in soil treated with CTGA and BHA generally decreased and the OMC generally increased as the CTGA and BHA concentration increased. The soaked CBR of the BHA-stabilized soil increased noticeably from about 38% (natural soil) to just over 80% (stabilized). No unconfined compressive strength was observed by BHA. This is caused by the absence of CaO in the ash's mineral composition [1].

Tables 2.1 and 2.2 show that both the area of harvest and product for barley production continuously increased from the market year 2008 to 2013.

Table 2.1: Barley area harvested (2008-2013)

Market year	Area harvested	Unit measure	Growth rate
2008	951	(1000HA)	-3.35%
2009	975	(1000HA)	2.52%
2010	1046	(1000HA)	7.28%
2011	1013	(1000HA)	-3.5%
2012	1020	(1000HA)	0.69%
2013	1020	(1000HA)	0.00%

Source: USAID, 2012

Table 2.2: Barley production (2008-2013)

Market year (MY)	Production	Unit of measure	Growth rate
2008	1484	(1000MT)	9.52%
2009	1569	(1000MT)	5.73%
2010	1525	(1000MT)	-2.8%
2011	1592	(1000MT)	4.39%
2012	1620	(1000MT)	1.76%
2013	1632	(1000MT)	0.74%

Source: USAID, 2012

CHAPTER THREE

METHOD AND MATERIALS

3.1 Introduction

This chapter presents and describes the approaches and techniques used to collect data and investigate the research problem.

3.2 Study Area

The study area is in Jimma Town, the main city in the southwest Oromia region of Ethiopia, which is situated in the country's southwest. Geographically it is located between 7º38’52” N and 7º38’52” N latitude, and between 36º48’00” E and 36º53’24” E longitude. It experiences a tropical monsoon climate that is comparatively cool. It has a lengthy rainy season that runs from March to October every year. Because of their low compressibility and limited load-bearing capacity, the majority of Jimma's subgrade soils are unsuitable for highway subgrade without modification [40].

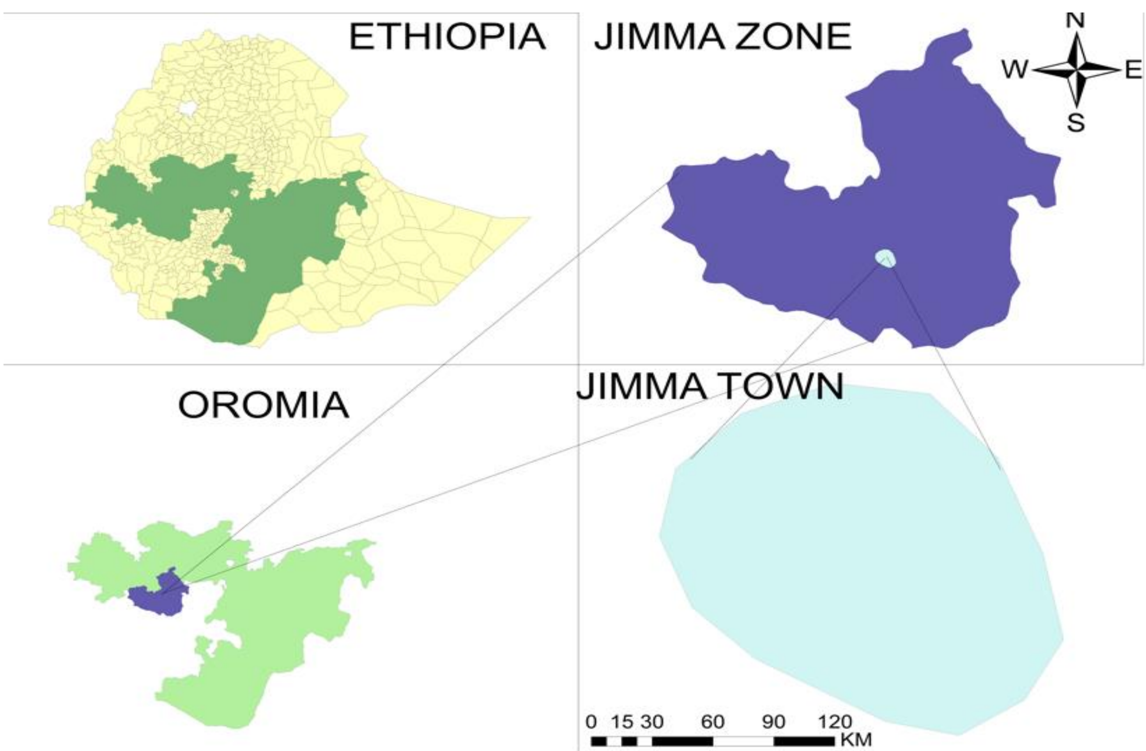


Figure 3.1: Map of the study area

3.3 Material Used and Standard Specification

Materials used for this study are;

- Expansive soil
- BHA and
- Lime.

Barley husk was obtained from Arsi Zone Assela town (Assela Malt Factory) which is a high potential area in Barley crop production. Soil samples were obtained from different locations in Jimma town; Shenen Gibe, Kochi, and Kito. Lime was purchased from suppliers in Jimma.

3.4 Research Design

This research study was conducted using a laboratory experimental research design. The study has evaluated the Engineering properties of expansive soil stabilized with BHA and lime for subgrade soil formation.

3.5 Standard Testing Procedure

In this research, laboratory testing was conducted to characterize subgrade soil stabilized with BHA and lime. The expansive soil was stabilized with lime using 5%, 10%, 15%, and 20% of the soil dry mass by weight to obtain the optimum amount of lime to be used. Then by using optimum lime and varying amounts of BHA 5%, 10%, 15%, and 20% engineering properties of the soil were studied to determine a partial replacement amount of BHA with lime. Standard testing procedures involved the following steps.

- Taking materials /preparation of materials
- Performing chemical tests (oxide composition) for BHA
- Preparation of material for laboratory tests
- Perform laboratory tests of each material used for stabilization.
- Preparing specimens /samples using standards
- Determining the optimum lime content used for stabilization
- With a varying amount of lime and BHA identifying the effect
- Find out the optimum amount of BHA to use with lime for stabilization
- Data analysis and evaluate the effect of BHA in subgrade soil stabilization.

Table 3.1 shows standards and specifications used for this study adopted from ASHTO and ASTM.

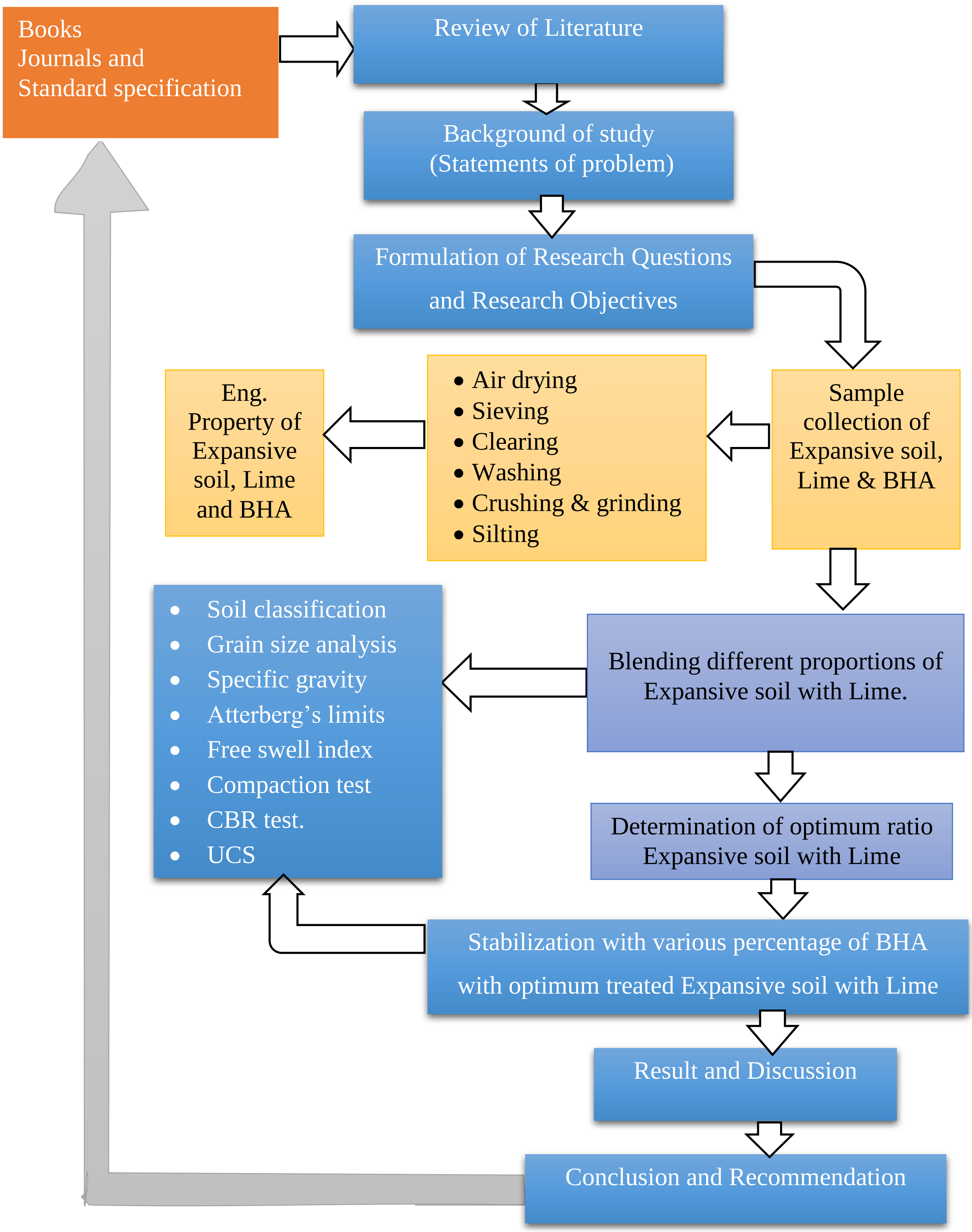


Figure 3.2: Research Design

Table 3.1: Standards and specifications for this study

No	Laboratory tests	Standards	
		AASHTO	ASTM
1	Major and minor Oxides		C-618
2	Moisture content	T-265	
3	Grain size analysis	T88	
4	Atterberg limits	T089-96	
5	Soil classification	M-145	D2487-98
6	Specific gravity		D854-83
7	Standard proctor compaction	T-99	
8	CBR	T193-93	
9	UCS	T 208-10	D2166

3.6 Populations

The study population includes the stabilization of expansive soil for subgrade formation using BHA and Lime to identify the suitability of BHA with lime for stabilization. Hence study population includes; expansive soil, BHA, and Lime.

3.7 Sampling Techniques and Procedure

The sampling technique used for this research is purposive sampling, which is a non-probability method. This sampling technique was proposed based on the intention to perform laboratory tests on the required materials to identify the strength behavior of stabilized weak soil with BHA and lime for subgrade formation. The Barley husk sample was taken from Assela Malt factory and burned in uncontrolled temperature. After the burning of the husk was completed the sample was prepared by sieving on sieve no 200 (0.075mm sieve size) for a chemical test (Oxide composition) test to identify pozzolanic characteristics of the material. Soil samples were obtained from three different places in Jimma town. The soil samples were selected based on location and soil type identified in previous studies. These are:

1. Shenen Gibe; it was taken from around Shenen Gibe Hospital having a GPS location of 0262106 easting and 0846501 northing. The soil has a color of gray.

2. Kochi; it was taken around kebele-5 having a GPS of 0262002 easting and 0849291 northing. The color of the soil is black.

3. Kito. It was taken from the JIT compound with a GPS location of 0258900 easting and 0850318 northing. The color of the soil is black.

A sample pit was prepared and the soil samples were taken from a 1.5m depth. After the samples were taken and transported to the laboratory center they were air dried for a week and using ASTM and AASHTO manual the sample was prepared for gradation, compaction, CBR, Atterberg limit, unconfined compression strength (UCS), and specific gravity tests. After the samples were prepared for the mentioned tests, the engineering properties of the soil samples were identified and the soil sample which showed the lowest bearing capacity was stabilized using lime and BHA for further analysis. To evaluate the engineering properties of the stabilized soil, the selected soil sample was tested using 5%, 10%, 15%, and 20% lime to obtain the optimum amount. With the optimum amount of soil stabilized with lime again it was tested using 5%, 10%, 15%, and 20% of BHA. Blending ratios of expansive soil, lime and BHA are tabulated in table 3.2 and 3.3.

Table 3.2: Blending ratios of lime and expansive soil

S.N	**% of lime used for stabilization**	**% of expansive soil used**
1	0%	100%
2	5%	95%
3	10%	90%
4	15%	85%
5	20%	80%

Table 3.3: Blending ratios of lime, BHA, and expansive soil

S.N	% of lime used	% of BHA used
1	Opt	0%
2	Opt	5%
3	Opt	10%
4	Opt	15%
5	Opt	20%

Using BHA in addition to optimum lime was aimed for further improvement of the soil's characteristics. According to ERA pavement design manual, as subgrade class increases thickness of the upper layers decreases. Hence if further improvement is achieved, overall construction cost has to be decreased.

3.8 Study Variables

Study variables are classified into two. These are dependent variables and independent variables.

3.8.1 Dependent Variables

Dependent variables are related to the general objectives of the study; hence, the optimum percentage of BHA and lime used for the stabilization of expansive soil is a dependent variable.

3.8.2 Independent Variables

Independent variables of this study are results of laboratory tests that describe engineering properties of expansive soil, BHA, lime, and BHA stabilized soil. These are;

- Atterberg limit
- Gradation
- Unconfined compression strength (UCS)
- Free swell
- Compaction
  - ✓ MDD
  - ✓ OMC
- CBR value
- Percentage by weight

3.9 Data Collection Process

For the accomplishment of this research required data was primary and secondary data. Primary data include Soil, BHA, and Lime. The tests were conducted to check the effectiveness/quality of the material based on the standard. Data was obtained from laboratory tests to investigate and stabilize the soil with lime and BHA. The soil sample was collected from Jimma town. Barley husk was obtained from Assela town Assela Malt Factory. Then it was burned in the open air to obtain BHA. The laboratory Tests were conducted to identify the effect of BHA on the Atterberg limit, Compaction (MDD and OMC), CBR, FSI, SG, UCS, and index properties to determine the engineering properties of the treated expansive soil and lime in the laboratory the optimum amount of lime to be used. Then expansive soil was treated with the optimum amount of lime and varying amounts of BHA to get the amount of BHA to be used in partial replacement. Figure 3.3 (a) and (b) shows sample collection from Assela malt factory and burning barley husk in open air respectively. Figure 3.4 (a) and (b) shows collection of expansive soil from different test pits.

a) b)

Figure 3.3: Sample preparation of BHA photos (captured by Solomon)

a) b)

Figure 3.4: Sample collection of natural soil from test pits (captured by Jemal)

3.10 Laboratory Tests Conducted

This is the data that has been obtained from the results of experimental studies at the laboratory. The laboratory tests were conducted for natural soil to evaluate the mechanical and engineering properties of expansive soil in detail procedure for the identification of the engineering properties of the soil. The mixing was designed to analyze the effect of lime and BHA on the engineering property of expansive soil with the aspect of using the mixed expansive soil with partial replacement of BHA in the construction of the subgrade of a highway. Before starting the laboratory test, the prepared samples were first air-dried under the sun to allow moisture to evaporate and obtain air-dry samples for the test, then the required sample was taken according to ASTM and ASHTO sampling and testing procedures.

3.10.1 Gradation

3.10.1.1 Sieve Analysis

Sieve analysis test allows the determination of the distribution of particle sizes in materials. For the present study (AASHTO T-88) method was used for testing analysis. A type of sieve analysis used was wet sieve analysis. This test was aimed at the particle size distribution or gradation of the disturbed soil sample used for the sample particle distribution. Figure 3.5 shows photos captured during sieve analysis test.

Figure 3.5: Sieve analysis test photos (captured by Anwar)

3.10.1.2 Hydrometer Analysis

The main purpose of hydrometer analysis is to determine a fine-grained soil's grain size distribution. The sieve analysis test yields unreliable results in fine-grained soil. This is true because particles smaller than 0.075 mm make up fine-grained soil. Therefore, designing a sieve with a grain size that fine is not feasible. Moreover, sample loss during sieving is a possibility. As a result, hydrometer analysis is used to analyze the grain size of fine-grained soils. Stokes's law forms the basis of hydrometer analysis. This Law states that, when all other things are equal, the shape, weight, and size of the grain size of the particles determine the velocity at which the grains settle down out of suspension. Getting an estimate of the distribution of soil particle sizes smaller than sieve No. 200 (0.075 mm) can be accomplished by the widely used technique of hydrometer analysis.

3.10.2 Specific Gravity

Soil is a three-phase material composed of air and water-filled spaces and solid particles. The ratio of a soil's mass per unit volume at a given temperature to the mass of the same volume of gas-free distilled water at the same temperature is known as the soil's specific gravity. As per ASTM D854-98, the following procedures are offered for completing the specific gravity: Method A- method for oven drying specimens. Using a Pycnometer, the specific gravity of the soil was ascertained in this laboratory experiment. To establish particle sizes for hydrometer analysis, it is crucial to ascertain the specific gravity in this investigation. Additionally, soil-specific gravity is a crucial measure that is regularly utilized in both laboratory and real-world settings to determine various soil qualities. It will be employed in the current testing to compute zero air-void curves for the compaction test and the percentage finer in hydrometer analysis.

3.10.3 Free Swell

The free swelling test is used to determine the increase in the volume of soil without any external constraint when the sample of the soil is subjected to submergence in the water. This testing is provided to reflect the potential of the soil to swell under different simulated conditions. For the given clay the free swell test is conducted by using the following formula.

$$S_f = \frac{Vf - vo}{Vo}$$

Where: V_f = the volume of soil specimen read from a graduated cylinder containing distilled water

V_o = the volume of soil specimen read from a graduated cylinder containing kerosene

The procedure includes oven-drying soil by sieving through a 0.425 mm sieve. Two samples of each 10g are required for each test to complete. The two samples are filled with 100mm kerosene and water in a graduated cylinder and the change in volume after 24 hours is recorded. Figure 3.6 shows photos captured during free swell test fr this study.

Figure 3.6: Free swell test Photos (captured by Gizaw)

3.10.4 Atterberg Limits

A basic way to describe the characteristics of fine-grained soil is to use the Atterberg limits. It can exist in four different states: solid, semi-solid, plastic, and liquid, depending on the amount of water in the soil. These four states are based on how the behavior of the soil has changed. As both AASHTO and USCS employ the Atterberg limit of the soil, determining the limitations of the soil helped assess the consistency of the soil and was also used to identify the soil type. It is also used to compare the engineering behavior of soils to the Atterberg limit, which makes it easier to determine the other engineering properties of soil; on the other hand, the Atterberg limit can be used to distinguish between different engineering properties of soils.

Contrarily, the Atterberg limit can be used to distinguish between silt and clay; these distinctions in soil are employed in evaluating the soils that will support the construction of structures. When soil is wet, it absorbs water and may even increase in size. The soil's capacity to absorb water and the composition of its structure both affect how much the soil expands. Since expansive soils are the ones that expand and contract as a result of moisture content variation, these tests are typically performed on them. These tests are frequently performed in the early stages of planning any structure to check that the soil was used to acquire the necessary amount of shear strength and volume change since clays and silts react with water and change in volume. Figure 3.7 shows atterberg limit test photos.

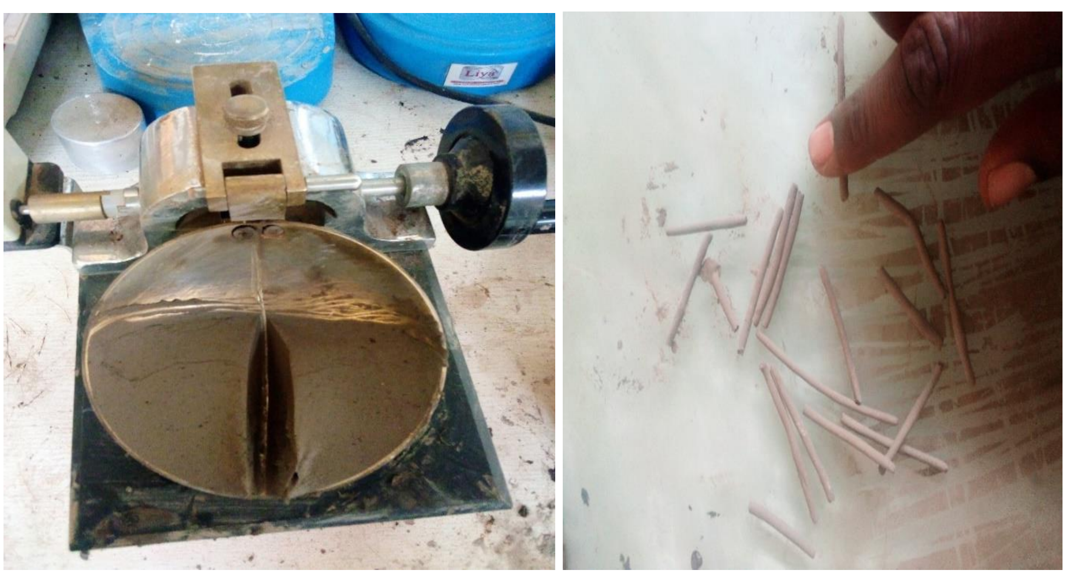


Figure 3.7: Atterberg limit test photos (captured by Gizaw)

3.10.5 Compaction Test

The purpose of the laboratory compaction test is to ascertain how soil's dry density and moisture content are related. Through experimentation, the optimal amount of moisture for a particular soil type to become compacted, dense, and reach its maximum dry density can be determined in the laboratory using the compaction test. There is a certain moisture content for each type of soil which enables maximal compaction.

In general, the engineering properties of expansive soil improve the geotechnical properties of the soil, by increasing the soil density. This test was done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the sample material. Photos captured during compaction test are shown in figure 3.8.

Figure 3.8: Compaction test photos (captured by Gizaw)

3.10.6 California Bearing Ratio (CBR)

California bearing ratio (CBR) is the most useful parameter in subgrade soil classification. It is also used for sub-grade classification in pavement design criteria according to ERA Pavement Design Manual 2013.

The CBR values are determined by the force needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimens. The method uses material passing 19 mm in size and provides the CBR value of the material at optimum water content. The specimen shall be soaked before penetration. A surcharge is placed on the surface to represent the mass of pavement material above the subgrade. Expansion of the sample is measured during soaking to check for potential swelling. To determine the strength and swelling potential of the samples, a test has been carried out by a 4-day soaking three-point CBR and loaded Swell testing procedure. The material strength has been used for design purposes by interpolating the CBR values at different compaction levels, with 10, 30, and 65 blows, and compacting in 5 layers by heavy compaction. Water to be added was calculated from compaction test results which are the OMC obtained at MDD and by considering the natural moisture content of the material on the test.

The laboratory CBR test is generally carried out on remolded samples. The sample should be compacted to the expected field dry density of the appropriate water content. There are two types of CBR - one-point CBR and three-point CBR Three points is recommended to get good and accurate for analysis -Three-point CBR Their difference is in the number of molds and layers. The CBR value that the present study got of 2.54mm is greater than that of the CBR Value of 5.08mm. If the result at 5.08mm is greater than that of 2.54mm the test should be repeated. If the result has no changes the ratio corresponding to 5.08mm should be considered for design [41]. To consider the worst case, the sample was soaked for 4 days. The 95% of maximum dry density of the sample was found by multiplying the Maximum dry density at each sample. Figure 3.9 shows CBR test photos captured during the test.

3.10.7 Unconfined Compressive Strength Test

Since it is one of the quickest and least expensive ways to determine shear strength, the Unconfined Compression test is the most often used technique for soil shear testing. It is strain-controlled, and when the soil sample is loaded quickly, changes in the pore pressures (the water in the soil) occur that do not have time to dissipate. Since the rate of construction is highly rapid and the pore fluids do not have time to dissipate it is indicative of soils in construction sites.

Unconfined compressive strength (UCS) is the maximum axial compressive stress that a specimen can bear without constraining tension. Because the load is applied along the longitudinal axis, the Unconfined Compression Test is also known as the Uniaxial Compression Test. While UCS is a frequently employed measurement in geotechnical design, it may not be a reliable indicator of in-situ strength. Figure 3.10 shows photos captured during UCS test.

Figure 3.9: CBR test photos (captured by Gizaw)

Figure 3.10: UCS test photos (captured by Haile)

3.10.8 SEM Photograph

Microstructure of the soil is becoming more useful in analyzing the changes in the component. The analysis of elementary components of soil and their arrangement is useful in the understanding of macroscopic properties. The description of microstructure and a multi-scale approach is now largely used to understand in detail the reactivity of the system and the macroscopic differences recorded [42].

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presented the results of blending expansive soil with lime and BHA, and the data analysis of that experimental laboratory study on the effect of using BHA with lime mixing with expansive soil for subgrade soil formation purposes. The expansive soil sample was mixed with lime at 0%, 5%, 10%, 15%, and 20% proportion by weight and the optimum result was selected again for mixing with BHA 5%, 10%, 15%, and 20% proportions by mass. Laboratory tests such as the Atterberg's limit, gradation test, compaction, CBR, UCS, and free swell are carried out on expansive soil, and mixing with lime and BHA is carried out for the improvement of engineering properties of expansive soil.

4.1 Laboratory Test Results and Discussion

The main purpose of this experimental study was to determine the suitability of BHA with lime to stabilize expansive soil for subgrade formation, which may help to reduce the problem of time and money consumption, due to replacing expansive soil with other non-expansive soil. The following laboratory tests have been carried out for the improvement of engineering properties of expansive soil. The Complete Silicate Analysis of BHA, The Atterberg's limit, gradation test, free swell, compaction, and CBR test and CBR swell test for mixed soil was performed.

4.1.1 Complete Silicate Analysis

Table 4.1: complete silicate analysis

Constitute (Oxides)		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Remark
BHA	%	40.54	5.86	2.6	2.06	2.48	0.88	18.38	0.12	11.46	0.2	5.00	11.03	Obtained from laboratory results of this study
Lime	%	18.91	1.28	0.58	67.2	0.89	0.12	0.3						[43]

The chemical composition of BHA that was obtained for the present study test result as shown in table 4.1 indicates that the composition of the elements of [SiO_2 (40.54%) +Al_2O_3 (5.86%) +Fe_2O_3 (2.6%)] is 49 % which does not fulfill the minimum requirement of 70 % to be pozzolanic material which is written in the ASTM C-618 [44]. Hence BHA is non-pozolanic material.

From the previous study of: M. Aluga, N. Chilukwa, and N. Lushinga, "Potentials of Common Thatching Grass Ash (CTGA) And Barley Husk Ash ((BHA) for Soil Stabilization in Road Construction" [1]; the summation of [SiO_2 (31.77%) +Al_2O_3 (1.55%) +Fe_2O_3 (2.01%)] is 35.33% which makes non-pozzolanic as well.

4.1.2 Natural Soil

The most important parameters used to evaluate the geotechnical engineering properties and identification of natural soil used to evaluate road construction are discussed. In this study determination of natural soil gradation, FS, Atterberg limit, Specific gravity, compaction characteristics, UCS, and CBR tests were conducted. SEM photograph was also included to study microstructure characteristics. Laboratory test results of all natural soil samples are tabulated below in table 4.2.

Table 4.2: Laboratory test results of natural soil samples

Location	Free swell (%)	Specific gravity	Atterberg limit			Compaction		CBR test		UCS
			LL (%)	PL (%)	PI (%)	MDD (g/cm^3)	OMC (%)	CBR (%)	CBR swell (%)	C (kpa)
Shenen Gibe	109	2.63	72	33	39	1.417	23.5	0.8	14.64	65
Kochi	100	2.6	76	37	39	1.402	27.2	1.3	11.94	82
Kito	91	2.67	70	35	35	1.399	28.6	1.2	10.79	79

From the laboratory test results obtained, all soil samples are highly plastic soil depending on the plasticity index value. In comparison, the Shenen Gibe soil sample and the Kochi soil sample are highly plastic soils relative to the Kito soil sample. Both had a PI value of 39%. From the CBR test result, the Shenen Gibe Soil sample has a CBR value of 0.8 while the Kochi soil sample has a

CBR value of 1.3. This shows that the Shenen Gibe soil sample has a lower bearing capacity compared to other soil samples. Hence soil sample from Shenen Gibe was selected for stabilization using lime and BHA for further analysis.

4.1.3 Gradation

4.1.3.1 Sieve Analysis

Sieve analysis result of natural soil is tabulated in Table 4.3 below

Table 4.3: Sieve analysis test result of natural soil

Sieve size (mm)	Percent pass by mass (%)		
	Shenen Gibe	Kochi	Kito
9.5	100	100.00	100.00
4.75	*98.32*	97.90	*97.60*
2.36	*96.53*	96.30	*95.50*
2	95.06	94.50	94.00
1.18	93.80	93.40	92.90
0.6	92.65	92.00	91.70
0.425	91.07	90.10	89.90
0.3	*90.13*	89.10	*88.90*
0.15	88.76	87.90	87.50
0.075	87.71	86.20	85.90

4.1.3.2 Hydrometer Analysis

Hydrometer test was conducted for all soil samples since sieve analysis alone is not sufficient to evaluate the gradation of fine-grained soil. The hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the #200 (0.075 mm) sieve to around 0.001 mm. The data are plotted on a semi-log plot of percent finer versus grain diameters to represent the particle size distribution. Both sieve analysis and hydrometer analysis are used to complete the gradation curve. Table 4.4 shows hydrometer test results of Shenen Gibe soil sample. Figure 4.1 shows particle size distribution curve of all soil samples for this study.

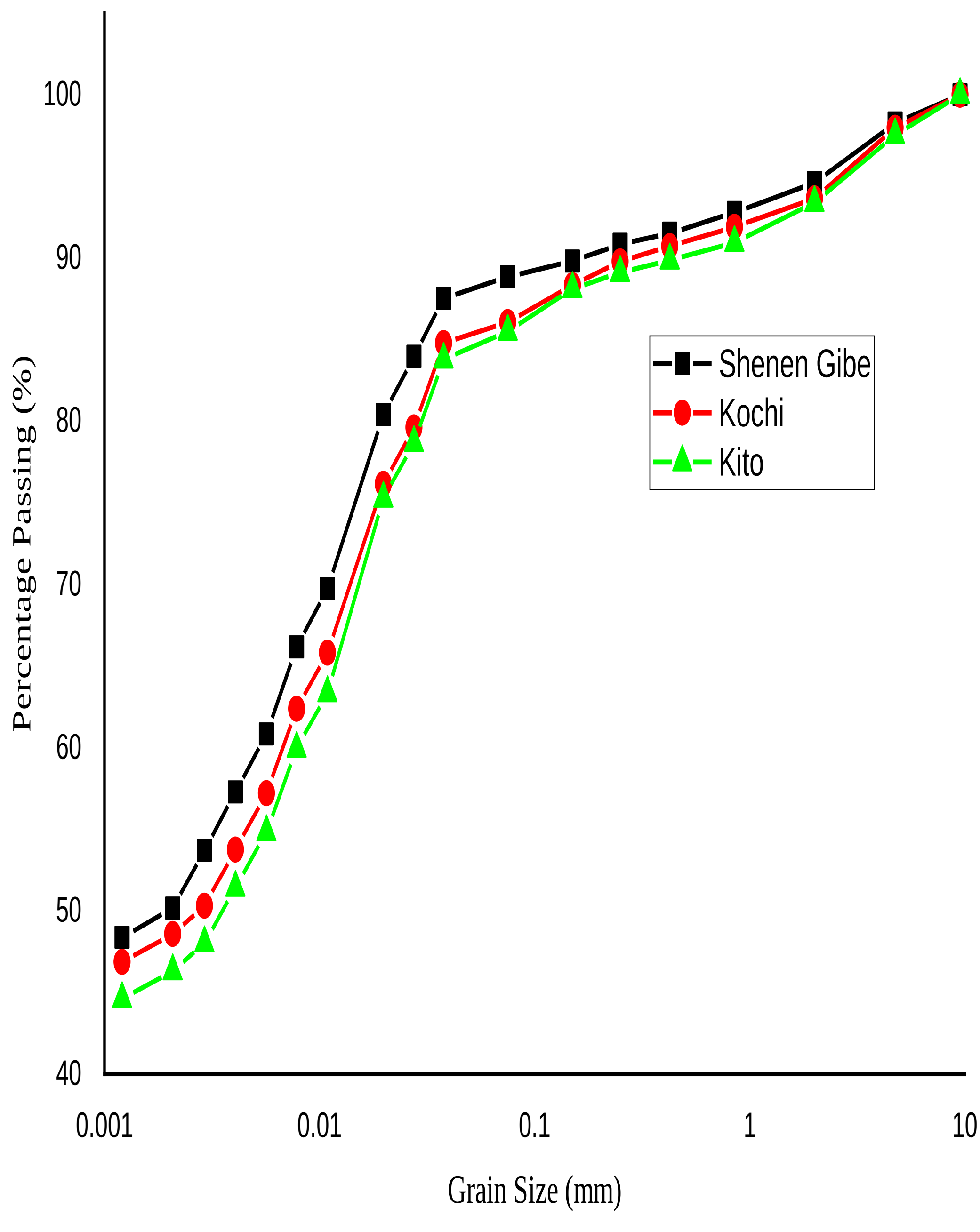


Figure 4.1: Particle size distribution

Table 4.4: Hydrometer analysis test result for Shenen Gibe soil sample

Time	Elapsed time t in min	Actual Hydrometer Reading	Eff. Depth, L (cm)	Temperature (c^0)	K	C_T	Part. diameter D (mm)	Value of 'a' for Gs	Corrected hydrometer reading	Percent of Fine parts. (%)	Adjusted percent of fines part. (%)
17/11/2022/ 9:45:00 AM	0										
9:46:00 AM	1	50	7.9	21	0.01348	0.2	0.0380	1.00101434	49.2	98.5	87.53
9:47:00 AM	2	48	8.3	21	0.01348	0.2	0.0274	1.00101434	47.2	94.5	83.97
9:50:00 AM	4	46	8.6	21	0.01348	0.2	0.0198	1.00101434	45.2	90.5	80.41
9:53:00 AM	8	43	9.1	21	0.01348	0.2	0.0144	1.00101434	42.2	84.5	75.07
10:00:00 AM	15	40	9.6	21	0.01348	0.2	0.0108	1.00101434	39.2	78.5	69.74
10:15:00 AM	30	38	9.9	21	0.01348	0.2	0.0077	1.00101434	37.2	74.5	66.18
10:45:00 AM	60	35	10.4	21	0.01348	0.2	0.0056	1.00101434	34.2	68.5	60.84
11:45:00 AM	120	33	10.7	21	0.01348	0.2	0.0040	1.00101434	32.2	64.5	57.28
1:45:00 PM	240	31	11.0	21	0.01348	0.2	0.0029	1.00101434	30.2	60.5	53.73
5:45:00 PM	480	29	11.4	21	0.01348	0.2	0.0021	1.00101434	28.2	56.5	50.17
18/11/2022/ 9:45:00 AM	1440	28	11.5	21	0.01348	0.2	0.0012	1.00101434	27.2	54.5	48.39

4.1.4 Classification of the Soil Samples

Table 4.5 shows classification of Shenen Gibe soil sample using ASHTO soil classification system. According to AASHTO soil classification system, all soil samples are generally classified as silt clay material with a group classification of A-7-5 which is highly plastic soil. According to the USCS soil classification system the soil samples are classified as CH (Fat clay)

Table 4.5: AASHTO soil classification of Shenen Gibe soil sample

Shenen Gibe					
Determination of PI		Grading			
LL	72	ASTM Sieve No	10	40	200
PL	33	Dimension, mm	2	0.425	0.075
PI=LL-PL	39	% passing	95.06	91.07	87.71
Group Index(GI)	0.0	AASHTO Soil Classification	A-7-5 Silt clay materials		

4.1.5 Atterberg Limit

Atterberg limit test was conducted for natural soil and the result was analyzed according to ERA design manual as shown in table 4.6. According to ERA Pavement Design Manual 2013, the natural soil is not suitable for subgrade construction.

Lime was added into natural soil to check the effect on the laboratory test result of the atterberg limit. The result is tabulated in Table 4.7 below. The liquid limit of the natural soil is 72%. Which shows the natural soil is highly expansive soil. The addition of lime improved the strength characteristics of the soil by decreasing LL from 72% to 45% with a 20% lime addition. The decrease is due to the lime cementitious process where the soil particles become grain and decreased attraction forces between particles. The plastic limit was also decreased from 33% to 29% with 20% lime addition. Lime greatly improved the strength of the soil by decreasing the plasticity index of the soil. PI value continuously decreased from 39% to 16% for 0% lime content and 20% lime content respectively. The PI value decreased by 59% with a 20% lime addition. Hence lime improved the properties of the soil by decreasing swelling and shrinkage potential of the soil. Figure 4.2, 4.3, and 4.4 shows the relationship between lime content and liquid limit, lime content and plastic limit, and lime content and plasticity index respectively.

From the previous study of [7] the following results were obtained. Liquid limit continuously decreased with increasing lime content similarly as it was in this study. It decreased from 47.33% for natural soil to 26.87% for 20% lime addition. However, the plastic limit continuously increased from 17.45% to 20.65% with a 20% lime addition. Plasticity index was also decreased from 29.88% to 6.22% with 20% lime addition.

Table 4.6: Laboratory test result of atterberg limit test for natural soils

S.N	Sample Source	LL (%)	PL (%)	PI (%)	ERA requirement for PI	Remark
1	Shenen Gibe	72	33	39	<30	Poor
2	Kochi	76	37	39	<30	Poor
3	Kito	70	35	35	<30	Poor

Table 4.7: Effect of lime on atterberg limit

S.N	Sample Source	Lime Content														
		0%			5%			10%			15%			20%		
		LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)
1	Shenen Gibe	72	33	39	60	32	28	52	30	22	49	29	20	45	29	16

4.1.6 Effect of Lime on Specific Gravity

The specific gravity conducted for natural soil is 2.63. As it is shown in table 4.8, specific gravity generally decreased with the increase of lime content. It decreased from 2.63 to 2.57 for addition of 20% lime. This shows that expansive soil has relatively higher specific gravity compared to lime. The relationship between lime content and specific gravity was shown in figure 4.5.

Table 4.8: Effect of lime on specific gravity

Lime Content (%)	0	5	10	15	20
Specific Gravity	2.63	2.6	2.59	2.57	2.57

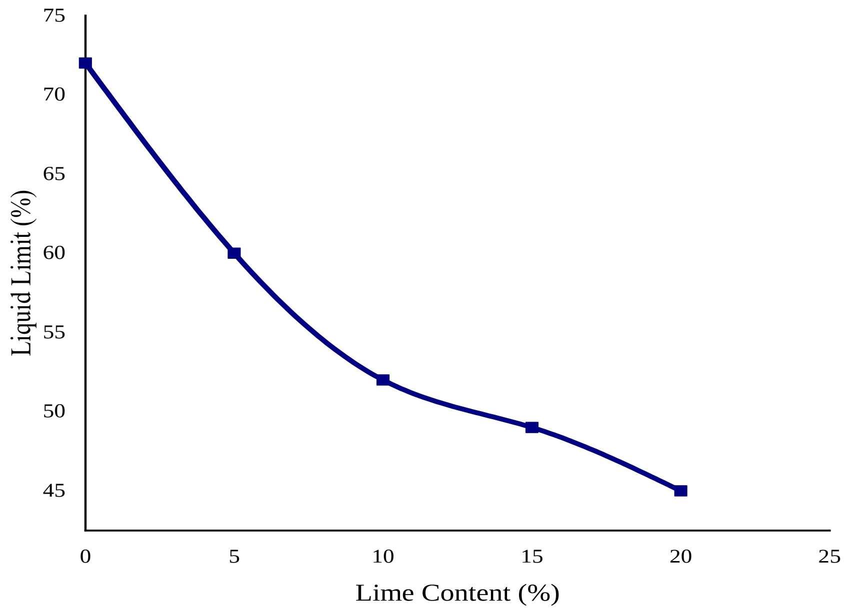


Figure 4.2: Effect of lime on Liquid limit

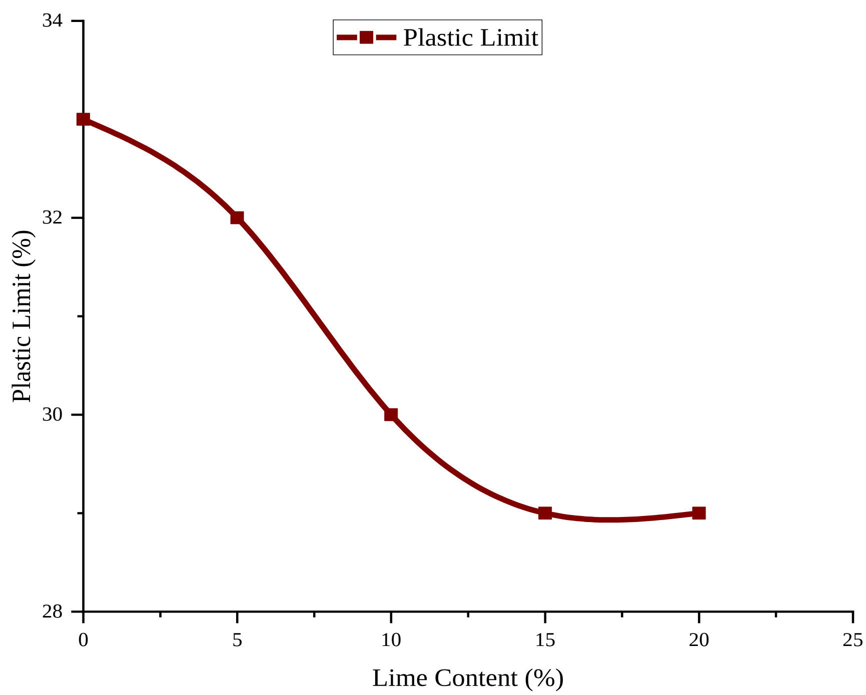


Figure 4.3: Effect of lime on Plastic limit

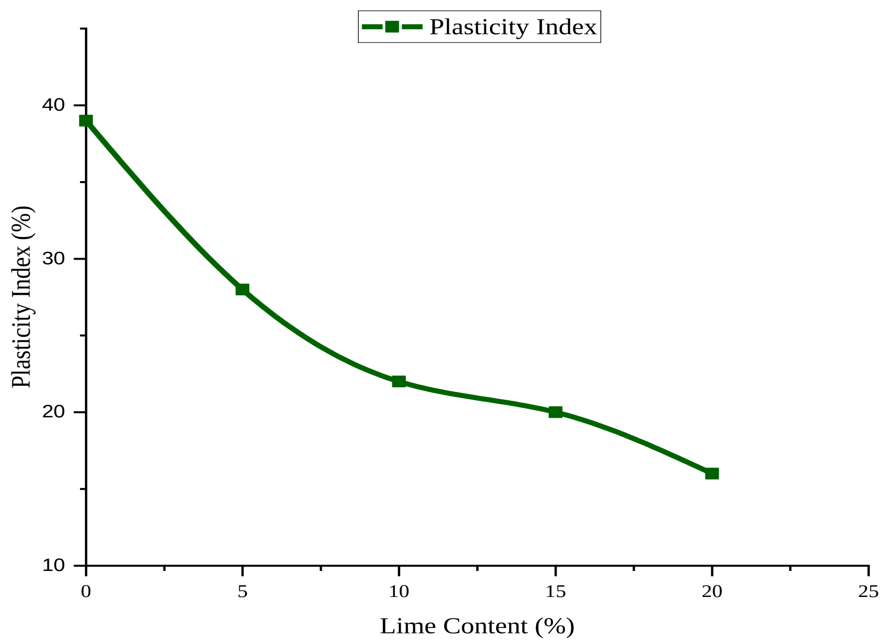


Figure 4.4: Effect of lime on Plasticity Index

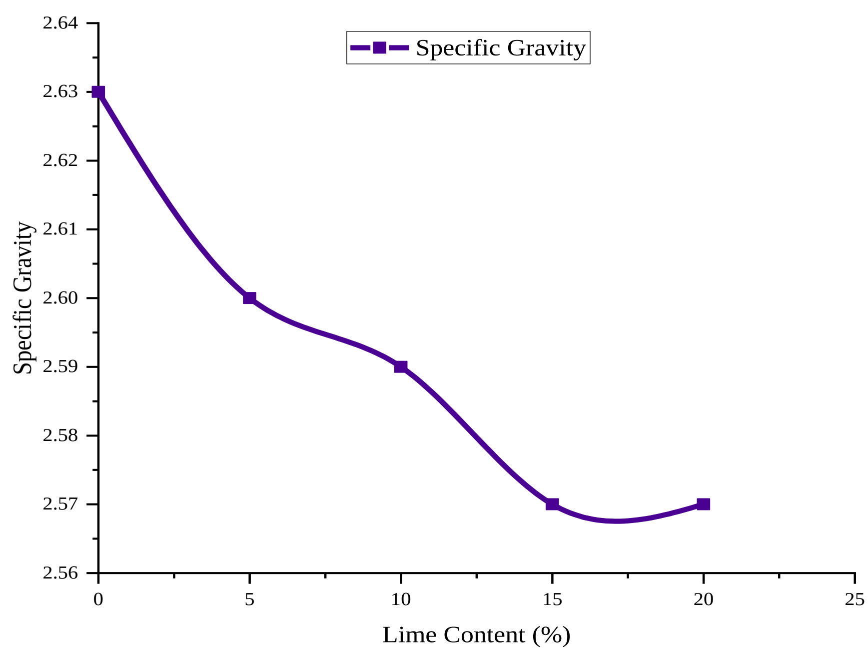


Figure 4.5: Effect of lime on specific gravity

4.1.7 Effect of Lime on Free Swell Index

Free swell test is used to know the expansiveness of the soil. Free swell index of natural soil is 109%. With this result the natural soil is classified under highly expansive soil. As it is clearly observed from table 4.9 with the increase of lime content in expansive soil, the free swell index highly decreased. It decreased from 109% to 33% with the addition of 20% lime into expansive soil. The improvement with 20% lime addition on the free swell index is 70%. Hence lime improved the property of expansive soil by decreasing its swelling and shrinkage potential. The relationship of lime content with free swell was also shown in figure 4.6.

Table 4.9: Effect of lime on free swell index

Lime Content (%)	0	5	10	15	20
FSI (%)	109	67	42	36	33

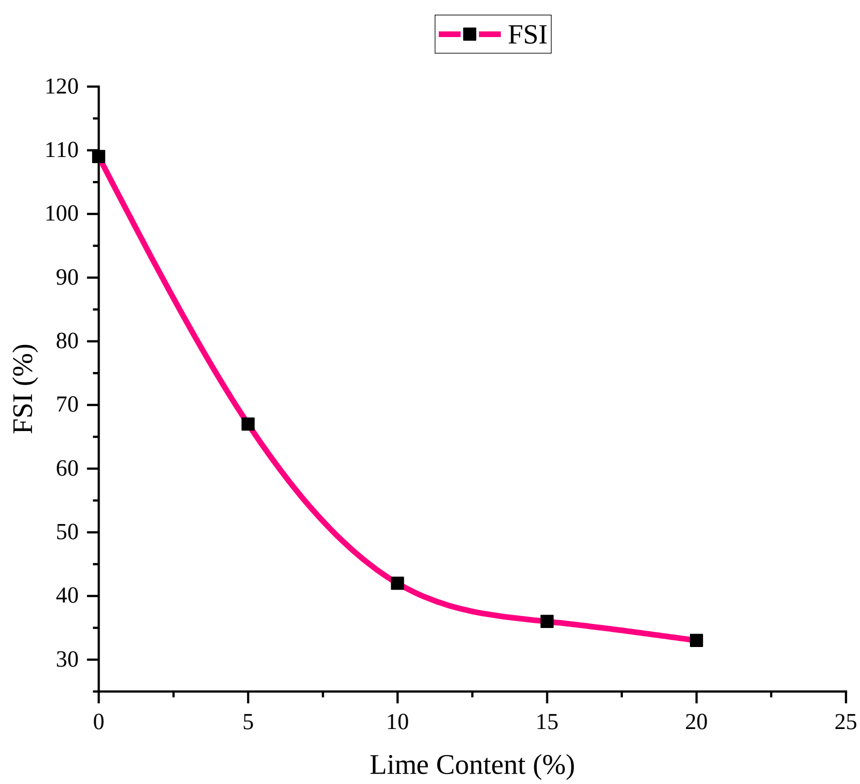


Figure 4.6: Effect of lime on FSI

4.1.8 Effect of Lime on Compaction Characteristics

Compaction test was conducted to correlate Optimum Moisture Content and Maximum Dry Density. Table 4.10 shows that the addition of lime to the expansive soil changed the moisture content firstly by decreasing from 23.5 % to 23.3 % & 23.0% with the addition of 5% and 10% lime respectively. Then the OMC starts increasing with more lime addition to 24.0% and 24.5% with 15% and 20% lime addition. MDD of expansive soil increased from 1.417 to 1.42 and 1.423 with 5% and 10% lime addition respectively. It then starts decreasing to 1.413 and 1.408 with 15% and 20% lime addition. The decrease in MDD is due to an increase in OMC with the addition of lime content. Hence lime improved Engineering property of the soil by increasing its density. Figure 4.7 shows relationship between lime content with OMC and MDD.

From a previous study of [7], MDD decreased until 10% lime addition. After that, it started increasing with further lime addition. OMC increased with increasing lime content, but after a 10% lime addition, it started decreasing.

Figure 4.7: Effect of lime on compaction characteristics

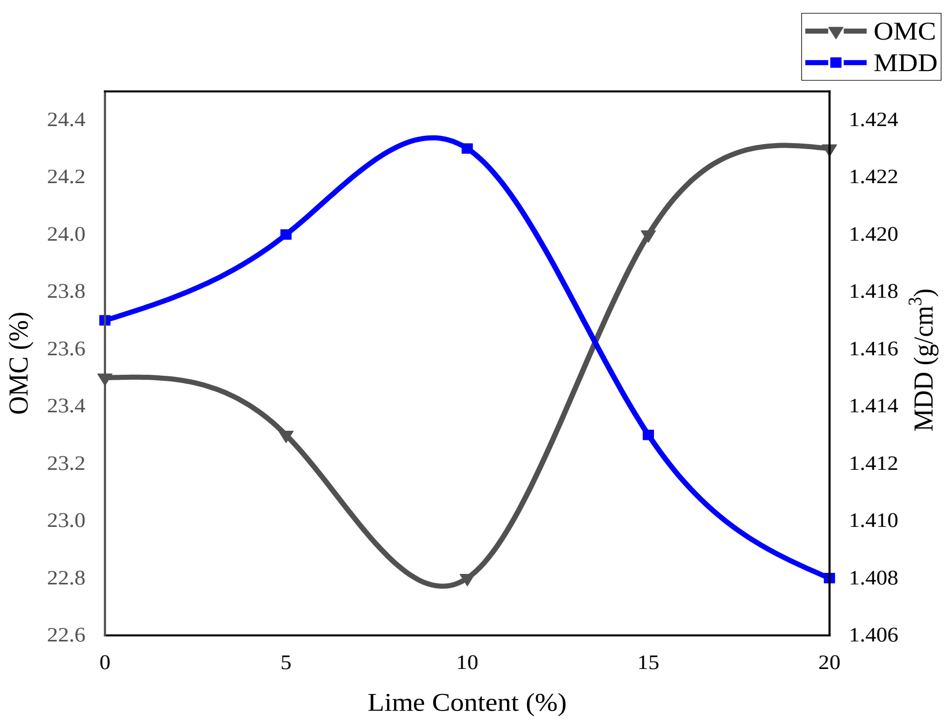


Table 4.10: Effect of lime on OMC and MDD

S.N	Sample Source	Lime content (%)									
		0		5		10		15		20	
		OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)
1	Shenen Gibe	23.5	1.417	23.3	1.420	22.8	1.423	24	1.413	24.3	1.408

4.1.9 California Bearing Ratio (CBR)

It is very important to analyze the bearing capacity of the soil and whether it satisfies the required design standard for all causes. As can be seen from Table 4.11 the CBR result of expansive soil obtained from laboratory test results is 1.27%. This result cannot fulfill the ERA pavement design manual 2013 requirement for subgrade construction. Hence the expansive soil needs improvement to be used for subgrade in road construction.

A soaked CBR test was conducted to study the effect of lime on expansive soil. From the laboratory test result obtained it is found that CBR value increased as lime content increased and then decreased at 15% and 20% lime content. It increased from 1.27% to 6.51% with a 5% lime addition. With the addition of 10% lime, the CBR value increased to 9.72%, and with the addition of 15% & 20% lime, the CBR value decreased to 9.13 & 6.98 respectively. Hence, the optimum amount of lime used to stabilize the soil is 10%. With a 10% optimum amount of lime, the CBR value was improved by 845%. The decrease of CBR value with further addition of lime is due to the reduction of weight volume of the soil because pores are filled with lime which results reduction in penetration. The relationship between lime content with CBR and CBR swell was shown in figure 4.8.

In a previous study of [7] CBR test conducted it was observed that the maximum CBR value was obtained with 10% lime content which increased the CBR value from 6.29% to 8.75%.

The result obtained at 10% lime fulfills ERA pavement design manual for subgrade with subgrade class of S4. According to this research design, 10% of lime was used for studying the effect of adding BHA which was discussed in section 4.2.

Table 4.11: Effect of lime on California bearing ratio (CBR)

	No of Blows	Pen (mm)	Load (KN)	Corrected CBR (%)	Max Cor. CBR (%)	Max CBR @ 95% MDD	CBR Swell
Natural soil (Expansive Soil)	10 Blows	2.54	0.10	0.76	0.76	1.27	11.93
		5.08	0.14	0.68			
	30 Blows	2.54	0.13	0.95	0.95		15.95
		5.08	0.18	0.86			
	65 Blows	2.54	0.18	1.33	1.33		16.03
		5.08	0.24	1.15			
Natural soil + 5% lime	10 Blows	2.54	0.48	3.65	3.65	6.51	11.64
		5.08	0.58	2.80			
	30 Blows	2.54	0.76	5.74	5.74		11.70
		5.08	0.92	4.44			
	65 Blows	2.54	0.91	6.86	6.86		12.47
		5.08	1.20	5.84			
Natural soil + 10% lime	10 Blows	2.54	0.85	6.45	6.45	9.72	10.09
		5.08	1.28	6.22			
	30 Blows	2.54	1.16	8.80	8.80		9.62
		5.08	1.64	7.98			
	65 Blows	2.54	1.35	10.23	10.23		8.49
		5.08	1.98	9.66			
Natural soil + 15% lime	10 Blows	2.54	0.84	6.36	6.60	9.13	8.30
		5.08	1.36	6.60			
	30 Blows	2.54	1.02	7.73	7.98		8.71
		5.08	1.64	7.98			
	65 Blows	2.54	1.22	9.24	9.61		9.08
		5.08	1.98	9.61			

Natural soil + 20% lime	10 Blows	2.54	0.70	5.30	5.66	6.98	6.89
		5.08	1.16	5.66			
	30 Blows	2.54	0.84	6.36	6.46		7.13
		5.08	1.33	6.46			
	65 Blows	2.54	0.97	7.35	7.35		7.33
		5.08	1.48	7.18			

Table 4.12: Lime content Vs CBR value

Lime Content (%)	0	5	10	15	20
MDD (g/cm^3)	1.417	1.418	1.423	1.413	1.408
CBR @95% of MDD (%)	1.27	6.51	9.72	9.13	6.98
CBR Swell (%)	14.64	12.51	9.4	8.7	7.12

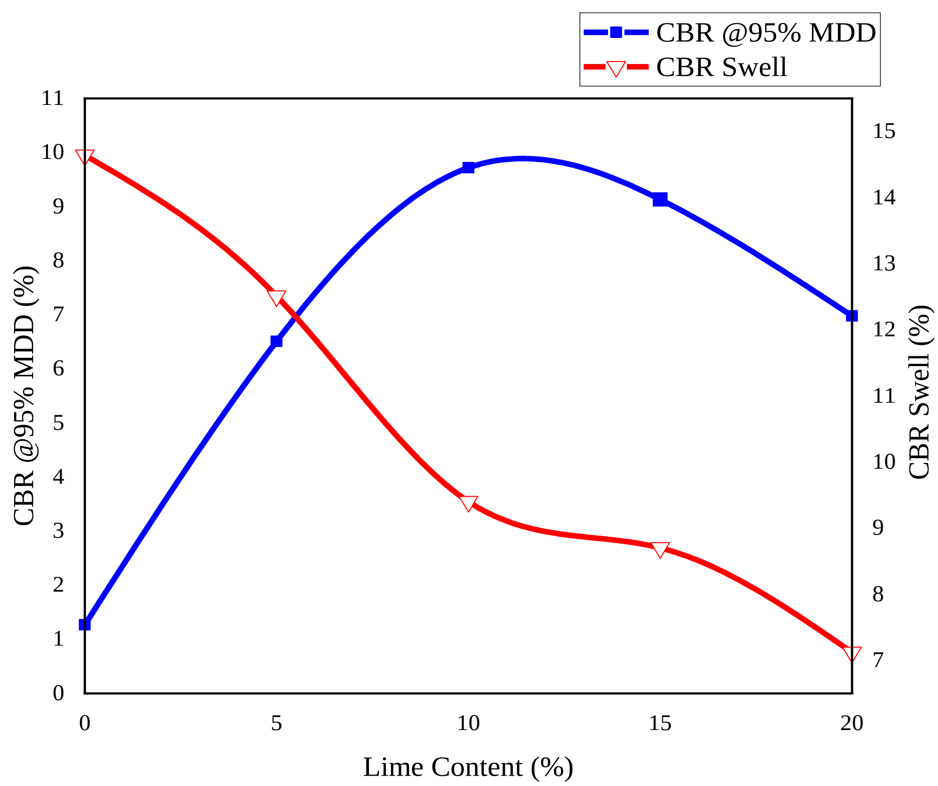


Figure 4.8: Effect of lime on CBR value @95% MDD and CBR swell

4.1.10 Unconfined Compressive Strength

Laboratory test was conducted for natural soil and different percentage additions of lime. For natural soil, the test was done for 0 days or an immediate test. For the addition of lime percentage two tests were conducted both for 0 days and 7 days of curing time. As shown in table 4.13 UCS results for 0 days show that cohesion (C) value increased from 65kpa to 120kpa for 5% lime addition. Then cohesion value continuously decreased with further lime addition. For 7 days curing test the UCS result shows increasing in cohesion from 65kpa to 124kpa and 137kpa for 5% and 10% lime addition respectively. For further addition of lime, the UCS result shows decreasing in cohesion. Hence optimum lime content to be used is 10%. With this optimum amount of lime UCS value had been improved by 111%.

Table 4.13: Effect of lime on UCS value

Lime content (%)		0	5	10	15	20
0 Day	Peak UCS value (kpa)	130	241	126	94	55
	Cohession, C (kpa)	65	120	63	47	28
7 Days	Peak UCS value (kpa)	130	248	274	212	95
	Cohession, C (kpa)	65	124	137	106	48

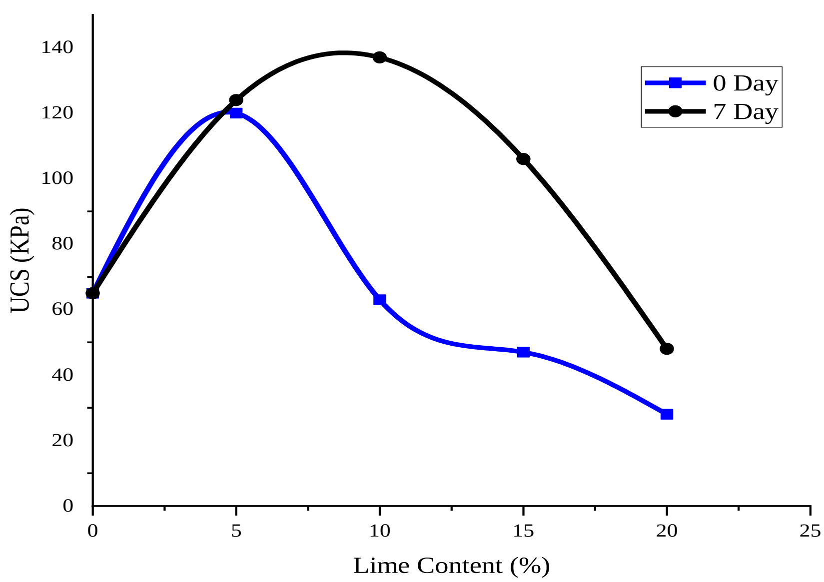
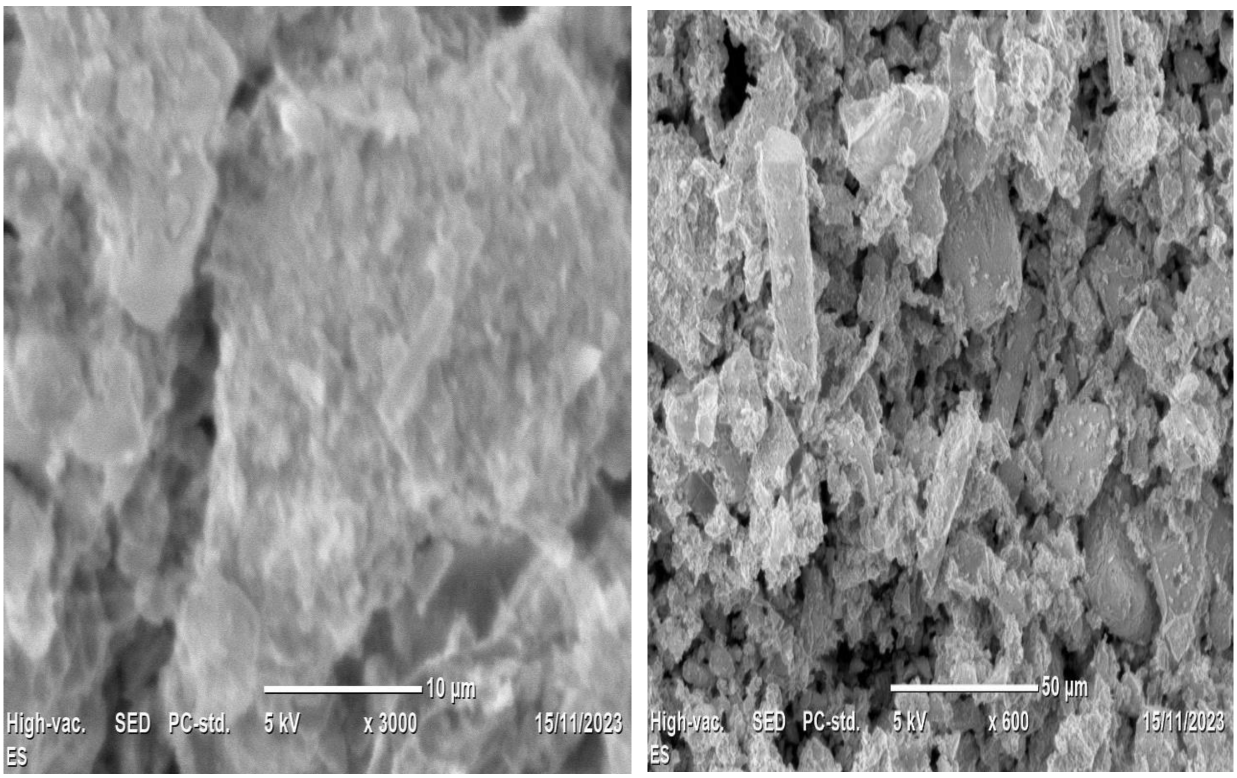


Figure 4.9: Effect of lime on UCS value

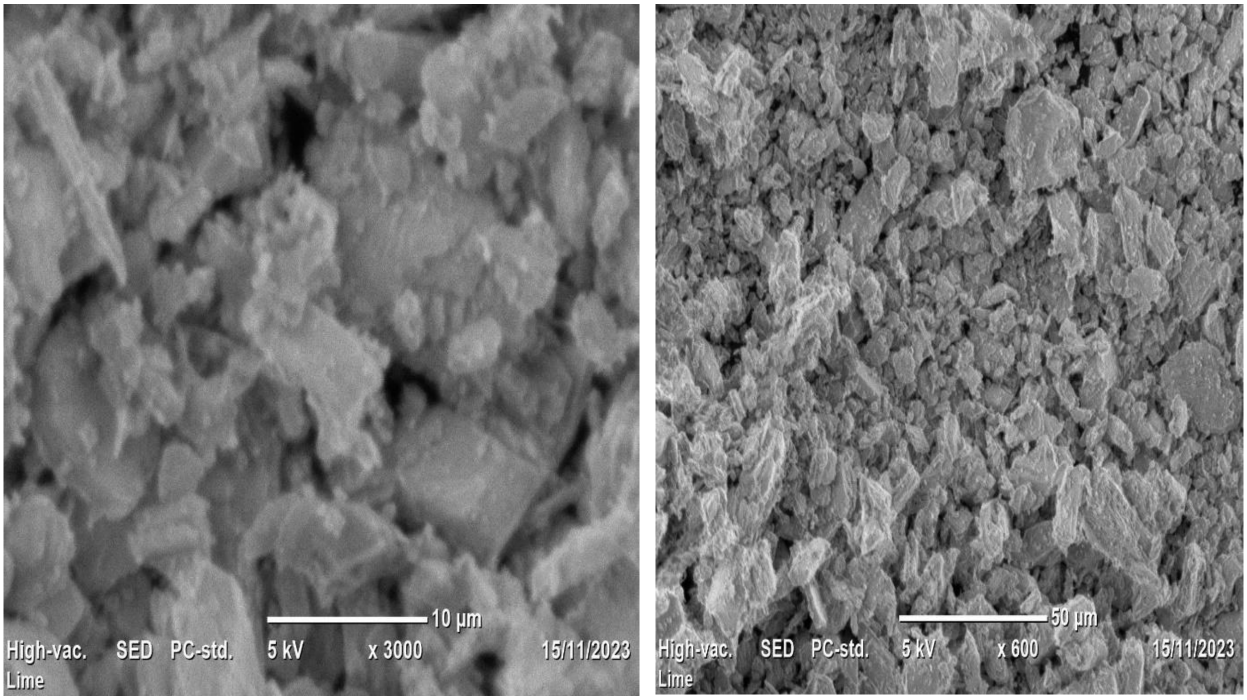
4.1.11 Effect of Lime on Microstructure

To understand how the microstructure of the soil is changed, an SEM examination was conducted on expansive soil, lime, and 10% lime + 90% expansive soil. Two different scales of micrograph 10µm and 50µm were used to describe the microstructure of the samples as indicated in figures 4.10, 4.11, and 4.12. As indicated in Figure 4.12 the soil treated with 10% lime shows less void and is densely spaced compared to untreated soil. Hence lime improved the property of the soil by increasing the density of the soil.



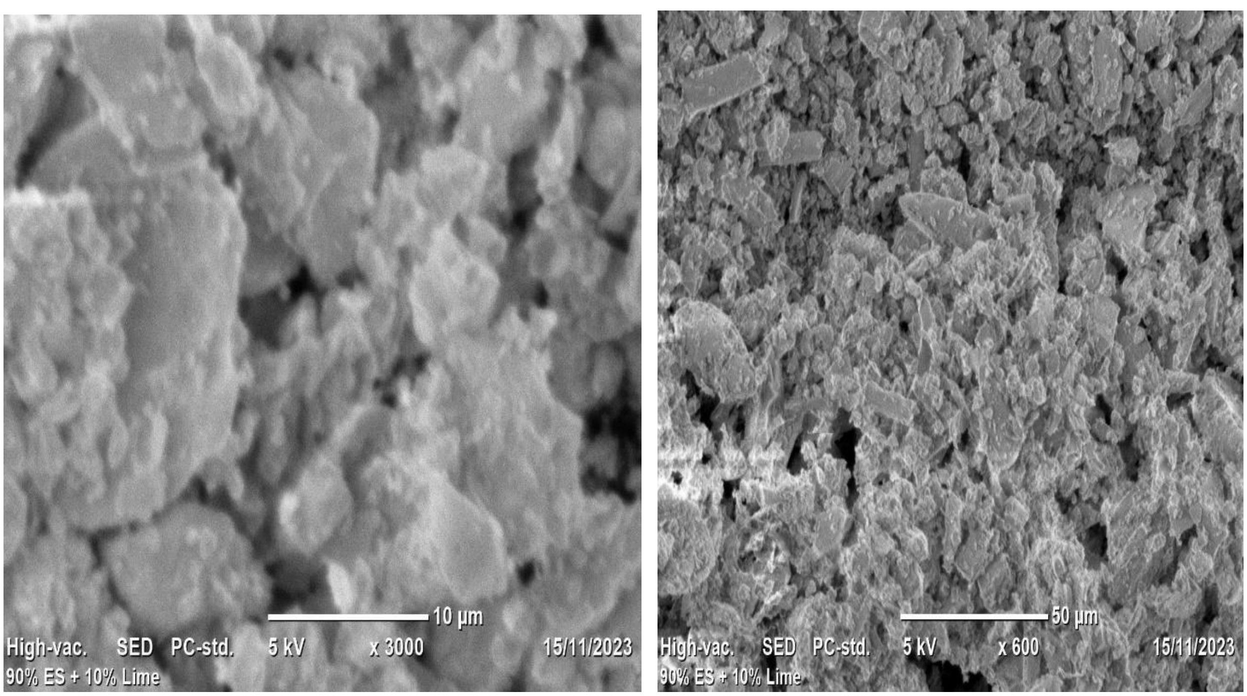
a) High magnification b) Low magnification

Figure 4.10: SEM photograph of expansive soil



a) High magnification b) Low magnification

Figure 4.11: SEM photograph of lime



a) High magnification b) Low magnification

Figure 4.12: SEM photograph of Optimum lime and expansive soil

4.2 Effect of BHA on Engineering and Physical Properties

In this section, all tests that have been conducted with lime are again conducted by using the optimum amount of lime and varying amounts of BHA to check the effect of adding BHA on the physical and engineering properties of the soil.

4.2.1 Atterber Limit

BHA was added to the optimum content of lime to study its effect on the Atterberg limit. Complete results are tabulated in Table 4.14 below. BHA addition on optimum lime showed decreasing in the Liquid limit. It decreased the Liquid limit from 52% to 47% with 0% BHA addition and 20% BHA addition respectively. Hence Liquid limit decreased by 9.6%. This result shows BHA increased the Engineering properties of the soil by decreasing the Liquid limit. As BHA content added on optimum lime increases plastic limit showed generally increasing. Plastic limit generally increased from 30% for 0% BHA to 33% for 20% BHA content. PI decreased from 21% to 14% for 0% BHA and 20% BHA content respectively. Hence the addition of BHA to optimum lime content has further decreased the swelling and shrinkage potential of the soil by decreasing PI. PI value with addition of 20% BHA into optimum lime has decreased by 36%. According to ERA Manual all results obtained with 5%, 10%, 15%, and 20% BHA content fulfills the requirement of LL<60 and PI<30. To obtain optimum amount of BHA other test results can be considered. Figure 4.13, 4.14, and 4.15 shows the relationship between BHA content and liquid limit, plastic limit, and plasticity index respectively.

Table 4.14: Effect of BHA on Atterbrg's limit

Atterberg's Limit Vs BHA Content					
BHA Content (%)	0	5	10	15	20
Liquid Limit (LL)	52.0	51.0	49.0	47.0	47.0
Plastic Limit (PL)	30	30	31	31	33
Plasticity Index (PI)	22.0	21.0	18.0	17.0	14.0

4.2.2 Specific Gravity

BHA is mixed with the optimum amount of lime i.e. 10% which has a specific gravity of 2.59. As it is clearly observed from table 4.15 specific gravity generally decreased with increasing BHA content. It decreased continuously to 2.42, 2.25, 2.03, and 1.93 with 5%, 10%, 15% and 20% BHA content respectively. This shows that BHA has much lower specific gravity compared to expansive soil. Figure 4.16 shows the relationship of BHA content with specific gravity.

Table 4.15: Effect of BHA on specific gravity

BHA Content (%)	0	5	10	15	20
Specific Gravity	2.59	2.42	2.25	2.03	1.93

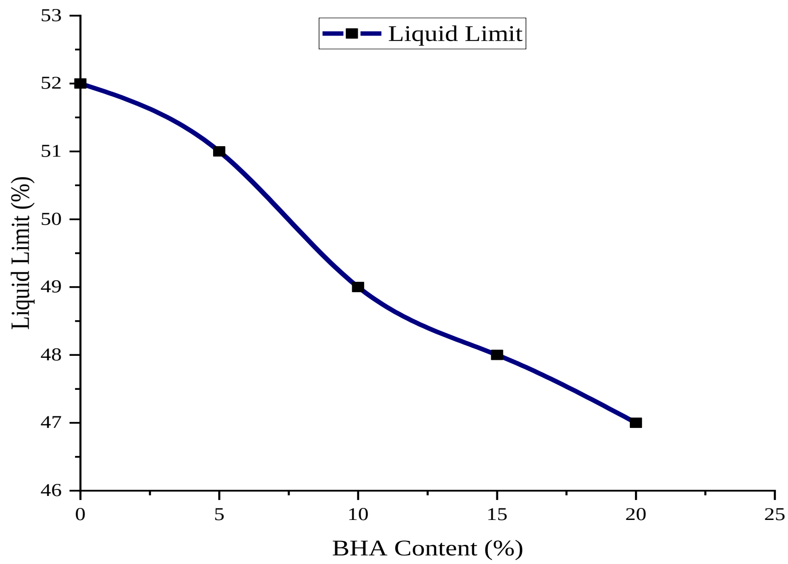


Figure 4.13: Effect of BHA on Liquid limit

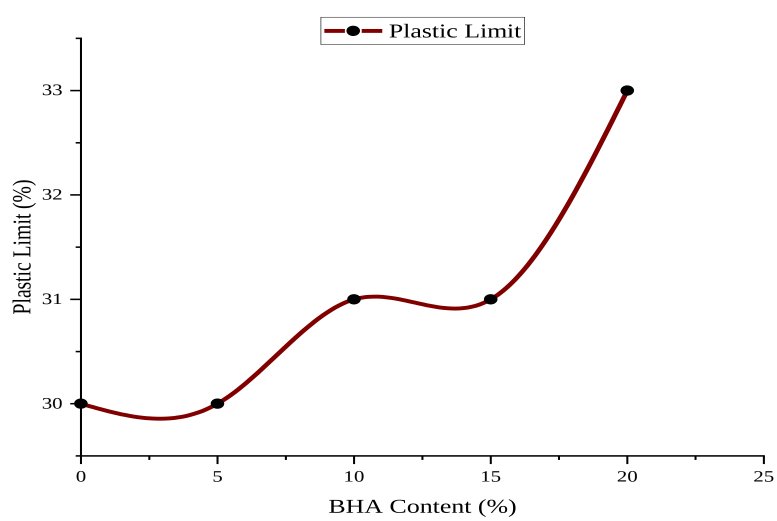


Figure 4.14: Effect of BHA on Plastic limit

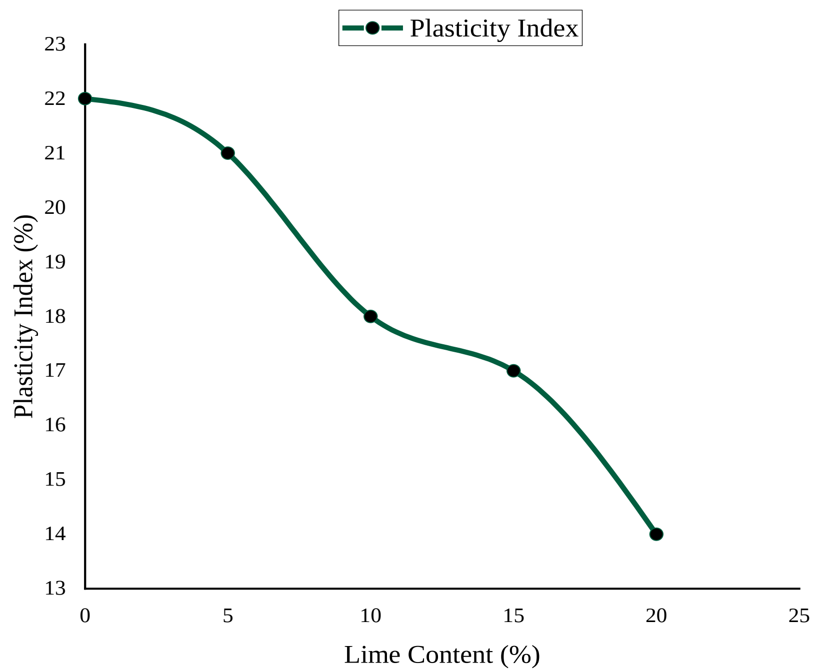


Figure 4.15: Effect of BHA on Plasticity Index

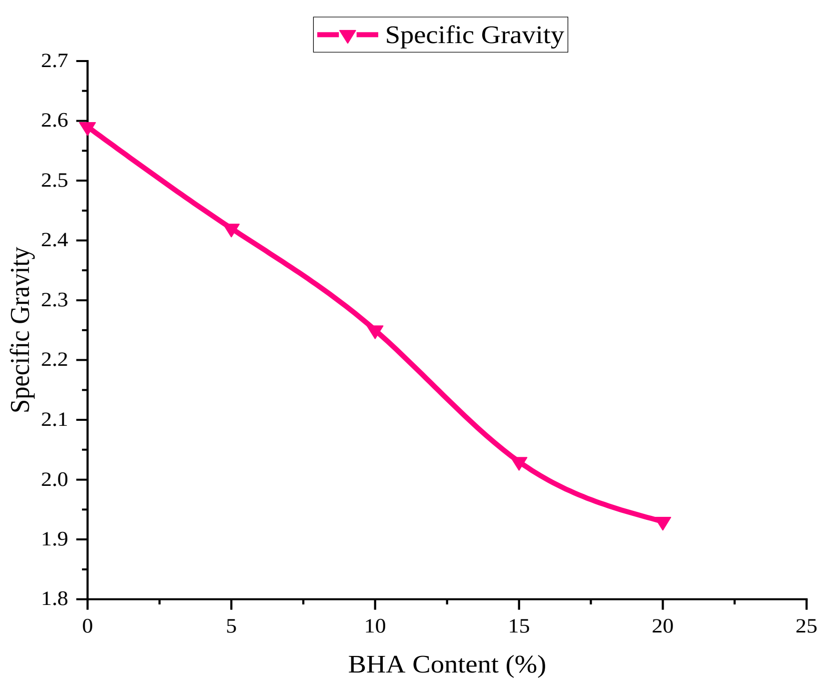


Figure 4.16: Effect of BHA on Specific gravity

4.2.3 Free Swell Index

Expansive soil and the optimum amount of lime are mixed with 0%, 5%, 10%, 15%, and 20% of BHA to check the effect of BHA on the free swell index. The free swell index for all proportions is tabulated in Table 4.16 below. The addition of BHA to the optimum amount of lime and expansive soil has further decreased the swelling and shrinkage potential of the expansive soil. With 20% of BHA addition, FSI has decreased by 40%.

Table 4.16: Effect of BHA on free swell index

BHA Content (%)	0	5	10	15	20
FSI (%)	42	43	33	27	25

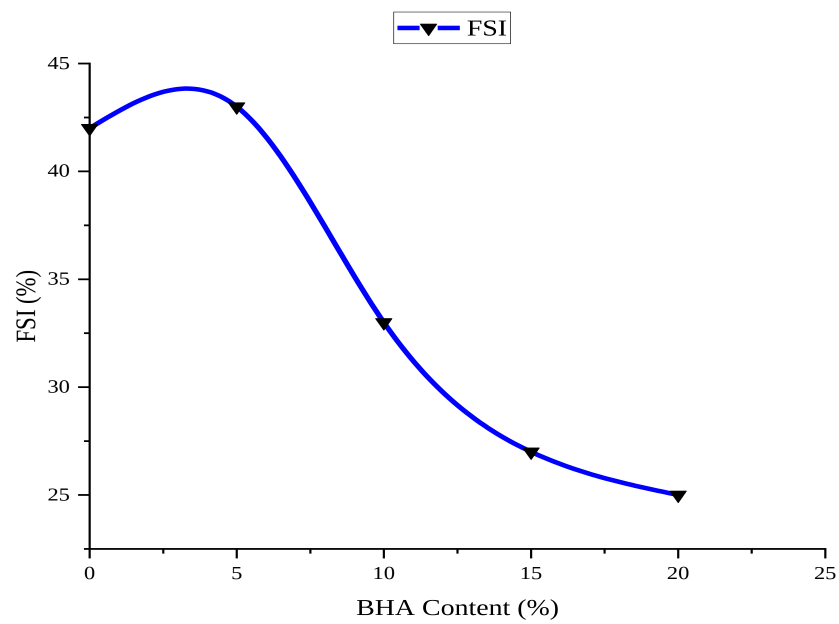


Figure 4.17: Effect of BHA on free swell index

4.2.4 Compaction Test

As is observed from Table 4.17, with an increase in BHA content, moisture content continuously increased from 22.7% to 29.4% for 0% BHA and 20% BHA respectively. MDD continuously decreased from 1.422g/cm3 to 1.165g/cm3 for 0% and 20% BHA content respectively. Hence BHA has an effect in increasing moisture content and decreasing MDD. Decreasing in MDD is due to the lower specific gravity of BHA compared to lime and expansive soil.

According to a previous study of 'M. Aluga, N. Chilukwa, and N. Lushinga, "Potentials of Common Thatching Grass Ash (CTGA) and Barley Husk Ash (BHA) for Soil Stabilization in Road Construction," [1] MDD continuously decreased from 2020Kg/m^3 to 1970kg/m^3 for 9% BHA addition and OMC increased from 9.2% to 10.4% for 9% BHA addition into natural soil.

Table 4.17: Effect of BHA on OMC and MDD

BHA Content (%)	**0**	**5**	**10**	**15**	**20**
OMC (%)	22.8	25.0	27.2	28	29.4
MDD (g/cm^3)	1.423	1.360	1.315	1.264	1.22

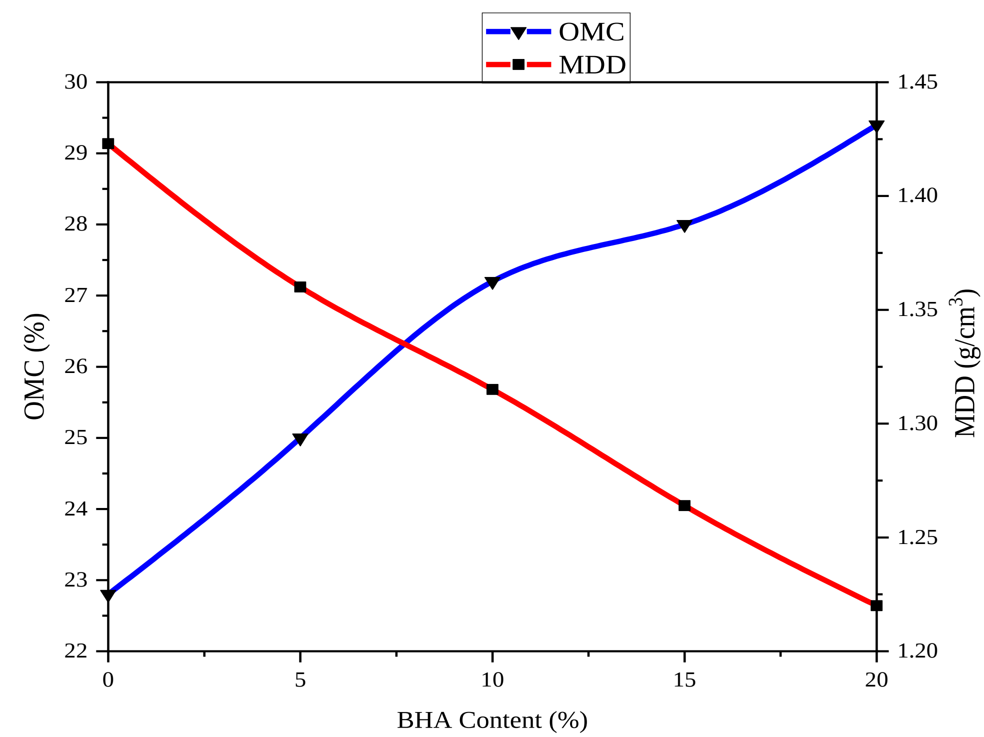


Figure 4.18: Effect of BHA on compaction characteristics

4.2.5 California Bearing Ratio (CBR)

With the increase in BHA content to optimum lime firstly increased and with further addition of BHA it decreased. The increment in CBR value can be attributed to the gradual formation of cementitious material with BHA and CaOH contained in soil and lime. Maximum soaked CBR value was obtained at optimum lime and 10% BHA content with a CBR value of 18.42% which increased CBR value by 89.5%. Due to maximum CBR result percentage of BHA that is used with optimum lime is 10%. According to ERA pavement design manual, the subgrade soil with 18.42% CBR is classified into the subgrade class of S5. An increase in subgrade class decreases the thickness of top layer pavements which in turn reduces the cost of pavement construction.

From a previous study [1] CBR for 100% MOD has increased from 38% to 80% with the addition of 9% BHA into natural soil.

Table 4.18: Effect of BHA on California Bearing Ratio

	No of Blows	Pen (mm)	Load (KN)	Corrected CBR (%)	Max CBR (%)	Max CBR @ 95% MDD	CBR Swell
Opt. Lime + Natural soil (10%lime + 90% Natural soil)	10 Blows	2.54	0.85	6.45	6.45	9.72	10.09
		5.08	1.28	6.22			
	30 Blows	2.54	1.16	8.80	8.80		9.62
		5.08	1.64	7.98			
	65 Blows	2.54	1.35	10.23	10.23		8.49
		5.08	1.98	9.66			
10% lime + 5% BHA + 85% Natural soil	10 Blows	2.54	0.55	4.17	4.17	7.10	8.90
		5.08	0.80	3.88			
	30 Blows	2.54	0.76	5.74	5.74		9.54
		5.08	1.12	5.46			
	65 Blows	2.54	0.99	7.47	7.47		9.42
		5.08	1.46	7.11			
10% lime + 10% BHA + 80% Natural soil	10 Blows	2.54	1.27	9.62	9.62	18.42	3.72
		5.08	1.98	9.61			
	30 Blows	2.54	1.84	13.94	15.00		2.16
		5.08	3.09	15.00			
	65 Blows	2.54	2.56	19.39	19.39		6.30
		5.08	3.98	19.32			
10% lime + 15% BHA + 75% Natural soil	10 Blows	2.54	0.93	7.05	7.60	9.85	3.40
		5.08	1.57	7.60			
	30 Blows	2.54	1.17	8.83	8.83		2.08
		5.08	1.81	8.78			
	65 Blows	2.54	1.37	10.36	10.36		6.13
		5.08	2.08	10.10			

10% lime + 20% BHA + 70% Natural soil	10 Blows	2.54	0.62	4.69	4.69	6.77	2.59
		5.08	0.83	4.00			
	30 Blows	2.54	0.84	6.33	6.33		3.04
		5.08	1.13	5.46			
	65 Blows	2.54	0.94	7.12	7.12		5.35
		5.08	1.26	6.12			

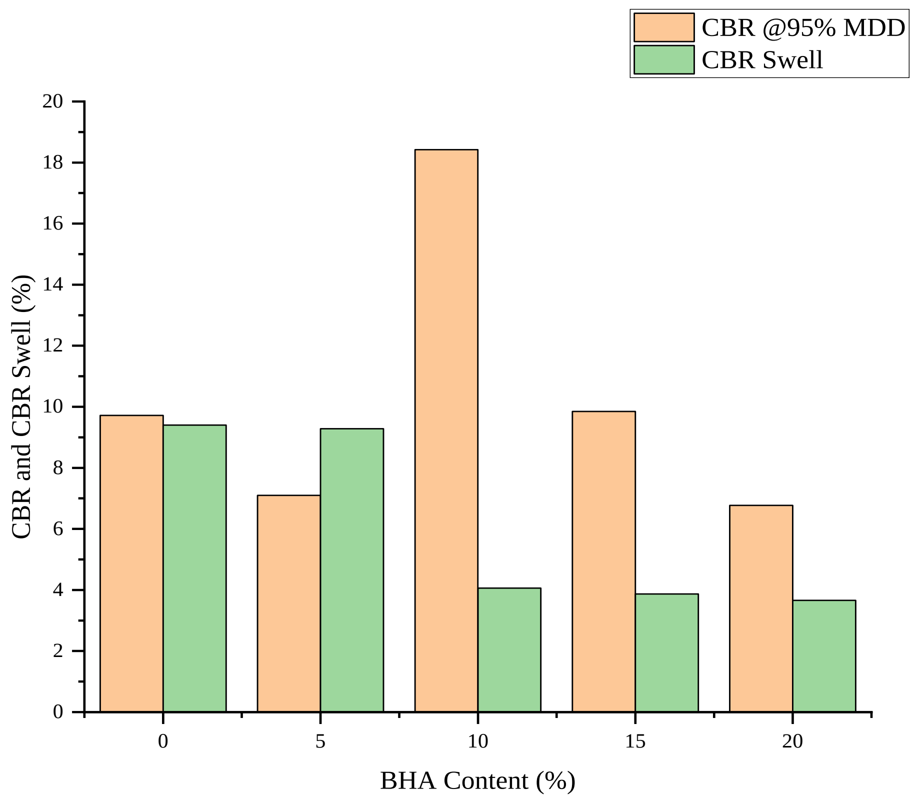


Figure 4.19: Effect of BHA on CBR and CBR swell

4.2.6 Unconfined Compressive Strength (UCS)

From Table 4.15 it can be observed that UCS value generally decreased with increasing BHA content for both 7 days and 0 days (immediate). The cohesion of the soil (c) decreased from 63 kpa for optimum lime content to 30 kpa, 47 kpa, 27 kpa, and 32 kpa for 5%, 10%, 15%, and 20% BHA content respectively for 0-day test results. It also decreased from 137 kpa for optimum lime content to 117 kpa, 101 kpa, 88 kpa, and 66 kpa for 5%, 10%, 15%, and 20% BHA content for the

7-day test result. The continuous decrease of UCS results in an increase in BHA due to less amount of calcium oxide composition in BHA. Figure 4.20 shows the relationship between BHA content and UCS value.

In a previous study [1], the soil samples were cured for 7 days and soaked for 4 hours before testing for UCS, and the samples failed before testing.

Table 4.19: Test Results of UCS value with BHA Addition

Lime content (%)			**0**	**5**	**10**	**15**	**20**
UCS Value	0 Day	Peak UCS value (kpa)	126	60	93	54	64
		Cohession, C (kpa)	63	30	47	27	32
	7 Days	Peak UCS value (kpa)	274	234	202	175	132
		Cohession, C (kpa)	137	117	101	88	66

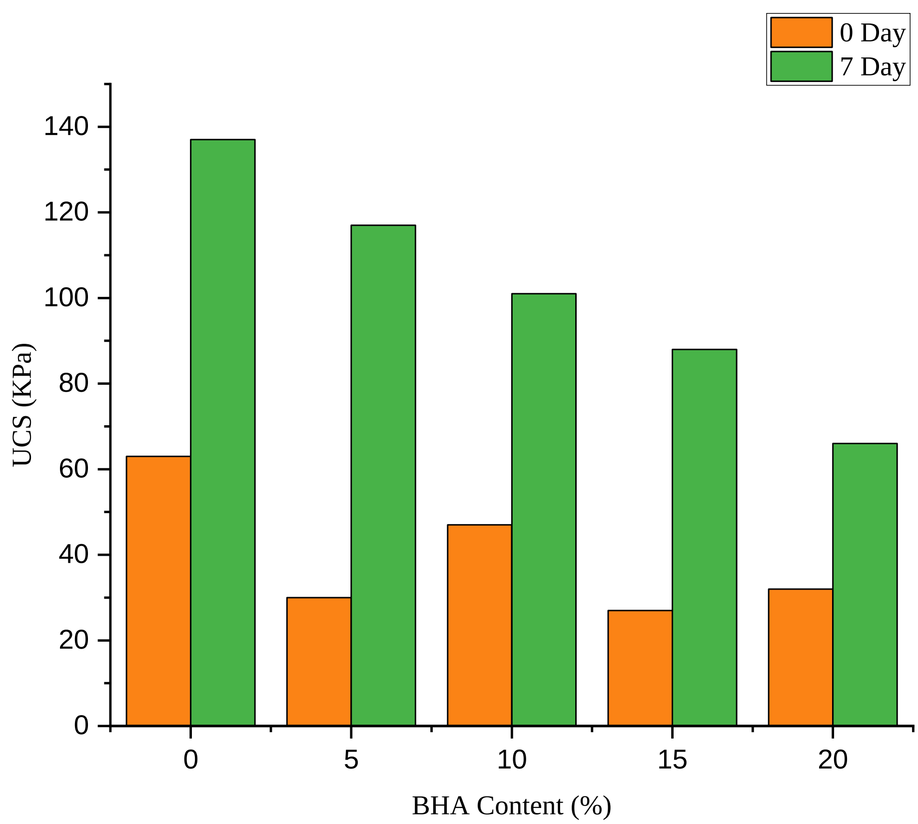
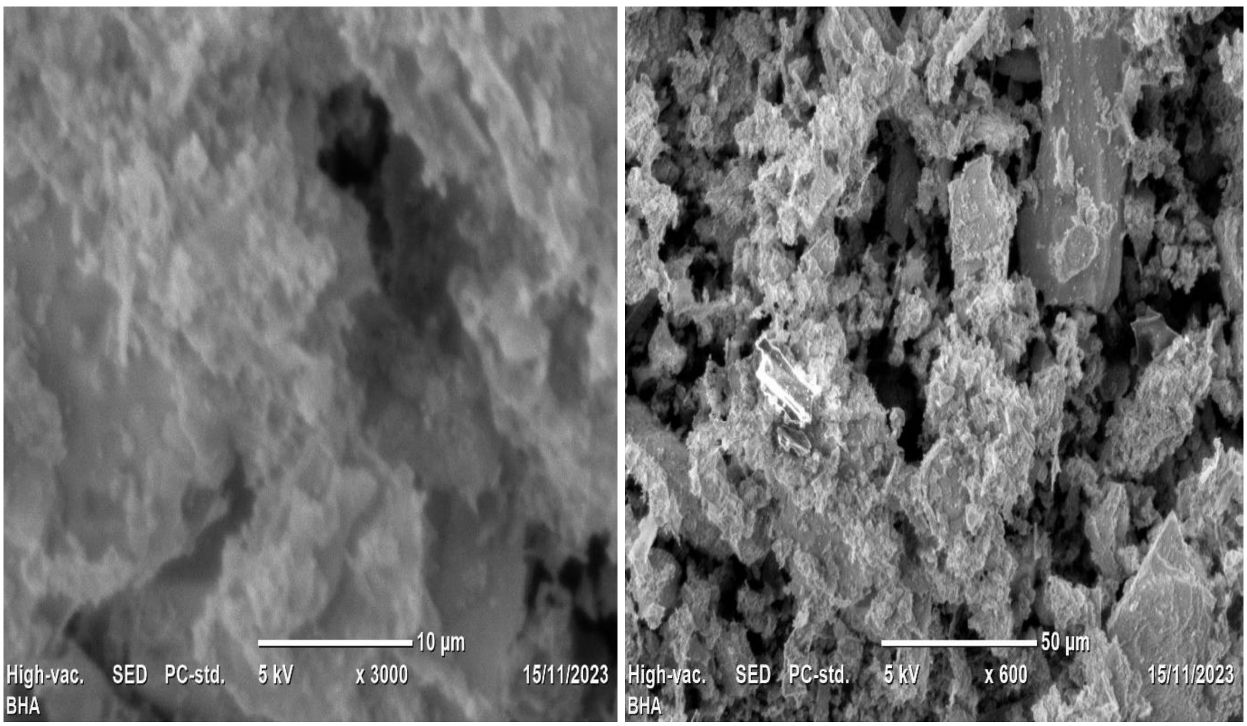


Figure 4.20: Effect of BHA on UCS value (Cohesion)

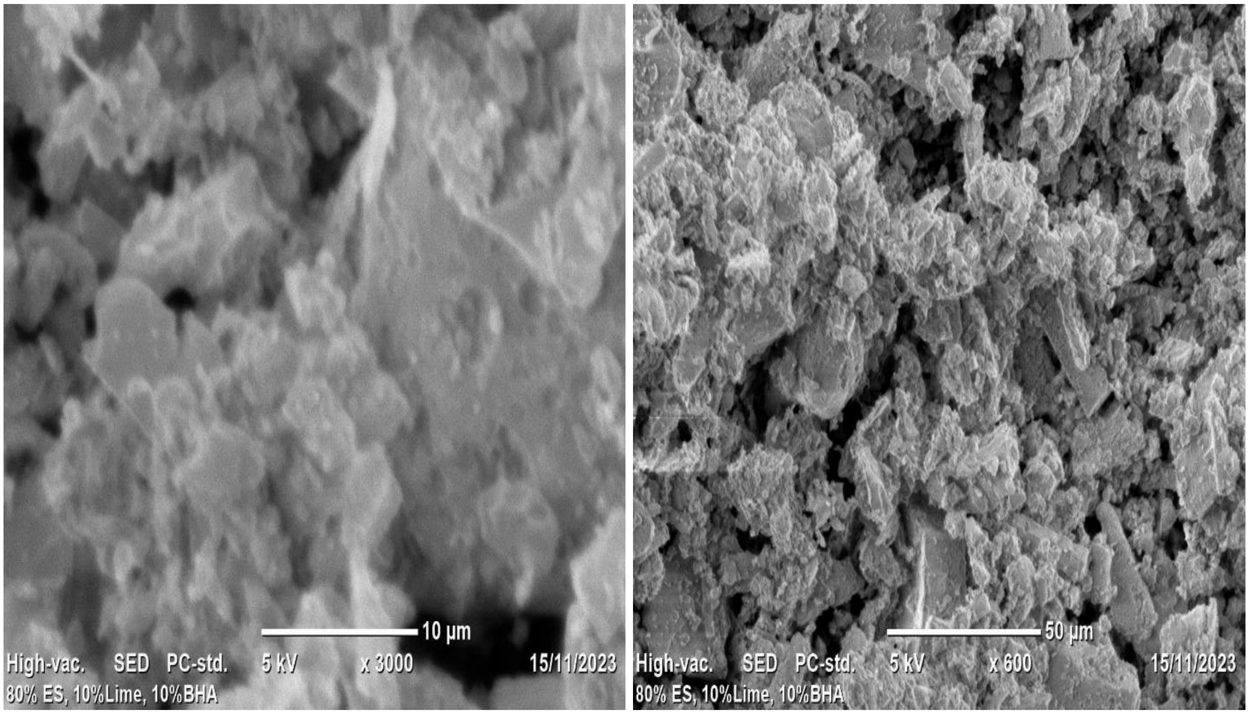
4.2.7 Effect of BHA on Microstructure

The effect of BHA addition on the microstructure of the soil was studied using an SEM micrograph. The optimum amount of lime and BHA was used for this study. From Figure 4.21 BHA particles are dispersedly spaced and contain more void which shows lower density of BHA. From Figure 4.22 it is observed that the soil treated with the optimum amount of lime and BHA shows the particles are smaller in size when compared with the soil treated with lime, but closely spaced. This shows the tendency of this blended material to form better material.



a) High Magnification b) Low magnification

Figure 4.21: SEM photograph of BHA showing its microstructure



a) High Magnification b) Low magnification

Figure 4.22: SEM photograph of 10% lime + 10% BHA + 80% ES

4.3 Summary of Results

All test results are summarized in Table 4.20 below. Atterberg limit test results and CBR test results are also shown in Figures 4.23 and 4.24 below respectively. The percentage of lime and BHA used in this study are 10% lime and 10% BHA. Laboratory test results of these percentages for; PI, LL, PL, SG, MDD, OMC, CBR, CBR Swell, FSI, and UCS are 18%, 49%, 31%, 2.25, 1.315g/cm^3, 27.2%, 18.42%, 5.27%, 33%, 101kpa.

Table 4.20: Summary of all test results

S.N	Material Description	Atterberg limit			Specific gravity	Compaction test		CBR test		FSI (%)	UCS (kpa)
		LL (%)	PL (%)	PI (%)		MDD (g/cm^3)	OMC (%)	CBR (%)	CBR Swell (%)		
1	NS	72	33	39	2.63	1.417	23.5	1.27	14.64	109	65
2	95%NS + 5%Lime	60	32	28	2.6	1.420	23.3	6.51	11.94	67	124
3	90%NS + 10%Lime	52	30	22	2.59	1.423	23.0	9.72	9.40	42	137
4	85%NS + 15%Lime	49	29	20	2.57	1.410	24.0	9.13	8.70	36	106
5	80%NS + 20%Lime	45	29	16	2.57	1.408	24.3	6.98	7.12	33	48
6	85%NS + 10%Lime + 5%BHA	51	30	21	2.42	1.360	25.0	7.10	9.28	43	117
7	80%NS + 10%Lime + 10%BHA	49	31	18	2.25	1.315	27.2	18.42	5.27	33	101
8	75%NS + 10%Lime + 15%BHA	48	31	17	2.03	1.264	28.0	9.85	3.87	27	88
9	70%NS + 10%Lime + 20%BHA	47	33	14	1.93	1.220	29.4	6.77	3.66	25	66

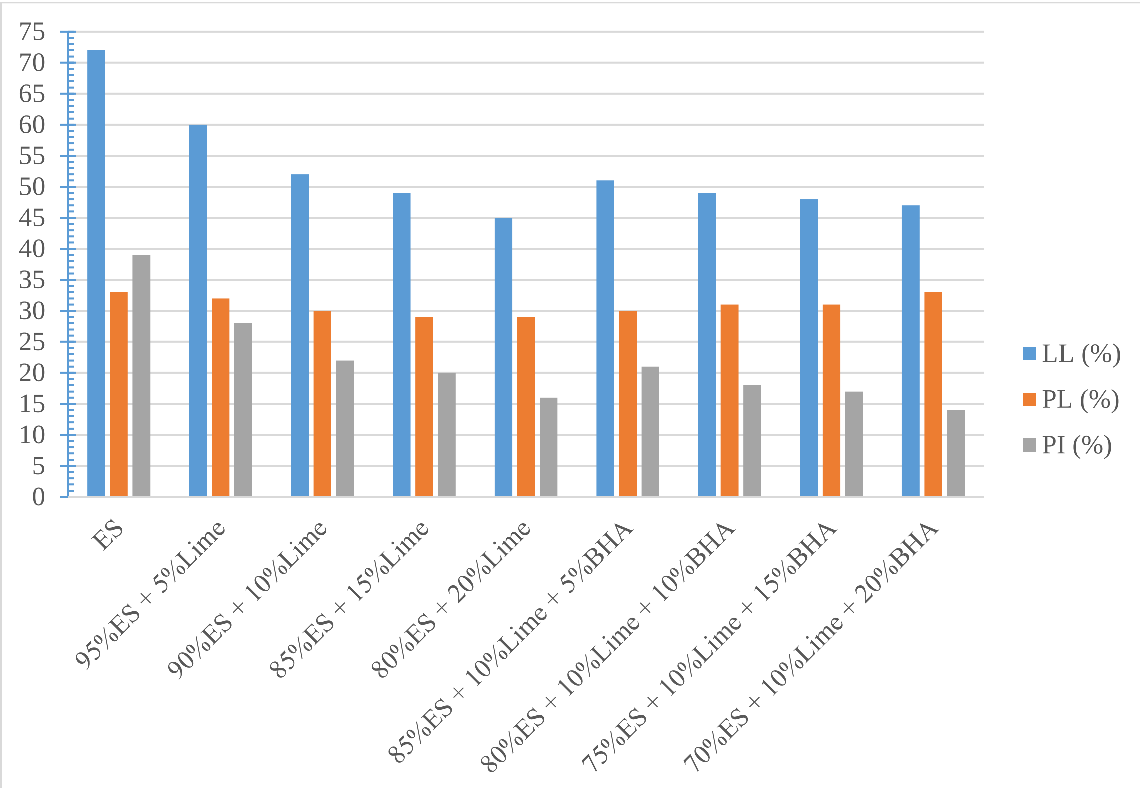


Figure 4.23: Summary of atterberg limit test results

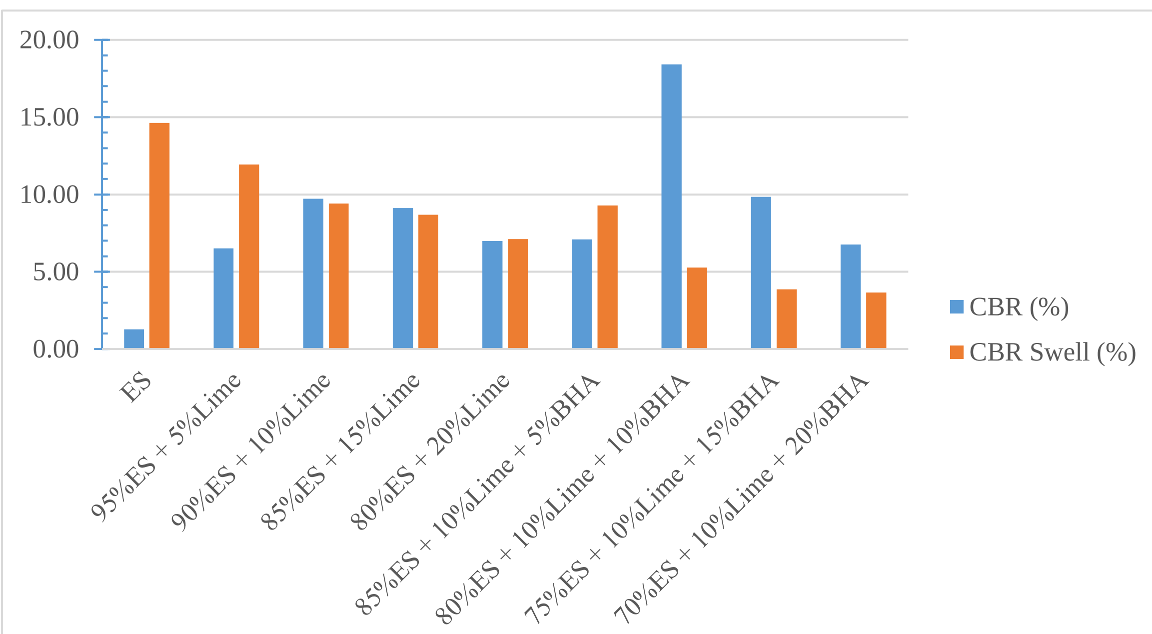


Figure 4.24: Summary of CBR test results

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the laboratory results obtained and present studies, the soil sample is highly expansive soil. Hence the expansive soil is not good (suitable) for highway subgrade construction. The following conclusions are drawn.

- The laboratory test results of expansive soil: LL, PL, PI, OMC, MDD, SG, CBR, FSI, and UCS are; 72%, 33%, 39%, 23.3%, 1.42g/cm3, 2.65, 0.8%, 109%, and 65 kpa respectively. From the laboratory test results it is observed that the soil sample is highly expansive and has low bearing capacity, hence it is not suitable for subgrade soil formation without modification.
- The optimum percentage of lime used to stabilize the soil is 10% and the optimum amount of BHA used with optimum lime is also 10%.
- The addition of 10% (opt.) lime decreased LL from 72% to 52% and increased CBR value from 1.27% to 9.72%. Addition of BHA to opt. lime content increased CBR value from 9.72% to 18.42% which increased the result by 189.5%. Whereas:
- MDD was increased from 1.417g/cm^3 to 1.423g/cm^3 for 10% lime addition and decreased from 1.423g/cm^3 to 1.315g/cm^3 for 10% addition of BHA to opt. lime. A decrease in MDD is the indication of a lower specific gravity of BHA. OMC decreased from 23.5% to 23% for the 10% addition of lime whereas it increased from 23% to 27.2% for the 10% addition of BHA to opt. lime.
- With 10% lime addition into expansive soil CBR value has increased from 1.27% to 9.72%. CBR swell also decreased from 14.64% to 9.4%. Hence strength of the soil has improved and satisfies ERA Pavement Design Manual 2013 with a subgrade class of S4.
- The addition of lime increased the UCS value of the soil. It has increased the soil cohesion from 65kpa to 137kpa with 10% lime addition. However, the addition of BHA generally decreased the cohesion of the soil. The addition of 10% BHA on optimum soil decreased

the cohesion of the soil from 137kpa to 101kpa and continuously decreased with further addition of BHA content.

- Generally addition of BHA on optimum lime content increased CBR, and OMC and decreased LL, PL, PI, MDD, FSI, CBR Swell, and UCS of expansive soil.
- The result obtained at 10% lime and 10% BHA satisfies the requirement according to ERA pavement design manual 2013 with a subgrade class of S5. Hence BHA can be used with lime for subgrade soil stabilization in partial replacement.

5.2 Recommendation

Depending on the stabilizing of expansive soil with lime and BHA, the following points were recommended.

- The effect of mixing time and drying method has to be evaluated on optimum stabilizers ratio shall be considered.
- To evaluate the interaction between soil and lime, soil and BHA, and lime & BHA detailed chemical tests should be conducted on natural soil and lime.
- To understand the economic benefit of BHA, a detailed investigation should be conducted on the production cost of BHA and compare it with common stabilizing materials in the Ethiopian context.
- Finally it is recommended that further research study would be undertaken to consider similar issues in different study areas.

REFERENCE

[1] M. Aluga, N. Chilukwa, and N. Lushinga, "Potentials of Common Thatching Grass Ash (Ctga) and Barley Husk Ash (Bha) for Soil Stabilization in Road Construction," no. November, pp. 1–16, 2017.

[2] A. T. Tessema, N. M. Wolelaw, A. E. Abebe, G. A. Alene, and B. T. Abeje, "Utilization of Coffee Husk Ash on the Geotechnical Properties of Gypsum-Stabilized Expansive Clayey Soil," *Adv. Civ. Eng.*, vol. 2023, pp. 1–13, 2023, doi: 10.1155/2023/3101774.

[3] S. A. L. K. G. Gyanen. Takhelmayum, "Soil Stabilization By Fly Ash," *Int. J. Eng. Sci. Innov. Technol. Vol. 2, Issue 1, January 2013*, vol. 2, no. 1, pp. 1–6, 2013.

[4] T. Jayasurya and G. C. Shwetha, "Soil Stabilization using Lime and Polypropylene Fiber Material," *Int. J. Civ. Eng.*, vol. 7, no. 5, pp. 510–518, 2017.

[5] Y. Liu, Y. Su, A. Namdar, G. Zhou, Y. She, and Q. Yang, "Utilization of cementitious material from residual rice husk ash and lime in the stabilization of expansive soil," Hindawi, *Adv. Civ. Eng.*, vol. 2019, 2019, doi: 10.1155/2019/5205276.

[6] D. Neguse, E. Assefa, and S. M. Assefa, "Study on the Performance of Expansive Subgrade Soil Stabilized with Enset Ash," Hindawi, *Adv. Civ. Eng.*, vol. 2023, 2023, doi: 10.1155/2023/7851261.

[7] I. P. Hastuty, Roesyanto, M. N. Limbong, and S. J Oberlyn, "California Bearing Ratio (CBR) test on stabilization of clay with lime addition," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 309, no. 1, pp. 0–7, 2018, doi: 10.1088/1757-899X/309/1/012076.

[8] K. Srinivasa Reddy, P. Sai Vivek, and K. Syam Chambrelin, "Stabilization of expansive soil using bagasse ash," *Int. J. Civ. Eng. Technol.*, vol. 8, no. 4, pp. 1730–1736, 2017.

[9] M. Alhassan, "Potentials of Rice Husk Ash for Soil Stabilization," *Au J. Technol.*, vol. 11, no. 4, pp. 246–250, 2008.

[10] A. S. Negi, M. Faizan, and D. P. Siddharth, "Soil stabilization using lime," Int. J. Innovative Research in Science, Engineering, and Technology, vol. 2, no. 2, pp. 448–453, 2013.

[11] B. H. J. Pushpakumara and W. S. W. Mendis, "Suitability of Rice Husk Ash (RHA) with lime as a soil stabilizer in geotechnical applications," *Int. J. Geo-Engineering*, vol. 13, no. 1, 2022, doi: 10.1186/s40703-021-00169-w.

[12] C. M. V. & J. P. Dhruv Vyas, "Utilization of Barley Husk Ash in Clay Bricks in Aspect of Indian Context: a Literature Review," *Int. J. Civil, Struct. Environ. Infrastruct. Eng. Res. Dev. (IJCSEIERD*, vol. 4, no. 1, pp. 61–68, 2014.

[13] A. Bhardwaj, D. Parashar, A. Dutta, A. K. Saini, P. Batra, and A. Tiwari, "Soil Stabilization Using Wheat Husk and Lime," *Int. Res. J. Eng. Technol.*, vol. 5135, no. May, pp. 5135–5139, 2008.

[14] ERA, "The Federal Democratic Republic Of Ethiopia Ethiopian Roads Authority Pavement Design Manual Volume I: Flexible Pavements," *Pavement Des.*, vol. I, no. March, p. 281, 2013.

[15] S. Roy and S. Kumar Bhalla, "Role of Geotechnical Properties of Soil on Civil Engineering Structures," *Resour. Environ.*, vol. 7, no. 4, pp. 103–109, 2017.

[16] K. Chibuzor, "Soil Stabilization Techniques and Procedures in the Developing Countries- Nigeria," *Glob. Jour. Engg. Tech*, vol. 5, no. 1, pp. 65–69, 2012.

[17] A. K. Sabat, "Engineering properties of an expansive soil stabilized with rice husk ash and lime sludge," *Int. J. Eng. Technol.*, vol. 5, no. 6, pp. 4826–4833, 2013.

[18] M. Vrunda Sule, V. Brinda, C. Vandana, and K. Sohel, "Use of Locally available material for Stabilizing Expansive Soil," *Int. Res. J. Eng. Technol.*, pp. 5–8, 2018.

[19] F. A. Gidebo, H. Yasuhara, and N. Kinoshita, "Stabilization of expansive soil with agricultural waste additives: a review," *Int. J. Geo-Engineering*, vol. 14, no. 1, 2023, doi: 10.1186/s40703-023-00194-x.

[20] D. Alemu, B. Lakew, K. Kelemu, and A. Bezabih, "Increasing the Income of Malt Barley Farmers in Ethiopia through More Effective Cooperative Management," Self Help Africa, EIAR, 2015.

[21] K. C. Dennis, “Expansive soils,” *Constr. Specif.*, vol. 47, no. 11, pp. 413–441, 1994, doi: 10.1007/978-3-642-41714-6_52078.

[22] G. A. Archibong, E. U. Sunday, J. C. Okeke, and O. C. Amadi, “A Review of the Principles and Methods of Soil Stabilization,” *Int. J. Adv. Acad. Res. | Sci.*, vol. 6, no. 3, pp. 2488–9849, 2020.

[23] I. Ahmad, L. Er, and N. Singh, “Stabilisation of Expansive Soil Using Fly Ash,” Int. J. Creative Research Thoughts, vol. 11, no. 6, pp. 952–962, 2023.

[24] H. Afrin, “A Review on Different Types Soil Stabilization Techniques,” *Int. J. Transp. Eng. Technol.*, vol. 3, no. 2, p. 19, 2017, doi: 10.11648/j.ijtet.20170302.12.

[25] A. Gbenga Matthew and A. Shola Paul, “Soil Stabilization Using Bitumen Emulsion and Cement Combination as Additive,” *J. Earth Sci. Eng.*, vol. 8, pp. 66–74, 2018, doi: 10.17265/2159-581X/2018.02.000.

[26] S. Roy, “Use of Additives in Soil Stabilization,” *J. Geotech. Eng.*, vol. 8, no. 1, pp. 33–40, 2021, doi: 10.37591/JoGE.

[27] A. Paikiey and A. Rabbani, “Soil stabilization using cement,” *Int. J. Civ. Eng. Technol.*, vol. 8, no. 6, pp. 316–322, 2017, doi: 10.1016/0148-9062(77)90919-6.

[28] O. Dinka, E. Agon, and A. Geremew, “Performance Studies on Subgrade Formation Using Lime and Cement in Road Projects,” *Ann. Fac. Eng. Hunedoara*, no. January, pp. 23–30, 2019.

[29] S. O. Manzoor and A. Yousuf, “Stabilisation of soils with lime : a review,” *J. Mater. Environ. Sci.*, vol. 11, no. 9, pp. 1538–1551, 2020.

[30] E. N. and A. Dinku, “Investigation on the effects of combining lime and sodium silicate for expansive subgrade stabilization,” *Zede J.*, vol. 31, no. 0, pp. 33–44, 2014.

[31] A. Kumar, “A Review on Soil Stabilization in Road Construction by Using Bituminous Mixture,” Journal of Emerging Technologies and Innovative Research vol. 5, no. 1, pp. 877–883, 2018.

[32] The Navy and The Air Force, “Air Force Afjman 32-1019 Soil Stabilization for Pavements Approved for Public Release ; Distribution Is Unlimited,” no. October, pp. 1–57, 1994.

[33] V. Sahu, A. Srivastava, A. K. Misra, and A. K. Sharma, “Stabilization of fly ash and lime sludge composites: Assessment of its performance as base course material,” *Arch. Civ. Mech. Eng.*, vol. 17, no. 3, pp. 475–485, 2017, doi: 10.1016/j.acme.2016.12.010.

[34] N. S. Wales and P. Power, “Microstructural Development of Stabilized Fly Ash,” vol. 80, no. May, pp. 157–163, 2000.

[35] E. Seyrek, “Engineering behavior of clay soils stabilized with class C and class F fly ashes,” *IEEE J. Sel. Top. Quantum Electron.*, vol. 25, no. 2, pp. 273–287, 2018, doi: 10.1515/secm-2016-0084.

[36] S. Yadav and D. C. Dubey, “Stabilization of Expansive Soils Employing Activated Fly Ash: A Review,” *Int. Res. J. Eng. Technol.*, pp. 654–659, 2022.

[37] P. Sarathi Parhi, “Stabilization of expansive soils using alkali-activated fly ash,” *Proc. Indian Geotech. Conf.*, vol. 2, no. December 2013, pp. 1–4, 2014.

[38] D. Alemshet, B. Fayissa, A. Geremew, and G. Chala, “Amelioration Effect of Fly Ash and Powdered Ground Steel Slag for Improving Expansive Subgrade Soil,” *J. Eng. (United Kingdom)*, vol. 2023, 2023, doi: 10.1155/2023/1652373.

[39] Mulatu, B. and Grando, S. (eds), “Barley Research and Development in Ethiopia. Proceedings of the 2nd National Barley Research and Development Review Workshop. 28-30 November 2006, ” HARC, Holetta, Ethiopia. ICARDA, 2011.

[40] A. Sorsa, S. Senadheera, and Y. Birru, “Engineering Characterization of Subgrade Soils of Jimma Town,” Geosciences, pp. 1–17, 2020.

[41] N. S. Pandian, A. Sridharan, and P. S. R. N. Raju, “California Bearing Ratio Test Simplified,” *J. Test. Eval.*, vol. 27, no. 1, pp. 72–75, 1999, doi: 10.1520/jte12043j.

[42] D. Deneele, “Scanning Electron Microscope (SEM) investigations in soil microstructure description,” *1st IMEKO TC4 Int. Work. Metrol. Geotech. MetroGeotechnics 2016*, pp. 7–

11, 2016.

[43] W. Gallala, M. E. Gaied, A. Tlili, and M. Montacer, "Factors influencing the reactivity of quicklime," *Proc. Inst. Civ. Eng. Constr. Mater.*, vol. 161, no. 1, pp. 25–30, 2008, doi: 10.1680/coma.2008.161.1.25.

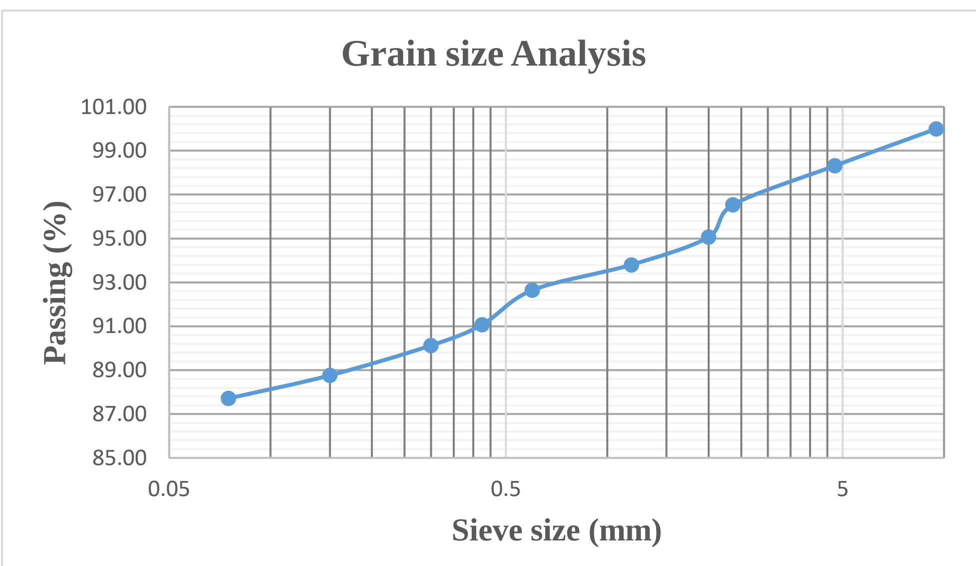
[44] P. Suraneni, L. Burris, C. R. Shearer, and R. D. Hooton, "ASTM C618 fly ash specification: Comparison with other specifications, shortcomings, and solutions," *ACI Mater. J.*, vol. 118, no. 1, pp. 157–167, 2021, doi: 10.14359/51725994.

APPENDIX- Laboratory Test Results

Appendix -1 Sieve Analysis

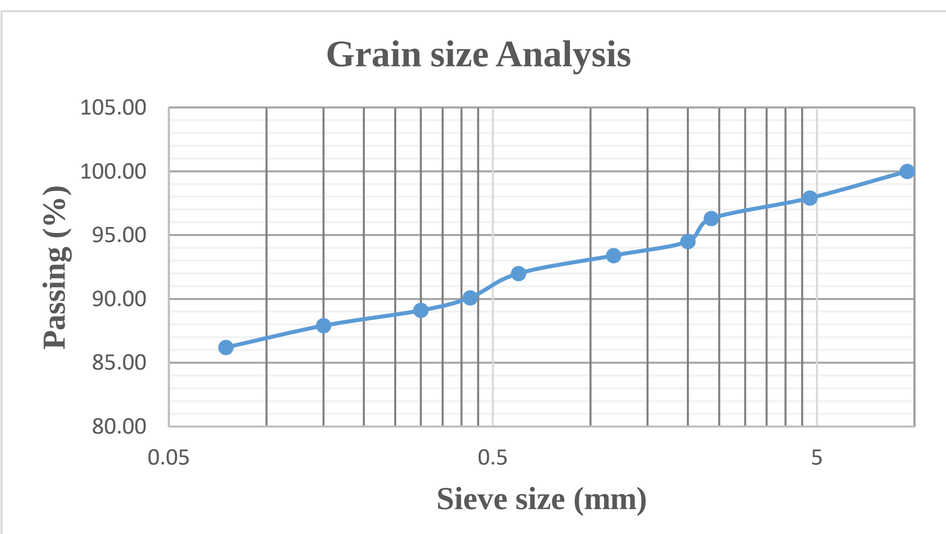
i) Sieve analysis result of Shenen Gibe Soil

Sieve size (mm)	Mass of retained on each sieve (g)	Percentage of retained soil (%)	Cumulative percentage of retained soil	Percentage of passing particle (%)
9.5	0.00	0.00	0.00	100.00
4.75	8.00	1.68	1.68	98.32
2.36	8.50	1.79	3.47	96.53
2	7.00	1.47	4.94	95.06
1.18	6.00	1.26	6.20	93.80
0.6	5.50	1.16	7.35	92.65
0.425	7.50	1.58	8.93	91.07
0.3	4.50	0.95	9.87	90.13
0.15	6.50	1.37	11.24	88.76
0.075	5.00	1.05	12.29	87.71
pan	417.5	87.71	100.00	0.00
Sum	476.0			



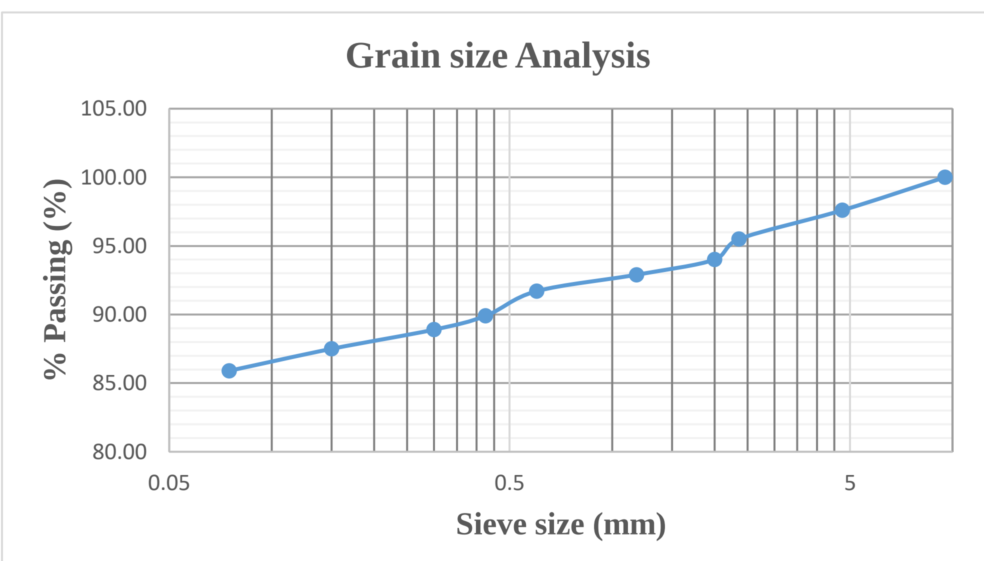
ii) Sieve analysis result of Kochi Soil

PARTICLE SIZE DISTRIBUTION (TEST METHOD: AASHTO T-88)				
Material Description:- Subgrade Material			Date Sampled:- Sep 05/2022	
			Date Tested:- Sept 20, 2022	
Sieve size (mm)	Mass of retain on each sieve (g)	Percentage of retained soil (%)	Cumulative % of retained soil	Percentage of passing particle
9.5	0.00	0.00	0.00	100.00
4.75	10.50	2.10	2.10	97.90
2.36	8.00	1.60	3.70	96.30
2	9.00	1.80	5.50	94.50
1.18	5.50	1.10	6.60	93.40
0.6	7.00	1.40	8.00	92.00
0.425	9.50	1.90	9.90	90.10
0.3	5.00	1.00	10.90	89.10
0.15	6.00	1.20	12.10	87.90
0.075	8.50	1.70	13.80	86.20
pan	431.0	86.20	100.00	0.00
Sum	500.0			



iii) Sieve analysis of Kito Soil

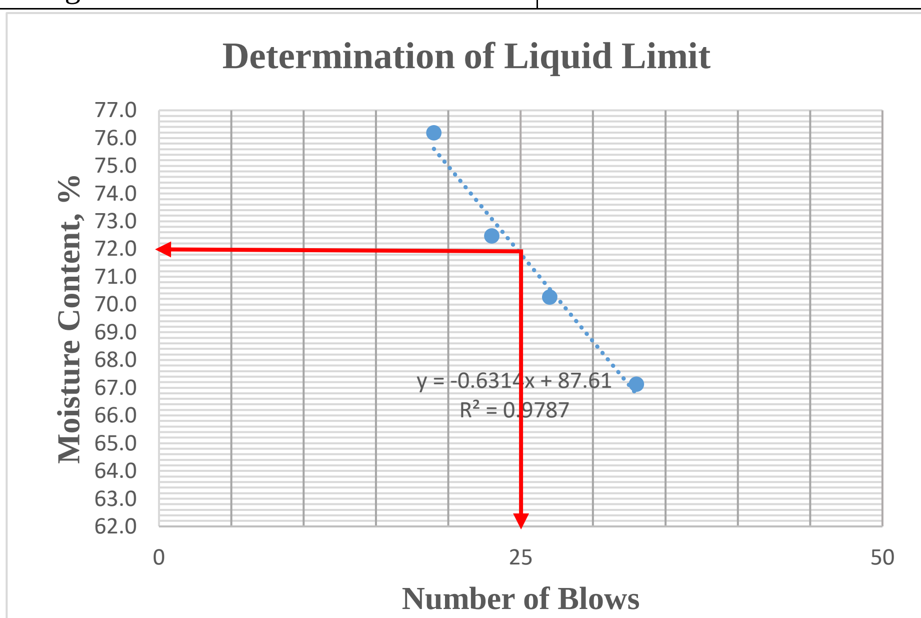
PARTICLE SIZE DISTRIBUTION (TEST METHOD: AASHTO T-88)				
Material Description:- Subgrade Material			Date Sampled:- Sep 05/2022	
			Date Tested:- Sept 20, 2022	
Sieve size (mm)	Mass of retain on each sieve(g)	Percentage of retained soil	Cumulative % of retained soil	Percentage of passing particle
9.5	0.00	0.00	0.00	100.00
4.75	12.00	2.40	2.40	97.60
2.36	10.50	2.10	4.50	95.50
2	7.50	1.50	6.00	94.00
1.18	5.50	1.10	7.10	92.90
0.6	6.00	1.20	8.30	91.70
0.425	9.00	1.80	10.10	89.90
0.3	5.00	1.00	11.10	88.90
0.15	7.00	1.40	12.50	87.50
0.075	8.00	1.60	14.10	85.90
pan	429.5	85.90	100.00	0.00
Sum	500.0			



Appendix-2 Atterberg Limit

i) Shenen Gibe Soil

ATTERBERG Limit (AASHTO T089-94, T09-96)						
Material description:-Expansive Black cotton soil				Date sampled:-Sep 12/2022		
Expansive Soil				Date Tested:- Sept 13, 2022		
Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**33**	**27**	**23**	**19**		
Trial	1	2	3	4	1	2
Container	3L	C9	A4	B9	E13	4
Wt. of container + wet soil, g	35.47	32.24	33.87	37.13	29.69	29.17
Wt. of container + dry soil, g	29.1	25.98	26.79	29.58	26.57	26.21
Wt. of container, g	19.61	17.07	17.02	19.67	17.52	17.06
Wt. of water, g	6.37	6.26	7.08	7.55	3.1	2.96
Wt. of dry soil, g	9.49	8.91	9.77	9.91	9.05	9.15
Moisture content, %	67.1	70.3	72.5	76.2	34.5	32.3
Average	**72**				**33**	



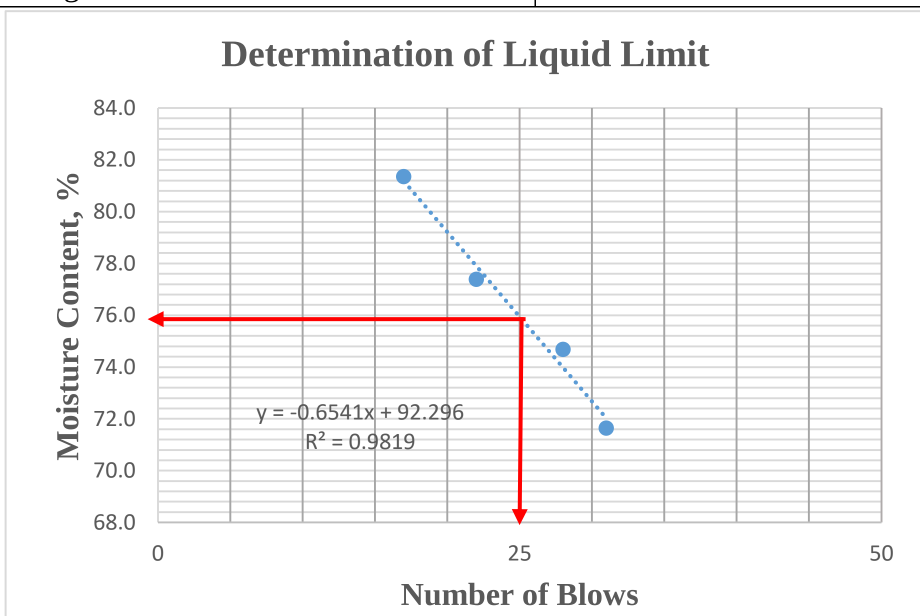
LL= <u>72</u>

PL= <u>33</u>

PI= <u>39</u>

ii) Kochi Soil

ATTERBERG Limit (AASHTO T089-94, T09-96)						
Material description:- Expansive Soil				Date sampled:-Sep 12/2022		
Expansive Soil (Kochi)				Date Tested:- Sept 13, 2022		
Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**31**	**28**	**22**	**17**		
Trial	1	2	3	4	1	2
Container	C1	G8	H23	B9	L3	B1
Wt. of container + wet soil, g	35.47	32.24	33.87	37.13	23.52	21.74
Wt. of container + dry soil, g	29.43	26.37	27.16	29.32	18.93	17.31
Wt. of container, g	21	18.51	18.49	19.72	6.43	5.5
Wt. of water, g	6.04	5.87	6.71	7.81	4.6	4.43
Wt. of dry soil, g	8.43	7.86	8.67	9.6	12.5	11.81
Moisture content,%	71.6	74.7	77.4	81.4	36.7	37.5
Average	**76**				**37**	

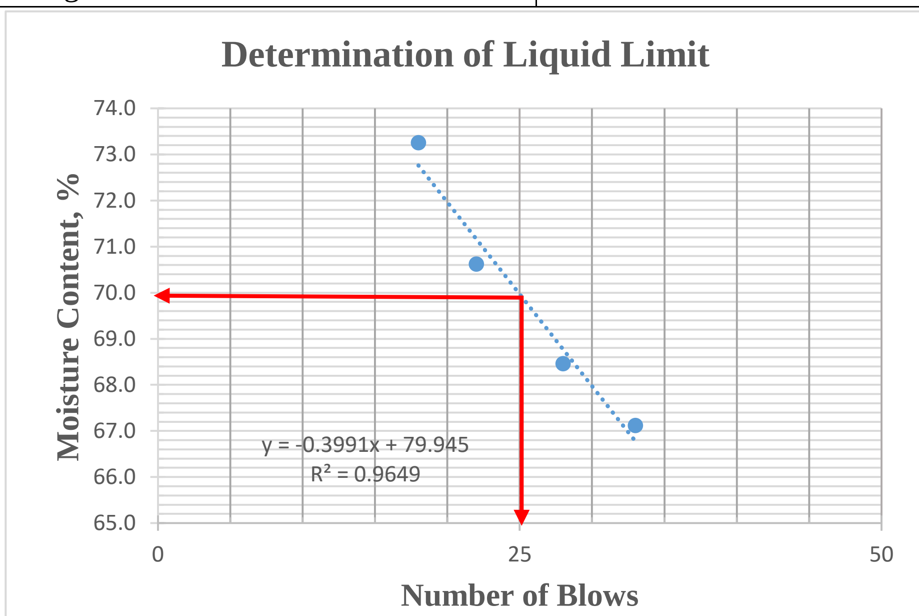


LL= 76

PL= 37

PI= 39

ATTERBERG Limit (AASHTO T089-94, T09-96)						
Material description:-Expansive Soil				Date sampled:-Sep 12/2022		
Expansive Soil (Kito)				Date Tested:- Sept 13, 2022		
Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**33**	**28**	**22**	**18**		
Trial	1	2	3	4	1	2
Container	3L	C9	A4	B9	T1	G
Wt. of container + wet soil, g	35.47	32.08	33.69	36.84	18.46	17.32
Wt. of container + dry soil, g	29.1	25.98	26.79	29.58	15.29	14.3
Wt. of container, g	19.61	17.07	17.02	19.67	6.1	5.9
Wt. of water, g	6.37	6.1	6.9	7.26	3.2	3.02
Wt. of dry soil, g	9.49	8.91	9.77	9.91	9.19	8.4
Moisture content,%	67.1	68.5	70.6	73.3	34.5	36.0
Average	**70**				**35**	

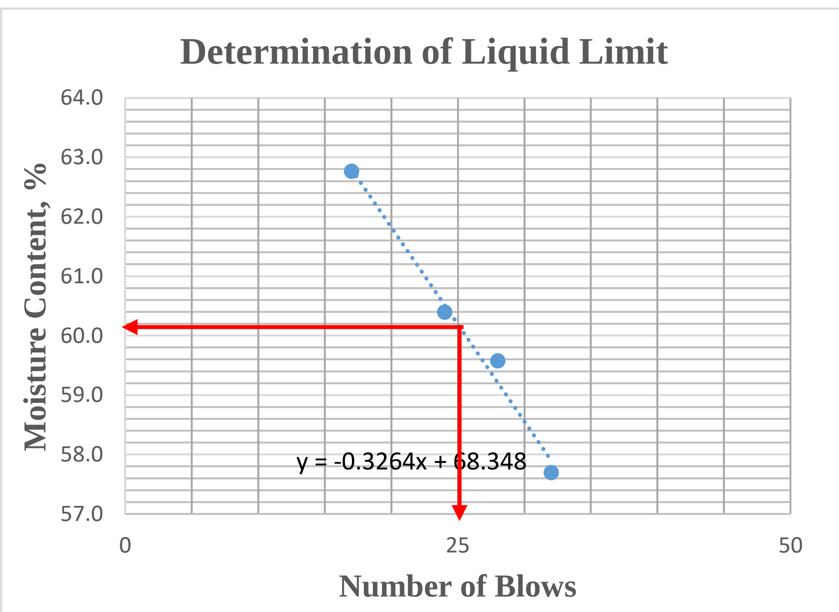


LL= 70

PL= 35

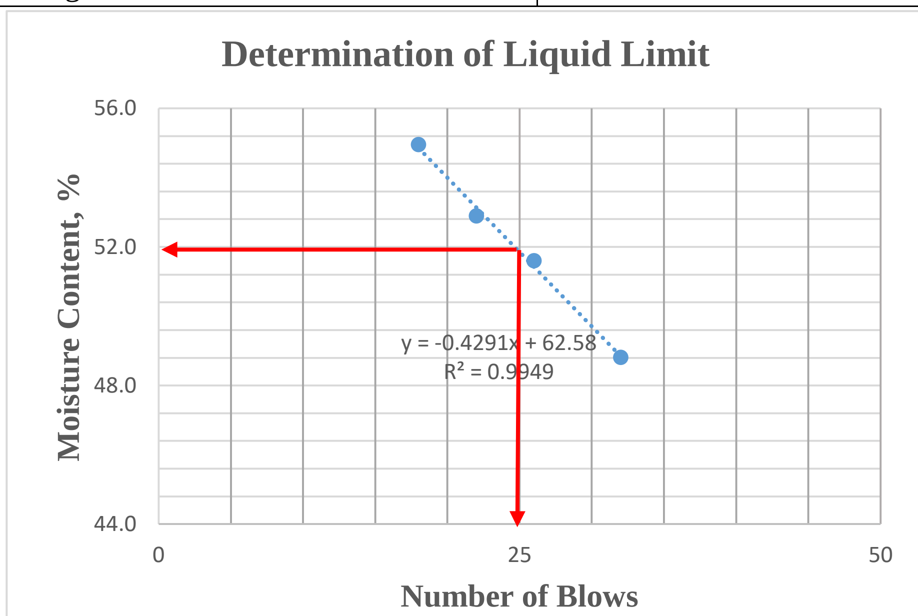
PI= 35

ATTERBERG LIMIT (AASHTO T089-94, T09-96)						
Material description:-Expansive Black cotton soil			Date sampled:-Sep 17/2022			
5%Lime+Expansive Soil			Date Tested:- Sept 18, 2022			
Determination of Liquid limit					Plastic Limit	
Number of blows	**32**	**28**	**24**	**17**		
Trial	1	2	3	4	1	2
Container	A4	H23	2	1	T1	T4
Wt. of container + wet soil, g	29.34	33.76	35.37	35.31	18.44	17.26
Wt. of container + dry soil, g	24.83	28.15	29.26	28.95	15.43	14.54
Wt. of container, g	17.01	18.73	19.14	19.56	6.1	5.9
Wt. of water, g	4.51	5.61	6.11	5.90	3.01	2.72
Wt. of dry soil, g	7.82	9.42	10.12	9.39	9.33	8.64
Moisture content, %	57.7	59.6	60.4	62.8	32.3	31.5
Average	**60**				**32**	



LL (%) = 60
PL (%) = 32
PI (%) = 28

ATTERBERG Limit (AASHTO T089-94, T09-96)						
Material description:-Expansive Black cotton soil				Date sampled:-Sep 17/2022		
10%Lime+Expansive Soil				Date Tested:- Sept 18, 2022		
Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**32**	**26**	**22**	**18**		
Trial	1	2	3	4	1	2
Container	G8	3L	A17	F5	G	L3
Wt. of container + wet soil, g	33.52	35.21	37.77	37.63	19.89	18.32
Wt. of container + dry soil, g	28.58	29.89	32.38	30.75	16.74	15.53
Wt. of container, g	18.46	19.58	22.19	18.23	5.83	6.43
Wt. of water, g	4.94	5.32	5.39	6.88	3.15	2.79
Wt. of dry soil, g	10.12	10.31	10.19	12.52	10.91	9.1
Moisture content,%	48.8	51.6	52.9	55.0	28.9	30.7
Average	**52**				**30**	

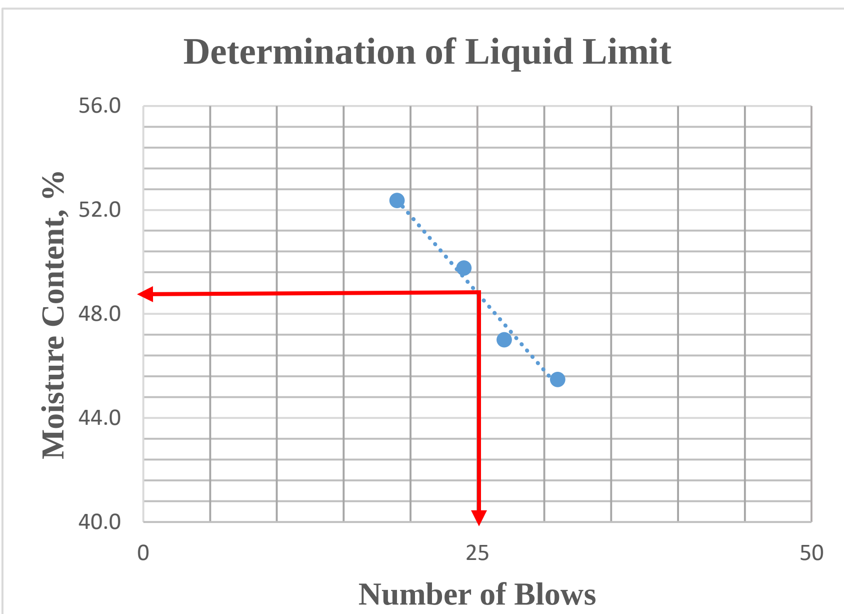


LL= 52

PL= 30

PI= 22

ATTERBERG LIMIT (AASHTO T089-94, T09-96)						
Material description:-Expansive Soil			Date sampled:-Sep 17/2022			
15%Lime+Expansive Soil			Date Tested:- Sept 18, 2022			
Determination of Liquid limit					Plastic Limit	
Number of blows	**31**	**27**	**24**	**19**		
Trial	1	2	3	4	1	2
Container	C1	A7	E-13	C9	16	B1
Wt. of container + wet soil, g	34.75	33.93	33.81	35.42	18.9	18.8
Wt. of container + dry soil, g	30.42	29.38	28.39	29.09	16.34	15.87
Wt. of container, g	20.9	19.7	17.5	17	7.6	5.5
Wt. of water, g	4.33	4.55	5.42	6.33	2.6	2.93
Wt. of dry soil, g	9.52	9.68	10.89	12.09	8.74	10.37
Moisture content, %	45.5	47.0	49.8	52.4	29.3	28.3
Average	**49**				**29**	

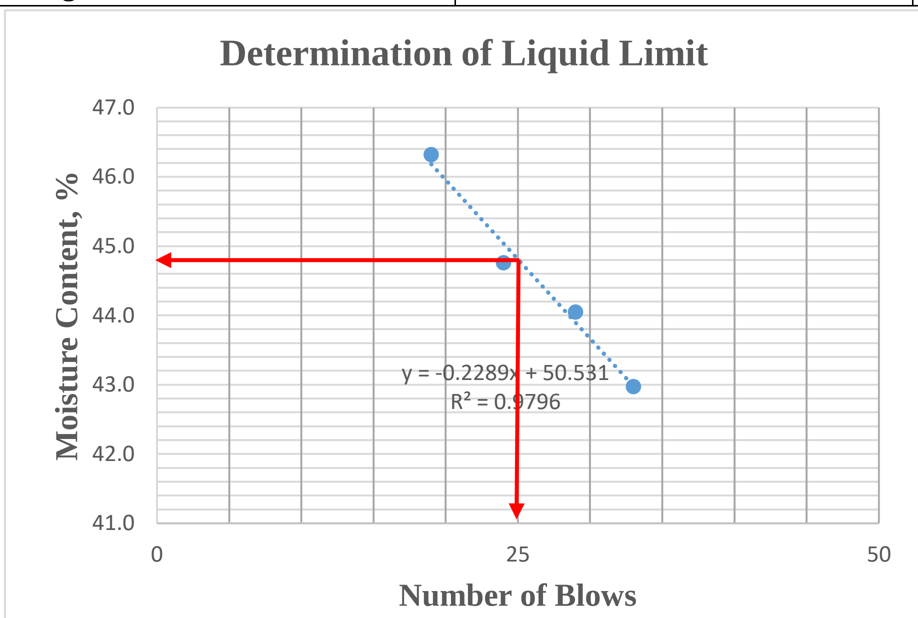


LL (%) = 49

PL (%) = 29

PI (%) = 20

Material description:-Expansive Soil					Date sampled:-Sep 17/2022	
20%Lime+Expansive Soil					Date Tested:- Sept 18, 2022	
Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**33**	**29**	**24**	**19**		
Trial	1	2	3	4	1	2
Container	B9	3,3	4	BB	D	A
Wt. of container + wet soil, g	37.6	41.3	35.5	22.5	20.24	19.83
Wt. of container + dry soil, g	32.16	36.01	29.78	17.34	17.21	16.89
Wt. of container, g	19.63	24	17	6.2	6.91	6.3
Wt. of water, g	5.44	5.29	5.72	5.16	3.0	2.94
Wt. of dry soil, g	12.66	12.01	12.78	11.14	10.3	10.59
Moisture content,%	43.4	44.0	44.8	46.3	29.4	27.8
Average	**45**				**29**	

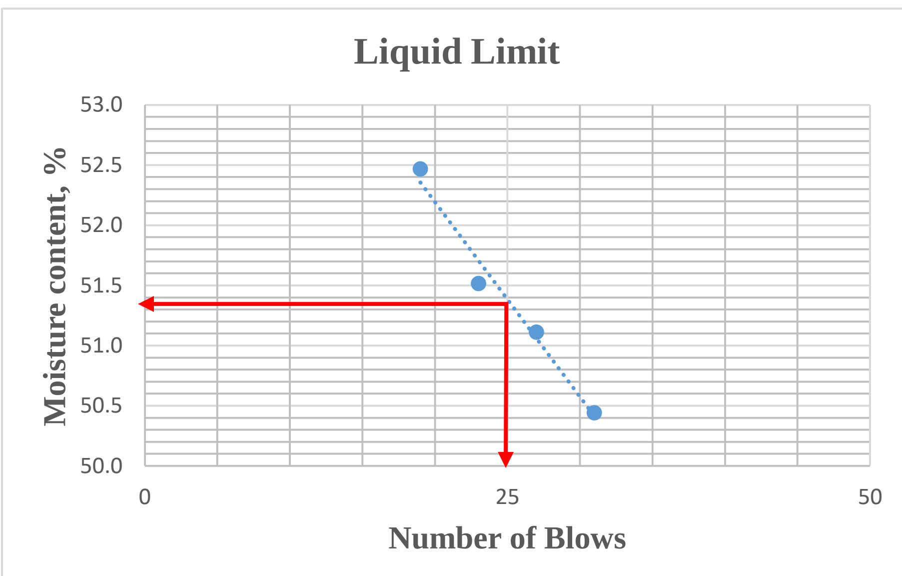


LL (%) = 45

PL (%) = 29

PI (%) = 16

ATTERBERG Limit (AASHTO T089-94, T09-96)						
Material description:-Expansive Soil				Date sampled:-Sep 20/2022		
OPT Lime+5%BHA+Expansive Soil				Date Tested:- Sept 21, 2022		
Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**31**	**27**	**23**	**19**		
Trial	1	2	3	4	1	2
Container	A4	H23	2	1	T1	T4
Wt. of container + wet soil, g	34	35.5	35	36.5	18.23	17.5
Wt. of container + dry soil, g	28.3	29.75	29.56	30.65	15.4	14.9
Wt. of container, g	17	18.5	19	19.5	6	6
Wt. of water, g	5.7	5.75	5.44	5.85	2.8	2.6
Wt. of dry soil, g	11.3	11.25	10.56	11.15	9.4	8.9
Moisture content,%	50.4	51.1	51.5	52.5	30.1	29.2
Average	**51**				**30**	

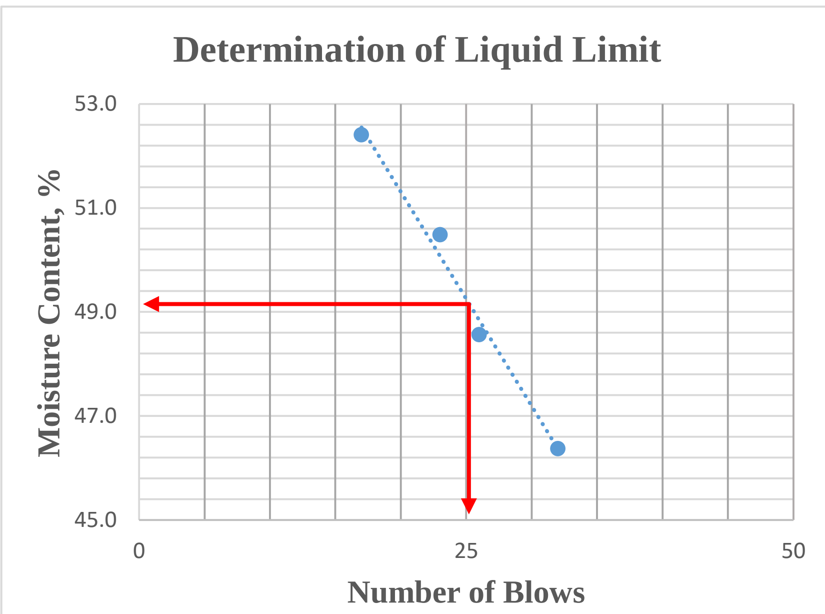


LL (%) = 51

PL (%) = 30

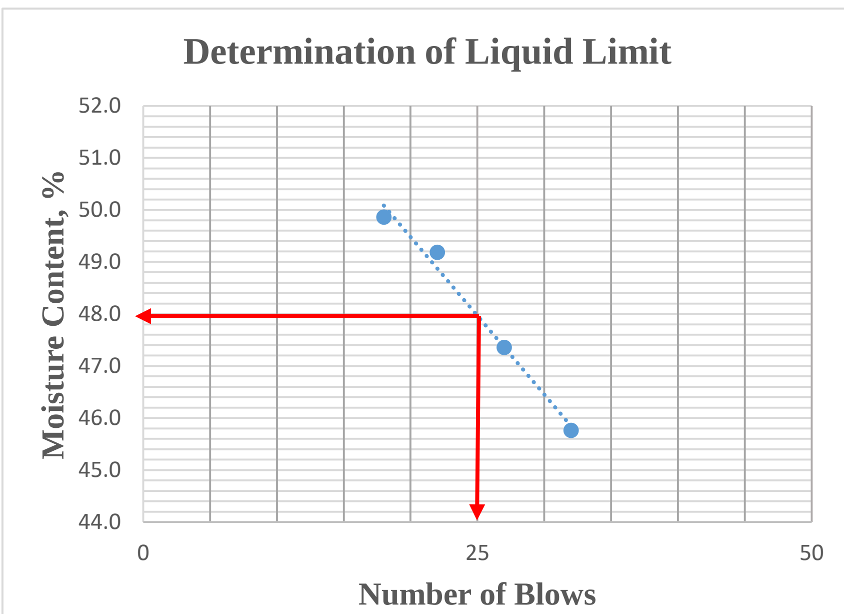
PI (%) = 21

ATTERBERG LIMIT (AASHTO T089-94, T09-96)						
Material description:-Expansive Soil			Date sampled:-Sep 20/2022			
OPT Lime+10%BHA+Expansive Soil			Date Tested:- Sept 21, 2022			
Determination of Liquid limit					Plastic Limit	
Number of blows	**32**	**26**	**23**	**17**		
Trial	1	2	3	4	1	2
Container	C1	A7	E-13	C9	16	B1
Wt. of container + wet soil, g	33.5	34.5	33	32.5	21.53	19.47
Wt. of container + dry soil, g	29.54	29.76	27.8	27.17	18.19	16.13
Wt. of container, g	21	20	17.5	17	7	5.5
Wt. of water, g	3.96	4.74	5.2	5.33	3.3	3.34
Wt. of dry soil, g	8.54	9.76	10.3	10.17	11.19	10.63
Moisture content, %	46.4	48.6	50.5	52.4	29.8	31.4
Average	**49**				**31**	



LL (%) = 49
PL (%) = 31
PI (%) = 18

ATTERBERG LIMIT (AASHTO T089-94, T09-96)						
Material description:-Expansive Soil				Date sampled:-Sep 20/2022		
Opt %Lime+15%BHA+Expansive Soil				Date Tested:- Sept 21, 2022		
Determination of Liquid limit					Plastic Limit	
Number of blows	**32**	**27**	**22**	**18**		
Trial	1	2	3	4	1	2
Container	G8	3L	A17	F5	L3	TY
Wt. of container + wet soil, g	35	34	38.5	34.5	19.42	18.51
Wt. of container + dry soil, g	29.82	29.34	33.06	29.01	16.38	15.57
Wt. of container, g	18.5	19.5	22	18	6.45	6.22
Wt. of water, g	5.18	4.66	5.44	5.49	3.0	2.94
Wt. of dry soil, g	11.32	9.84	11.06	11.01	9.93	9.35
Moisture content,%	45.8	47.4	49.2	49.9	30.6	31.4
Average	**48**				**31**	

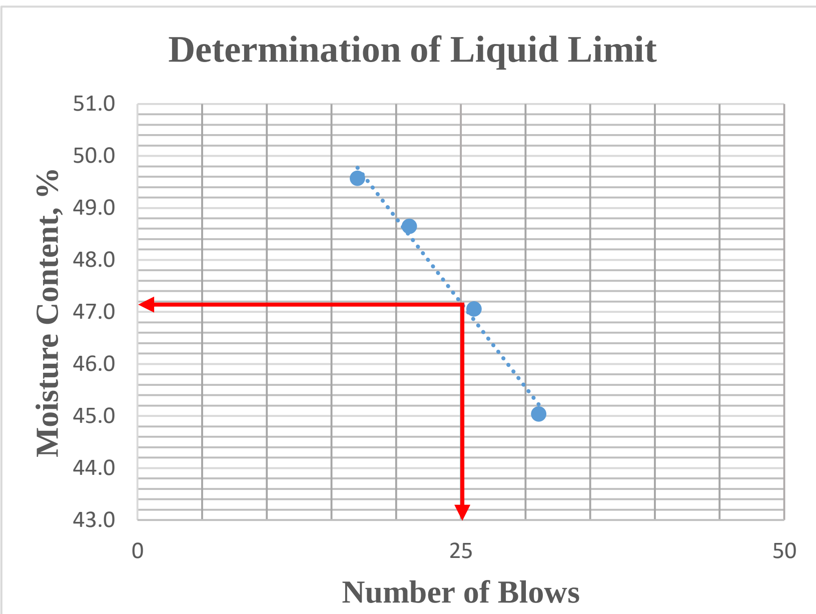


LL (%) = 48

PL (%) = 31

PI (%) = 17

ATTERBERG LIMIT (AASHTO T089-94, T09-96)						
Material description:-Expansive Soil				Date sampled:-Sep 20/2022		
OPT Lime+20%BHA+Expansive Soil				Date Tested:- Sept 21, 2022		
Determination of Liquid limit					Plastic Limit	
Number of blows	**31**	**26**	**21**	**17**		
Trial	1	2	3	4	1	2
Container	B9	3,3	4	BB	D	A
Wt. of container + wet soil, g	38.5	37	33.5	23.5	22.59	20.65
Wt. of container + dry soil, g	32.6	33	28.2	17.7	18.67	17.24
Wt. of container, g	19.5	24.5	17	6	6.91	6.5
Wt. of water, g	5.9	4	5.3	5.8	3.9	3.41
Wt. of dry soil, g	13.1	8.5	11.2	11.7	11.76	10.74
Moisture content, %	45.0	47.1	47.3	49.6	33.3	31.8
Average	**48**				**33**	



LL (%) = 47

PL (%) = 33

PI (%) = 14

Appendix-3 Specific Gravity

Specific Gravity of Natural soil (Shenen Gibe)		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	T	C
Wp= Mass of empty, clean pycnometer (A), g	29.7	26.5
Wps=Mass of pycnometer + dry soil(B), g	54.7	51.5
WB= Mass of pycnometer + dry soil + water (C), g	136.2	98.7
Mass of pycnometer + water (D), g	120.8	83.1
Temperature, ºC	19	19
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(E+(B-C))	2.60	2.66
Average specific gravity	2.63	
Specific Gravity of 5%Lime+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	D	O3
Wp= Mass of empty, clean pycnometer (A), g	21.65	31.54
Wps=Mass of pycnometer + dry soil(B), g	46.65	56.54
WB= Mass of pycnometer + dry soil + water (C), g	86.63	136.86
Mass of pycnometer + water (D), g	71.2	121.5
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(E+(D-C))	2.61	2.59
Average specific gravity	2.60	

Specific Gravity of 10%Lime+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	O	C
Wp= Mass of empty, clean pycnometer (A), g	30.57	26.96
Wps=Mass of pycnometer + dry soil(B), g	55.57	51.95
WB= Mass of pycnometer + dry soil + water (C), g	127.58	86.52
Mass of pycnometer + water (D), g	112.27	71.11
Temperature, ºC	18	18
Mass of dry soil (E), g =B-A	25	24.99
Specific gravity=E/(E+(D-C))	2.58	2.61
Average specific gravity	2.59	

Specific Gravity of 15%Lime+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	T	17
Wp= Mass of empty, clean pycnometer (A), g	28.2	29.8
Wps=Mass of pycnometer+dry soil(B), g	53.2	54.8
WB= Mass of pycnometer+dry soil+water (C), g	94.48	139.96
Mass of pycnometer+water (D), g	79.27	124.64
Temperature, ºC	19	19
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(E+(D-C))	2.55	2.58
Average specific gravity	2.57	

Specific Gravity of 20%Lime+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	O3	B
Wp= Mass of empty, clean pycnometer (A), g	31.54	21.61
Wps=Mass of pycnometer+ dry soil(B), g	56.52	46.57
WB= Mass of pycnometer+ dry soil+ water (C), g	138.77	137.43
Mass of pycnometer+ water (D), g	123.45	122.26
Temperature, ºC	21	21
Mass of dry soil (E), g =B-A	24.98	24.96
Specific gravity=E/(E+(D-C))	2.59	2.55
Average specific gravity	2.57	

Specific Gravity of OPT Lime+5%BHA+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	B	T
Wp= Mass of empty, clean pycnometer (A), g	21.61	28.2
Wps=Mass of pycnometer + dry soil(B), g	46.6	53.1
WB= Mass of pycnometer + dry soil +water (C), g	89.31	136.92
Mass of pycnometer + water (D), g	74.73	122.19
Temperature, ⁰C	21	21
Mass of dry soil (E), g =B-A	24.99	24.9
Specific gravity=E/(E+(D-C))	2.40	2.45
Average specific gravity	2.42	
Specific Gravity of OPT Lime+10%BHA+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	17	K
Wp= Mass of empty, clean pycnometer (A), g	29.71	27.94
Wps=Mass of pycnometer+dry soil(B), g	54.71	52.92
WB= Mass of pycnometer+dry soil+water (C), g	138.71	91.37
Mass of pycnometer+water (D), g	124.7	77.62
Temperature, ⁰C	24	24
Mass of dry soil (E), g =B-A	25	24.98
Specific gravity=E/(A+(D-C))	2.27	2.22
Average specific gravity	2.25	
Specific Gravity of OPT Lime+15%BHA+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	C	G
Wp= Mass of empty, clean pycnometer (A), g	26.96	30.37
Wps=Mass of pycnometer+dry soil(B), g	51.96	55.37
WB= Mass of pycnometer+dry soil+water (C), g	89.74	135.67
Mass of pycnometer+water (D), g	76.88	123.13
Temperature, ⁰C	24	24
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(A+(D-C))	2.06	2.01
Average specific gravity	2.03	

Specific Gravity of OPT Lime+20%BHA+ Expansive Soil		
STANDARD METHOD: ASTM D 854-00		
Trials	1	2
Pycnometer code	O	W
Wp = Mass of empty, clean pycnometer (A), g	30.56	17
Wps =Mass of pycnometer + dry soil(B), g	55.56	42
WB= Mass of pycnometer + dry soil + water (C), g	134.98	60.45
Mass of pycnometer + water (D), g	122.81	48.53
Temperature, ºC	25	24
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(A+(D-C))	1.95	1.91
Average specific gravity	1.93	

Appendix-4 Free Swell Index

FREE SWELL INDEX

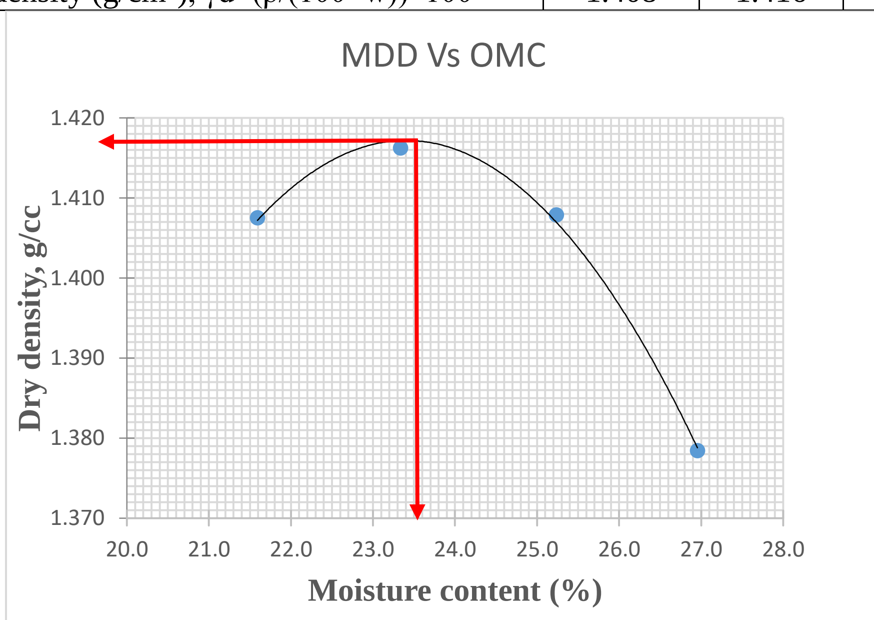
STATION	Measuring Cylinder No.(ml)		Reading after 24 hrs(ml)		Free Swell Index, %
	Kerosene	Distilled water	Kerosene	Distilled water	
Shenen Gibe Soil Sample	11	13	11	23	**109**
5%Lime+Expansive Soil	12	13	12	20	**67**
10%Lime+Expansive Soil	12	13	12	17	**42**
15%Lime+Expansive Soil	11	12	11	15	**36**
20%Lime+Expansive Soil	13	14	12	16	**33**
5%BHA+opt. Lime + Expansive Soil	14	20	14	20	**43**
10%BHA+ opt. Lime + Expansive Soil	14	18	15	20	**33**
15%BHA+opt Lime + Expansive Soil	14	15	15	19	**27**
20%BHA+opt. Lime + Expansive Soil	15	17	16	20	**25**

Only BHA	25	27	25	28	**12**
Only Lime	11	11	11	12	**9**

Appendix-5 Compaction Test

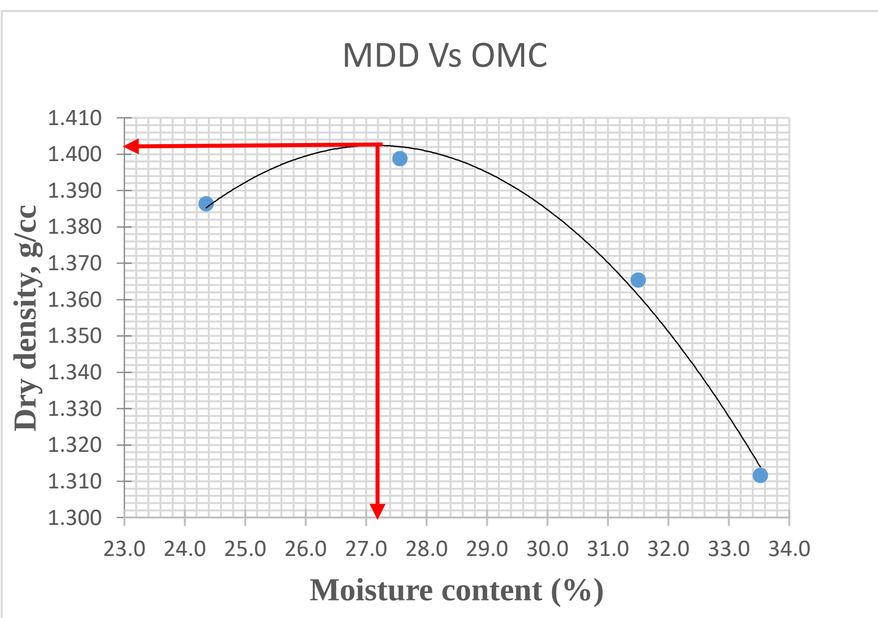
i) Shenen Gibe Soil Sample

MOISTURE DENSITY RELATION FOR NATURAL SOIL					
TEST METHOD: ASHTO T-180-95					
Material description:-Expansive Soil			Date Sampled:- Sep 06, 2022		
			Date Tested:- Sept 07, 2022		
DENSITY	Trial Numbers	1	2	3	4
	Mass of sample (g)	4000	4000	4000	4000
	Water Added (cc)	360	540	720	900
	Mass of Mold +Wet soil (g),=m1	6353.0	6428	6463	6435
	Mass of Mold (g)=m2	2718	2718	2718	2718
	Mass of Wet soil (g), m3=m1-m2	3635.0	3710	3745	3717.0
	Volume of Mold (cc), V	2124	2124	2124	2124
	Bulk Density (g/cc), ρ=m3/V	1.71	1.75	1.76	1.75
MOISTURE	Container code	Q63	K51	B	02,1
	Mass of wet soil + cont. (g), m4	181.5	136.5	124	137.73
	Mass of dry soil + cont. (g), m5	153.8	115.5	102.54	114.5
	Mass of container (g), m6	25.5	25.5	17.5	28.32
	Mass of moisture (g), m7=m4-m5	27.7	21	21.46	23.2
	Mass of dry soil (g), m8=m5-m6	128.3	90	85.04	86.18
	Moisture content (%), w =(m7/m8)*100	21.6	23.33	25.24	27.0
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.408	1.416	1.408	1.378



ii) Kochi Soil Sample

MOISTURE DENSITY RELATION FOR NATURAL SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Soil From Kochi				Date sampled:- Sep 01, 2022 Date Tested:- Sept 03, 2022		
DENSITY	Trial Numbers	1	2	3	4	
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of Mold +Wet soil (g),=m1	6377.0	6505	6529	6435	
	Mass of Mold (g)=m2	2715	2715	2715	2715	
	Mass of Wet soil (g), m3=m1-m2	3662.0	3790	3814	3720.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.72	1.78	1.80	1.75	
MOISTURE	Container code	Q63	K51	B	02,1	NMC(P65)
	Mass of wet soil +cont. (g), m4	170	125	113.5	126.7	242.00
	Mass of dry soil + cont. (g), m5	141.7	103.5	90.5	102	221.50
	Mass of container (g), m6	25.5	25.5	17.5	28.32	39.79
	Mass of moisture (g), m7=m4-m5	28.3	21.5	23	24.7	20.50
	Mass of dry soil (g), m8=m5-m6	116.2	78	73	73.68	181.71
	Moisture content (%), w =(m7/m8)*100	24.4	27.56	31.51	33.5	11.3
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.386	1.399	1.365	1.312	

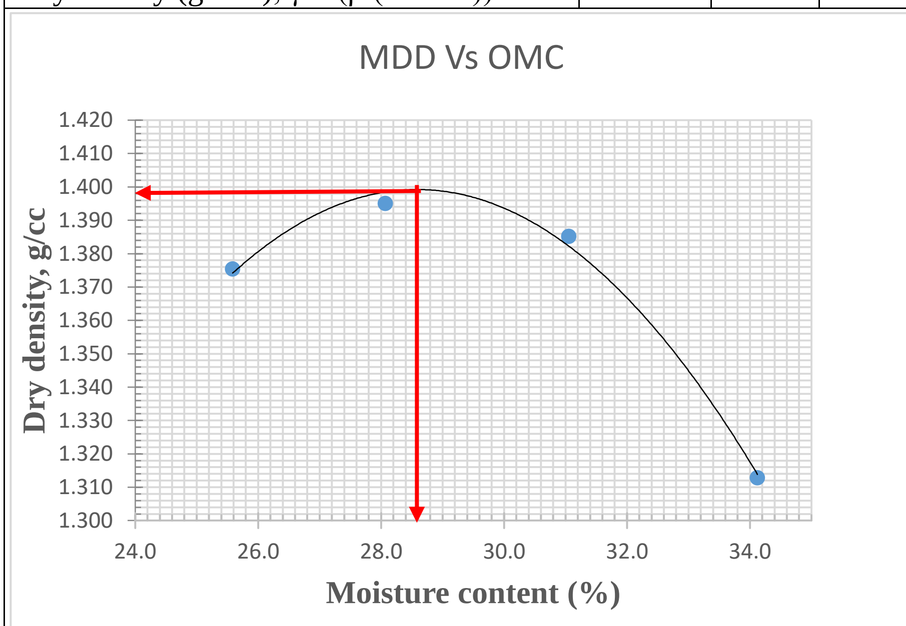


MDD (g/cm^3)= **1.402**

OMC (%)= **27.2**

iii) Kito Soil Sample

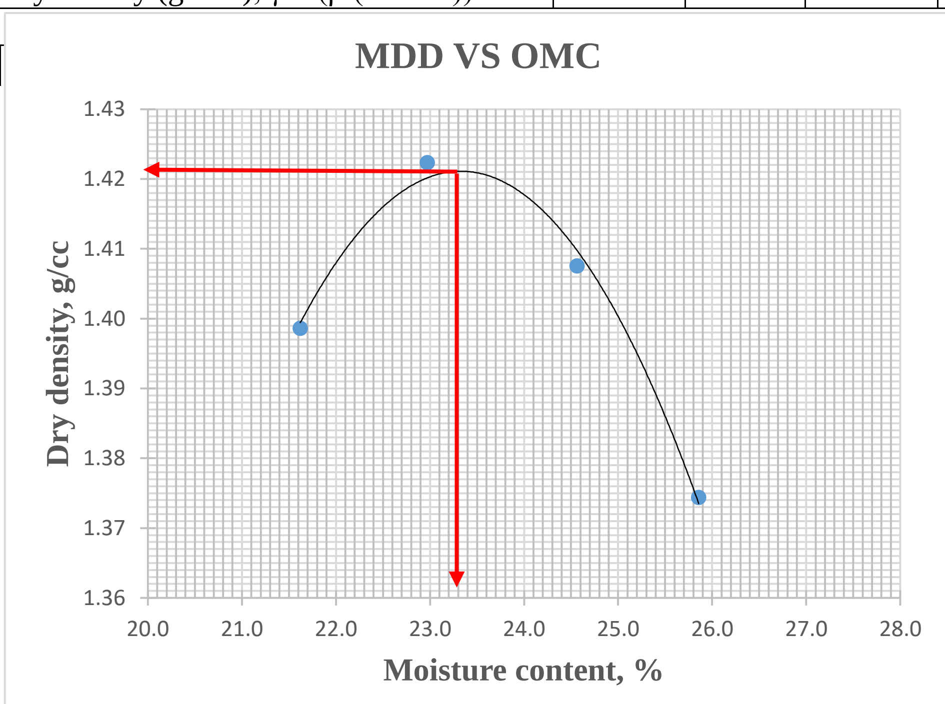
MOISTURE DENSITY RELATION FOR NATURAL SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Soil From Kito		Date sampled:- Sep 01, 2022				
		Date Tested:- Sept 03, 2022				
DENSITY	Trial Numbers	1	2	3	4	Expansive Black cotton soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of Mold +Wet soil (g),=m1	6384.0	6510	6571	6455	
	Mass of Mold (g)=m2	2715	2715	2715	2715	
	Mass of Wet soil (g), m3=m1-m2	3669.0	3795	3856	3740.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.73	1.79	1.82	1.76	
MOISTURE	Container code	P65	K51	B	02,1	NMC(M)
	Mass of wet soil +cont (g), m4	167.9	142.3	126.8	131.3	229.30
	Mass of dry soil + cont (g), m5	141.8	116.7	100.9	105.1	211.50
	Mass of container (g), m6	39.79	25.5	17.5	28.32	36.00
	Mass of moisture (g), m7=m4-m5	26.1	25.6	25.9	26.2	17.80
	Mass of dry soil (g), m8=m5-m6	102.01	91.2	83.4	76.78	175.50
	Moisture content (%), w =(m7/m8)*100	25.6	28.07	31.06	34.1	10.1
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.375	1.395	1.385	1.313	



MDD (g/cm^3)= **1.399**

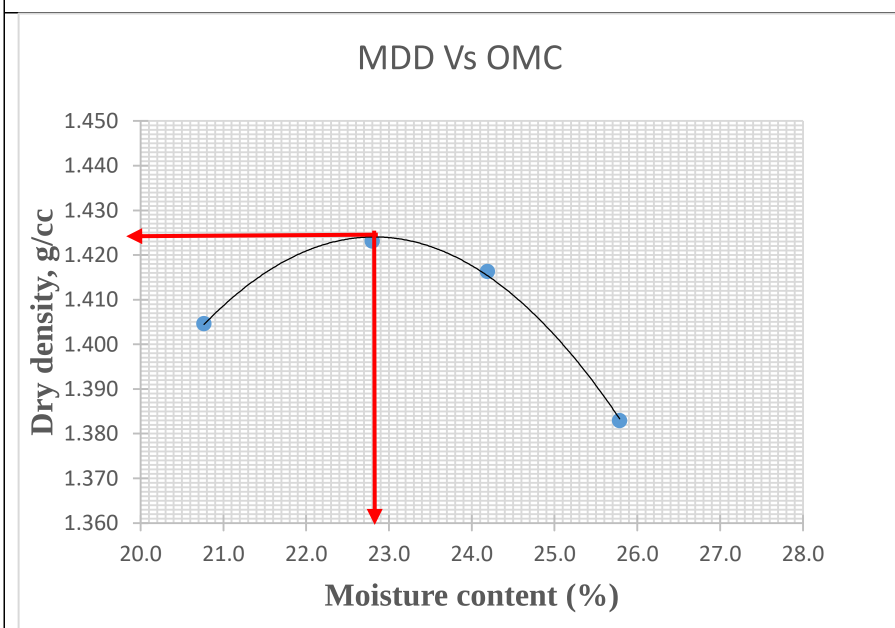
OMC (%)= **28.6**

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-5% Lime +Expansive Soil			Date sampled:-Sep 06, 2022 Date Tested:- Sept 07, 2022			
DENSITY	Trial Numbers	1	2	3	4	5%Lime + Expansive Soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of Mold +Wet soil (g),=m1	6321	6423	6432	6382	
	Mass of Mold (g)=m2	2708	2708	2708	2708	
	Mass of Wet soil (g), m3=m1-m2	3613	3715	3724	3674	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.75	1.75	1.73	
MOISTURE	Container code	G19	A-16	G3T2	P65	NMC (ZE)
	Mass of wet soil +cont (g), m4	180.1	186.1	206.2	211.22	231.20
	Mass of dry soil + cont (g), m5	154.5	157.5	172.4	176	211.14
	Mass of container (g), m6	36.1	33	34.8	39.79	33.00
	Mass of moisture (g), m7=m4-m5	25.6	28.6	33.8	35.22	20.06
	Mass of dry soil (g), m8=m5-m6	118.4	124.5	137.6	136.21	178.14
	Moisture content (%), w =(m7/m8)*100	21.6	23.0	24.6	25.9	11.3
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.40	1.42	1.41	1.37	



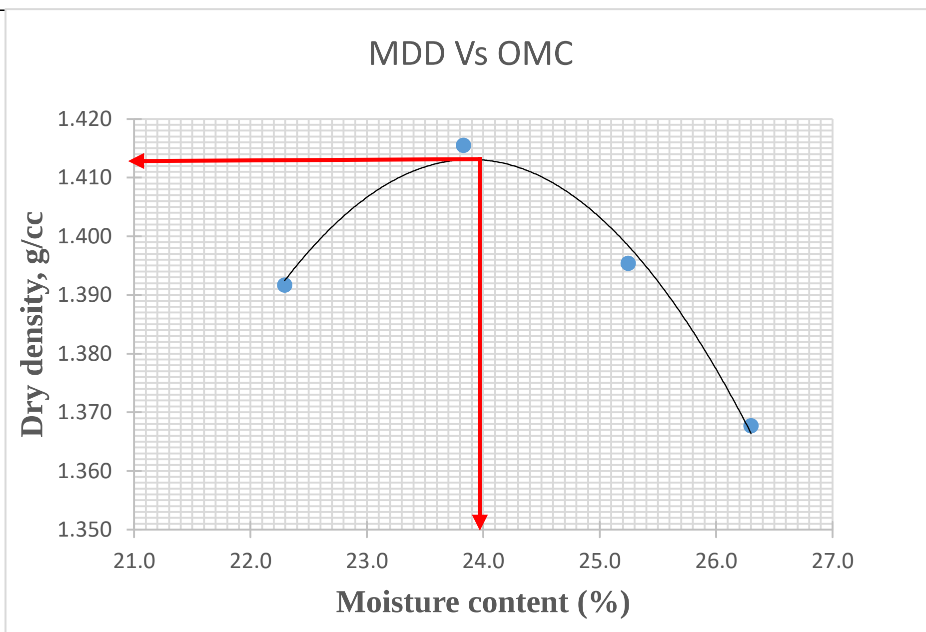
MDD(g/cm^3) =**1.420**
OMC(%) = **23.3**

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-10%Lime+Expansive Soil			Date sampled:-Sep 06, 2022			
			Date Tested:- Sept 07, 2022			
DENSITY	Trial Numbers	1	2	3	4	10%Lime + Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	180	360	540	720	
	Mass of Mold +Wet soil (g),=m1	6318.0	6427	6451	6410	
	Mass of Mold (g)=m2	2715	2715	2715	2715	
	Mass of Wet soil (g), m3=m1-m2	3603.0	3712	3736	3695.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.75	1.76	1.74	
MOISTURE	Container code	C10	G3T3	W11	GY	NMC(ZE)
	Mass of wet soil +cont (g), m4	205.9	194.1	201.7	177.73	231.20
	Mass of dry soil + cont (g), m5	176.6	165.1	170.3	147.1	211.14
	Mass of container (g), m6	35.5	37.9	40.5	28.32	33.00
	Mass of moisture (g), m7=m4-m5	29.3	29	31.4	30.6	20.06
	Mass of dry soil (g), m8=m5-m6	141.1	127.2	129.8	118.78	178.14
	Moisture content (%), w =(m7/m8)*100	20.8	22.8	24.2	25.8	11.3
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.405	1.423	1.416	1.383	



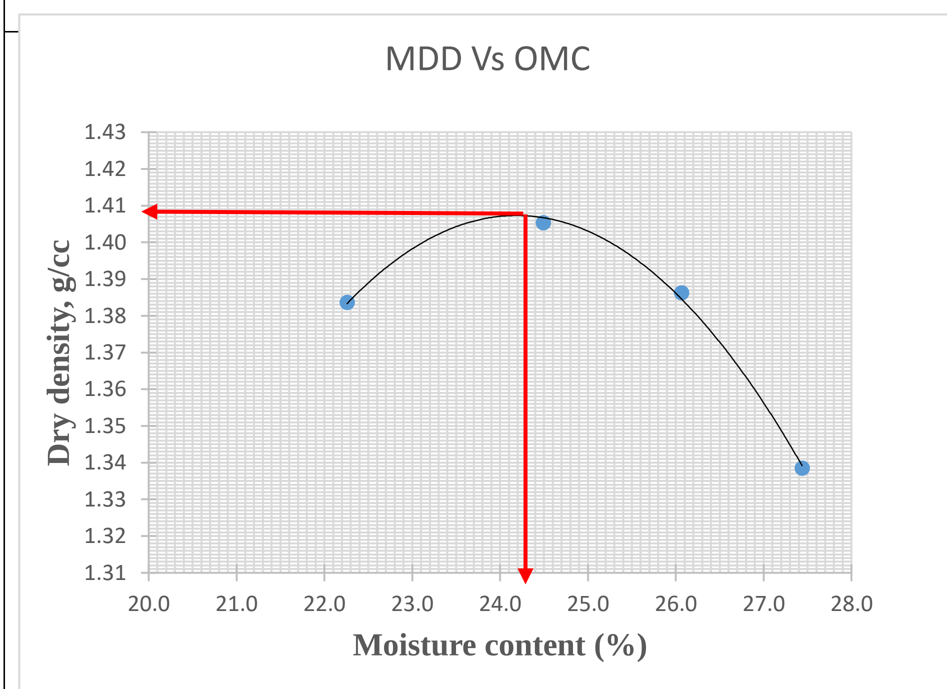
MDD (g/cm^3) = 1.423
OMC (%) = 22.8

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-15%Lime+Expansive Soil			Date sampled:-Sep 06/2021			
			Date Tested:- Sept 07, 2022			
DENSITY	Trial Numbers	1	2	3	4	15%Lime + Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of Mold +Wet soil (g),=m1	6323.0	6431	6420	6377	
	Mass of Mold (g)=m2	2708	2708	2708	2708	
	Mass of Wet soil (g), m3=m1-m2	3615.0	3723.0	3712.0	3669.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.75	1.75	1.73	
MOISTURE	Container code	02,1	P15	P66	KH	NMC(ZE)
	Mass of wet soil +cont (g), m4	198.9	186.8	203.5	167.73	231.20
	Mass of dry soil + cont (g), m5	167.8	157.3	170	138.7	211.14
	Mass of container (g), m6	28.3	33.5	37.3	28.32	33.00
	Mass of moisture (g), m7=m4-m5	31.1	29.5	33.5	29.0	20.06
	Mass of dry soil (g), m8=m5-m6	139.5	123.8	132.7	110.38	178.14
	Moisture content (%), w =(m7/m8)*100	22.3	23.8	25.2	26.3	11.3
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.392	1.416	1.395	1.368	



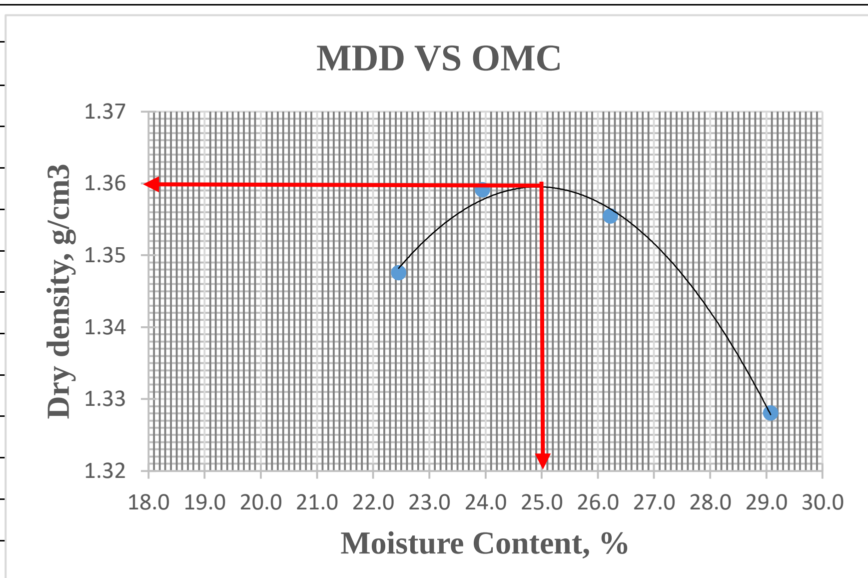
MDD (g/cm^3)=1.413
OMC (%)=24.0

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-20%Lime+Expansive Soil			Date sampled:-Sep 06/2022			
			Date Tested:- Sept 07, 2022			
DENSITY	Trial Numbers	1	2	3	4	20%Lime+ Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of Mold +Wet soil (g),=m1	6308.0	6431	6427	6338	
	Mass of Mold (g)=m2	2715	2715	2715	2715	
	Mass of Wet soil (g), m3=m1-m2	3593.0	3716	3712	3623.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.69	1.75	1.75	1.71	
MOISTURE	Container code	A1C	T1	A18	A2	NMC(ZE)
	Mass of wet soil +cont (g), m4	201.1	202.4	209.1	201.5	231.20
	Mass of dry soil + cont (g), m5	173.5	170	171.8	163.5	211.14
	Mass of container (g), m6	49.5	37.7	28.7	25	33.00
	Mass of moisture (g), m7=m4-m5	27.6	32.4	37.3	38.0	20.06
	Mass of dry soil (g), m8=m5-m6	124	132.3	143.1	138.5	178.14
	Moisture content (%), w =(m7/m8)*100	22.3	24.49	26.07	27.4	11.3
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.38	1.41	1.39	1.34	



MDD(g/cm^3)= 1.408
OMC (%)= 24.4

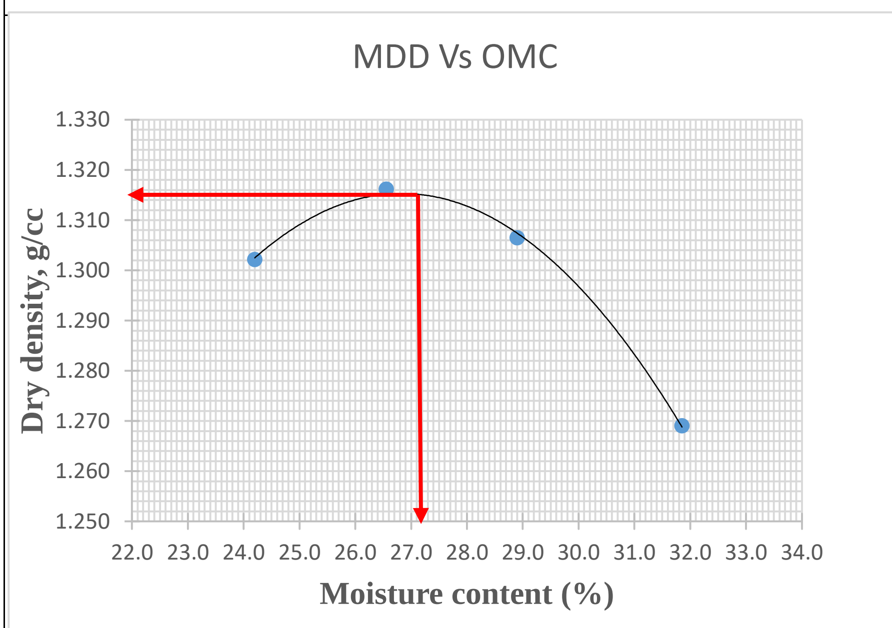
MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD: MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Soil+Opt Lime+5%BHA			Date sampled:-Sep 14/2022			
			Date Tested:- Sept 15, 2022			
DENSITY	Trial Numbers	1	2	3	4	Expansive soil + Opt Lime+5% BHA
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	180	360	540	720	
	Mass of Mold +Wet soil (g),=m1	6214.0	6287	6343	6350	
	Mass of Mold (g)=m2	2709	2709	2709	2709	
	Mass of Wet soil (g), m3=m1-m2	3505.0	3578	3634	3641.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.68	1.71	1.71	
MOISTURE	Container code	A-16	G3T3	G3T2	M	NMC(G19)
	Mass of wet soil +cont (g), m4	195.5	229	228.5	228.00	262.50
	Mass of dry soil + cont (g), m5	165.7	192.1	188.3	185.20	242.70
	Mass of container (g), m6	33	38	35	38.00	36.00
	Mass of moisture (g), m7=m4-m5	29.8	36.9	40.2	42.8	19.80
	Mass of dry soil (g), m8=m5-m6	132.7	154.1	153.3	147.2	206.70
	Moisture content (%), w =(m7/m8)*100	22.5	23.95	26.22	29.1	9.6
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.35	1.36	1.36	1.33	



MDD(g/cm^3)=1.360

OMC(%)=25.0

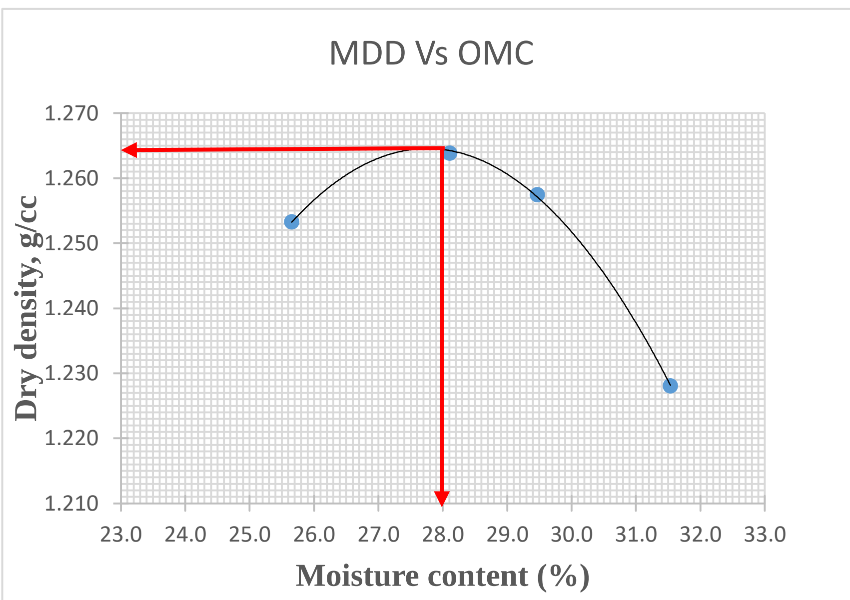
MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Soil + Opt. Lime + 10%BHA		Date sampled:-Sep 14/2022				
		Date Tested:- Sept 15/2022				
DENSITY	Trial Numbers	1	2	3	4	Expansive soil + Opt Lime+10% BHA
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mold +Wet soil (g),=m1	6151.0	6254	6293	6270	
	Mass of mold (g)=m2	2716	2716	2716	2716	
	Mass of Wet soil (g), m3=m1-m2	3435.0	3538	3577	3554.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.62	1.67	1.68	1.67	
MOISTURE	Container code	P16	P66	T1	SE	NMC (G19)
	Mass of wet soil + cont. (g), m4	207.5	200	195.4	137.73	262.50
	Mass of dry soil + cont. (g), m5	173.6	165.9	160	111.3	242.50
	Mass of container (g), m6	33.5	37.5	37.5	28.32	36.00
	Mass of moisture (g), m7=m4-m5	33.9	34.1	35.4	26.4	20.00
	Mass of dry soil (g), m8=m5-m6	140.1	128.4	122.5	82.98	206.50
	Moisture content (%), w =(m7/m8)*100	24.2	26.6	28.9	31.9	9.7
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.302	1.316	1.307	1.269	



MDD (g/cm^3)=<u>1.315</u>

OMC (%)=<u>27.2</u>

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Soil + Opt. Lime +15%BHA		Date sampled:-Sep 14/2022				
		Date Tested:-Sept 15/2022				
DENSITY	Trial Numbers	1	2	3	4	Expansive soil+ Opt Lime+ 15% BHA
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	180	360	540	720	
	Mass of Mold +Wet soil (g),=m1	6054.0	6148	6167	6140	
	Mass of Mold (g)=m2	2709	2709	2709	2709	
	Mass of Wet soil (g), m3=m1-m2	3345.0	3439	3458	3431.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.6	1.62	1.63	1.62	
MOISTURE	Container code	A-1C	02,1	W11	G3T3	NMC(G19)
	Mass of wet soil +cont (g), m4	217.5	193.5	218	196	262.50
	Mass of dry soil + cont (g), m5	183.2	157.3	177.6	158	242.70
	Mass of container (g), m6	49.5	28.5	40.5	37.5	36.00
	Mass of moisture (g), m7=m4-m5	34.3	36.2	40.4	38.0	19.80
	Mass of dry soil (g), m8=m5-m6	133.7	128.8	137.1	120.5	206.70
	Moisture content (%), w =(m7/m8)*100	25.7	28.1	29.5	31.5	9.6
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.253	1.264	1.258	1.228	

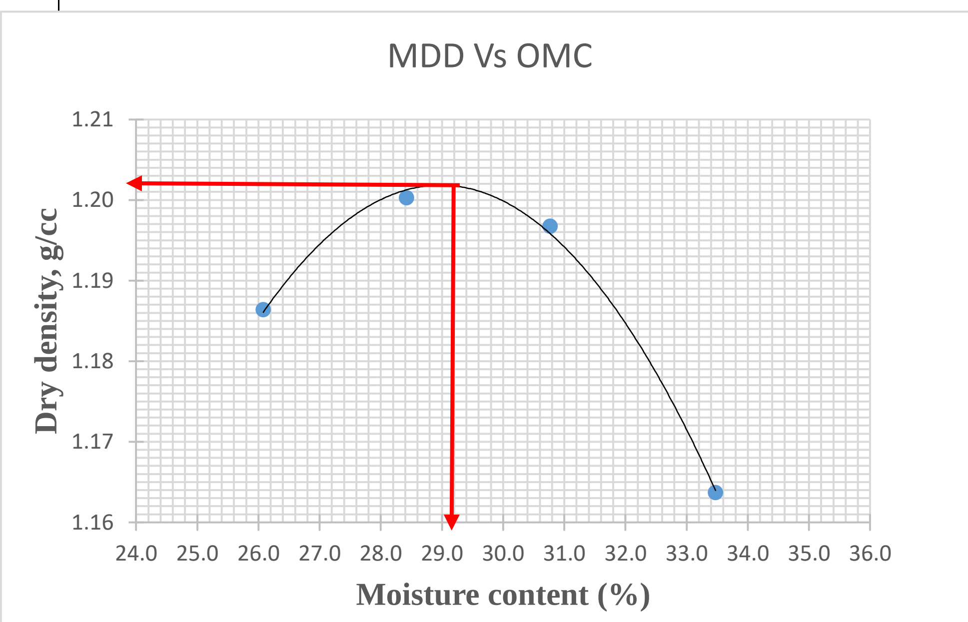


MDD (g/cm^3)=**1.264**
OMC (%)=**28.0**

MOISTURE DENSITY RELATIONSHIP OF SOIL

TEST METHOD: MODIFIED PROCTOR TEST AASHTO T180 -95

Material description:-Expansive Soil + Opt. Lime +20%BHA			Date sampled:-Sep 14/2022			
			Date Tested:-Sept 15, 2022			
DENSITY	Trial Numbers	1	2	3	4	Expansive soil+ Opt Lime+ 20%BHA
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of Mold +Wet soil (g),=m1	5893.0	5990	6040	6015	
	Mass of Mold (g)=m2	2716	2716	2716	2716	
	Mass of Wet soil (g), m3=m1-m2	3177.0	3274	3324	3299.0	
	Volume of Mold (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.5	1.54	1.56	1.55	
MOISTURE	Container code	33	ZE	E-11	BN	NMC (G19)
	Mass of wet soil +cont (g), m4	187	206.5	189.5	127.73	262.50
	Mass of dry soil + cont (g), m5	153.7	168.1	153.5	102.8	242.70
	Mass of container (g), m6	26	33	36.5	28.32	36.00
	Mass of moisture (g), m7=m4-m5	33.3	38.4	36	24.9	19.80
	Mass of dry soil (g), m8=m5-m6	127.7	135.1	117	74.48	206.70
	Moisture content (%), w =(m7/m8)*100	26.1	28.4	30.8	33.5	9.6
	Dry density (g/cm^3), γd=(ρ/(100+w))*100	1.19	1.20	1.20	1.16	

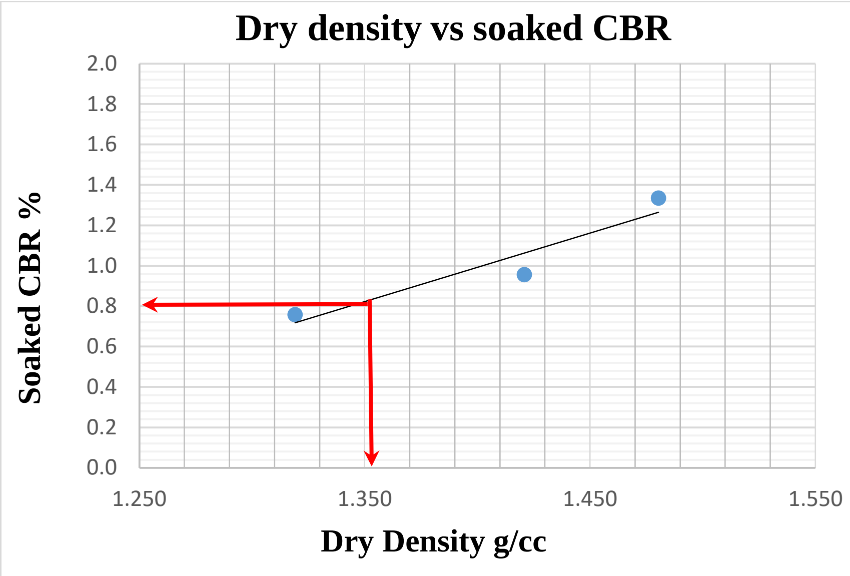


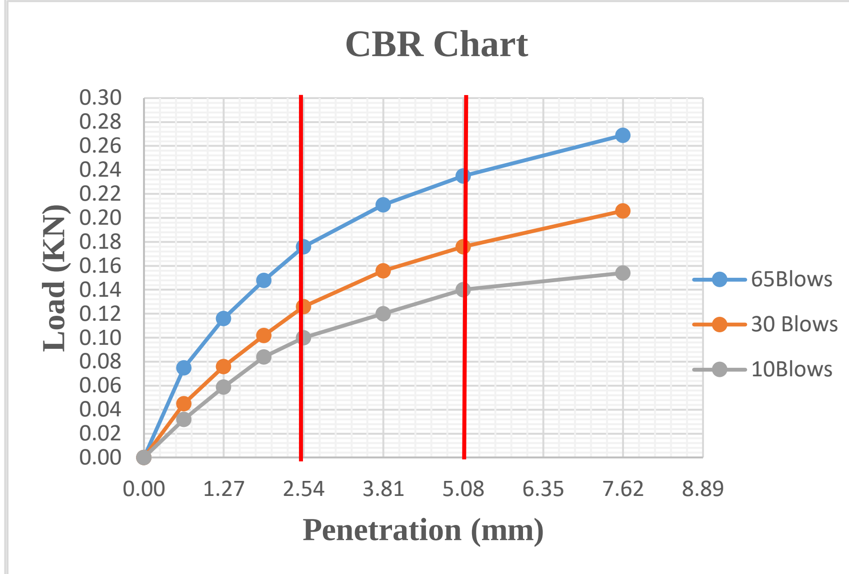
MDD (g/cm^3)=1.220
OMC (%)=29.4

Appendix-6 CBR tests

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-04, SEPT 2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL						
EXPANSIVE SOIL			Test NO:-121-124			
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	N2	N2	N70	N70	Ny	Ny
Mass of wet soil + Mold, g	10851	11218	10627	11030	10421	
Mass Mold, g	6983	6983	6935	6935	6973	6973
Mass of Soil, g	3868	4235	3692	4095	3448	4117.1
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.82	1.99	1.738	1.928	1.623	1.938
Dry density of soil, g/cc	1.48	1.22	1.41	1.21	1.32	1.22
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	LC51	ZE	33	P3	A	02,1
Mass of wet soil + Container, g	151	195	187.0	178.5	179.0	169.5
Mass of dry soil + Container, g	127.52	131.93	156.2	121.5	153.0	117.3
Mass of container, g	25.5	33	25.50	26.00	40.00	28.50
Mass of water, g	23.48	63.07	30.8	57.0	26.1	52.3
Mass of dry soil,g	102.02	98.93	130.7	95.5	113.0	88.8
Moisture content, %	23.0	63.8	23.6	59.7	24.0	58.9

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**			
	65 Blows		**30Blows**		**10Blows**	
Pen. mm	**Load, KN**	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.08		0.05		0.03	
1.27	0.12		0.08		0.06	
1.91	0.15		0.10		0.08	
2.54	0.18	1.33	0.13	0.95	0.10	0.76
3.81	0.21		0.16		0.12	
5.08	0.24	1.15	0.18	0.86	0.14	0.68
7.62	0.27		0.21		0.15	
Modified Max.Dry Density g/cc	**1.42**			**OMC %**	**23.33**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
04, SEPT 2022 (Initial)	0.2	16.03	1.00	15.95	0.88	11.93
08, SEPT 2022 (Final)	18.86		19.56		14.77	





Dry Density at 95% of MDD:					**1.345**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	23.1	1.319	0.8	92	
30	23.0	1.421	1.0	99	
65	23.0	1.480	1.3	105	
CBR (%) @ 95 % MDD			**0.8**	**% Swell**	**14.64**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 08/2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 12/2022			
5% lime + Expansive Soil						
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	N2	N2	N12	N12	N13	N13
Mass of wet soil + Mold, g	10838	11093	10692	11101	10360	11568
Mass Mold, g	6935	6935	6972	6972	6962	6962
Mass of Soil, g	3903	4158	3720	4129	3398	4606
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.84	1.96	1.751	1.944	1.600	2.169
Dry density of soil, g/cc	1.48	1.50	1.42	1.48	1.29	1.61
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	G3T2	A-1C	A-16	ZE	G19	33
Mass of wet soil + Container, g	159.5	217	213.5	218.0	175.5	218.5
Mass of dry soil + Container, g	135.5	178	179.5	174.0	148.4	169.0
Mass of container, g	34.8	49.50	33.0	33.00	36.20	26.00
Mass of water, g	24	39	34.0	44.0	27.1	49.5
Mass of dry soil, g	100.7	128.5	146.5	141.0	112.2	143.0
Moisture content, %	23.8	30.4	23.2	31.2	24.2	34.6

<table>
<tr><th colspan="7">CBR Penetration Determination</th></tr>
<tr><th colspan="3">Penetration after 96 hrs Soaking Period</th><th colspan="4">Surcharge Weight:-4.55 KG</th></tr>
<tr><th rowspan="2">Pen. mm</th><th colspan="2">65 Blows</th><th colspan="2">30Blows</th><th colspan="2">10Blows</th></tr>
<tr><th>Load, KN</th><th>CBR%</th><th>Load, KN</th><th>CBR%</th><th>Load, KN</th><th>CBR %</th></tr>
<tr><td>0.00</td><td>0.00</td><td></td><td>0.00</td><td></td><td>0.00</td><td></td></tr>
<tr><td>0.64</td><td>0.39</td><td></td><td>0.31</td><td></td><td>0.26</td><td></td></tr>
<tr><td>1.27</td><td>0.62</td><td></td><td>0.55</td><td></td><td>0.38</td><td></td></tr>
<tr><td>1.91</td><td>0.80</td><td></td><td>0.68</td><td></td><td>0.44</td><td></td></tr>
<tr><td>2.54</td><td>0.91</td><td>6.86</td><td>0.76</td><td>5.74</td><td>0.48</td><td>3.65</td></tr>
<tr><td>3.81</td><td>1.08</td><td></td><td>0.86</td><td></td><td>0.54</td><td></td></tr>
<tr><td>5.08</td><td>1.20</td><td>5.84</td><td>0.92</td><td>4.44</td><td>0.58</td><td>2.80</td></tr>
<tr><td>7.62</td><td>1.37</td><td></td><td>0.99</td><td></td><td>0.62</td><td></td></tr>
<tr><td>Modified Max. Dry Density g/cc</td><td colspan="2">1.41</td><td></td><td>OMC %</td><td colspan="2">23.27</td></tr>
<tr><th colspan="7">Swell Determination</th></tr>
<tr><th rowspan="2">Date</th><th colspan="2">65 Blows</th><th colspan="2">30 Blow</th><th>10Blows</th><th></th></tr>
<tr><th>Gauge reading (mm)</th><th>Swell in %</th><th>Gauge reading(mm)</th><th>Swell in %</th><th>Gauge reading(mm)</th><th>Swell in %</th></tr>
<tr><td>Sept 08/2022 (Initial)</td><td>0.3</td><td rowspan="2">12.47</td><td>0.31</td><td rowspan="2">12.56</td><td>0.22</td><td rowspan="2">12.50</td></tr>
<tr><td>Sept 12/2022 (Final)</td><td>14.82</td><td>14.93</td><td>14.77</td></tr>
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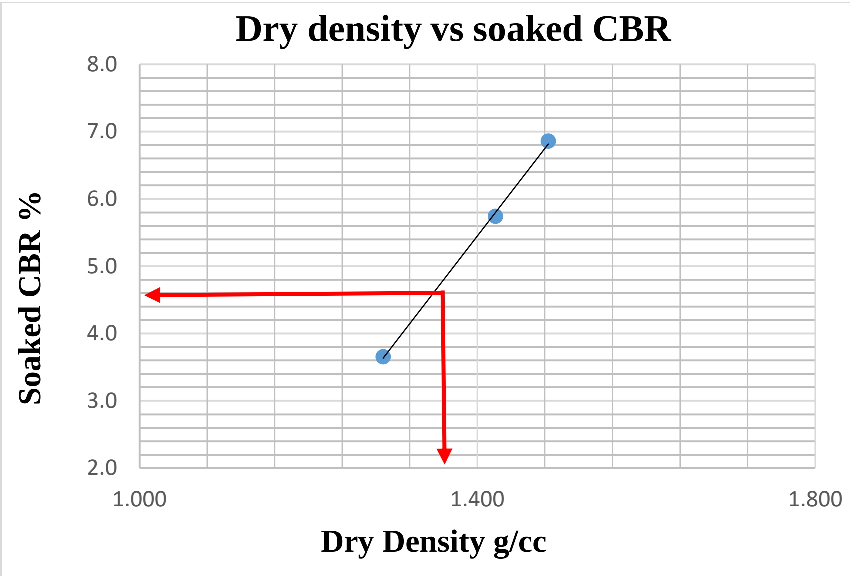
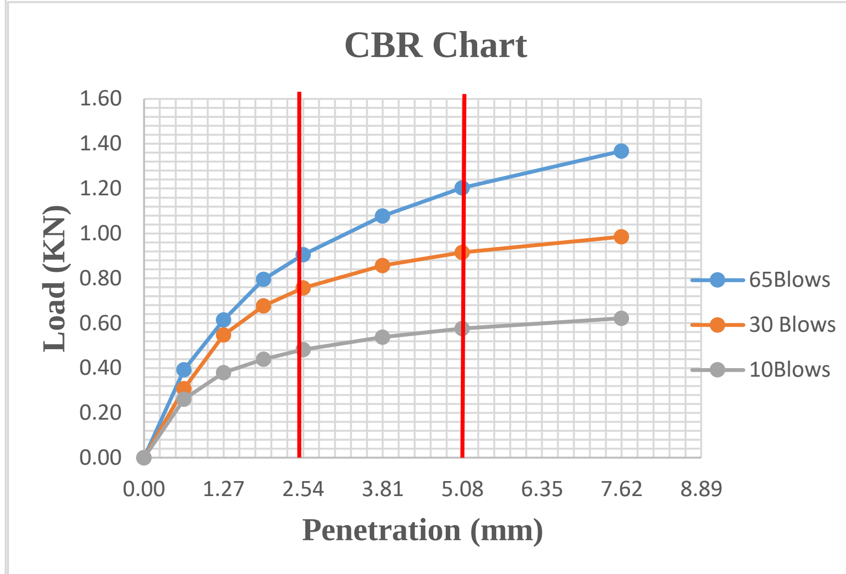
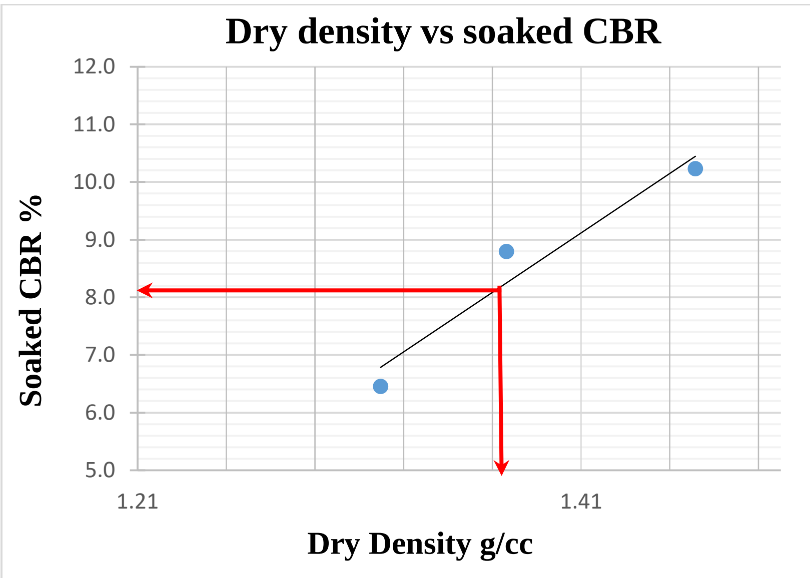


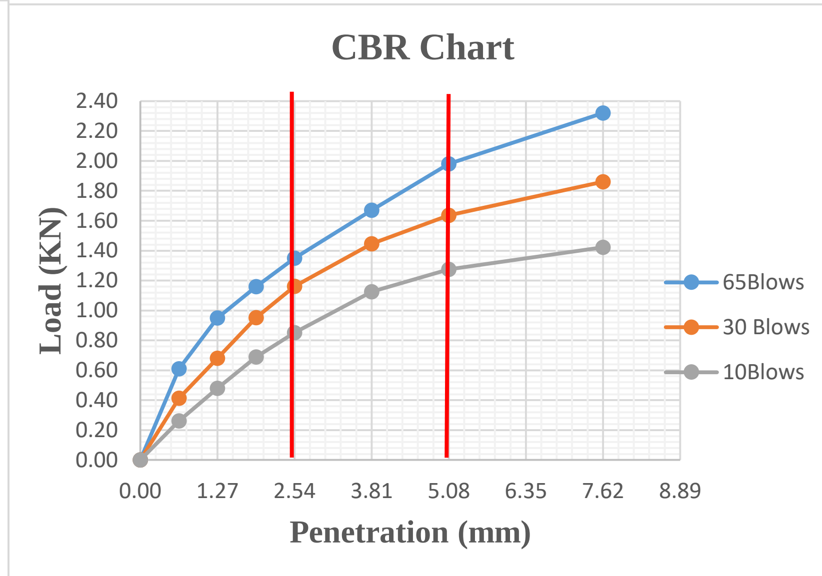


Dry Density at 95% of MDD:					**1.34**
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	24.2	1.289	3.7	91	
30	23.2	1.422	5.7	101	
65	23.8	1.484	6.9	105	
CBR (%) @ 95 % MDD			**4.5**	**% Swell**	**12.51**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 08/2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 12/2022			
10%Lime + Expansive Soil			Test NO:-127-130			
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	A	A	N4	N4	N1	N1
Mass of wet soil + Mold, g	10808	11292	10597	10884	10413	10605
Mass Mold, g	6988	6988	6985	6985	6939	6939
Mass of Soil, g	3820	4304	3612	3899	3474	3666
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.80	2.03	1.701	1.836	1.636	1.726
Dry density of soil, g/cc	1.46	1.54	1.38	1.39	1.32	1.27
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	G3T3	W11	W11	P15	C10	G3T3
Mass of wet soil + Container, g	167.5	221.5	211.5	215.5	242.0	193.5
Mass of dry soil + Container, g	143.2	178.5	178.9	171.0	202.1	152.5
Mass of container, g	37.8	40.5	40.50	33.50	35.50	38.00
Mass of water, g	24.3	43	32.6	44.5	39.9	41.0
Mass of dry soil,g	105.4	138	138.4	137.5	166.6	114.5
Moisture content, %	23.1	31.2	23.6	32.4	23.9	35.8

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		**Surcharge Weight:-4.55 KG**				
	65 Blows		**30Blows**		**10Blows**	
Pen. mm	**Load, KN**	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.61		0.41		0.26	
1.27	0.95		0.68		0.48	
1.91	1.16		0.95		0.69	
2.54	1.35	10.23	1.16	8.80	0.85	6.45
3.81	1.67		1.45		1.13	
5.08	1.98	9.66	1.64	7.98	1.28	6.22
7.62	2.32		1.86		1.42	
Modified Max.Dry Density g/cc	**1.43**			**OMC %**	**22.60**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
Sept 08/2022 (Initial)	0.26	8.49	0.28	9.62	0.28	10.09
Sept 12/2022 (Final)	10.14		11.48		12.03	

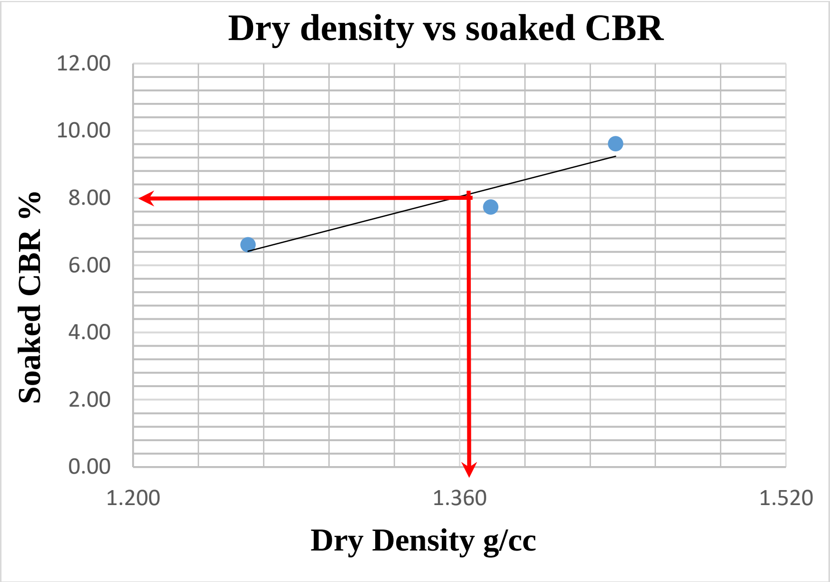


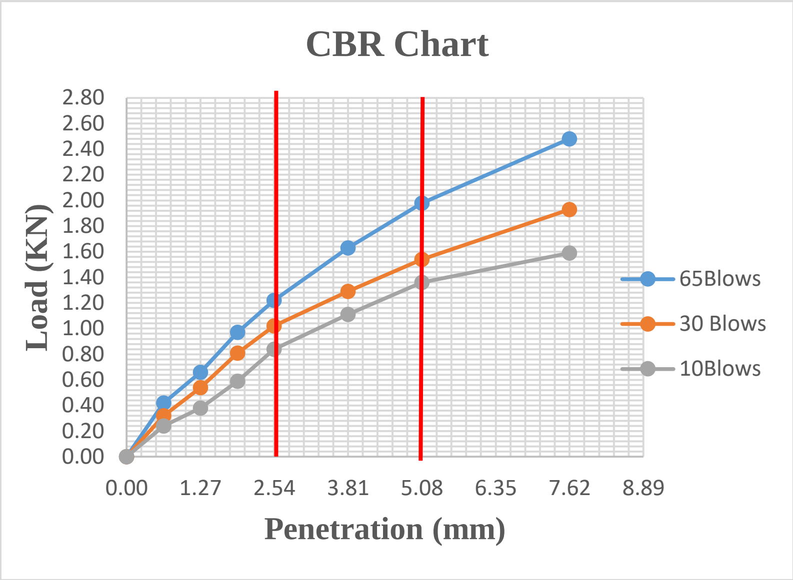


Dry Density at 95% of MDD:					**1.36**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	23.9	1.32	6.5	92	
30	23.6	1.38	8.8	96	
65	23.1	1.46	10.2	102	
CBR (%) @ 95 % MDD			**8.1**	**% Swell**	**9.40**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 08/2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 12/2022			
15% Lime + Expansive Soil			Test NO:-130-133			
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	M30	M30	N7	N7	M65	M65
Mass of wet soil + Mold, g	10702	11239	10492	11162	10226	10913
Mass Mold, g	6994	6994	6913	6913	6951	6951
Mass of Soil, g	3708	4245	3579	4249	3275	3962
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.75	2.00	1.685	2.000	1.542	1.865
Dry density of soil, g/cc	1.44	1.53	1.38	1.50	1.26	1.38
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	02,1	T1	P15	02,1	P66	P66
Mass of wet soil + Container, g	223	235	231.5	256.0	230.0	252.0
Mass of dry soil + Container, g	188.5	189	195.1	199.0	194.3	196.5
Mass of container, g	28.3	37.50	33.5	28.50	37.30	37.30
Mass of water, g	34.5	46	36.4	57.0	35.7	55.5
Mass of dry soil,g	160.2	151.5	161.6	170.5	157.0	159.2
Moisture content, %	21.5	30.4	22.5	33.4	22.7	34.9

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**			
	65 Blows		**30Blows**		**10Blows**	
Pen. mm	**Load, KN**	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.42		0.32		0.24	
1.27	0.66		0.54		0.38	
1.91	0.97		0.81		0.59	
2.54	1.22	9.24	1.02	7.73	0.84	6.36
3.81	1.63		1.29		1.11	
5.08	1.98	9.61	1.54	7.48	1.36	6.60
7.62	2.48		1.93		1.59	
Modified Max.Dry Density g/cc	**1.41**			**OMC %**	**24.23**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
Sept 08/2022 (Initial)	**0.2**	9.08	0.20	8.71	**0.3**	8.30
Sept 12/2022 (Final)	10.77		10.34		9.96	

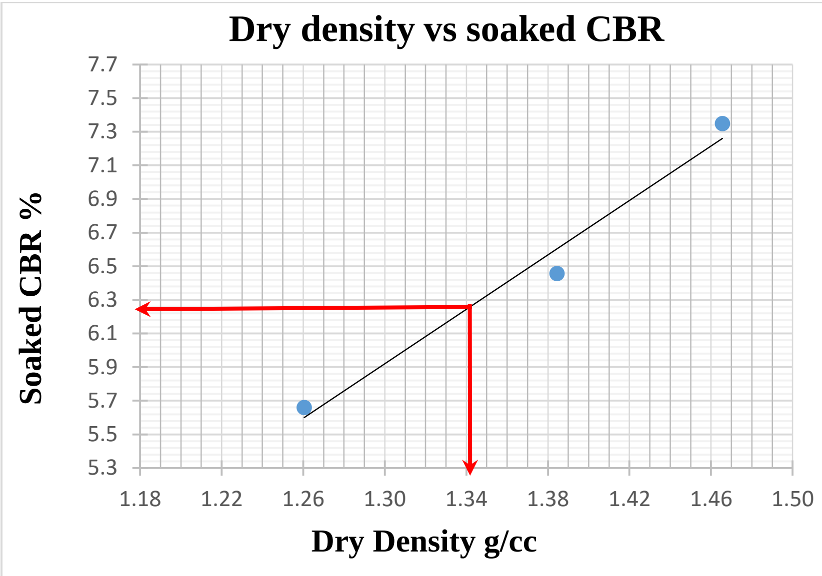


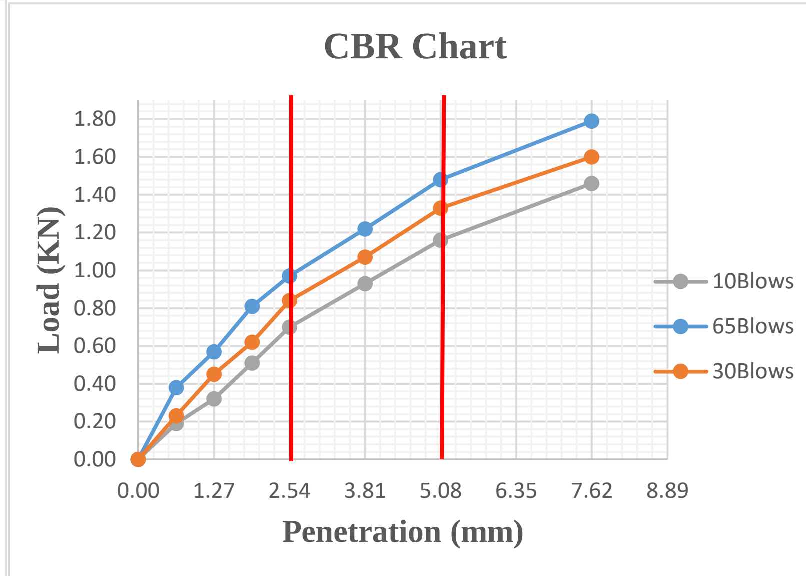


Dry Density at 95% of MDD:					**1.34**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	22.7	1.256	6.60	89	
30	22.5	1.375	7.73	98	
65	21.5	1.436	9.61	102	
CBR (%) @ 95 % MDD			**7.3**	**% Swell**	**8.70**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 08/2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 12/2022			
20%Lime+Expansive Soil			Test NO:-133-136			
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	I65	I65	N	N	C	C
Mass of wet soil + Mold, g	10804	11220	10598	11170	10305	11109
Mass Mold, g	6969	6969	6975	6975	7003	7003
Mass of Soil, g	3835	4251	3623	4195	3302	4106
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.81	2.00	1.706	1.975	1.555	1.933
Dry density of soil, g/cc	1.47	1.57	1.38	1.50	1.26	1.45
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	A-1C	G19	T1	G3T2	A18	A-16
Mass of wet soil + Container, g	237	201.5	205.5	238.0	191.0	245.0
Mass of dry soil + Container, g	201.7	165.5	173.9	189.5	160.3	192.5
Mass of container, g	49.5	36	37.70	35.00	28.70	33.00
Mass of water, g	35.3	36	31.6	48.5	30.7	52.5
Mass of dry soil,g	152.2	129.5	136.2	154.5	131.6	159.5
Moisture content, %	23.2	27.8	23.2	31.4	23.3	32.9

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG			
	65 Blows		30Blows		10Blows	
Pen. mm	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.38		0.23		0.19	
1.27	0.57		0.45		0.32	
1.91	0.81		0.62		0.51	
2.54	0.97	7.35	0.84	6.36	0.70	5.30
3.81	1.22		1.07		0.93	
5.08	1.48	7.18	1.33	6.46	1.16	5.66
7.62	1.79		1.60		1.46	
Modified Max.Dry Density g/cc	1.42			OMC %	22.36	
Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
Sept 08/2022 (Initial)	1	7.33	0.20	7.13	0.4	6.89
Sept 12/2022 (Final)	9.53		8.50		8.42	



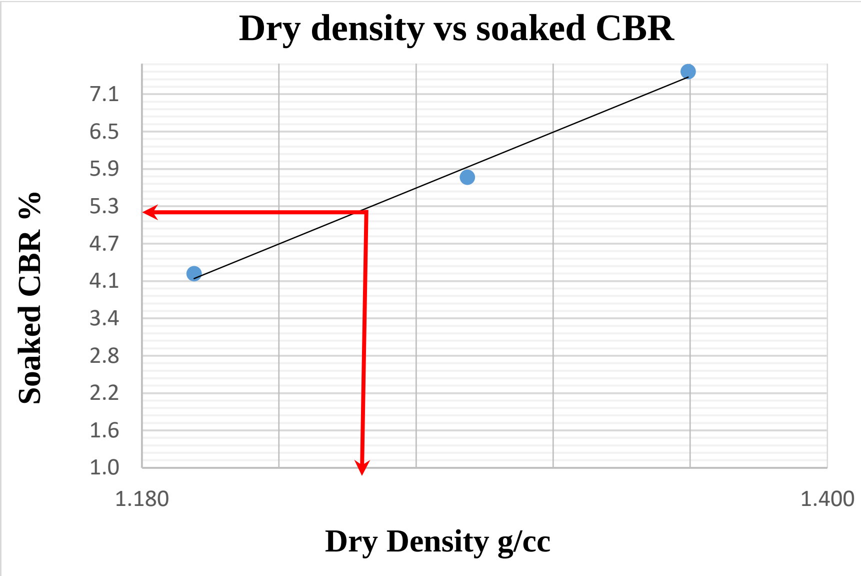


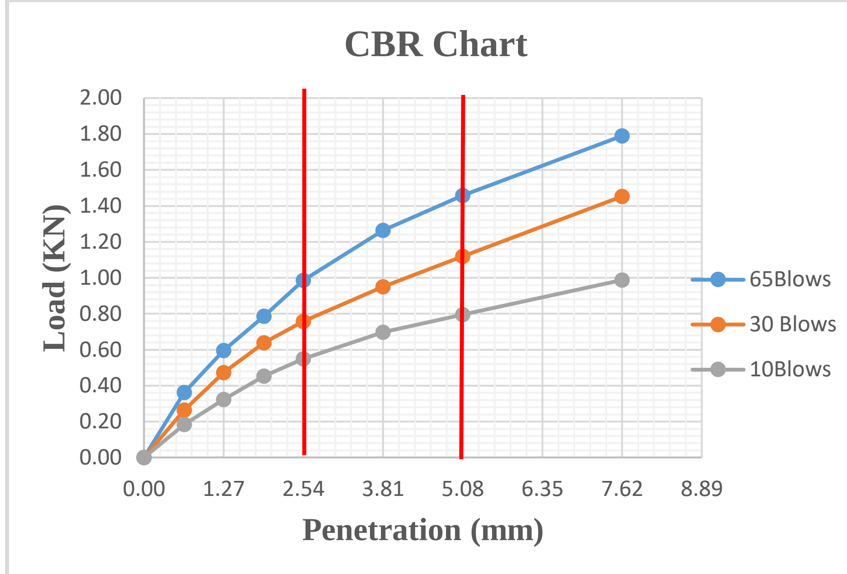
Dry Density at 95% of MDD:					**1.346**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	23.3	1.26	5.7	89	
30	23.2	1.38	6.5	98	
65	23.2	1.47	7.3	103	
CBR (%) @ 95 % MDD			**6.2**	**% Swell**	**7.12**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 16, 2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 20, 2022			
OPT Lime+5%BHA+Expansive Soil			Test NO:-151-154			
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	N4	N4	M65	M65	J8	J8
Mass of wet soil + Mold, g	10597	11492	10359	11312	10116	11126
Mass Mold, g	7012	7012	6949	6949	6937	6937
Mass of Soil, g	3585	4480	3410	4363	3179	4189
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.69	2.11	1.605	2.054	1.497	1.972
Dry density of soil, g/cc	1.36	1.57	1.28	1.45	1.20	1.38
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	T1	G3T2	P66	P15	W11	02,1
Mass of wet soil + Container, g	243.3	209.5	241.0	191.0	254.6	187.5
Mass of dry soil + Container, g	202.8	165.5	200.3	145.0	211.7	139.5
Mass of container, g	37.7	37.8	37.40	33.50	40.50	28.30
Mass of water, g	40.5	44	40.7	46.0	42.9	48.0
Mass of dry soil,g	165.1	127.7	162.9	111.5	171.2	111.2
Moisture content, %	24.5	34.5	25.0	41.3	25.1	43.2

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		**Surcharge Weight:-4.55 KG**				
	65 Blows		**30Blows**		**10Blows**	
Pen. mm	**Load, KN**	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.36		0.27		0.19	
1.27	0.60		0.47		0.32	
1.91	0.79		0.64		0.45	
2.54	0.99	7.47	0.76	5.74	0.55	4.17
3.81	1.26		0.95		0.70	
5.08	1.46	7.11	1.12	5.46	0.80	3.88
7.62	1.79		1.45		0.99	
Modified Max.Dry Density g/cc	**1.32**			**OMC %**	**23.95**	

Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
Sept 16, 2022 (Initial)	0.3	10.27	0.25	9.84	0.27	9.16
Sept 20, 2022 (Final)	12.26		11.70		10.93	

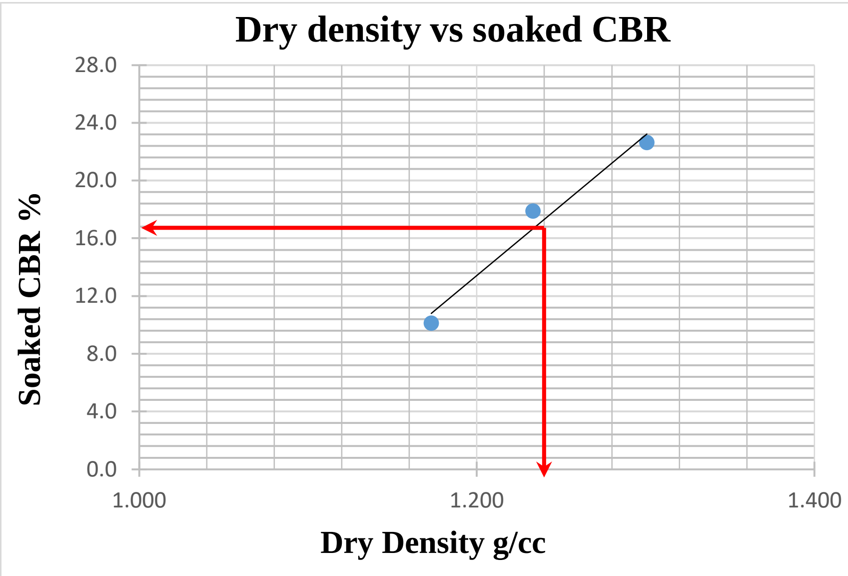


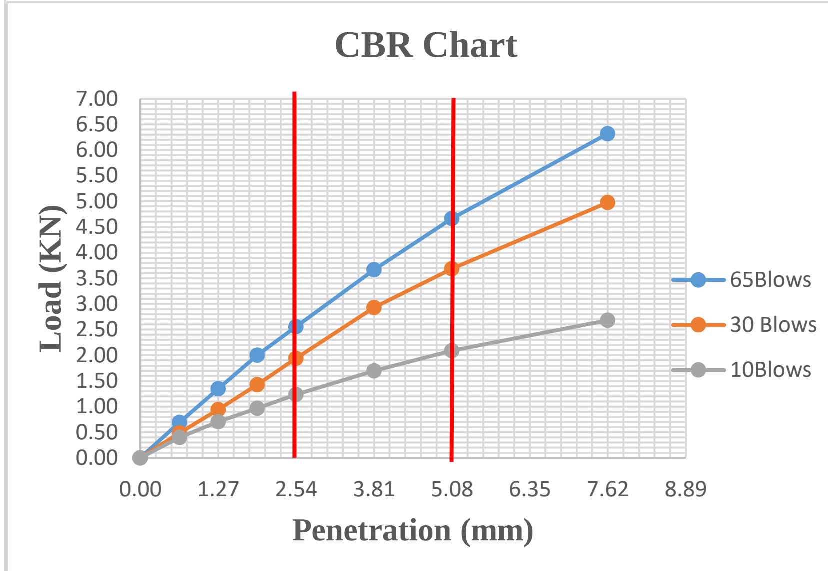


Dry Density at 95% of MDD:					**1.26**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	25.1	1.197	4.2	91	
30	25.0	1.285	5.7	97	
65	24.5	1.355	7.5	103	
CBR (%) @ 95 % MDD			**5.2**	**% Swell**	**9.76**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD: AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 16, 2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 20, 2022			
Opt. Lime + 10% BHA + Expansive Soil						
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	I65	I65	N70	N70	CB	CB
Mass of wet soil + Mold, g	10445	10975	10251	10712	10102	10579
Mass Mold, g	6972	6972	6937	6937	6937	6937
Mass of Soil, g	3473	4003	3314	3775	3165	3642
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.64	1.88	1.560	1.777	1.490	1.715
Dry density of soil, g/cc	1.301	1.448	1.233	1.343	1.173	1.259
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	E-11	T1	G19	P66	G3T2	W11
Mass of wet soil + Container, g	189.3	238	191.3	225.5	191.8	236.0
Mass of dry soil + Container, g	158.1	191.5	158.8	179.5	158.4	184.0
Mass of container, g	36.7	37.50	36.2	37.10	34.80	40.50
Mass of water, g	31.2	46.5	32.5	46.0	33.4	52.0
Mass of dry soil,g	121.4	154	122.6	142.4	123.6	143.5
Moisture content, %	25.7	30.2	26.5	32.3	27.0	36.2

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		**Surcharge Weight:-4.55 KG**				
Pen. mm	**65 Blows**		**30Blows**		**10Blows**	
	Load, KN	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.70		0.49		0.40	
1.27	1.35		0.94		0.70	
1.91	2.00		1.43		0.97	
2.54	2.56	19.39	1.94	14.72	1.24	9.36
3.81	3.67		2.93		1.70	
5.08	4.66	22.64	3.69	17.89	2.09	10.14
7.62	6.32		4.98		2.68	
Modified Max.Dry Density g/cc	**1.28**			**OMC %**	**26.36**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
Sept 16, 2022 (Initial)	**0.29**	6.30	0.08	2.16	**0.31**	3.72
Sept 20, 2022 (Final)	7.62		2.60		4.64	





Dry Density at 95% of MDD:					**1.21**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	27.0	1.173	10.1	92	
30	26.5	1.233	17.9	97	
65	25.7	1.301	22.6	102	
CBR (%) @ 95 % MDD			**16.5**	**% Swell**	**4.06**

CALIFORNIA BEARING RATIO TEST

TEST METHOD： AASHTO T 193-93

THREE-POINT CBR TEST METHOD	DATE SOAKED:-Sept 16, 2022
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL	DATE TESTED:-Sept 20, 2022
Opt. Lime + 15% BHA + Expansive Soil	

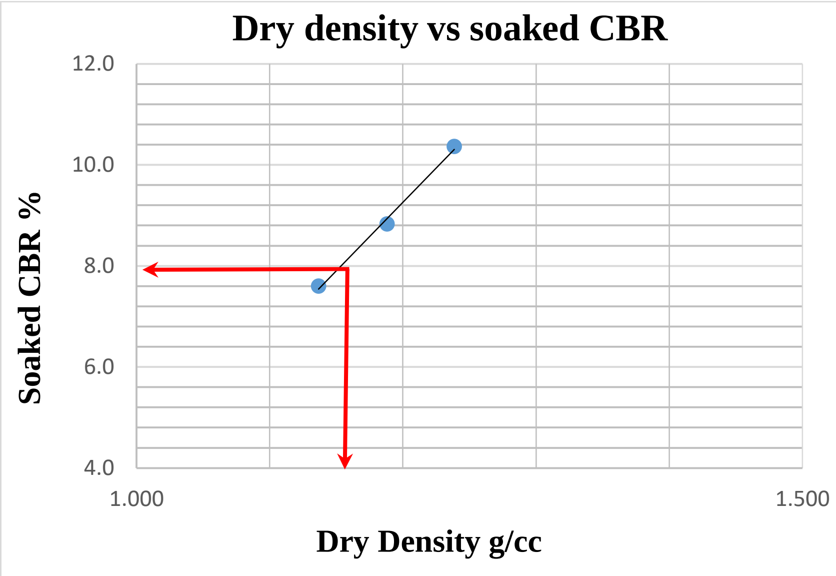
Compaction Determination

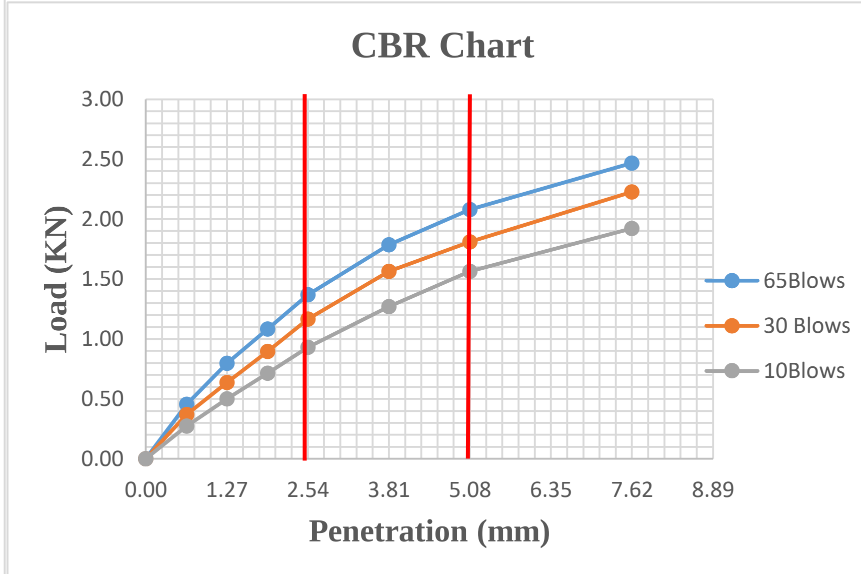
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	N1	N1	C	C	M30	M30
Mass of wet soil + Mold, g	10321	11302	10873	11423	10041	10598
Mass Mold, g	6975	6975	7678	7678	6969	6969
Mass of Soil, g	3346	4327	3195	3745	3072	3629
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.58	2.04	1.504	1.763	1.446	1.709
Dry density of soil, g/cc	1.24	1.52	1.19	1.32	1.14	1.25

Moisture Determination

MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	A-16	A-16	ZE	ZE	A-1C	A-1C
Mass of wet soil + Container, g	197.7	205	236.9	218.0	233.1	227.5
Mass of dry soil + Container, g	162.5	161.5	194.1	171.0	193.8	179.5
Mass of container, g	33	33.00	33.2	33.00	49.50	49.50
Mass of water, g	35.2	43.5	42.8	47.0	39.3	48.0
Mass of dry soil,g	129.5	128.5	160.9	138.0	144.3	130.0
Moisture content, %	27.2	33.9	26.6	34.1	27.2	36.9

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**			
Pen. mm	**65 Blows**		**30Blows**		**10Blows**	
	Load, KN	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.46		0.37		0.27	
1.27	0.80		0.64		0.50	
1.91	1.08		0.90		0.71	
2.54	1.37	10.36	1.17	8.83	0.93	7.05
3.81	1.79		1.56		1.27	
5.08	2.08	10.10	1.81	8.78	1.57	7.60
7.62	2.47		2.23		1.92	
Modified Max.Dry Density g/cc	**1.21**			**OMC %**	**28.00**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
Sept 16, 2022 (Initial)	0.21	9.99	0.21	1.54	0.2	3.40
Sept 20, 2022 (Final)	11.84		2.00		4.16	

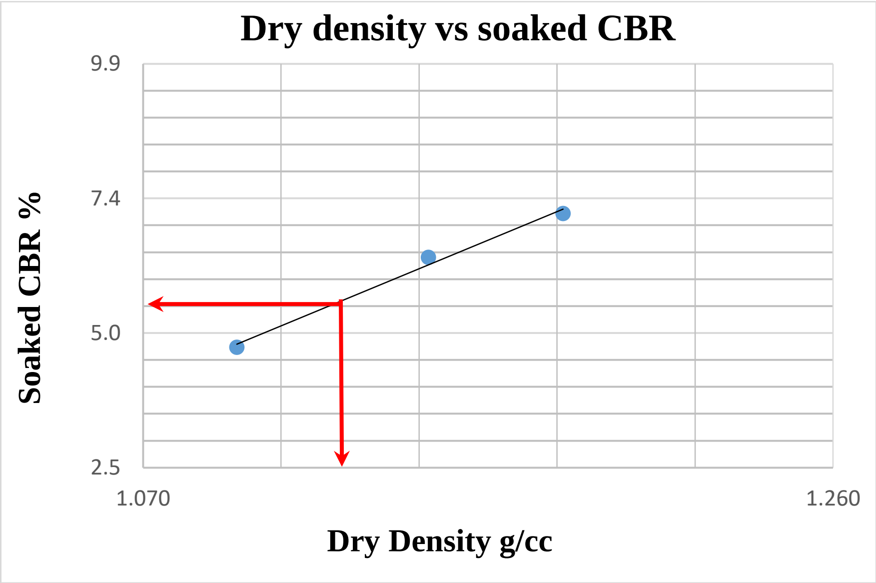


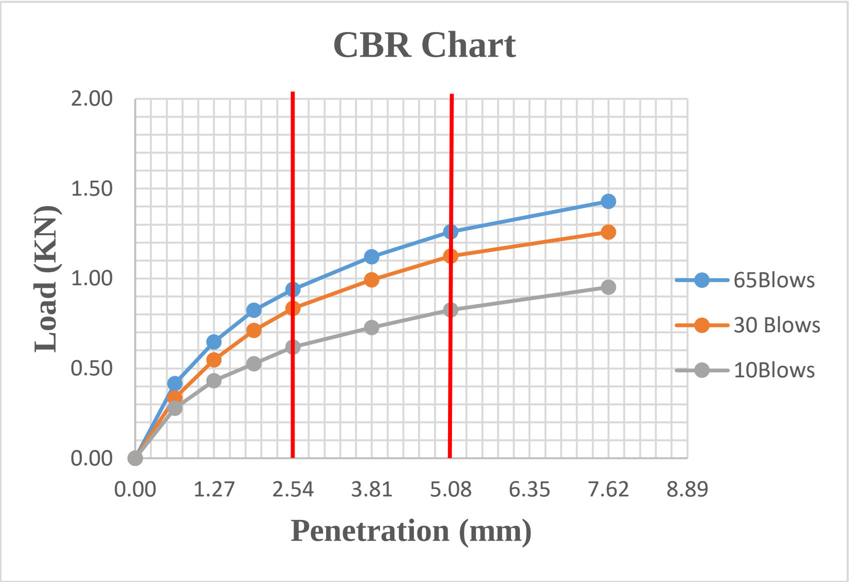


Dry Density at 95% of MDD:					**1.15**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	27.2	1.137	7.6	94	
30	26.6	1.188	8.8	98	
65	27.2	1.239	10.4	103	
CBR (%) @ 95 % MDD			**7.6**	**% Swell**	**4.98**

CALIFORNIA BEARING RATIO TEST						
TEST METHOD : AASHTO T 193-93						
THREE-POINT CBR TEST METHOD			DATE SOAKED:-Sept 16, 2022			
MATERIAL DESCRIPTION:- SUB-GRADE MATERIAL			DATE TESTED:-Sept 20, 2022			
Opt. Lime + 20% BHA + Expansive Soil			Test NO:-160-163			
Compaction Determination						
COMPACTION DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Mold No.	N2	N2	N3	N3	N12	N12
Mass of wet soil + Mold, g	10151	11453	10089	11431	9946	11122
Mass Mold, g	6942	6942	6977	6977	6969	6969
Mass of Soil, g	3209	4511	3112	4454	2977	4153
Volume of Mold, cc	2124	2124	2124	2124	2124	2124
Wet density of soil, g/cc	1.51	2.12	1.465	2.097	1.402	1.955
Dry density of soil, g/cc	1.19	1.60	1.15	1.51	1.10	1.41
Moisture Determination						
MOISTURE CONTENT DATA	**65Blows**		**30Blows**		**10Blows**	
	Before soak	**After soak**	**Before soak**	**After soak**	**Before soak**	**After soak**
Container no.	G3T3	E-11	P15	G19	02,1	G3T2
Mass of wet soil + Container, g	175.8	177.5	222.3	202.0	243.7	192.0
Mass of dry soil + Container, g	146.1	142.5	181.5	155.5	196.7	148.0
Mass of container, g	37.8	36.60	33.5	36.20	28.30	34.90
Mass of water, g	29.7	35	40.8	46.5	47.0	44.0
Mass of dry soil,g	108.3	105.9	148.0	119.3	168.4	113.1
Moisture content, %	27.4	33.1	27.6	39.0	27.9	38.9

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		**Surcharge Weight:-4.55 KG**				
Pen. mm	**65 Blows**		**30Blows**		**10Blows**	
	Load, KN	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.42		0.34		0.28	
1.27	0.65		0.55		0.43	
1.91	0.82		0.71		0.53	
2.54	0.94	7.12	0.84	6.33	0.62	4.69
3.81	1.12		0.99		0.73	
5.08	1.26	6.12	1.13	5.46	0.83	4.00
7.62	1.43		1.26		0.95	
Modified Max. Dry Density g/cc	**1.16**			**OMC %**	**29.00**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
Sept 16, 2022 (Initial)	0.33	7.93	0.39	3.30	0.63	2.67
Sept 20, 2022 (Final)	9.56		4.23		3.74	





Dry Density at 95% of MDD:					**1.10**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	27.9	1.096	4.7	94	
30	27.6	1.149	6.3	99	
65	27.4	1.186	7.1	102	
CBR (%) @ 95 % MDD			**5.3**	**% Swell**	**4.63**

Appendix-7 UCS Tests

Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Remolded
Sample Diameter	38mm
Materials	Natural Soil

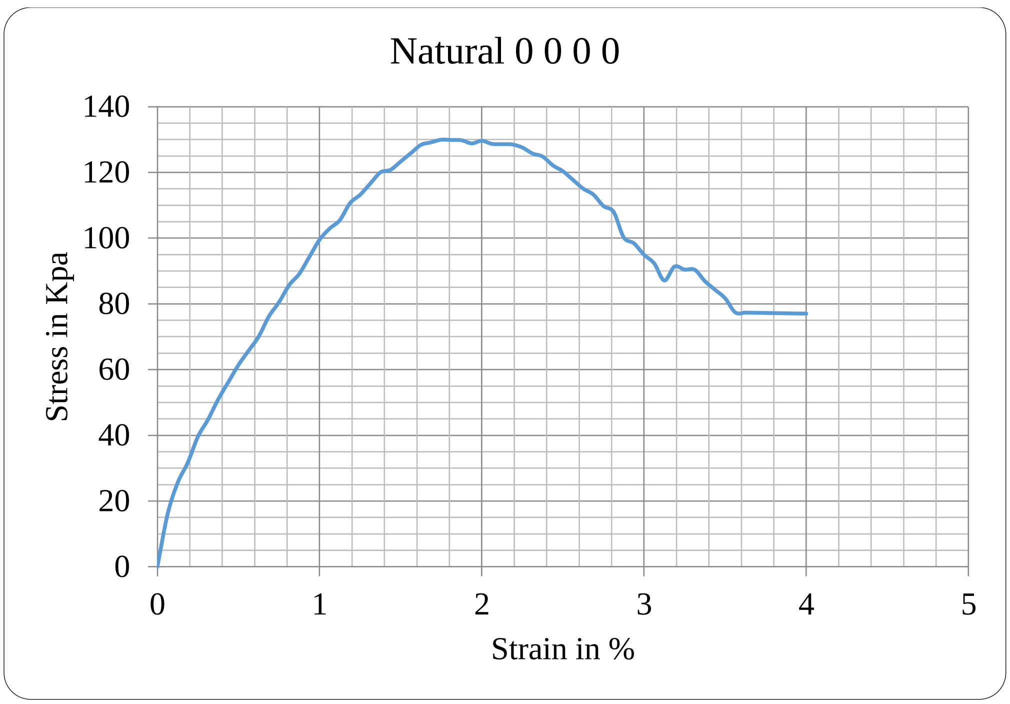
Sample Height (mm)	Peak UCS, (kpa)	Cohesion, (kpa)
80	130	65

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.00	80.00	11.34	0.000	0.00	11.34	0.00
0.05	18	80.00	11.34	0.001	0.06	11.35	15.86
0.10	29	80.00	11.34	0.001	0.13	11.36	25.54
0.15	36	80.00	11.34	0.002	0.19	11.36	31.68
0.20	45	80.00	11.34	0.003	0.25	11.37	39.58
0.25	51	80.00	11.34	0.003	0.31	11.38	44.83
0.30	58	80.00	11.34	0.004	0.38	11.38	50.95
0.35	64	80.00	11.34	0.004	0.44	11.39	56.18
0.40	70	80.00	11.34	0.005	0.50	11.40	61.41
0.45	75	80.00	11.34	0.006	0.56	11.41	65.76
0.50	80	80.00	11.34	0.006	0.63	11.41	70.10
0.55	87	80.00	11.34	0.007	0.69	11.42	76.18
0.60	92	80.00	11.34	0.008	0.75	11.43	80.51
0.65	98	80.00	11.34	0.008	0.81	11.43	85.71
0.70	102	80.00	11.34	0.009	0.88	11.44	89.15
0.75	108	80.00	11.34	0.009	0.94	11.45	94.34
0.80	114	80.00	11.34	0.010	1.00	11.46	99.51
0.85	118	80.00	11.34	0.011	1.06	11.46	102.94
0.90	121	80.00	11.34	0.011	1.13	11.47	105.49
0.95	127	80.00	11.34	0.012	1.19	11.48	110.65

1.00	130	80.00	11.34	0.013	1.25	11.48	113.19
1.05	134	80.00	11.34	0.013	1.31	11.49	116.60
1.10	138	80.00	11.34	0.014	1.38	11.50	120.01
1.15	139	80.00	11.34	0.014	1.44	11.51	120.80
1.20	142	80.00	11.34	0.015	1.50	11.51	123.33
1.25	145	80.00	11.34	0.016	1.56	11.52	125.86
1.30	148	80.00	11.34	0.016	1.63	11.53	128.38
1.35	149	80.00	11.34	0.017	1.69	11.54	129.16
1.40	150	80.00	11.34	0.018	1.75	11.54	129.95
1.45	150	80.00	11.34	0.018	1.81	11.55	129.86
1.50	150	80.00	11.34	0.019	1.88	11.56	129.78
1.55	149	80.00	11.34	0.019	1.94	11.57	128.83
1.60	150	80.00	11.34	0.020	2.00	11.57	129.62
1.65	149	80.00	11.34	0.021	2.06	11.58	128.67
1.70	149	80.00	11.34	0.021	2.13	11.59	128.59
1.75	149	80.00	11.34	0.022	2.19	11.59	128.51
1.80	148	80.00	11.34	0.023	2.25	11.60	127.56
1.85	146	80.00	11.34	0.023	2.31	11.61	125.76
1.90	145	80.00	11.34	0.024	2.38	11.62	124.82
1.95	142	80.00	11.34	0.024	2.44	11.62	122.16
2.00	140	80.00	11.34	0.025	2.50	11.63	120.36
2.05	137	80.00	11.34	0.026	2.56	11.64	117.70
2.10	134	80.00	11.34	0.026	2.63	11.65	115.05
2.15	132	80.00	11.34	0.027	2.69	11.65	113.26
2.20	128	80.00	11.34	0.028	2.75	11.66	109.76
2.25	126	80.00	11.34	0.028	2.81	11.67	107.98
2.30	117	80.00	11.34	0.029	2.88	11.68	100.20
2.35	115	80.00	11.34	0.029	2.94	11.68	98.42
2.40	111	80.00	11.34	0.030	3.00	11.69	94.94
2.45	108	80.00	11.34	0.031	3.06	11.70	92.31
2.50	102	80.00	11.34	0.031	3.13	11.71	87.13
2.55	107	80.00	11.34	0.032	3.19	11.71	91.34
2.60	106	80.00	11.34	0.033	3.25	11.72	90.43

2.65	106	80.00	11.34	0.033	3.31	11.73	90.37
2.70	102	80.00	11.34	0.034	3.38	11.74	86.90
2.75	99	80.00	11.34	0.034	3.44	11.74	84.29
2.80	96	80.00	11.34	0.035	3.50	11.75	81.68
2.85	91	80.00	11.34	0.036	3.56	11.76	77.38
2.90	91	80.00	11.34	0.036	3.63	11.77	77.33
2.95	91	80.00	11.34	0.037	3.69	11.78	77.28
3.00	91	80.00	11.34	0.038	3.75	11.78	77.23
3.05	91	80.00	11.34	0.038	3.81	11.79	77.18
3.10	91	80.00	11.34	0.039	3.88	11.80	77.13
3.15	91	80.00	11.34	0.039	3.94	11.81	77.08
3.20	91	80.00	11.34	0.040	4.00	11.81	77.03



Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 5% Lime

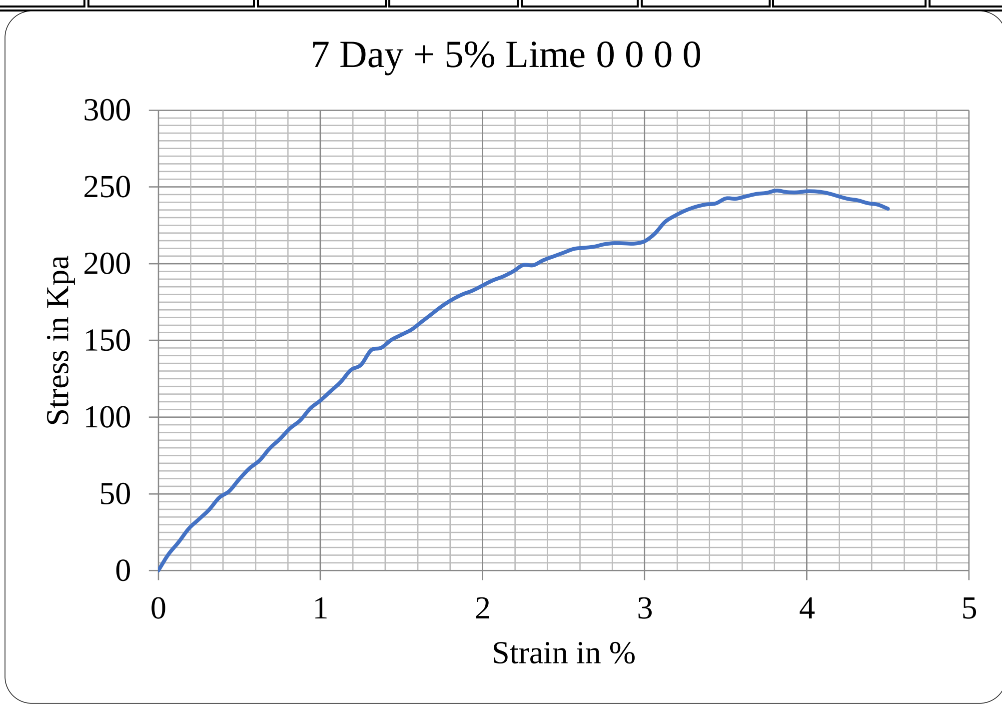
Sample Height (mm)	Peak UCS, (kpa)	Cohesion, (kpa)
80	**248**	**124**

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (Kpa)
0.00	0.0	80.00	11.34	0.000	0.00	11.34	0.00
0.05	12.0	80.00	11.34	0.001	0.06	11.35	10.57
0.10	21.0	80.00	11.34	0.001	0.13	11.36	18.49
0.15	31.0	80.00	11.34	0.002	0.19	11.36	27.28
0.20	38.0	80.00	11.34	0.003	0.25	11.37	33.42
0.25	45.0	80.00	11.34	0.003	0.31	11.38	39.55
0.30	54.0	80.00	11.34	0.004	0.38	11.38	47.44
0.35	59.0	80.00	11.34	0.004	0.44	11.39	51.80
0.40	68.0	80.00	11.34	0.005	0.50	11.40	59.66
0.45	76.0	80.00	11.34	0.006	0.56	11.41	66.64
0.50	82.0	80.00	11.34	0.006	0.63	11.41	71.85
0.55	91.0	80.00	11.34	0.007	0.69	11.42	79.69
0.60	98.0	80.00	11.34	0.008	0.75	11.43	85.76
0.65	106.0	80.00	11.34	0.008	0.81	11.43	92.71
0.70	112.0	80.00	11.34	0.009	0.88	11.44	97.89
0.75	121.0	80.00	11.34	0.009	0.94	11.45	105.69
0.80	127.0	80.00	11.34	0.010	1.00	11.46	110.86
0.85	134.0	80.00	11.34	0.011	1.06	11.46	116.90
0.90	141.0	80.00	11.34	0.011	1.13	11.47	122.93
0.95	150.0	80.00	11.34	0.012	1.19	11.48	130.69
1.00	154.0	80.00	11.34	0.013	1.25	11.48	134.09

1.05	165.0	80.00	11.34	0.013	1.31	11.49	143.58
1.10	167.0	80.00	11.34	0.014	1.38	11.50	145.23
1.15	173.0	80.00	11.34	0.014	1.44	11.51	150.35
1.20	177.0	80.00	11.34	0.015	1.50	11.51	153.73
1.25	181.0	80.00	11.34	0.016	1.56	11.52	157.10
1.30	187.0	80.00	11.34	0.016	1.63	11.53	162.21
1.35	193.0	80.00	11.34	0.017	1.69	11.54	167.31
1.40	199.0	80.00	11.34	0.018	1.75	11.54	172.40
1.45	204.0	80.00	11.34	0.018	1.81	11.55	176.62
1.50	208.0	80.00	11.34	0.019	1.88	11.56	179.96
1.55	211.0	80.00	11.34	0.019	1.94	11.57	182.44
1.60	215.0	80.00	11.34	0.020	2.00	11.57	185.78
1.65	219.0	80.00	11.34	0.021	2.06	11.58	189.12
1.70	222.0	80.00	11.34	0.021	2.13	11.59	191.59
1.75	226.0	80.00	11.34	0.022	2.19	11.59	194.92
1.80	231.0	80.00	11.34	0.023	2.25	11.60	199.10
1.85	231.0	80.00	11.34	0.023	2.31	11.61	198.97
1.90	235.0	80.00	11.34	0.024	2.38	11.62	202.29
1.95	238.0	80.00	11.34	0.024	2.44	11.62	204.74
2.00	241.0	80.00	11.34	0.025	2.50	11.63	207.19
2.05	244.0	80.00	11.34	0.026	2.56	11.64	209.63
2.10	245.0	80.00	11.34	0.026	2.63	11.65	210.36
2.15	246.0	80.00	11.34	0.027	2.69	11.65	211.08
2.20	248.0	80.00	11.34	0.028	2.75	11.66	212.66
2.25	249.0	80.00	11.34	0.028	2.81	11.67	213.38
2.30	249.0	80.00	11.34	0.029	2.88	11.68	213.24
2.35	249.0	80.00	11.34	0.029	2.94	11.68	213.11
2.40	251.0	80.00	11.34	0.030	3.00	11.69	214.68
2.45	257.0	80.00	11.34	0.031	3.06	11.70	219.67
2.50	266.0	80.00	11.34	0.031	3.13	11.71	227.21
2.55	271.0	80.00	11.34	0.032	3.19	11.71	231.34
2.60	275.0	80.00	11.34	0.033	3.25	11.72	234.60
2.65	278.0	80.00	11.34	0.033	3.31	11.73	237.01

2.70	280.0	80.00	11.34	0.034	3.38	11.74	238.56
2.75	281.0	80.00	11.34	0.034	3.44	11.74	239.25
2.80	285.0	80.00	11.34	0.035	3.50	11.75	242.50
2.85	285.0	80.00	11.34	0.036	3.56	11.76	242.34
2.90	287.0	80.00	11.34	0.036	3.63	11.77	243.89
2.95	289.0	80.00	11.34	0.037	3.69	11.78	245.43
3.00	290.0	80.00	11.34	0.038	3.75	11.78	246.12
3.05	292.0	80.00	11.34	0.038	3.81	11.79	247.65
3.10	291.0	80.00	11.34	0.039	3.88	11.80	246.64
3.15	291.0	80.00	11.34	0.039	3.94	11.81	246.48
3.20	292.0	80.00	11.34	0.040	4.00	11.81	247.17
3.25	292.0	80.00	11.34	0.041	4.06	11.82	247.01
3.30	291.0	80.00	11.34	0.041	4.13	11.83	246.00
3.35	289.0	80.00	11.34	0.042	4.19	11.84	244.15
3.40	287.0	80.00	11.34	0.043	4.25	11.84	242.31
3.45	286.0	80.00	11.34	0.043	4.31	11.85	241.30
3.50	284.0	80.00	11.34	0.044	4.38	11.86	239.46
3.55	283.0	80.00	11.34	0.044	4.44	11.87	238.46
3.60	280.0	80.00	11.34	0.045	4.50	11.88	235.78



Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 10% Lime

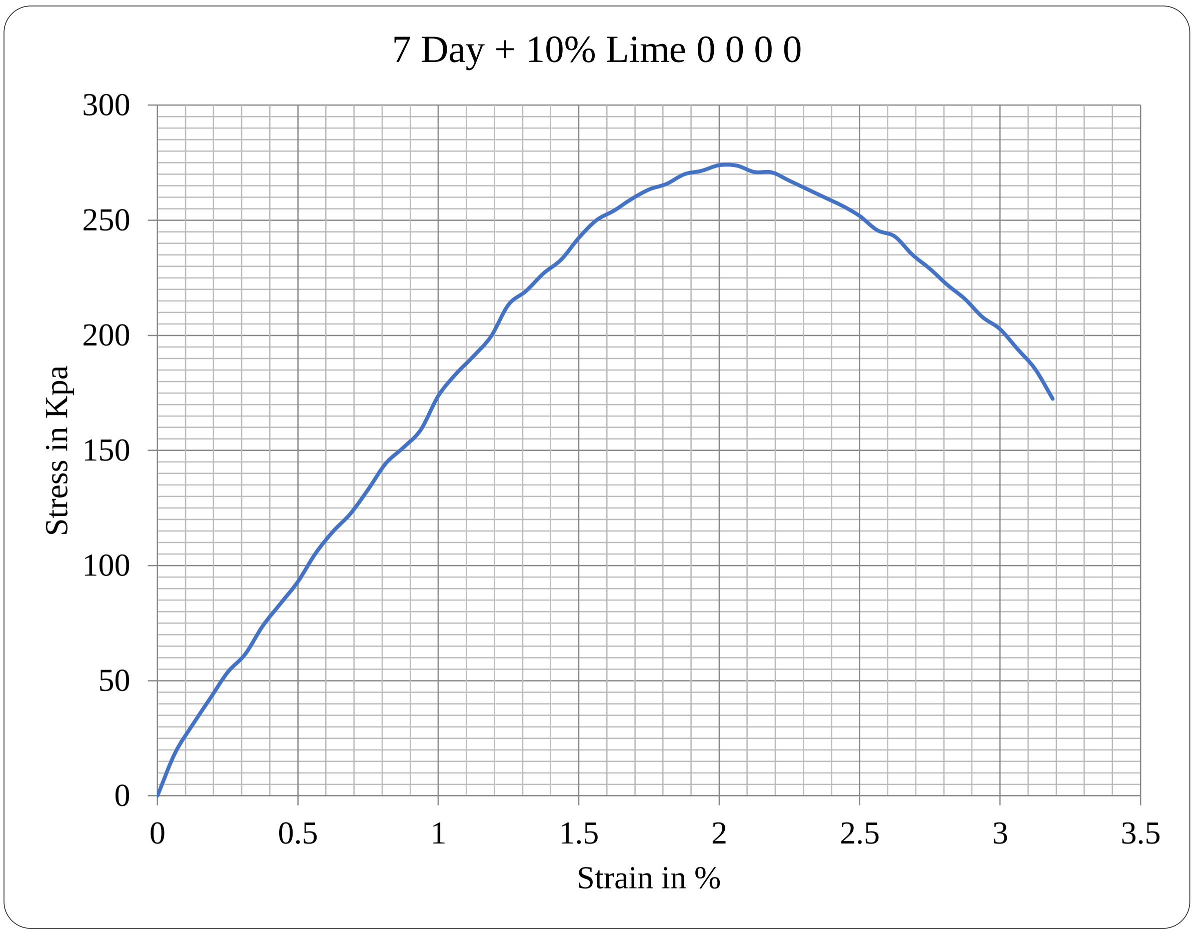
Sample Height (mm)	Peak UCS, (kpa)	Cohesion, (kpa)
80.00	274	137

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.0	80.00	11.34	0.000	0.00	11.34	0.00
0.05	21.0	80.00	11.34	0.001	0.06	11.35	18.51
0.10	35.0	80.00	11.34	0.001	0.13	11.36	30.82
0.15	48.0	80.00	11.34	0.002	0.19	11.36	42.24
0.20	61.0	80.00	11.34	0.003	0.25	11.37	53.65
0.25	70.0	80.00	11.34	0.003	0.31	11.38	61.53
0.30	84.0	80.00	11.34	0.004	0.38	11.38	73.79
0.35	95.0	80.00	11.34	0.004	0.44	11.39	83.40
0.40	106.0	80.00	11.34	0.005	0.50	11.40	93.00
0.45	120.0	80.00	11.34	0.006	0.56	11.41	105.21
0.50	131.0	80.00	11.34	0.006	0.63	11.41	114.79
0.55	140.0	80.00	11.34	0.007	0.69	11.42	122.60
0.60	152.0	80.00	11.34	0.008	0.75	11.43	133.02
0.65	165.0	80.00	11.34	0.008	0.81	11.43	144.31
0.70	173.0	80.00	11.34	0.009	0.88	11.44	151.21
0.75	182.0	80.00	11.34	0.009	0.94	11.45	158.97
0.80	199.0	80.00	11.34	0.010	1.00	11.46	173.71
0.85	210.0	80.00	11.34	0.011	1.06	11.46	183.20
0.90	219.0	80.00	11.34	0.011	1.13	11.47	190.93
0.95	229.0	80.00	11.34	0.012	1.19	11.48	199.52
1.00	245.0	80.00	11.34	0.013	1.25	11.48	213.33
1.05	252.0	80.00	11.34	0.013	1.31	11.49	219.28

1.10	261.0	80.00	11.34	0.014	1.38	11.50	226.97
1.15	268.0	80.00	11.34	0.014	1.44	11.51	232.91
1.20	279.0	80.00	11.34	0.015	1.50	11.51	242.32
1.25	288.0	80.00	11.34	0.016	1.56	11.52	249.97
1.30	293.0	80.00	11.34	0.016	1.63	11.53	254.15
1.35	299.0	80.00	11.34	0.017	1.69	11.54	259.19
1.40	304.0	80.00	11.34	0.018	1.75	11.54	263.36
1.45	307.0	80.00	11.34	0.018	1.81	11.55	265.79
1.50	312.0	80.00	11.34	0.019	1.88	11.56	269.95
1.55	314.0	80.00	11.34	0.019	1.94	11.57	271.50
1.60	317.0	80.00	11.34	0.020	2.00	11.57	273.92
1.65	317.0	80.00	11.34	0.021	2.06	11.58	273.75
1.70	314.0	80.00	11.34	0.021	2.13	11.59	270.98
1.75	314.0	80.00	11.34	0.022	2.19	11.59	270.81
1.80	310.0	80.00	11.34	0.023	2.25	11.60	267.19
1.85	306.0	80.00	11.34	0.023	2.31	11.61	263.57
1.90	302.0	80.00	11.34	0.024	2.38	11.62	259.96
1.95	298.0	80.00	11.34	0.024	2.44	11.62	256.36
2.00	293.0	80.00	11.34	0.025	2.50	11.63	251.89
2.05	286.0	80.00	11.34	0.026	2.56	11.64	245.72
2.10	283.0	80.00	11.34	0.026	2.63	11.65	242.98
2.15	274.0	80.00	11.34	0.027	2.69	11.65	235.11
2.20	267.0	80.00	11.34	0.028	2.75	11.66	228.95
2.25	259.0	80.00	11.34	0.028	2.81	11.67	221.95
2.30	252.0	80.00	11.34	0.029	2.88	11.68	215.81
2.35	243.0	80.00	11.34	0.029	2.94	11.68	207.97
2.40	237.0	80.00	11.34	0.030	3.00	11.69	202.70
2.45	227.0	80.00	11.34	0.031	3.06	11.70	194.03
2.50	217.0	80.00	11.34	0.031	3.13	11.71	185.36
2.55	202.0	80.00	11.34	0.032	3.19	11.71	172.44
2.60	191.0	80.00	11.34	0.033	3.25	11.72	162.94
2.65	181.0	80.00	11.34	0.033	3.31	11.73	154.31
2.70	171.0	80.00	11.34	0.034	3.38	11.74	145.69

2.75	156.0	80.00	11.34	0.034	3.44	11.74	132.82
2.80	142.0	80.00	11.34	0.035	3.50	11.75	120.83
2.85	128.0	80.00	11.34	0.036	3.56	11.76	108.84
2.90	113.0	80.00	11.34	0.036	3.63	11.77	96.03
2.95	102.0	80.00	11.34	0.037	3.69	11.78	86.62
3.00	87.0	80.00	11.34	0.038	3.75	11.78	73.84
3.05	73.0	80.00	11.34	0.038	3.81	11.79	61.91



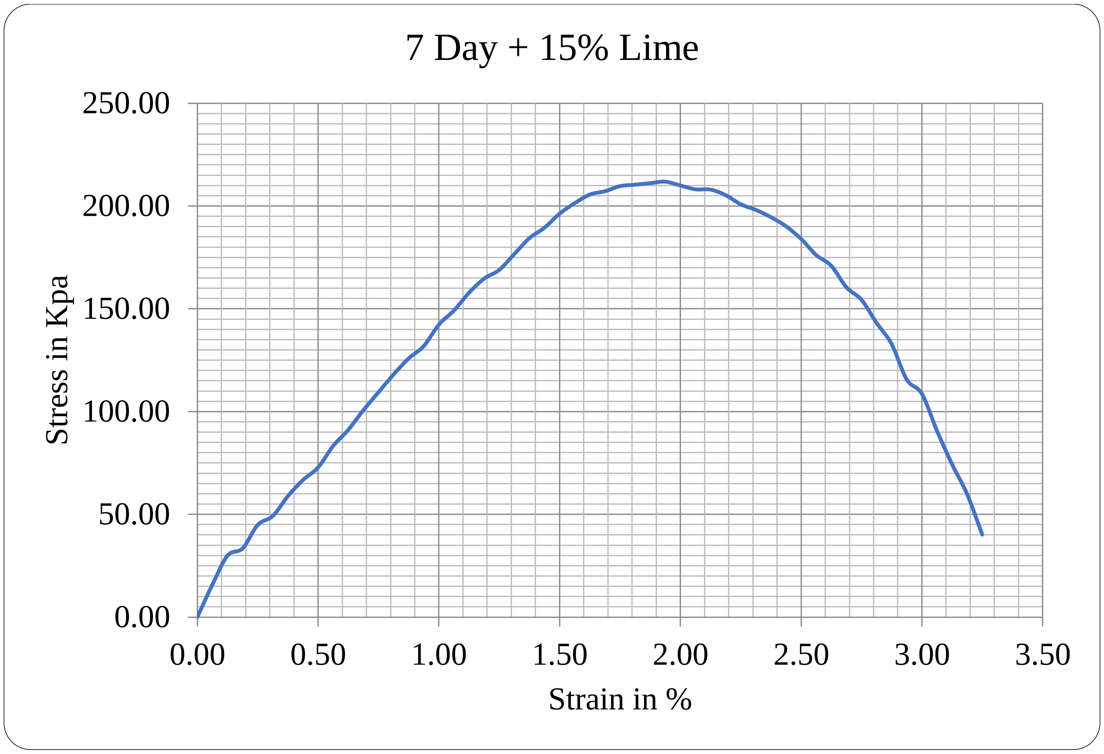
Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 15% Lime

Sample Height (mm)	Peak UCS, (kpa)	Cohesion, (kpa)
80.00	212	106

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.0	80.00	11.34	0.000	0.00	11.34	0.00
0.05	18.0	80.00	11.34	0.001	0.06	11.35	15.86
0.10	34.0	80.00	11.34	0.001	0.13	11.36	29.94
0.15	38.0	80.00	11.34	0.002	0.19	11.36	33.44
0.20	51.0	80.00	11.34	0.003	0.25	11.37	44.86
0.25	56.0	80.00	11.34	0.003	0.31	11.38	49.22
0.30	67.0	80.00	11.34	0.004	0.38	11.38	58.86
0.35	76.0	80.00	11.34	0.004	0.44	11.39	66.72
0.40	83.0	80.00	11.34	0.005	0.50	11.40	72.82
0.45	95.0	80.00	11.34	0.006	0.56	11.41	83.29
0.50	104.0	80.00	11.34	0.006	0.63	11.41	91.13
0.55	115.0	80.00	11.34	0.007	0.69	11.42	100.70
0.60	125.0	80.00	11.34	0.008	0.75	11.43	109.39
0.65	135.0	80.00	11.34	0.008	0.81	11.43	118.07
0.70	144.0	80.00	11.34	0.009	0.88	11.44	125.86
0.75	151.0	80.00	11.34	0.009	0.94	11.45	131.90
0.80	163.0	80.00	11.34	0.010	1.00	11.46	142.29
0.85	171.0	80.00	11.34	0.011	1.06	11.46	149.18
0.90	181.0	80.00	11.34	0.011	1.13	11.47	157.80
0.95	189.0	80.00	11.34	0.012	1.19	11.48	164.67
1.00	194.0	80.00	11.34	0.013	1.25	11.48	168.92

1.05	203.0	80.00	11.34	0.013	1.31	11.49	176.64
1.10	212.0	80.00	11.34	0.014	1.38	11.50	184.36
1.15	218.0	80.00	11.34	0.014	1.44	11.51	189.46
1.20	226.0	80.00	11.34	0.015	1.50	11.51	196.29
1.25	232.0	80.00	11.34	0.016	1.56	11.52	201.37
1.30	237.0	80.00	11.34	0.016	1.63	11.53	205.58
1.35	239.0	80.00	11.34	0.017	1.69	11.54	207.18
1.40	242.0	80.00	11.34	0.018	1.75	11.54	209.65
1.45	243.0	80.00	11.34	0.018	1.81	11.55	210.38
1.50	244.0	80.00	11.34	0.019	1.88	11.56	211.11
1.55	245.0	80.00	11.34	0.019	1.94	11.57	211.84
1.60	243.0	80.00	11.34	0.020	2.00	11.57	209.98
1.65	241.0	80.00	11.34	0.021	2.06	11.58	208.12
1.70	241.0	80.00	11.34	0.021	2.13	11.59	207.98
1.75	238.0	80.00	11.34	0.022	2.19	11.59	205.26
1.80	233.0	80.00	11.34	0.023	2.25	11.60	200.82
1.85	230.0	80.00	11.34	0.023	2.31	11.61	198.11
1.90	226.0	80.00	11.34	0.024	2.38	11.62	194.54
1.95	221.0	80.00	11.34	0.024	2.44	11.62	190.12
2.00	214.0	80.00	11.34	0.025	2.50	11.63	183.98
2.05	205.0	80.00	11.34	0.026	2.56	11.64	176.13
2.10	199.0	80.00	11.34	0.026	2.63	11.65	170.86
2.15	187.0	80.00	11.34	0.027	2.69	11.65	160.45
2.20	180.0	80.00	11.34	0.028	2.75	11.66	154.35
2.25	167.0	80.00	11.34	0.028	2.81	11.67	143.11
2.30	155.0	80.00	11.34	0.029	2.88	11.68	132.74
2.35	135.0	80.00	11.34	0.029	2.94	11.68	115.54
2.40	127.0	80.00	11.34	0.030	3.00	11.69	108.62
2.45	106.0	80.00	11.34	0.031	3.06	11.70	90.60
2.50	87.0	80.00	11.34	0.031	3.13	11.71	74.31
2.55	70.0	80.00	11.34	0.032	3.19	11.71	59.75
2.60	47.0	80.00	11.34	0.033	3.25	11.72	40.10



Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 20% Lime

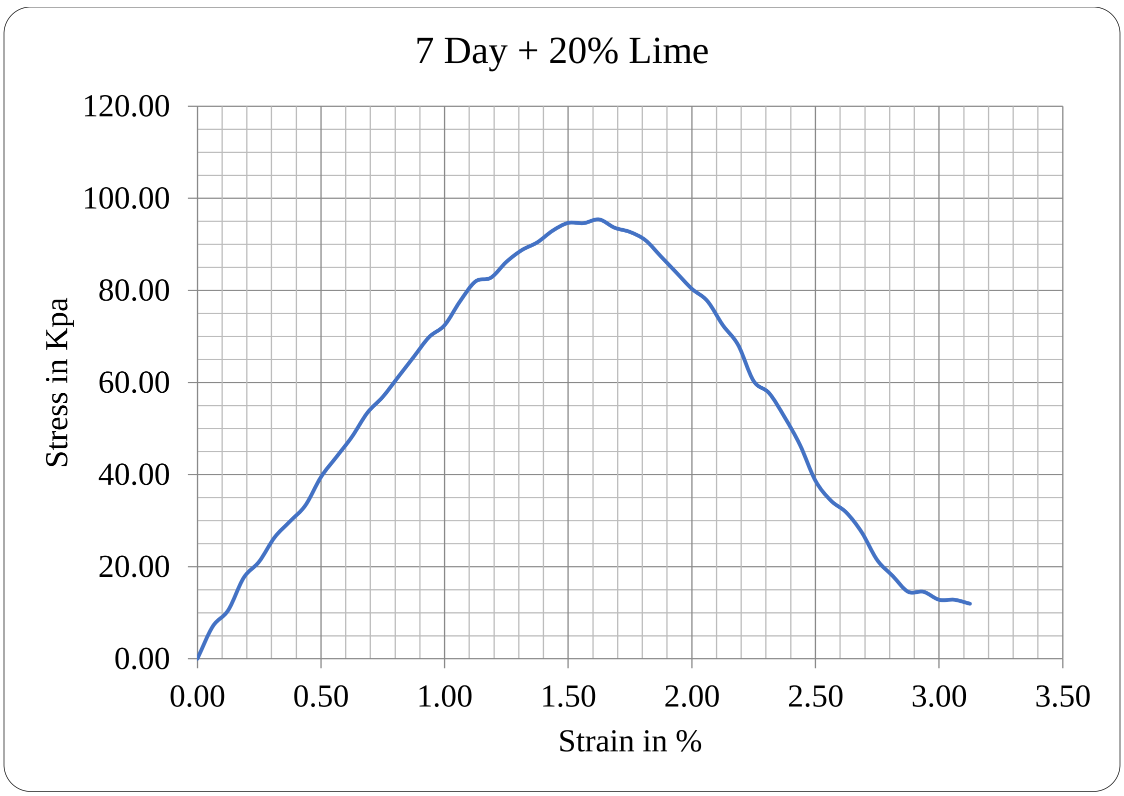
Sample Height (mm)	Peak UCS, (kpa)	Cohesion, (kpa)
80.00	**95**	**48**

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.0	80.00	11.34	0.000	0.00	11.34	0.00
0.05	8.0	80.00	11.34	0.001	0.06	11.35	7.05
0.10	12.0	80.00	11.34	0.001	0.13	11.36	10.57
0.15	20.0	80.00	11.34	0.002	0.19	11.36	17.60
0.20	24.0	80.00	11.34	0.003	0.25	11.37	21.11

0.25	30.0	80.00	11.34	0.003	0.31	11.38	26.37
0.30	34.0	80.00	11.34	0.004	0.38	11.38	29.87
0.35	38.0	80.00	11.34	0.004	0.44	11.39	33.36
0.40	45.0	80.00	11.34	0.005	0.50	11.40	39.48
0.45	50.0	80.00	11.34	0.006	0.56	11.41	43.84
0.50	55.0	80.00	11.34	0.006	0.63	11.41	48.19
0.55	61.0	80.00	11.34	0.007	0.69	11.42	53.42
0.60	65.0	80.00	11.34	0.008	0.75	11.43	56.88
0.65	70.0	80.00	11.34	0.008	0.81	11.43	61.22
0.70	75.0	80.00	11.34	0.009	0.88	11.44	65.55
0.75	80.0	80.00	11.34	0.009	0.94	11.45	69.88
0.80	83.0	80.00	11.34	0.010	1.00	11.46	72.45
0.85	89.0	80.00	11.34	0.011	1.06	11.46	77.64
0.90	94.0	80.00	11.34	0.011	1.13	11.47	81.95
0.95	95.0	80.00	11.34	0.012	1.19	11.48	82.77
1.00	99.0	80.00	11.34	0.013	1.25	11.48	86.20
1.05	102.0	80.00	11.34	0.013	1.31	11.49	88.76
1.10	104.0	80.00	11.34	0.014	1.38	11.50	90.44
1.15	107.0	80.00	11.34	0.014	1.44	11.51	92.99
1.20	109.0	80.00	11.34	0.015	1.50	11.51	94.67
1.25	109.0	80.00	11.34	0.016	1.56	11.52	94.61
1.30	110.0	80.00	11.34	0.016	1.63	11.53	95.42
1.35	108.0	80.00	11.34	0.017	1.69	11.54	93.62
1.40	107.0	80.00	11.34	0.018	1.75	11.54	92.70
1.45	105.0	80.00	11.34	0.018	1.81	11.55	90.91
1.50	101.0	80.00	11.34	0.019	1.88	11.56	87.39
1.55	97.0	80.00	11.34	0.019	1.94	11.57	83.87
1.60	93.0	80.00	11.34	0.020	2.00	11.57	80.36
1.65	90.0	80.00	11.34	0.021	2.06	11.58	77.72
1.70	84.0	80.00	11.34	0.021	2.13	11.59	72.49
1.75	79.0	80.00	11.34	0.022	2.19	11.59	68.13
1.80	70.0	80.00	11.34	0.023	2.25	11.60	60.33
1.85	67.0	80.00	11.34	0.023	2.31	11.61	57.71

1.90	61.0	80.00	11.34	0.024	2.38	11.62	52.51
1.95	54.0	80.00	11.34	0.024	2.44	11.62	46.45
2.00	45.0	80.00	11.34	0.025	2.50	11.63	38.69
2.05	40.0	80.00	11.34	0.026	2.56	11.64	34.37
2.10	37.0	80.00	11.34	0.026	2.63	11.65	31.77
2.15	32.0	80.00	11.34	0.027	2.69	11.65	27.46
2.20	25.0	80.00	11.34	0.028	2.75	11.66	21.44
2.25	21.0	80.00	11.34	0.028	2.81	11.67	18.00
2.30	17.0	80.00	11.34	0.029	2.88	11.68	14.56
2.35	17.0	80.00	11.34	0.029	2.94	11.68	14.55
2.40	15.0	80.00	11.34	0.030	3.00	11.69	12.83
2.45	15.0	80.00	11.34	0.031	3.06	11.70	12.82
2.50	14.0	80.00	11.34	0.031	3.13	11.71	11.96



Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 10% Lime + 5% BHA

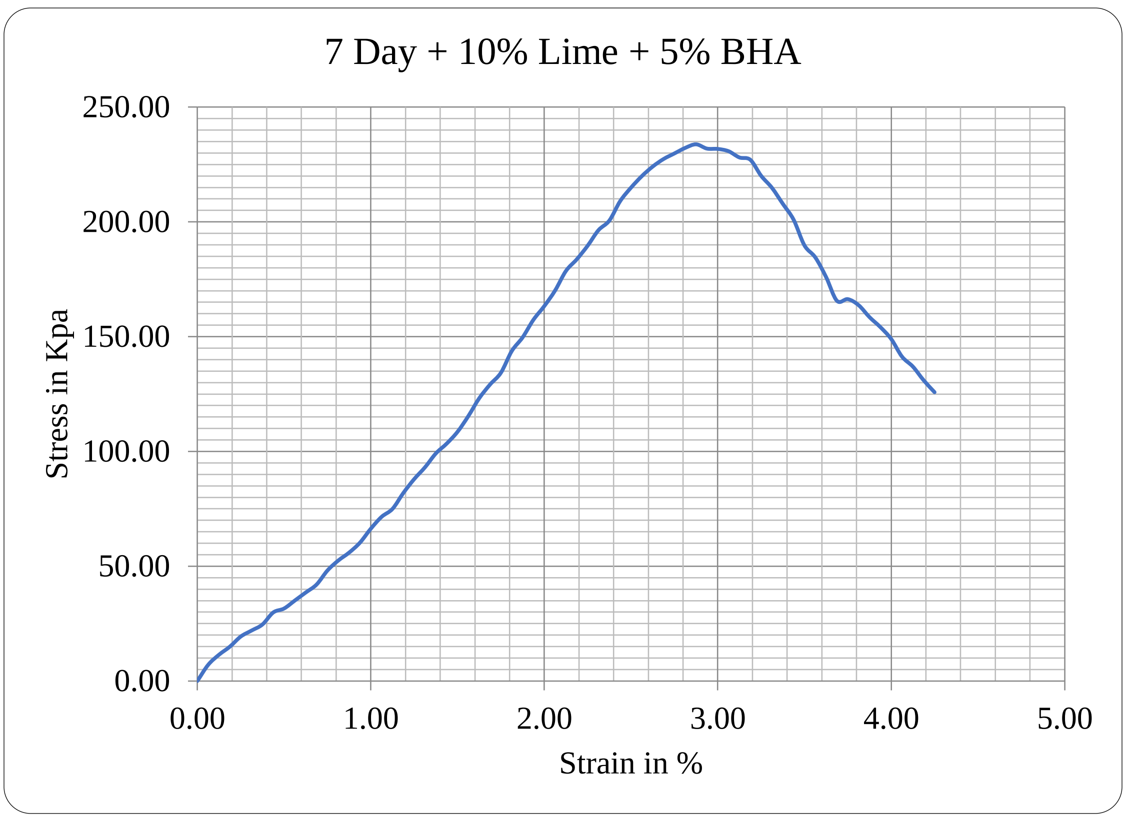
Sample Height (mm)	**Peak UCS, (kpa)**	**Cohesion, (kpa)**
80.00	**234**	**117**

Trial 1

Specimens Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.0	80.00	11.34	0.000	0.00	11.34	0.00
0.05	8.0	80.00	11.34	0.001	0.06	11.35	7.05
0.10	13.0	80.00	11.34	0.001	0.13	11.36	11.45
0.15	17.0	80.00	11.34	0.002	0.19	11.36	14.96
0.20	22.0	80.00	11.34	0.003	0.25	11.37	19.35
0.25	25.0	80.00	11.34	0.003	0.31	11.38	21.97
0.30	28.0	80.00	11.34	0.004	0.38	11.38	24.60
0.35	34.0	80.00	11.34	0.004	0.44	11.39	29.85
0.40	36.0	80.00	11.34	0.005	0.50	11.40	31.58
0.45	40.0	80.00	11.34	0.006	0.56	11.41	35.07
0.50	44.0	80.00	11.34	0.006	0.63	11.41	38.55
0.55	48.0	80.00	11.34	0.007	0.69	11.42	42.03
0.60	55.0	80.00	11.34	0.008	0.75	11.43	48.13
0.65	60.0	80.00	11.34	0.008	0.81	11.43	52.47
0.70	64.0	80.00	11.34	0.009	0.88	11.44	55.94
0.75	69.0	80.00	11.34	0.009	0.94	11.45	60.27
0.80	76.0	80.00	11.34	0.010	1.00	11.46	66.34
0.85	82.0	80.00	11.34	0.011	1.06	11.46	71.53
0.90	86.0	80.00	11.34	0.011	1.13	11.47	74.98
0.95	94.0	80.00	11.34	0.012	1.19	11.48	81.90
1.00	101.0	80.00	11.34	0.013	1.25	11.48	87.94

1.05	107.0	80.00	11.34	0.013	1.31	11.49	93.11
1.10	114.0	80.00	11.34	0.014	1.38	11.50	99.14
1.15	119.0	80.00	11.34	0.014	1.44	11.51	103.42
1.20	125.0	80.00	11.34	0.015	1.50	11.51	108.56
1.25	133.0	80.00	11.34	0.016	1.56	11.52	115.44
1.30	142.0	80.00	11.34	0.016	1.63	11.53	123.17
1.35	149.0	80.00	11.34	0.017	1.69	11.54	129.16
1.40	155.0	80.00	11.34	0.018	1.75	11.54	134.28
1.45	166.0	80.00	11.34	0.018	1.81	11.55	143.72
1.50	173.0	80.00	11.34	0.019	1.88	11.56	149.68
1.55	182.0	80.00	11.34	0.019	1.94	11.57	157.37
1.60	189.0	80.00	11.34	0.020	2.00	11.57	163.32
1.65	197.0	80.00	11.34	0.021	2.06	11.58	170.12
1.70	207.0	80.00	11.34	0.021	2.13	11.59	178.64
1.75	213.0	80.00	11.34	0.022	2.19	11.59	183.70
1.80	220.0	80.00	11.34	0.023	2.25	11.60	189.62
1.85	228.0	80.00	11.34	0.023	2.31	11.61	196.39
1.90	233.0	80.00	11.34	0.024	2.38	11.62	200.57
1.95	243.0	80.00	11.34	0.024	2.44	11.62	209.04
2.00	250.0	80.00	11.34	0.025	2.50	11.63	214.93
2.05	256.0	80.00	11.34	0.026	2.56	11.64	219.94
2.10	261.0	80.00	11.34	0.026	2.63	11.65	224.09
2.15	265.0	80.00	11.34	0.027	2.69	11.65	227.38
2.20	268.0	80.00	11.34	0.028	2.75	11.66	229.81
2.25	271.0	80.00	11.34	0.028	2.81	11.67	232.23
2.30	273.0	80.00	11.34	0.029	2.88	11.68	233.80
2.35	271.0	80.00	11.34	0.029	2.94	11.68	231.93
2.40	271.0	80.00	11.34	0.030	3.00	11.69	231.78
2.45	270.0	80.00	11.34	0.031	3.06	11.70	230.78
2.50	267.0	80.00	11.34	0.031	3.13	11.71	228.07
2.55	266.0	80.00	11.34	0.032	3.19	11.71	227.07
2.60	258.0	80.00	11.34	0.033	3.25	11.72	220.10
2.65	252.0	80.00	11.34	0.033	3.31	11.73	214.84

2.70	244.0	80.00	11.34	0.034	3.38	11.74	207.88
2.75	236.0	80.00	11.34	0.034	3.44	11.74	200.94
2.80	223.0	80.00	11.34	0.035	3.50	11.75	189.75
2.85	217.0	80.00	11.34	0.036	3.56	11.76	184.52
2.90	207.0	80.00	11.34	0.036	3.63	11.77	175.90
2.95	195.0	80.00	11.34	0.037	3.69	11.78	165.60
3.00	196.0	80.00	11.34	0.038	3.75	11.78	166.34
3.05	193.0	80.00	11.34	0.038	3.81	11.79	163.69
3.10	187.0	80.00	11.34	0.039	3.88	11.80	158.50
3.15	182.0	80.00	11.34	0.039	3.94	11.81	154.16
3.20	176.0	80.00	11.34	0.040	4.00	11.81	148.98
3.25	167.0	80.00	11.34	0.041	4.06	11.82	141.27
3.30	162.0	80.00	11.34	0.041	4.13	11.83	136.95
3.35	155.0	80.00	11.34	0.042	4.19	11.84	130.95
3.40	149.0	80.00	11.34	0.043	4.25	11.84	125.80



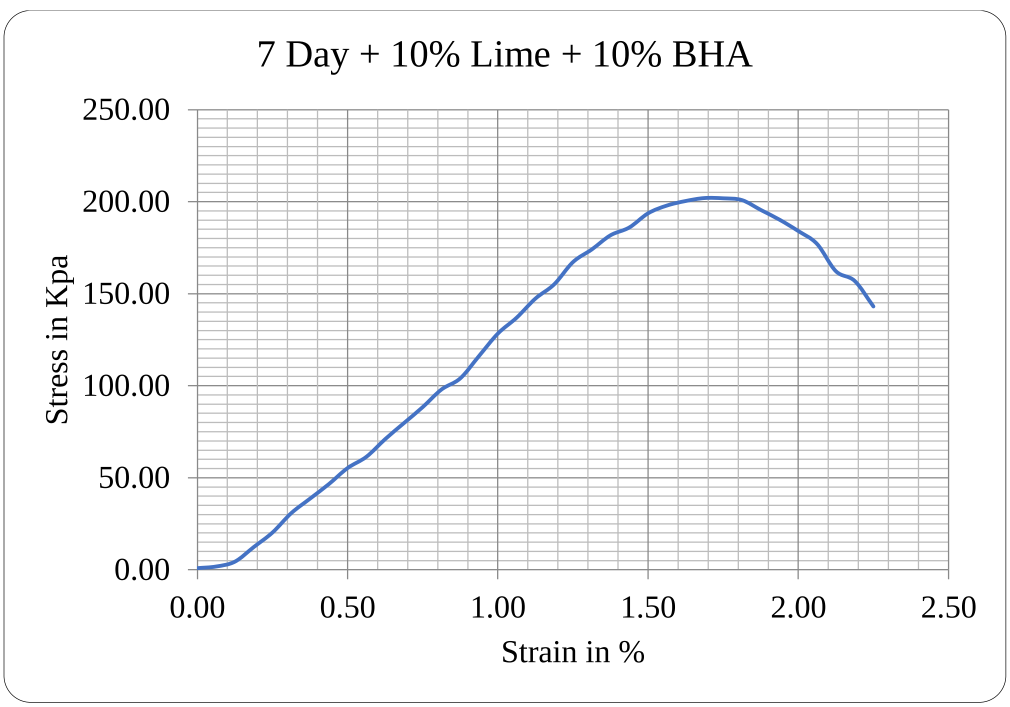
Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 10% Lime + 10% BHA

Sample Height (mm)	**Peak UCS, (kpa)**	**Cohesion, (kpa)**
80.00	**202**	**101**

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	1.00	80.00	11.34	0.000	0.00	11.34	0.88
0.05	2.00	80.00	11.34	0.001	0.06	11.35	1.76
0.10	5.00	80.00	11.34	0.001	0.13	11.36	4.40
0.15	14.00	80.00	11.34	0.002	0.19	11.36	12.32
0.20	23.00	80.00	11.34	0.003	0.25	11.37	20.23
0.25	35.00	80.00	11.34	0.003	0.31	11.38	30.76
0.30	44.00	80.00	11.34	0.004	0.38	11.38	38.65
0.35	53.00	80.00	11.34	0.004	0.44	11.39	46.53
0.40	63.00	80.00	11.34	0.005	0.50	11.40	55.27
0.45	70.00	80.00	11.34	0.006	0.56	11.41	61.37
0.50	81.00	80.00	11.34	0.006	0.63	11.41	70.97
0.55	91.00	80.00	11.34	0.007	0.69	11.42	79.69
0.60	101.00	80.00	11.34	0.008	0.75	11.43	88.39
0.65	112.00	80.00	11.34	0.008	0.81	11.43	97.95
0.70	119.00	80.00	11.34	0.009	0.88	11.44	104.01
0.75	133.00	80.00	11.34	0.009	0.94	11.45	116.17
0.80	147.00	80.00	11.34	0.010	1.00	11.46	128.32
0.85	157.00	80.00	11.34	0.011	1.06	11.46	136.96
0.90	169.00	80.00	11.34	0.011	1.13	11.47	147.34
0.95	178.00	80.00	11.34	0.012	1.19	11.48	155.09
1.00	192.00	80.00	11.34	0.013	1.25	11.48	167.18

1.05	200.00	80.00	11.34	0.013	1.31	11.49	174.03
1.10	209.00	80.00	11.34	0.014	1.38	11.50	181.75
1.15	214.00	80.00	11.34	0.014	1.44	11.51	185.98
1.20	223.00	80.00	11.34	0.015	1.50	11.51	193.68
1.25	228.00	80.00	11.34	0.016	1.56	11.52	197.90
1.30	231.00	80.00	11.34	0.016	1.63	11.53	200.37
1.35	233.00	80.00	11.34	0.017	1.69	11.54	201.98
1.40	233.00	80.00	11.34	0.018	1.75	11.54	201.85
1.45	232.00	80.00	11.34	0.018	1.81	11.55	200.86
1.50	226.00	80.00	11.34	0.019	1.88	11.56	195.54
1.55	220.00	80.00	11.34	0.019	1.94	11.57	190.23
1.60	213.00	80.00	11.34	0.020	2.00	11.57	184.06
1.65	205.00	80.00	11.34	0.021	2.06	11.58	177.03
1.70	188.00	80.00	11.34	0.021	2.13	11.59	162.25
1.75	182.00	80.00	11.34	0.022	2.19	11.59	156.97
1.80	166.00	80.00	11.34	0.023	2.25	11.60	143.08



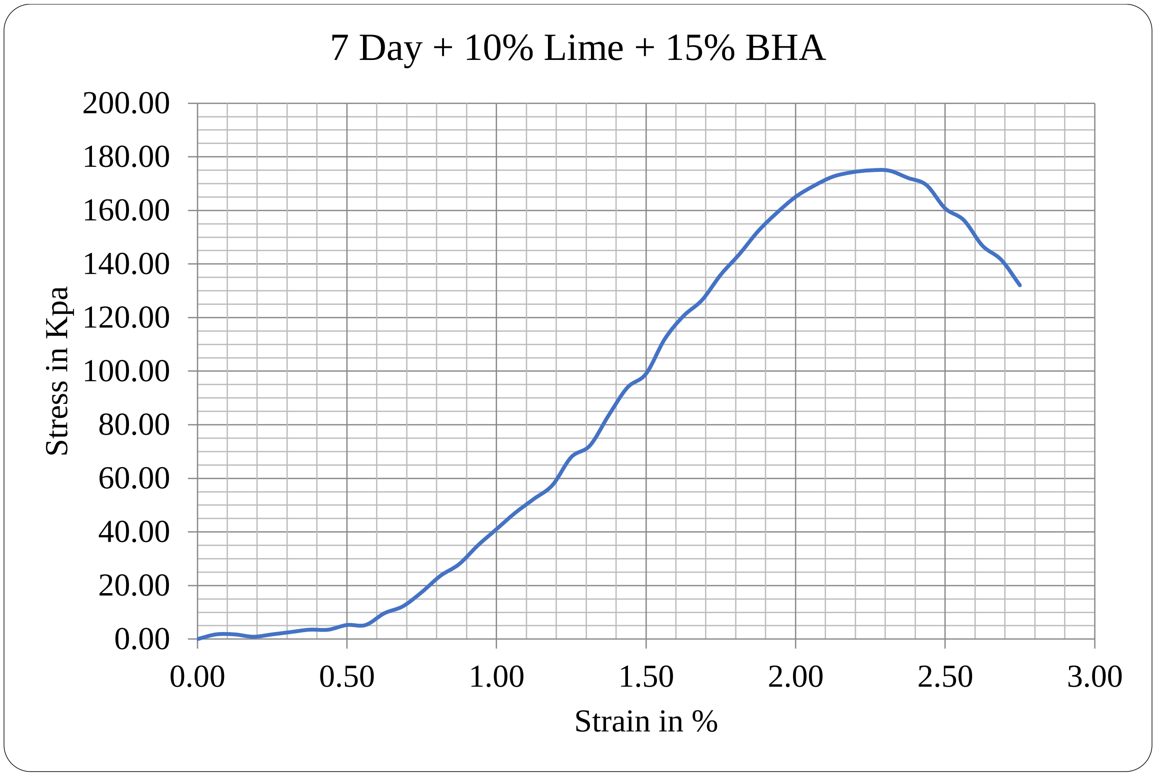
Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 10% Lime + 15% BHA

Sample Height (mm)	**Peak UCS, (kpa)**	**Cohesion, (kpa)**
80.00	**175**	**87**

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.00	80.00	11.34	0.000	0.00	11.34	0.00
0.05	2.00	80.00	11.34	0.001	0.06	11.35	1.76
0.10	2.00	80.00	11.34	0.001	0.13	11.36	1.76
0.15	1.00	80.00	11.34	0.002	0.19	11.36	0.88
0.20	2.00	80.00	11.34	0.003	0.25	11.37	1.76
0.25	3.00	80.00	11.34	0.003	0.31	11.38	2.64
0.30	4.00	80.00	11.34	0.004	0.38	11.38	3.51
0.35	4.00	80.00	11.34	0.004	0.44	11.39	3.51
0.40	6.00	80.00	11.34	0.005	0.50	11.40	5.26
0.45	6.00	80.00	11.34	0.006	0.56	11.41	5.26
0.50	11.00	80.00	11.34	0.006	0.63	11.41	9.64
0.55	14.00	80.00	11.34	0.007	0.69	11.42	12.26
0.60	20.00	80.00	11.34	0.008	0.75	11.43	17.50
0.65	27.00	80.00	11.34	0.008	0.81	11.43	23.61
0.70	32.00	80.00	11.34	0.009	0.88	11.44	27.97
0.75	40.00	80.00	11.34	0.009	0.94	11.45	34.94
0.80	47.00	80.00	11.34	0.010	1.00	11.46	41.03
0.85	54.00	80.00	11.34	0.011	1.06	11.46	47.11
0.90	60.00	80.00	11.34	0.011	1.13	11.47	52.31
0.95	66.00	80.00	11.34	0.012	1.19	11.48	57.50
1.00	78.00	80.00	11.34	0.013	1.25	11.48	67.92

1.05	83.00	80.00	11.34	0.013	1.31	11.49	72.22
1.10	96.00	80.00	11.34	0.014	1.38	11.50	83.48
1.15	108.00	80.00	11.34	0.014	1.44	11.51	93.86
1.20	114.00	80.00	11.34	0.015	1.50	11.51	99.01
1.25	129.00	80.00	11.34	0.016	1.56	11.52	111.97
1.30	139.00	80.00	11.34	0.016	1.63	11.53	120.57
1.35	146.00	80.00	11.34	0.017	1.69	11.54	126.56
1.40	157.00	80.00	11.34	0.018	1.75	11.54	136.01
1.45	166.00	80.00	11.34	0.018	1.81	11.55	143.72
1.50	176.00	80.00	11.34	0.019	1.88	11.56	152.28
1.55	184.00	80.00	11.34	0.019	1.94	11.57	159.10
1.60	191.00	80.00	11.34	0.020	2.00	11.57	165.04
1.65	196.00	80.00	11.34	0.021	2.06	11.58	169.26
1.70	200.00	80.00	11.34	0.021	2.13	11.59	172.60
1.75	202.00	80.00	11.34	0.022	2.19	11.59	174.22
1.80	203.00	80.00	11.34	0.023	2.25	11.60	174.97
1.85	203.00	80.00	11.34	0.023	2.31	11.61	174.85
1.90	200.00	80.00	11.34	0.024	2.38	11.62	172.16
1.95	197.00	80.00	11.34	0.024	2.44	11.62	169.47
2.00	187.00	80.00	11.34	0.025	2.50	11.63	160.76
2.05	182.00	80.00	11.34	0.026	2.56	11.64	156.37
2.10	171.00	80.00	11.34	0.026	2.63	11.65	146.82
2.15	165.00	80.00	11.34	0.027	2.69	11.65	141.58
2.20	154.00	80.00	11.34	0.028	2.75	11.66	132.05



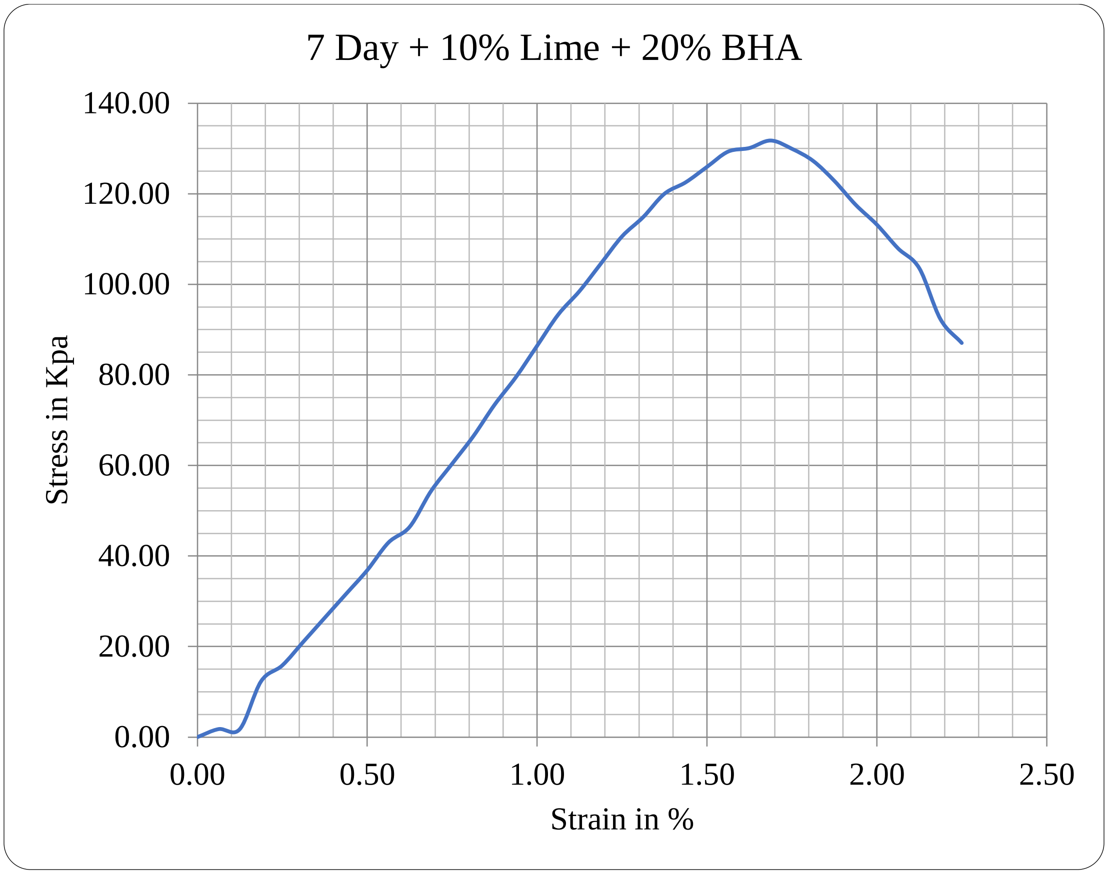
Test Type	Unconfined Compression Test (ASTM D-2166)
Type of Sample	Undisturbed Soil Sample
Sample Diameter	38mm
Test Pit Location	7 Day + 10% Lime + 20% BHA

Sample Height (mm)	Peak UCS, (kpa)	Cohesion, (kpa)
80.00	**132**	**66**

Trial 1

Specimens' Deformation ΔL (mm)	Resisting Reading Load (N)	Sample Height (mm)	Sample Actual Area (cm^2)	Strain	Strain in %	Corrected Area (cm^2)	Stress (kpa)
0.00	0.00	80.00	11.34	0.000	0.00	11.34	0.00
0.05	2.00	80.00	11.34	0.001	0.06	11.35	1.76
0.10	2.00	80.00	11.34	0.001	0.13	11.36	1.76
0.15	14.00	80.00	11.34	0.002	0.19	11.36	12.32
0.20	18.00	80.00	11.34	0.003	0.25	11.37	15.83

0.25	24.00	80.00	11.34	0.003	0.31	11.38	21.10
0.30	30.00	80.00	11.34	0.004	0.38	11.38	26.35
0.35	36.00	80.00	11.34	0.004	0.44	11.39	31.60
0.40	42.00	80.00	11.34	0.005	0.50	11.40	36.85
0.45	49.00	80.00	11.34	0.006	0.56	11.41	42.96
0.50	53.00	80.00	11.34	0.006	0.63	11.41	46.44
0.55	62.00	80.00	11.34	0.007	0.69	11.42	54.29
0.60	69.00	80.00	11.34	0.008	0.75	11.43	60.38
0.65	76.00	80.00	11.34	0.008	0.81	11.43	66.47
0.70	84.00	80.00	11.34	0.009	0.88	11.44	73.42
0.75	91.00	80.00	11.34	0.009	0.94	11.45	79.49
0.80	99.00	80.00	11.34	0.010	1.00	11.46	86.42
0.85	107.00	80.00	11.34	0.011	1.06	11.46	93.34
0.90	113.00	80.00	11.34	0.011	1.13	11.47	98.52
0.95	120.00	80.00	11.34	0.012	1.19	11.48	104.55
1.00	127.00	80.00	11.34	0.013	1.25	11.48	110.58
1.05	132.00	80.00	11.34	0.013	1.31	11.49	114.86
1.10	138.00	80.00	11.34	0.014	1.38	11.50	120.01
1.15	141.00	80.00	11.34	0.014	1.44	11.51	122.54
1.20	145.00	80.00	11.34	0.015	1.50	11.51	125.94
1.25	149.00	80.00	11.34	0.016	1.56	11.52	129.33
1.30	150.00	80.00	11.34	0.016	1.63	11.53	130.11
1.35	152.00	80.00	11.34	0.017	1.69	11.54	131.76
1.40	150.00	80.00	11.34	0.018	1.75	11.54	129.95
1.45	147.00	80.00	11.34	0.018	1.81	11.55	127.27
1.50	142.00	80.00	11.34	0.019	1.88	11.56	122.86
1.55	136.00	80.00	11.34	0.019	1.94	11.57	117.59
1.60	131.00	80.00	11.34	0.020	2.00	11.57	113.20
1.65	125.00	80.00	11.34	0.021	2.06	11.58	107.94
1.70	120.00	80.00	11.34	0.021	2.13	11.59	103.56
1.75	107.00	80.00	11.34	0.022	2.19	11.59	92.28
1.80	101.00	80.00	11.34	0.023	2.25	11.60	87.05


7 Day + 10% Lime + 20% BHA
Stress in Kpa
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
Strain in %

Appendix-8 Complete silicate analysis

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name:- Alemu Balcha

Issue Date:-10/03/2023

Sample type :-Powder

Request No:- GLD/RQ/880/23

Sample Preparation: -200 Mesh

Report No:- GLD/RN/1522/23

Date Submitted:- 23/02/2023

Number of Sample:-One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H2O	LOI	Weight of Sample
AB-11	40.54	5.86	2.60	2.06	2.48	0.88	18.38	0.12	11.46	0.20	5.00	11.03	450.00 gm

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Haimanot Bayeh
Gadisa Wakuma

Checked By
Lidet Endeshaw

Approved By
Yohannes Getachew

Quality Control
Negash Worku

Geological Survey of Ethiopia Central Geological Laboratory

Geochemical Laboratory Desk