JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Stabilization of Clayey Soil Using Lime and Lime with Prosopis Juliflora Fibers in Jimma Town

A final Thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By:

Ahmed Mohamed Ismail

October, 2021

Jimma ,Ethiopia

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APPROVED BY BOARD OF EXAMINERS

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Eng. Abel Tesfaye Co-Advisor	Signature	/ / . Date

DECLARATION

I, undersigned, declare that this thesis entitled: "**Stabilization of Clayey Soil Using Lime and Lime with Prosopis Juliflora Fibers 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 other any University, and all sources of material used for this thesis have been duly acknowledged.

Candidate:

Ahmed Mohamed Ismail	_______________	30/10/2021
	Signature	Date

As Master's research Advisor, I hereby certify that I have read and evaluated this MSc thesis prepared under my guidance by Mr. Ahmed Mohamed entitled: **"Stabilization of Clayey Soil Using Lime and Lime with Prosopis Juliflora Fibers in Jimma Town"**

I recommend that it can be submitted as fulfilling the MSc Thesis requirements.

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ABSTRACT

The properties of clayey soils can be problematic due to the damage it can bring to civil engineering structures such as roads, buildings and others infrastructures. This is because the clayey soil swell when contact water and shrink when it dry out. This type of soil occurs in many countries in the world, Ethiopia is one of those countries. The problematic nature of these soils can be improved by chemical stabilization techniques using cement, lime and fly ash. However, these chemicals are too expensive to develop countries such as Ethiopia. Therefore, it is important to discover low cost and available materials to utilize as soil stabilizer.

The general objective of this research was to investigate the effects of lime alone and mixture of lime with Prosopis Juliflora fibers on stabilization of clayey soils in Jimma town .In this study, was conducted by using experimental method. Two clayey soil samples were taken from the study area by observation and free swell index tests at a depth of 1.50 m to remove organic matter. Prosopis Juliflora fibers was extracted from the inner barks of the prosopis juliflora trees. In addition, hydrated Lime was obtained from Senkele Lime Factory.

Laboratory tests were carried out for moisture content, sieve analysis, specific gravity, atterberg limits, linear shrinkage, compaction tests, CBR and CBR swell tests. The laboratory test results, was compared with ERA, AASHTO and ASTM, specifications.

The laboratory test results, indicated that the natural sub-grade soil of the selected area has a low load bearing capacity and unsuitable for use as sub-grade material. Hence, to improve the engineering properties of the soil a stabilization techniques was used by adding different percentages of lime 4%, 6% and 8% alone and mixture of 5% lime with different percentages of Prosopis juliflora fibers 0.5%, 1%, 1.5% and 2%. From the laboratory test results, it was inferred that the optimum content of lime and lime with prosopis juliflora fibers required to achieve superior geotechnical properties in clayey soil was found to be 6% lime alone and mixture of 5% lime with 1.5% fibers. At this optimum combination, the CBR of sample-1 increased from 1.21% to 8.93% and 1.21% to 8.28% and the CBR of sample-2 increased from 1.96% to 9.93% and 1.96% to9.26% with the addition of 6% lime alone and 5% lime with 1.5% fibers, respectively. Furthermore, the result shows that the improvement of 6% of lime alone and 5% lime with 1.5% fibers are more likely same improvement. Therefore, 1% lime can be partially replaced by 1.5% fibers to reduce the cost of the lime.

The results was compared with standard specifications by compared the value obtained from the laboratory tests with the required value on the standard specifications .Hence, the obtained value from the test results fulfilled the required value on the standard specifications. Therefore, it is recommended to use 6% lime alone or mixture of 5% lime with 1.5% prosopis juliflora fibers.

Keywords: *Clayey soil, Fibers, Stabilization, Prosopis juliflora, Stabilizer*

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ABBREVIATIONS

AASHTO	American Association State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CAH	Calcium-Aluminate –Hydrates
CBR	California Bearing Ratio
CE	Cation exchange
CEC	Cation exchange capacity
CSH	Calcium-Silicate-Hydrates
EGME	Ethylene Glycol Mono-Ethyl Ether
EIAR	Ethiopia Institute of Agricultural Research
ERA	Ethiopian Roads Authority
FSI	Free swell Index
Gs	Specific Gravity
GSE	Geological Survey of Ethiopia
HDRA	Henry Doubleday Research Association
JIT	Jimma Institute of Technology
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
SSA	Specific Surface Area
USCS	Unified soil Classification System

CHAPTER ONE

INTRODUCTION

1.1 Background

Clayey soils pose problems to civil engineers in general and to geotechnical engineers in particular (Chen, 1988). They cause damage to structures founded in them because of their potential to react to changes in moisture content. They swell when contact water and shrink when it dry out. This alteration of swelling and shrinkage, finally results detrimental cracking in construction structures such as foundations, floors, basement walls and pavements.

Naturally occurring clay soils have been found in various regions all over the world and cause damages to foundations and associated structures (Kariuki, 2004). It has been identified that the problems caused by clay soils is more than millions of dollars compared to the total damage of the other natural hazards in every year in USA.(Jones and Holtz 1973 and Chen,1988) .Soils with higher percentage of clay minerals like montmorillonite, expandable illite and vermiculite, are susceptible to swelling and shrinkage. They cause numerous costly damages to roadways, buildings and other civil engineering infrastructures. Furthermore, clay soils are generally stiff in dry state but when become saturated, they lose their stiffness.

Similarly, (Alemayehu &Mesfin, 1999) stated that “clay soils are a problem in Ethiopia as in other countries”. Clay soil causes the strength and durability of structures to fail within a short period of time and these results heavy economic lose by repairing the buildings in Ethiopia.

In order to treat this problem, soil stabilization should be implemented with different stabilizing additives to achieve the required specification of sub-soil materials.

Soil stabilization is the alteration of one or more soil properties by mechanical or chemical means to create an improved soil material possessing the desired engineering properties. The process may include the blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture, or plasticity, or act as a binder for cementation of the soil (Bafyau. V, 1994). It also refers particularly to the mixing of the parent soil with other soil, cement, lime, bituminous products, silicates, and various other chemicals; natural or synthetic, organic, and inorganic materials as a stabilizer (Osinubi.K,2007).The cost of improving roads is expensive due to expansive soil that requires a replacement with imported materials or being stabilized. Moreover-dependence on industrially manufactured soil-improving additives (cement, lime, etc.) has kept the cost of construction of stabilized roads financially high.

Soft clay lacks enough strength to withstand the load from the structure .The strength of this type of soil is to improve to make use of the soil for any construction. Therefore, this study, was focused on how to stabilize clay soils by using lime and prosopis juliflora fibers to improve geotechnical properties of the soil. Prosopis juliflor fibers are one of the cheapest and abundantly available additives. The fibers were extracted from the stem of the prosopis juliflora tree. On the other hand, the prosopis juliflora trees have big problems in the environment they absorbed a lot of underground water because their roots penetrate a long distance beneath the ground (Sertse, D. and Pasiecznik, N.M. 2005) .This causes the other useful plants to not absorb enough water. Therefore, to get rid of the problems of water shortage as well as the sand scarcity, these prosopis juliflora fibers should be utilized as stabilizer agents.

1.2 Statement of the problem

Clayey soils are extensively distributed worldwide, and are a source of great damage to infrastructures. Ethiopia is covered by clayey soil; big cities like Addis Ababa, Bahir-Dar, Mekelle, and Jimma as well as main trunk roads are situated on this soil type, aerial coverage estimated to be 24.7 million acres (Nebro, D. 2002). Currently, different construction activities are taking place in the road and building sector on this soil types. It has been noticed that construction on expansive soil face numerous problems and the causes of the problems are not investigated in depth in Ethiopia. Most of the roads constructed in Ethiopia on this type of soil fail before their expected design life, in some cases after few months of completion (Sime, A. 2006).

Since most soil which is found in Jimma town have high plastic index and low bearing capacity. They are a consequence for clay and unstable subgrade soil (Mohamed.J, 2019). As the result, this leads cracking and excessive rutting of the surface of the structures. So, continuous maintenance of infrastructures such as road pavement causes heavy economic losses. With regard to this problem, treatment should be carried out before constructing any engineering structures by applying an appropriate, cost effective stabilization technique to improve the engineering properties of clayey soil. Previously there were many additives that were used as stabilizer for clayey soil such as cement and lime. From those common additives lime is one of higher cost. Therefore, it is important; to find out low cost additives to be utilized for soil stabilization.

In this study, lime and lime with prosopis juliflora fibers were used to improve geotechnical properties of the soil. These prosopis juliflora fibers have low cost and readily available.

1.3 Research questions

1. What type of engineering properties has a clayey soil in Jimma town of the study area?
2. What is the change in an engineering properties of clayey soil when stabilized with lime and lime with prosopis juliflora fibers?
3. What is the optimum percentage of lime additives and lime with prosopis juliflora fibers will be required to improve the engineering properties of clayey soil of the study area?
4. How the results compared and recommended its applicability?

1.4 Research objectives

1.4.1 General objectives

The general objective of this research is to assess the improvement of engineering properties of clayey soil using chemical stabilization of lime and lime with prosopis juliflora fibers.

1.4.2 Specific objectives

- To assess the engineering properties of clayey soil in Jimma town of the study area.
- To assess the change in an engineering properties of clayey soil when stabilized with lime and lime with prosopis juliflora fibers.

- To determine the optimum percentage of lime additives and lime with prosopis juliflora fibers will be required to improve the engineering properties of clayey soil in the study area.
- To compare the effects of lime and lime with prosopis juliflora fibers and recommended its applicability.

1.5 Significance of the study

The significance of the research study was to evaluate the performance of the use of lime and lime with prosopis juliflora fibers for stabilization of clayey soil. Benefits from the studies are cost saving because prosopis juliflora fibers are typically far cheaper than traditional stabilizers such as lime. Moreover, this research also serves as a reference guide for users, students and researchers who will study about the related area for the application of lime and lime with prosopis juliflora fibers as an innovative stabilizer**.**

1.6 Scope of the study

The scope of the study was covered the stabilization of clayey soil using lime and lime with prosopis juliflora fibers in Jimma town. Two representative samples of clay soil from different locations were collected. The collected samples were disturbed samples and taken from 1.5m depth to remove organic matter. Then a relevant laboratory tests were conducted for the natural soil and mixture of samples with lime alone and mixture of lime with prosopis juliflora fibers, the tests include; grain size analysis, standard proctor compaction, free swelling, atterberg limit, optimum moisture content (OMC), specific gravity, CBR and CBR swell tests. Correspondingly, the study results were compared with ERA, AASHTO and ASTM specifications. Similarly, recommendation were drawn and forwarded.

CHAPTER TWO

RELATED LITERATURE REVIEW

2.1 Introduction

Soil is the weathered material which consists of mainly sand and clay in the upper layers of the earth's crust. Much fine material has also been deposited by flooding of the land by the sea and the rivers. This process of sedimentation occur many areas in the world. The problems due to the behavior of soil as a result of human activities like settlement of a road or a railway under the influence of its own weight and the traffic (Verruijt, 2010).

Soil includes all earth materials, organic and inorganic, occurring in the zone overlying the rock crust. The behavior of a structure depends upon the properties of the soil materials on which the structure rests as well as properties of the soil materials depend upon the properties of the rocks from which they are derived. Soils are formed by the process of weathering of the parent rock might be by mechanical disintegration, and/or chemical decomposition process (Murthy, 1996).

2.2 Clayey soils

Clays are characterized by low compressive strength and excessive compressibility. The reduction in bearing capacity of soft clays results in compressive failure and excessive settlement, leading to severe damage to buildings and foundations (Mc.D, C, 1959). Maintenance and rehabilitation costs for the infrastructure on these soils reach billions of dollars annually. These problems primarily stem from the presence of montmorillonite clay minerals which are derived from basic and ultrabasic igneous rocks; essentially the minerals are by product of the decomposition of these rocks (Van Der Merwe. D, 1964) and (Jones, J. D. Parker, and J. Bridgwater, 2007).

These minerals swell when moisture is introduced and shrink when the same moisture is retracted. In the case where the soil undergoes excessive heat, i.e. drought, expansive soils tend to contract and shrink excessively (Chittoori, B.C.S, 2008). (Al-Rawas and Goosen ,2006) noted that clay minerals and cat ions come in various forms and that it is the relative quantities of each type of these minerals that are important factors contributing to the swell/shrink behavior along with the dry density, soil structure, and loading conditions present. Other researchers added that the arid climate, alkaline environment, and local geology are accountable for the expansive nature of soils (Firoozi, A.A and Baghini,A.A ,2016). There are many improvement methods of problematic soil. Soil stabilization is one of the most improved ways of clayey soil.

2.3 Origin of clayey soils

Generally, clays are naturally occurring material primarily composed of fine-grained minerals, show plasticity when mixed with appropriate amount of moisture and become hard when dried or fired. (Das. B, 2015) indicated the characteristics of clay, which included:

a) Small particle size (usually smaller than 0.002 mm)

b) Net negative charge

c) Show plasticity when mixed with moisture

Parent materials that can be associated with clay soils are either igneous rocks or sedimentary rocks. The basic igneous rocks comprise basalt, dolerite, sills, dykes, and gabbros. The second includes the sedimentary rocks that contain Montmorillonite as a constituent which breaks down physically to form expansive soils.

2.4 Distribution of Expansive Soil

Expansive soils are wide spread in parts of the world, case of expansive soils has been widely reported in countries like the USA, Australia, Canada, India, Spain, Israel, Turkey, Argentina, Venezuela, etc. In the continent of Africa, expansive soils occur in South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, Nigeria, etc. (Teffera.A, 1999).Besides, the aerial coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres (Nebro.D, 2002).They are widely spread in the central part of Ethiopia following the major truck roads like Addis-Ambo, Addis-Wolliso, Addis– Debrebirhan, Addis-Gohatsion, and Addis-Modjo are covered by expansive soils. Also, areas like Mekele, Gambella and Jimma are covered by expansive soil. The distributions are shown in Figure 2.1. (Tilahun.D, 2004)

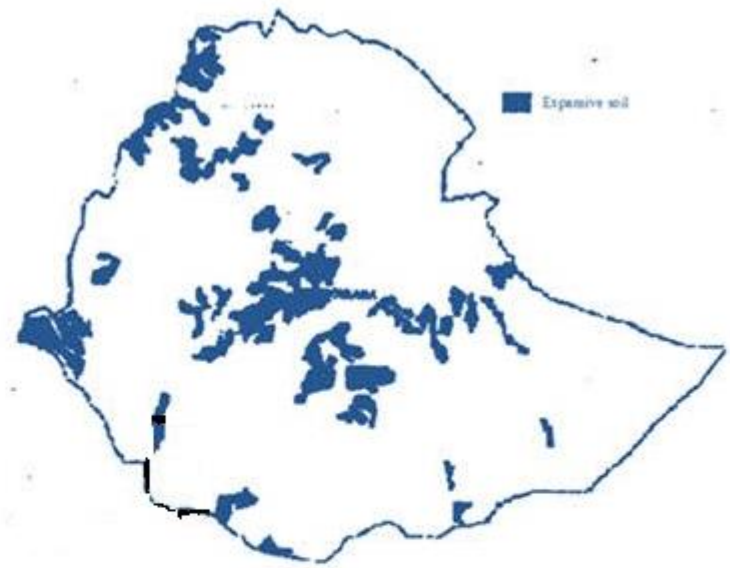


Figure 2.1: Distribution of expansive soil in Ethiopia**.** (Tilahun.D., 2004)

2.5 Clay Mineralogy

Clayey soils are due to the presence of clay minerals. Clay particles have sizes of 0.002mm or less. However, according to (Chain, 1988) the grain size alone does not determine clay minerals and the most important property of fine grained soils is their mineralogical composition. Clay minerals are crystalline hydrous alumino-silicates derived from parent rock by weathering. The basic building blocks of clay minerals are the silica tetrahedron and the alumina octahedron and combine into tetrahedral and octahedral sheets to form the various types of clays. The three most important groups of clay minerals are montmorillonite, Illite, and kaolinite,which are crystalline hydrous alumina-silicates with the help of X-ray technology minerals are identified (Alemayehu & Mesfin, 1999) (Chen , 1975).

2.5.1 Kaolinite

Kaolinite is a typical two layered mineral having a tetrahedral and an octahedral sheet joined to from 1 to 1-layer structure held by a relatively strong hydrogen bond. Kaolinite does not absorb water and hence does not expand when it comes in contact with water. The montmorillonite groups of clay minerals have 2 to 1-layer structure formed by an octahedron sandwiches between two tetra hedrons .These clay groups have significant amount of magnesium and iron sandwiched into the octahedral layers.

The most important aspect of the montmorilonite clay mineralogy group is the ability for water molecules to be absorbed between the layers, causing the volume of the minerals to increase when they come in contact with water. The Illite clay minerals have a structure similar to that of kaolinite, but are typically deficient in alkalis, with less aluminum substitution for silicon, magnesium and calcium can also sometimes substitute for potassium and illites are non-expanding type of clay minerals.

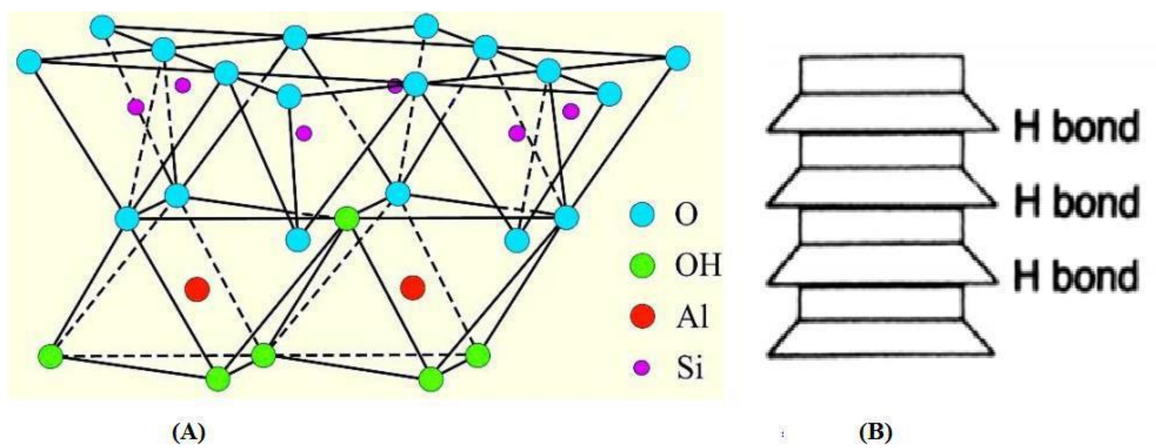


Figure 2.2: Diagrammatic and schematic representation of kaolinite (Craig., 1997)

2.5.2 Montmorillonite

Montmorillonite is a three-layer mineral having a single octahedral sheet sandwiched between two tetrahedral sheets. The space between the combined sheets is occupied by water molecules and exchangeable cations. There is very weak bond between the combined sheets due to these ions. Considerable swelling of Montmorillonite can occur due to additional water observed between the combined sheets.

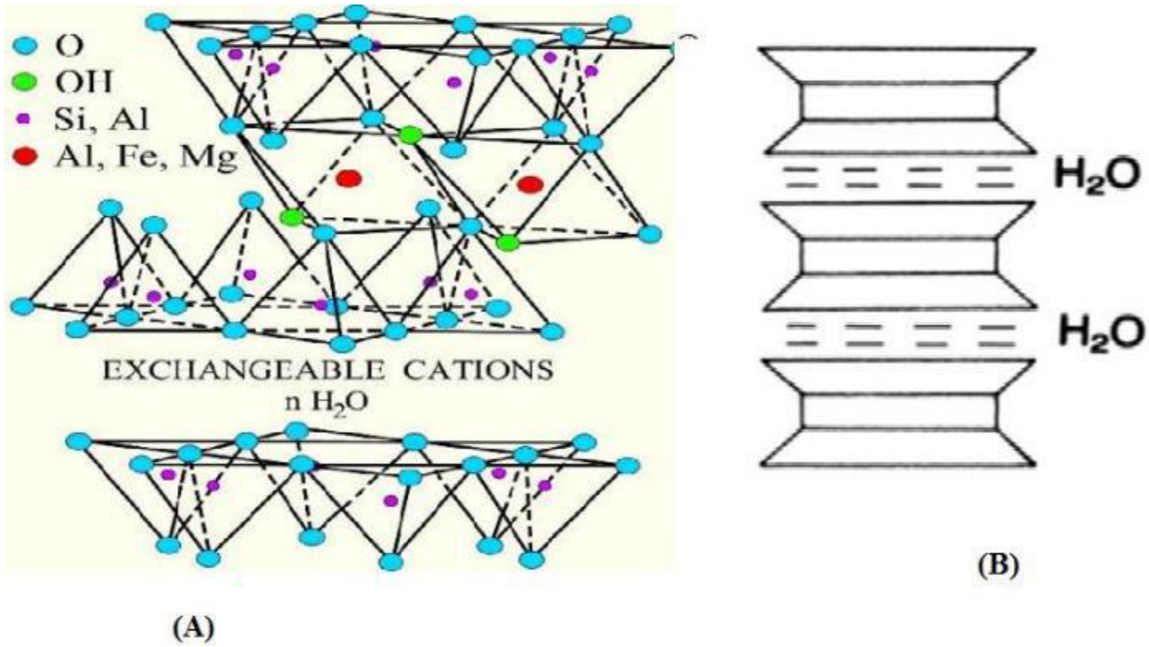


Figure 2.3: Diagrammatic and schematic representation of Montmorillonite (Craig, 1997)

2.5.3 Illite

Illite has similar structure with that of Montmorillonite, but some of the silicon atoms are replaced by aluminum and in addition potassium ions are present between the tetrahedral sheet and adjacent crystals. The layers of Illite clay minerals are more strongly bonded together than the Montmorillonites. In terms of Cation exchange capacity, inability to absorb and retain water and in physical characteristics Illite is intermediate in activity between clays of kaolinite and Montmorillonite. The layers of Illite clay minerals are linked together by fairly weak bonding to potassium ions held between them.

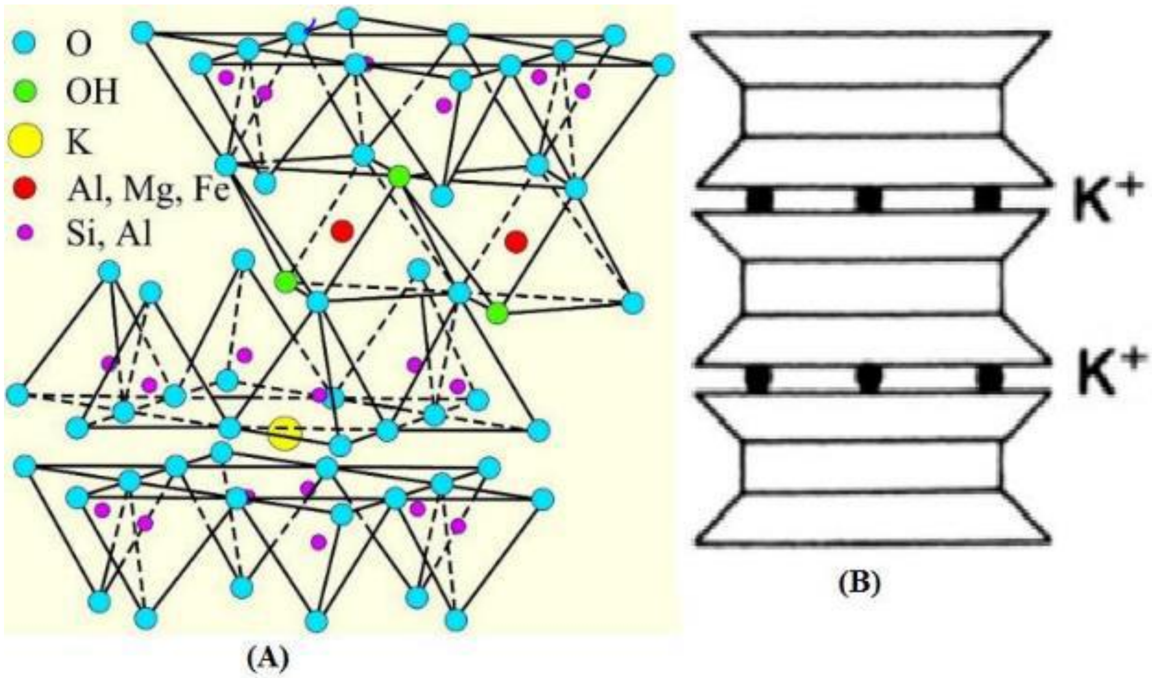


Figure 2.4: Diagrammatic and schematic representation of Illite (Craig., 1997)

Table 2.1: Chemical formulas of clay minerals (Kibria.G., 2014)

Clay Mineral	Layer Type	Typical Chemical formula
Kaolinite	1:1	$Al_2Si_2O_5(OH)_4$
Montmorillonite	2:1	(Na,Ca)0.3$(Al, Mg)_2Si_4O_{10}(OH)_2xnH_2O$
Illite	2:1	$(K, H_3O)(Al, Mg, Fe)_2(SiAl)_4O_{10}[(OH)_2H_2O]$

It is evident that the engineering and physico-chemical behavior of clay are largely influenced by the moisture. Therefore, it is important to know the mechanism of clay water interaction. The clay particles contain adsorbed counter ions and excess ions in the form of precipitated salts at dry condition. The addition of water hydrates the counter ions adsorbed in the particle surface. During the hydration process, some of the counter ions lose their primary hydration shell (all or partly) and develop inner sphere complex.

The ions with primary hydration shells also exist in the form of outer sphere complex. The hydrated counter ions are attached to the particles due to the presence of surfer charge. The rest of the counter ions are separated from the surface of the particles by water.

(Uday et al. 2015) summarized the possible causes of clay water interaction, which included hydrogen bonding, attraction by osmosis, hydration of exchangeable cations, charged surface dipole attraction, and presence of dispersion force as illustrated in Figure 2.5.

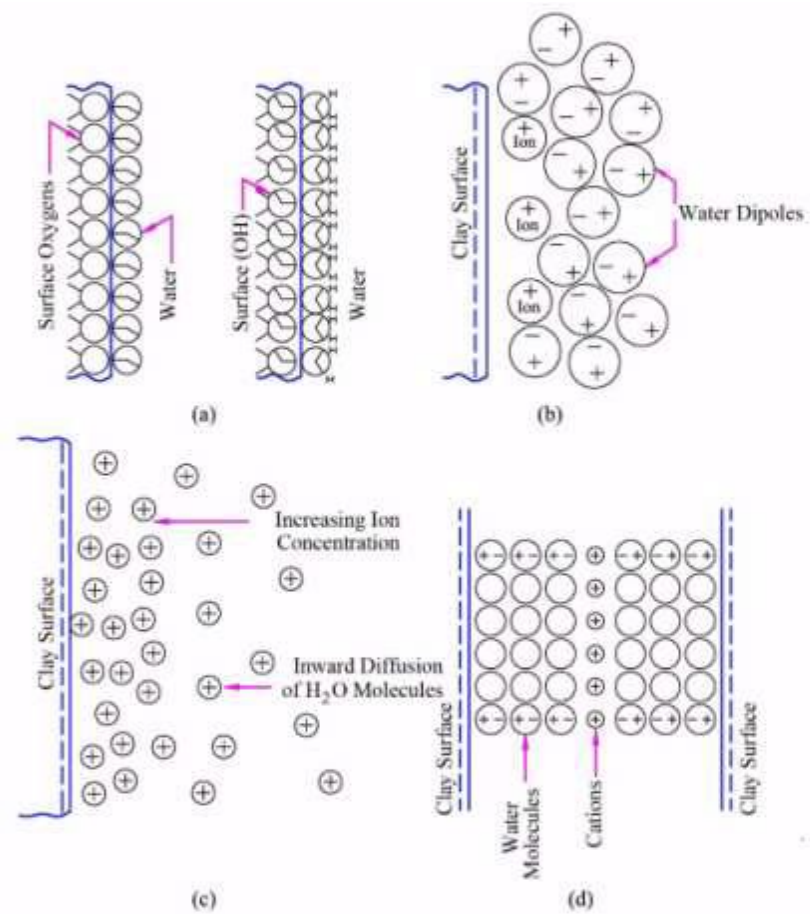


Figure 2.5: Different causes of clay water interaction (a) hydrogen bonding (b) ion hydration (c) attraction by osmosis (d) dipole attraction (Uday et al, 2015**)**

2.6 Characterization of Clay Minerals

The characterization of clay mineral is necessary for the identification of engineering and physico-chemical behavior of fine-grained soils. In addition, design of stabilizers also requires a specific determination of clay mineral .It is utilized Atterberg limits to determine the qualitative mineralogical content of soils. Similarly, (Das, B.2015) indicated that ranges of activities in clays minerals were different, and provided an indication about the dominant mineral in a soil sample.

The typical ranges of liquid limit (LL), plastic limit (PL) and activity of different minerals are presented in Table 2.2.

Table 2.2: Typical ranges of LL, PL and activity of minerals (Sirivitmaitrie, C., 2008)

Mineral	Liquid limits	Plastic limits	Activity
Montmorillonite	100−900	50−100	1−7
Illite	60−120	35−60	0.5−1
Kaolinite	30−110	25−40	0.5

2.6.1 Cation Exchange Capacity

The cation exchange capacity or the CEC level is the measure of isomorphic substitutions that occur with the clay minerals. (Pedarla, A. S and Puppala. A.J. 2011). The isomorphic substitutions are due to tetrahedral and octahedral sheets containing cations instead of an idealize structure (i.e. aluminum in the places of silicon, magnesium instead of aluminum, etc.).When the isomorphic substitution occurs, multiple cations are replaced with other cations of other valances within the structure to maintain equilibrium within the clay structure. The ability to measure the cation replacement is computed as milliequivalents (meq) per 100 g of clay. The milliequivalents are determined by knowing the atomic weight, and the weight and valance of the element. The CEC value is a guide to estimate the predominant clay mineral. In addition, the CEC shows how stable the clay mineral is to isomorphic substitution. When the measureable CEC increases the isomorphic substitution within the clay mineral also increases. Table 2.3 outlines CEC values for common clay minerals. As one can see, kaolinite has the lowest CEC, while vermiculite has the highest CEC.

Table 2.3: CEC value for common clay minerals (Mitchell,J., 2005)

Clay mineral	Meq/100g
Kaolinite	5
Halloysite	12
Illite	25
Vermiculite	150
Smectite	85
Chlorite	40

2.6.2 Specific Surface Area

The specific surface area (SSA) is the measure of the surface area of a clay sample, which is determined by the amount of the polar molecule (i.e. glycol, glycerol, or ethylene glycol mono-ethyl ether (EGME) retained under laboratory controlled conditions and it is then converted to SSA. The SSA of the sample is an indication the governing clay mineral within the test sample.

2.6.3 Atterberg Limits

The concept of the Atterberg limits was introduced to geotechnical engineering by (Casagrande, A.1931). Under Casagrande, a uniform test method was developed to determine the liquid limit (LL), plastic limit (PL), and the plasticity index (PI) of soil. The liquid limit and the plastic limit correspond to different shear strengths of the soils. (Holtz, R.D and Kovacs, W.D. 1981).Used the Atterberg limits to create a soil classification.

2.7 Soil Classification System

Dr.Arora (2004) stated that “Soil classification is the arrangement of soil into groups which have similar behavior”. The main objective of any soil classification system is predicting the Engineering properties and behavior of a soil based on a few simple laboratory or field tests. Based on the laboratory or field test results, identify the soil and categorized into groups with similar engineering characteristics. Although there are many classification systems like particle size, textural, AASHTO and USCS classification, the AASHTO and USCS classification systems are more common.

2.7.1 AASHTO Classification System

According to AASHTO, Particle size analysis and plasticity characteristics are required to classify soil for both coarse-grained and fine-grained from A-1 to A-7 of soil classification. This classification system required particle size analysis, plasticity index and liquid limit should be determined to group the soil with similar engineering characteristics (Dr.Arora, 2004).

2.7.2 USCS Classification System

Unified soil classfication system (USCS) was first developed by casagrande in 1948 and modified by Bureau of reclimetion and crop engineers of USA (Kalinski, 2011). It has also accepted by American Society of Testing Materials (ASTM) and most popular classification systems for all types of engineering problems are involving soil. This method is used to categorize the soil with similar engineering properties, including strength, permeability and compressibility which specifying soil types to achieve a desired performance (Kalinski, 2011).

According to USCS, soils are classified as coarse-grained or fine-grained as follows:

❖ Coarse-grained: when soil sample retained on sieve #200 (0.075 mm) more than 50 percent. Coarse-grained soils are further classified as:

✓ Gravels if 50 percent or more of the coarse fraction is retained on #4
(4.75mm) sieve.

✓ Sands if 50 percent or more of the coarse fraction passes through #4 (4.75mm) sieve.

❖ Fine-grained: if 50 percent or more of the sample passes #200 (0.075 mm) sieve.

Fine-grained soils are further classified according to whether their liquid limit is less than or greater than 50 percent.

2.8 Soil stabilization

Soil stabilization is the process of improving the engineering property of the soil and thus making it more stable. The term stabilization is general restrict to the process which alters the soil material itself for improvement of its property. Soil stabilization is used to reduce the permeability and compressibility of the soil mass in earth structures and to increase its shear strength.

2.8.1 Methods of stabilization

Nowadays there are so many methods to stabilize soils; but all of the methods are restricted to just two main groups which are mechanical and chemical

a) Mechanical stabilization process

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil. The main methods of mechanical stabilization can be categorized into compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation.

b) Chemical stabilization Process

Chemical additives are used as a stabilizer of expansive soils through different process. Those processes which are used for stabilize soils and modify their properties through cation exchange, flocculation, agglomeration and pozzolanic reactions.

(Dallas and Nair 2009) classify chemical stabilizers into three groups:

- **Traditional stabilizers** such as hydrated lime, Portland cement and Fly ash;
- **Non-traditional stabilizers** comprised of sulfonated oils, ammonium chloride, enzymes, polymers, and potassium compounds; and
- **By-product stabilizers** which include cement kiln dust, lime kiln dust etc.

2.9 Origin of prosopis juliflora tree in Ethiopia

Prosopis juliflora tree come to part of Ethiopia such as Weyane Dergi-.Hara (Afar), Biscuit (Dire-Dawa) and elsewhere. They come originally from the Americas, there are many species often confused, but work by the Ethiopian Agricultural Research Organization (EARO) and the Henry Doubleday Research Association (HDRA) has confirmed that prosopis juliflora is the one commonly found in the above regions of Ethiopia. Its first introduction is believed to have been in the late1970s at Goro-nursery, Dire-Dawa,possibly from India. In Afar, it may have been introduced possibly from Dira Dawa, or independently from Kenya or Sudan by foreigners working in the middle Awash irrigation project in the late 1970s and early1980s.

2.10 Effects of prosopis juliflora fibers on clayey soil

In this study, the effect of addition of lime and lime with prosopis juliflora fibers on the properties of clay soil was investigated through various tests. Different researches are conducted on the effect of prosopis juliflora fibers on clayey soil. (Park, 2011) studied "that the addition of prosopis juliflora fibers along with cement or lime can appreciably enhance the ductility and the failure strain of the soil". The California bearing ratio (CBR) resistance, UCS, and the shear strength of soft soils stabilized with both cement/lime and prosopis juliflora fibers appreciably increase with the increase in weight fraction and length of fibers and curing duration (Cai et al. 2006; Ahmad et al. 2010;Anggraini et al. 2015; Sharma et al. 2015). Characterization tests on the bark fibers of prosopis juliflora revealed the presence of higher lignin content (9.11%) which governs fiber rigidity and is found to possess higher tensile strength (558 ± 13.4 MPa) (Saravanakumaret al. 2013). Large global presence, abundant availability, and promising characteristic of prosopis juliflora fibers make it suitable for stabilizing weak soils.

2.11 Chemical composition of Prosopis Juliflora fibers

The chemical composition of Prosopis Juliflora fibers were studied by (Saravankumar, S.S., 2018).

Standard TPPI methods were used to determine various chemical composition such as Cellulose, Hemicelluloses and lignin contents.

Sartorious electronic moisture analyzer (model MA45) was employed to measure the moisture content. The wax content was evaluated by standard Conrad method.

The result was presented in Table 2.4.

Table 2.4: Chemical composition of Prosopis juliflora fibers (Saravankumar, S.S., 2018)

Parameter	Results (%)
Cellulose	74.42
Hemicelluloses	2.21
Lignin	9.11
Moisture content	3.48
Wax	0.24

2.12 Chemical composition of Lime

The chemical composition of Senkele hydrated Lime studied by (Solomon, H., 2011) using X-ray fluorescence. The composition result was presented in Table 2.5.

Table 2.5: Senkele hydrated Lime chemical composition (Solomon, H., 2011)

Constituent	SiO2	Al2O3	Fe2O3	Cao	MgO	Na2O	K2O	TiO2	P2O5	MnO	SO3
Percentage	6.210	2.180	3.570	59.47	3.910	0.610	0.790	0.329	0.208	0.279	0.580

2.13 Related literatures that was previously done in the study area

There were many researches that was previously done in the study area, some of those researches are listed below.

Abera, N. (2018) studied 'Combined effects of lime and marble dust on the properties of expansive subgrade soil in Jimma town'. Soaked CBR values of both soil samples increase with the increase in combined percentage of lime and marble dust, maximum increment in CBR value is achieved at the combination of 3% lime and 30% marble dust, the CBR increased from1.1% and 0.98% to 6.2% and 6.7% for sample 1 and 2, respectively. Hence, combination of lime and marble dust can actively improve the strength of the expansive soil.

Getu, N. (2018) studied 'Stabilization of week subgrade soil using maize cob ash mixed with cement (case study in Jimma town)'. As observed from the test that was performed under this study, the maximum result were achieved at 1.5% MCA and 6% cement. Since most parameters achieved the ERA requirements and have got maximum strength.

Mohammed, J. (2019) presented 'Investigating the effects of kaolin mixed with cement on strength of expansive subgrade soil'. The addition of kaolin-cement additive content improved the CBR values. The improvement is more significant when the sample was cured because curing allows pozzolonic reactions. Hence, combination of kaolin and cement can strongly improve the strength of the expansive soil. As observed from the result performed under this study, the maximum value of CBR for both soil samples were achieved at K2%+ C8% (with CBR value of 8.86% and 11.72%), and 10% cement (with CBR value of 8.62% and 11.01%) , respectively.

2.14 Summary

Currently, Prosopis juliflora has become the worst weed in Pastoral and agro-pastoral communities of Ethiopia, Kenya and generally in the eastern part of Africa. According to assessment made by Ethiopia Institute of Agricultural Research (EIAR) and other national and international organizations, Prosopis juliflora is number one priority invasive weeds in Ethiopia (Sertse, D, and Pasiecznik, N.M., 2005). As the result, it is important to make use this type of plants as innovative stabilizers for soil stabilization to minimize its problems from the environment. Furthermore, the use of prosopis juliflora fibers in clayey soil stabilization was not broadly attempt in Ethiopia. Therefore, in the current study, the potential of prosopis juliflora fibers on clayey soil stabilization was investigated.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Study Area

The study was conducted in Jimma town, Southwestern of Ethiopia, which is located around 355km away from Addis Ababa, the capital city of Ethiopia. It has latitude and longitude of $7^{\circ}\ 40'52''$ N and $36^{\circ}\ 50'14''$E, respectively. And elevation varies from 1,780m−2,000m above sea level .It is lies in the climatic zone locally known as Woyna – Dega which is considered ideal for agriculture as well as human settlement (GES, 2012).

Sample-1 has latitude and longitude of $7^{\circ}\ 44'12''$ N and $36^{\circ}\ 56'06''$E, respectively and also sample-2 has latitude and longitude of $7^{\circ}\ 41'14''$N and $36^{\circ}\ 48'52''$E, respectively.

Fig.3.1: Study area (source: from Google Earth, 2018)

3.2 Study Design and Period

This research was conducted by using laboratory experimental research design. The study evaluated the effects of lime and lime with prosopis juliflora fibers on clayey soils. Therefore, the result was evaluated to answer the research questions and meet its objectives based on experimental findings.

To meet the objectives of this research, generally the study design was divided into five stages

- Organizing literature review of different previous published researches and gathering as much as information as possible on the study area.
- Field identification
- Sampling and data collection
- Laboratory tests
- Finally, the research findings and recommendations were expressed based on the laboratory test results.

The study period to conduct this thesis was completed within twelve months, starting from September, 2020 up to August, 2021. The overall research design was shown in Figure 3.2.

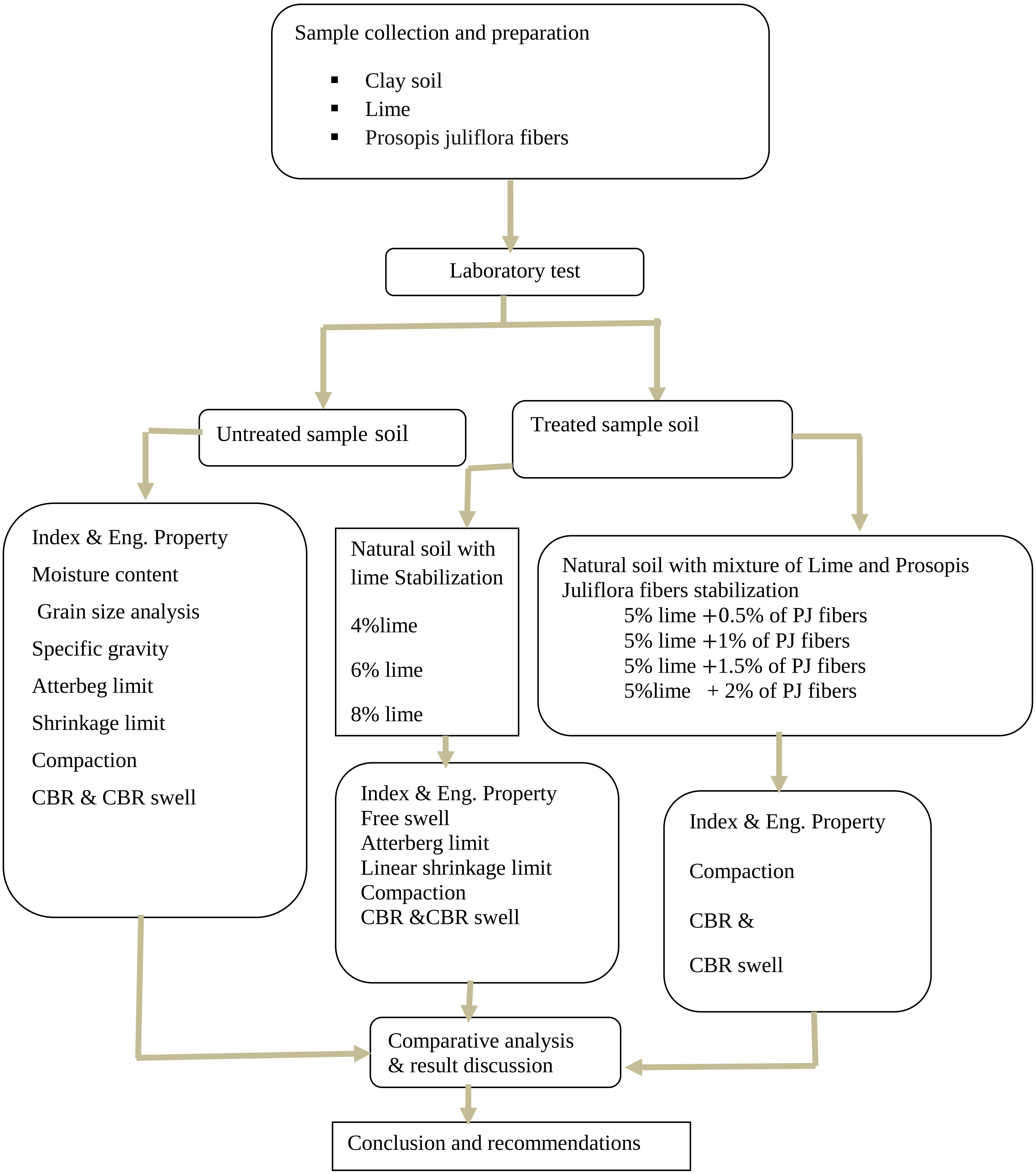


Figure.3.2: Flow chart of the study design

3.3 Population

The population of this study was lime, prosopis juliflora fibers and sample of clayey soil from the selected study area of Jimma town.

3.4 Sampling techniques and sample size

3.4.1 Sampling techniques

The sampling technique used for this research was a purposive sampling, which is a non-probability method. This sampling technique was proposed based on the information that is required to determine the strength of the expansive clayey soil.

3.4.2 Sample size

Based on observation and free swell test, clayey soil samples were selected from the study area of Jimma town. Two soil samples Kitto furdisa (sample-1) and Merkato (sample-2) with high free swell value were selected, and all the tests were performed.

3.5 Study Variables

The study variables in this research contain both independent and dependent variables

3.5.1 Independent variables

The independent variables were grain size analysis, linear shrinkage, compaction, free swelling, atterberg limit, optimum moisture content (OMC), specific gravity, CBR, CBR swell and content of lime and prosopis juliflora fibers.

3.5.2 Dependent variable

The dependent variables is the performance improvement of clayey soil using lime and lime with prosopis juliflora fibers in Jimma town.

3.6 Data collection and process

For the accomplishment of this research, both primary and secondary data sources were used.

3.6.1 Primary data

Primary data were obtained from both laboratory test results and field investigation.

Field investigation

In the field, clayey soils can be identified by applying several techniques. In this study the method listed under (Chen, F and Nelson D.J, 1988) was used to identify clayey soils of the study area during dry season.

According to this method clayey soils have the following properties:

- Have a color of black or gray.
- Polygon pattern of surface crack during dry season.
- A shiny surface when partly dry piece of soil is polished with finger
- High dry strength and low wet strength
- Sickness and low traffic ability when wet.

Based on the above methods, clayey soil of two different locations were identified.

3.6.2 Secondary data

It was collected from different literature reviews which are related to the study, from various sources such as books, international journals and other relevant documents.

3.7 Material source

3.7.1 Clayey soil

The soil used in this research was a clayey soil, which was collected from Jimma town. The soil sample with represents the clayey soil of Jimma town was brought from two different test pits, where clayey soil highly occurs. The first sample was collected from kitto furdisa and the second sample was collected from merkato. A disturbed sample soil of 300 Kg was collected from two boreholes which was excavated at a depth of 1.5m below the earth surface to remove organic matters. Then the samples were suitably packed into an air tight sac and labeled.

Figure3.3: Photo of soil sample collection (A) Excavated hole from the soil, (B) Collected soil sample (Captured by Abdirahman.A, 14/02/2021)

3.7.2 Prosopis Juliflora Fibers

Bark fibers from prosopis juliflora plant are accumulated from Jig Jig town, Somali region of Ethiopia. 25Kg of Prosopis juliflora fibers were extracted manually by hand plucking method and then barks of the plant was dipped in tap water to facilitate microbial degradation for a time of 14days for easy separation of fibers. The outer layer of the bark was gently removed and disposal of, while the required fibers were extracted from the inner bark by applying traditional combing process (Saravanakumar, S.S, 2014). After the extraction, the fibers were sun-dried for at least 14 days and cut into aspect ratio (L/W) of length of 20mm and average width of 1-2mm by using a clipper.

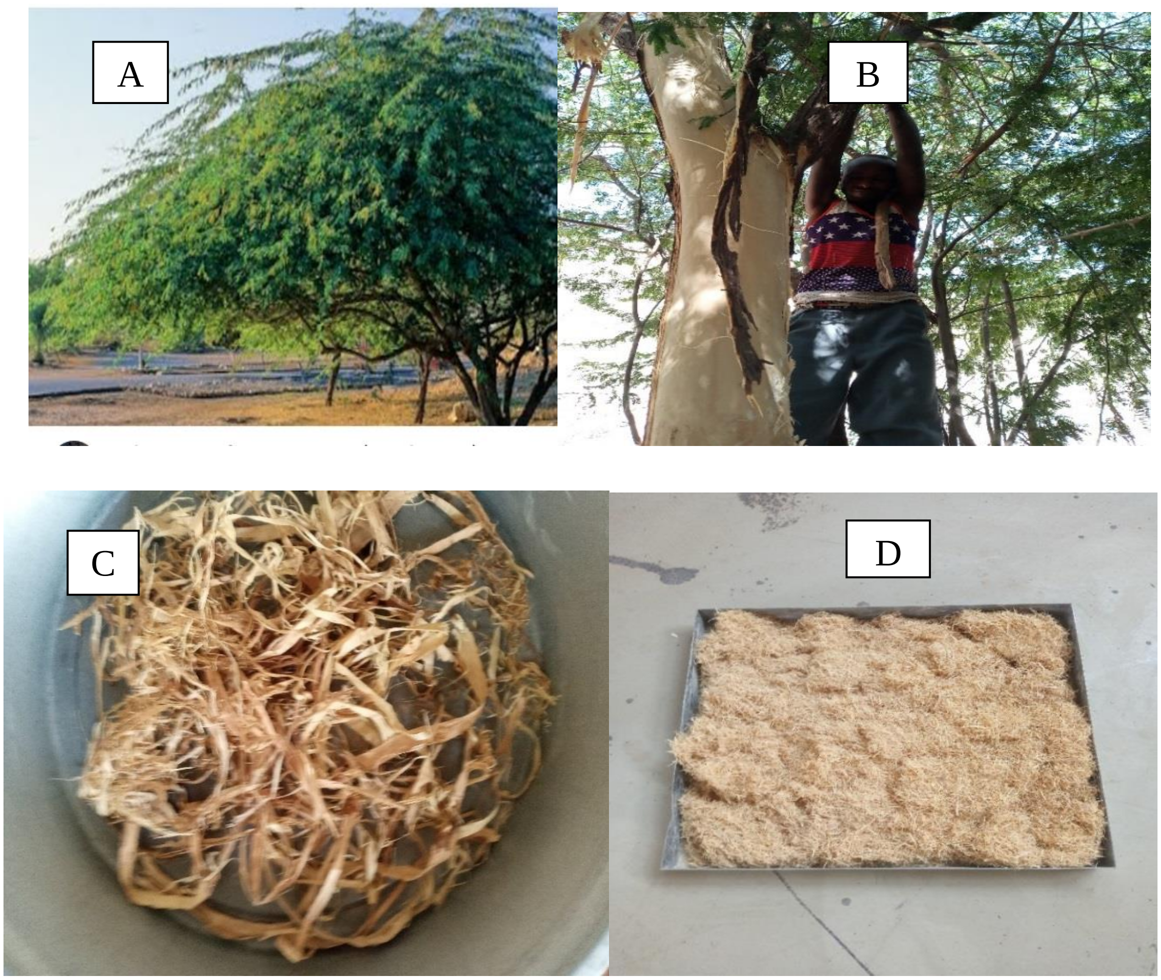


Figure 3.4: Preparation of Prosopis Juliflora fibers (A) Prosopis juliflora tree, (B) Removing the barks from the tree (C) Extracted fibers and (D) Process fibers (Captured by Ahmed.M, 15/02/2021)

3.7.3 Lime

The hydrated lime used for the study was obtained from senkele lime factory which is located Ambo town, Ethiopia.

Figure 3.5: Hydrated Lime (Captured by Abdirahman.A, 17/02/2021)

3.8 Laboratory tests

After collected the material, laboratory tests have been carried out for both untreated (Natural soil) and treated clayey soil samples separately by performed the following tests: moisture content, gradation (sieve analysis), specific gravity, atterberg limits (LL, PL and PI), linear shrinkage, compaction tests, California Bearing Ratio (CBR) and CBR swell tests for natural soil and treated soil.

The treated sample was used 4%, 6% and 8% lime alone and a mixture of 5% lime with four different percentages of Prosopis Juliflora fibers which are 0.5%, 1%, 1.5% and 2% by weigh of the soil. The basis of experimental procedures and comparative analysis was AASHTO, ASTM and ERA manuals. The experimental results were presented, discussed and analyzed using charts, Tables and graphs in chapter four. Besides, conclusions and recommendations were forwarded depending on the results of the laboratory investigation in chapter five. Furthermore, it was attached for more related graphs and Tables in the Appendix.

3.8.1 Moisture Content

Moisture content test for natural sub grade soil was conducted with accordance of AASHTO T265 procedure. Small representative sample of natural soil was obtained and weigh and kept in oven-dried at $105 \pm 5C^{\circ}$ for at least 16hours. Then the sample was reweighed, and the weight of dry soil divided the difference in weight is given moisture content.

3.8.2 Grain size distribution

This test was performed to determine the percentage of different grain sizes contained within natural soil. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger- size particles and hydrometer method was used to determine the distribution of finer particles. For this study, both wet sieve analysis and hydrometer analysis was conducted according to ASTM D422.

3.8.2.1 Wet sieve analysis

Wet sieve analysis test was carried out for natural soil sample, and the test was conducted as follows.

- 1000gram of the natural soil was taken and washed on sieve size of $75\mu m$.
- The retained soil on sieve size of $75\mu m$ was taken and oven dried overnight.
- Recording the weight of the dried sample.
- Clean all the sieves and assemble them in the ascending order of sieve numbers (# 4 sieves at the top and #200 sieves at the bottom) and place the pan below the #200 sieve.
- Finally, record the weight of the soil retained on each sieve.

Figure 3.6: Wet sieve analysis Test (A) washing the soil (B) Sieving the dry soil (Captured by Abdirahman.A, 19/03/2021)

3.8.2.2 Hydrometer test

To determine the distribution of fine particles 50g of air- dried soil sample passing sieve 75μm is used. The soil sample is soaked in 125ml (40g/lit) of sodiumhexametaphospahte solution as dispersed agent for 24hours, and then hydrometer readings were taken after elapsed time of 1,2 ,5,15 ,30 ,60 ,120, 240,480 minutes and 24hours.

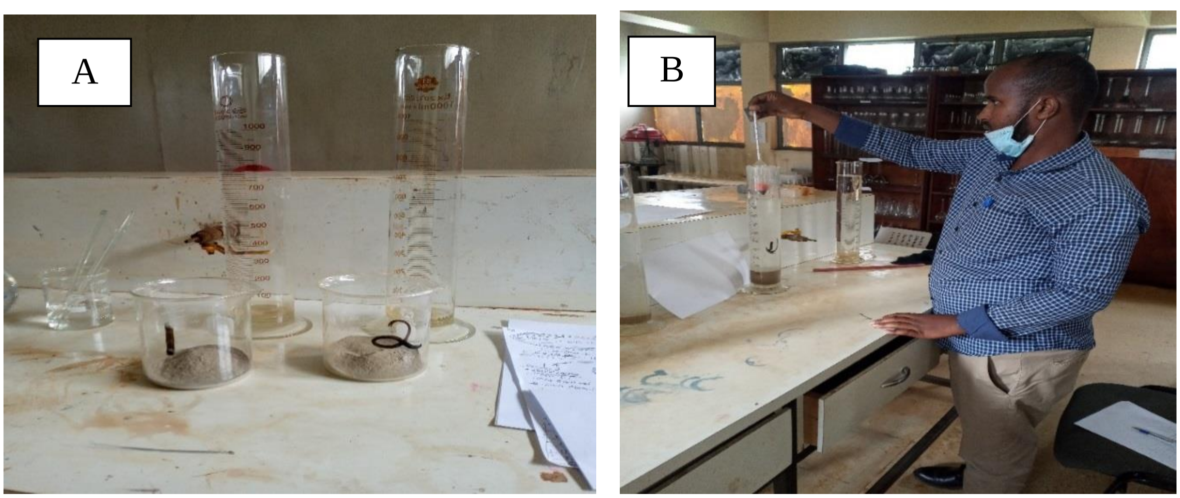


Figure 3.7: Hydrometer Test (A) Preparation of the samples, (B) Taking the hydrometer reading (Captured by Abdirahman.A, 21/3/2021**)**

3.8.3 Specific gravity

Specific gravity, which is the measurement of the heaviness of the soil particles are determined for the natural soil by Pycnometer method using a soil sample passing No .10

sieves and oven dried at 105± 5℃ for at least 16hours.The test was conducted with accordance of AASHTO T100−93 testing procedures.

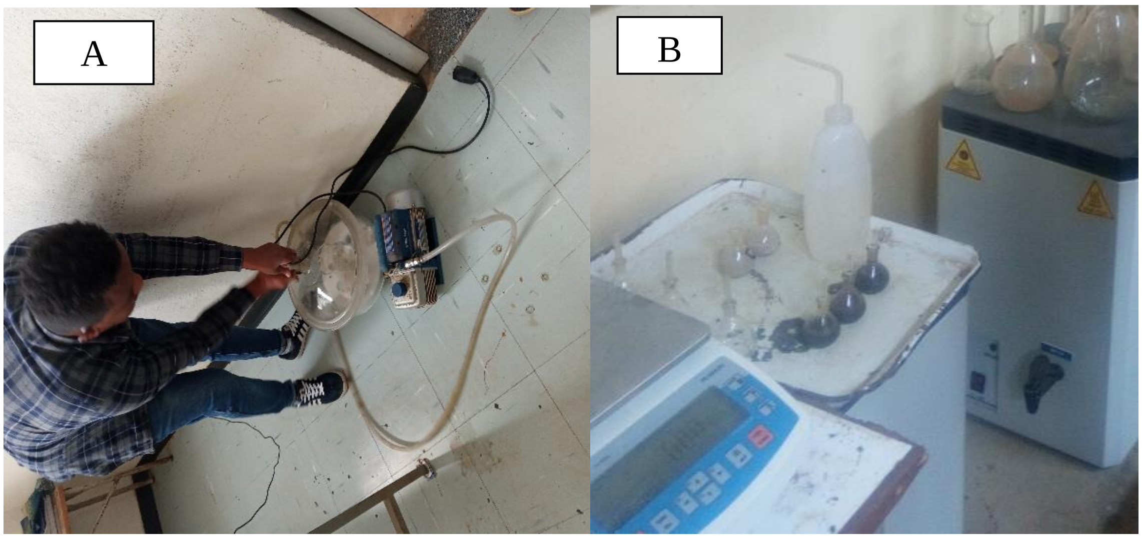


Figure 3.8: Specific gravity Test (A) Sample in Desiccator and (B) Sample in pycnometer (Captured by Ahmed. M, 28/02/2021)

3.8.4 Atterberg limit tests

The tests includes the determination of liquid limit, plastic limit and plasticity index were conducted for natural and treated soil with lime sample in accordance with AASHTO standard specifications.

3.8.4.1 Liquid limit

The soil sample for liquid limit is air dried and 250g of the material passing through No. 40 sieve (425μm aperature) was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate and soaked for at least 16 hours to ensure that the soil grained had absorbed water and soften through. Then a portion of the mixed soil was placed on the Casagrande apparatus and grooved by standard grooving tool. The cup is then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The number of blows at which the soil was contacted is recorded and a little quantity of the soil was taken and its moisture content determined by oven-dried for at least 16hours. For one test pit, it needs three trials by increasing its moisture content by 1−3% . The value of the moisture content (determined) and corresponding number of blows is then plotted on a semi-logarithmic graph, and the liquid limit is identified as the moisture content corresponding to 25 blows. The test was conducted in accordance with AASHTO T89.

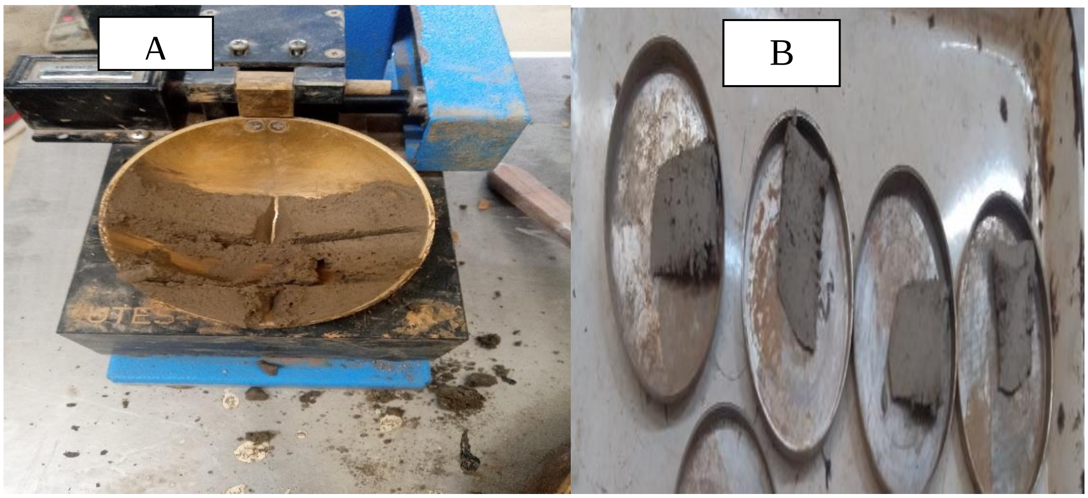


Figure 3.9: Liquid limit Test (A) Sample in Casagrande and (B) portion of the sample (Capture by Abdirahman.A, 22/02/2021)

3.8.4.2 Plastic limit

A portion of the soil used for the liquid limit test, was retained for the determination of plastic limit. Retained soil sample paste was remolded and rolled into the threads on glass plate until the threads began to crack about a diameter of 3mm.The crumbling soil is then put in the moisture container and the moisture content was determined. The test was conducted in accordance with AASHTO T90.

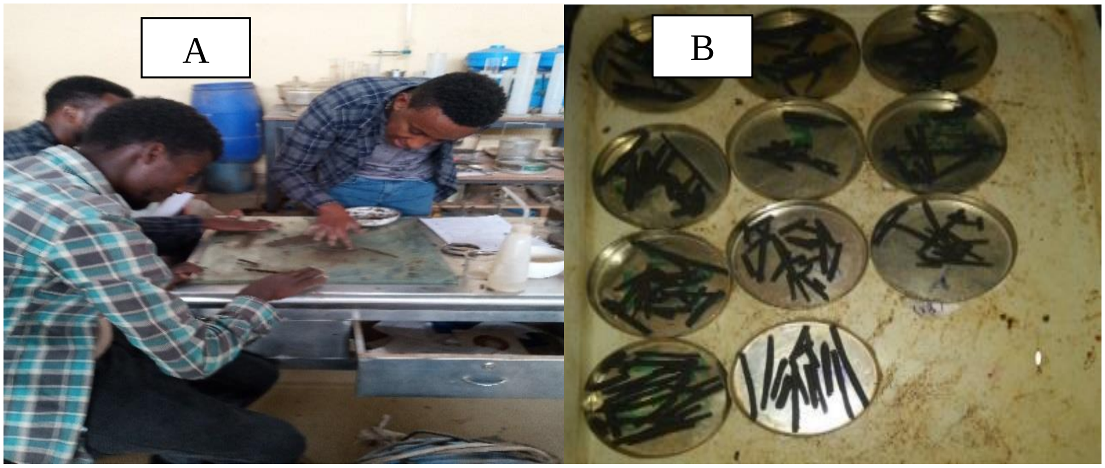


Figure3.10: Plastic limit Test (A) paste sample is rolling and (B) Crumbling soil (Captured by Ahmed.M, 22/02/2021)

3.8.4.3 Plasticity Index

The Plasticity Index is the difference between liquid limit and plastic limit value.

$$PI = LL - PL \qquad \ldots\ldots\ldots\ldots\ldots (3.1)$$

3.8.5 Linear shrinkage

Linear shrinkage of a soil is the water content, expressed as a percentage of the weight of the oven dried soil, at which the further loss in moisture will not cause a decrease in its volume. To find the linear shrinkage it was used a linear measurement on a standard bar of length 140mm with a semicircular section of a diameter 25mm, the groove was filled with a soil of passing through 0.425 test sieve. Then it was mixed with water to have the moisture content like the liquid limit. The test was conducted in accordance with BS 1377: Part 2:1990.

$$\text{Linear shrinkage} = \frac{\textit{Initial length} - \textit{Oven dried length of specimen}}{\textit{Initial length}} \times 100 \ldots\ldots\ldots\ldots\ldots (3.2)$$

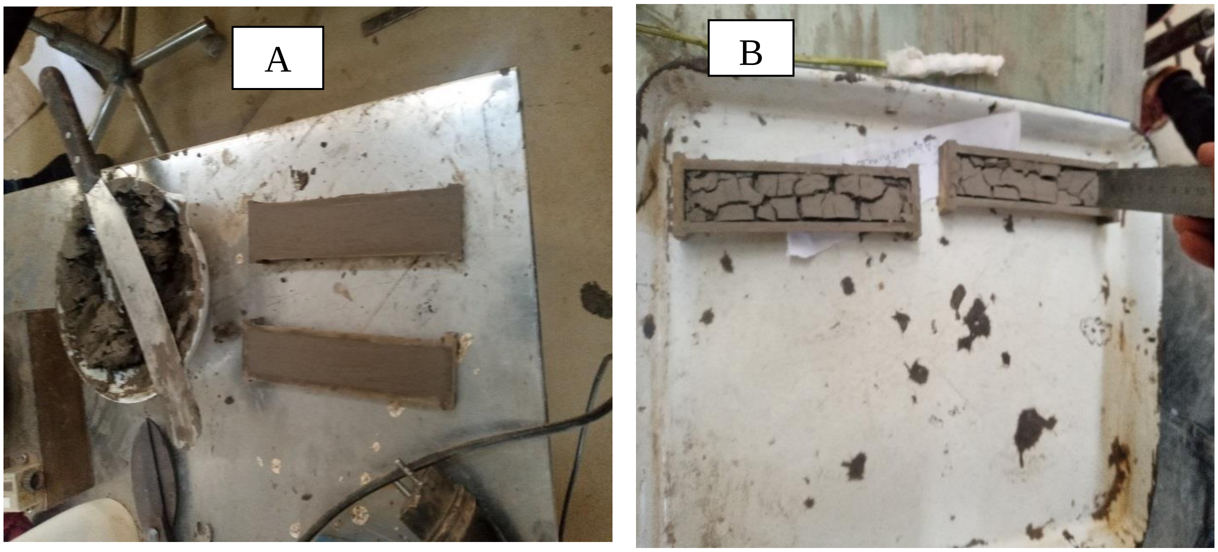


Figure 3.11: Linear shrinkage Test (A) Sample before oven dry and (B) Sample after oven dry (Captured by Ahmed. M, 22/02/2021)

3.8.6 Free swell tests

The test included the determination of the free swell for natural soil, this analysis has not yet been standardized by AASHTO and ASTM. Method was suggested by Holtz and Gibbs, (1956) and Indian standard IS 2720 (part 40) to measure the expansive potential of cohesive soil. But, in this research Indian standard IS 2720 (part 40) was used. The free swell test gives a fair approximation of the degree of expansiveness of the soil sample. The procedure involves in taking two oven dried soil samples passing through the 425μm sieve,10g each was placed separately in two 100ml graduated measuring cylinder. Distilled water was filled with one cylinder and kerosene in the other cylinder up to 100ml mark and letting the content stand for approximately 24hours until all the soil fully settled on the bottom of the graduating cylinder. Then the final volume of the soil is noted. Finally, the free swell value is calculated.

$$\text{Free swell } \% = \frac{\text{Final reading} - \text{initial reading after 24 hours}}{\text{Initial reading}} \times 100 \ldots\ldots..(3.3)$$

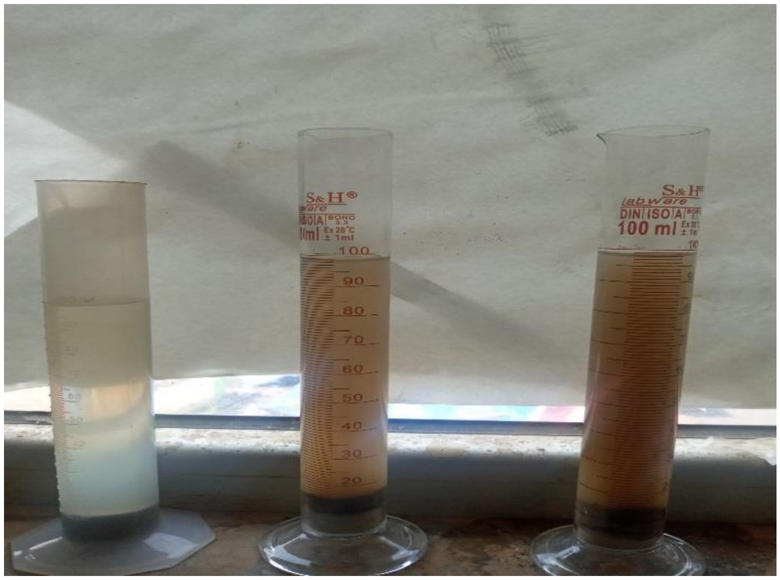


Figure 3.12: Free swell Test (Captured by Ahmed.M, 25/02/2021)

3.8.7 Compaction test

This laboratory test was conducted to determine optimum moisture content and maximum dry density for both natural and stabilized soil. The test was conducted in accordance with AASHTO T180. About 4.5kg of air dried soil sample passing through 19mm sieve was obtained then it was thoroughly mixed with sufficient water to dampen it by varying the moisture content. The sample is then compacted into the 2124 cm3 mold (M1) with collar; in five layers of approximately equal mass with each layer receiving 56blows from the hammer dropping free from a height of 457mm.The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample is leveled off at top of the mold with a straight edge. The mold containing the leveled sample is then weighed (M2). One small representative sample is then taken from the compacted soil for the determination of moisture content. The same procedure is repeated until of four sets of samples are taken for moisture content determination.

The bulky density (ρ) is then calculated for each compacted specimen using the following equation.

$\rho = \frac{M1-M2}{2124}$ ………… (3.4)

Similarly, the drying density (ρ_d) is calculated using the following equation.

$$\rho_d = \frac{100 \times \rho}{(100+w)} \quad \ldots\ldots\ldots\ldots (3.5)$$

Where; w is the moisture content of each compacted specimen.

The values of dry densities gained from the above equation are plotted against their respective moisture content. Maximum dry density (MDD) is deduced as the maximum point on the out coming graph. The corresponding value of moisture contents at maximum dry densities, which is deduced from the graph of dry densities against moisture content, gives the optimum moisture content (OMC).

Figure 3.13: Compaction Test (A) Sieving the sample and (B) Compacting the sample (Captured by Abdirahman.A, 30/02/2021)

3.8.8 California Bearing Ratio (CBR)

The CBR and CBR swell tests are conducted in accordance with AASHTO T193.For both natural and stabilized soil .The CBR is expressed by the force exerted by the plunger and the depth of its penetration into the specimen; it is aimed at the determining the relationship between force and penetration. The CBR test indirectly measures the shearing resistance of a soil under controlled moisture and density conditions. The CBR is obtained as the ratio of load required to affect a certain depth of penetration of a standard penetration piston into a compacted specimen of the soil at same water content and density to the standard load required to obtain the same depth of penetration on a standard sample of crushed stone.

4.5kg sample of the natural soil was used for untreated test and 4.5kg treated soil included the percentage of prosopis juliflora fibers and lime with their percentage of weight of soil. Optimum moisture content was determined from the modified compaction test is used for mixing of prepared soil sample for CBR test in 2124 cubic centimeters mold. A three point CBR test at 10, 30 and 65 blows from 4.54 kg hammer were conducted and the CBR values at 95% MDD was determined. The compacted soil samples of the CBR mold were soaked for 96 hours (4-days) in a water bath to get the soaked CBR value of the soil.

The following equation is obtained the CBR value

$$CBR = \frac{\text{Applied load on sample}}{\text{Standard load on the crushed stone}} \times 100 \ldots\ldots\ldots\ldots (3.6)$$

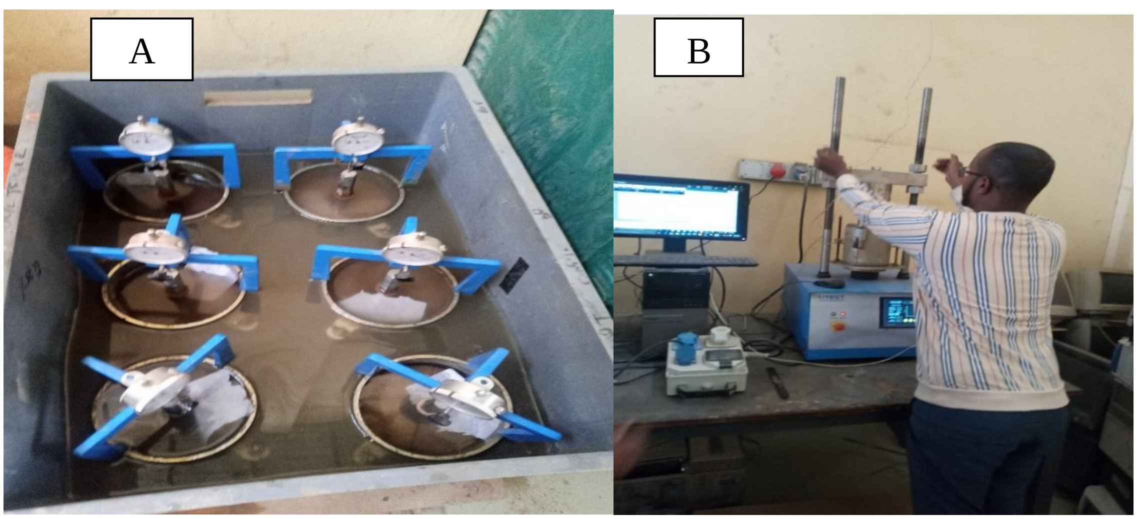


Figure 3.14: CBR test procedures (A) Soaked CBR mold in water bath and (B) Adjusting the plunger on the specimen (Captured by Abdirahman.A, 02/03/2021)

3.8.9 CBR swell

Road pavement structural design is usually based on 4-days soaked CBR values, to stimulate the anticipated “worst –case” soil condition on the field. The CBR swell was measured by placing the tripod with the dial indicator on the top of the soaked CBR mold. The initial dial reading of the dial indicator on the soaked CBR mold was taken just after soaked the sample. At the end of 96hours the final dial reading of the dial indicator was taken.

Hence, the CBR swell percentage is calculated by using the following equation:

$$\text{CBR swell} = \frac{\text{Change in length in mm during soaking}}{116.3\text{mm}} \times 100 \quad \text{………..} (3.7)$$

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the result of laboratory tests for both natural and stabilized soil samples separately and a discussion pertinent to the result of the laboratory tests. The tests included moisture content, gradation (sieve analysis), specific gravity, atterberg limits (LL, PL and PI), linear shrinkage, compaction tests, California Bearing Ratio (CBR) and CBR swell tests.

4.2 Properties of natural soil

The result of the tests conducted for identification and determination of the engineering properties of the natural soil samples before mixing with lime and lime with prosopis juliflora fibers were presented in Table 4.1. The soil sample used in this study were identified and taken from two pits Kitto furdisa (sample1) and Merkato (sample2) the color of the soil samples are gray and black, respectively.

From sieve analysis, percentage passing through sieve No.200 (0.075 mm sieve size) of sample1 and sample2 are 93.08% and 92.09%, respectively. While from the atterberg's limit test results, the soil sample contains a liquid limit of 108.4% and 98.1%, a plastic limit of 41.3% and 36.9% and plasticity index of 67.1 % and 61.2, respectively.

According to (Whitlow, R., 1995), Liquid limit less than35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity. Hence, these values indicate that both soil samples are highly plastic clay.

According to AASHTO soil classification system the soils are under the A-7-5 soil and CH (fat clay) according to ASTM soil class. This class are generally classified as a material of poor engineering property to be used as sub-grade material.

The results from free swell test indicated that the soil is highly expansive clay with a free swell of about 110% and 104% for sample 1 and sample 2, respectively. The soil samples have a maximum dry density of 1.260g/cm^3 and 1.257g/cm^3, the optimum moisture content of 40.80% and 40.91%, natural moisture content of 45.48% and 40.69% and soaked CBR value of 1.44% and 2.20% for sample-1 and sample-2, respectively. This was indicated that the soil has a low load bearing capacity when compared to ERA's specifications of CBR≥ 3%.

Table 4.1: Geotechnical properties of natural soil samples

Parameters	Laboratory results (%)	
	soil sample1	soil sample 2
Percentage passing No.200 sieve	93.08	92.09
Moisture content (%)	45.48	40.69
Liquid limit (%)	108.40	98.10
Plastic limit (%)	41.30	36.90
Plasticity index (%)	67.10	61.20
Linear shrinkage (%)	20.36	18.61
AASHTO classification system	A-7-5	A-7-5
USCS	CH	CH
Specific gravity	2.75	2.7
Free swell index (%)	110	104
Maximum dry density, (g/cm3)	1.260	1.257
Optimum moisture content (%)	40.80	40.91
Soaked CBR value (%)	1.44	2.20
CBR-swell (%)	5.03	4.21
Color	Gray	Black

4.2.1 Grain size distribution

The distribution of different grain size affects the engineering properties of the given soil. Grain size analysis provides the grain size distribution. Distribution of particle sizes greater than 0.075mm is determined by sieving (wet sieve analysis), while a sedimentation process (hydrometer test analysis) is used to determine the distribution of particle sizes smaller than 0.075mm.

To determine the distribution of coarser particles, 1000g of the natural sub-grade soil is taken and washed on sieve size of 75μm and the hydrometer test analysis is conducted on 50g of soil sample passing sieve No.200.The soil sample was soaked in a chemical solution (Sodium hexametaphospahte) as dispersing agent for 24hours then a plot of percent finer against soil grain size (sieve size) in millimeter on a semi-logarithm scale was plotted.

The tabular experimental results are presented in Appendix-C, and the particle size distribution curves are shown in Figure 4.1 and 4.2. Abscissa of the graphs are from largest to smallest according to AASHTO T88-00.

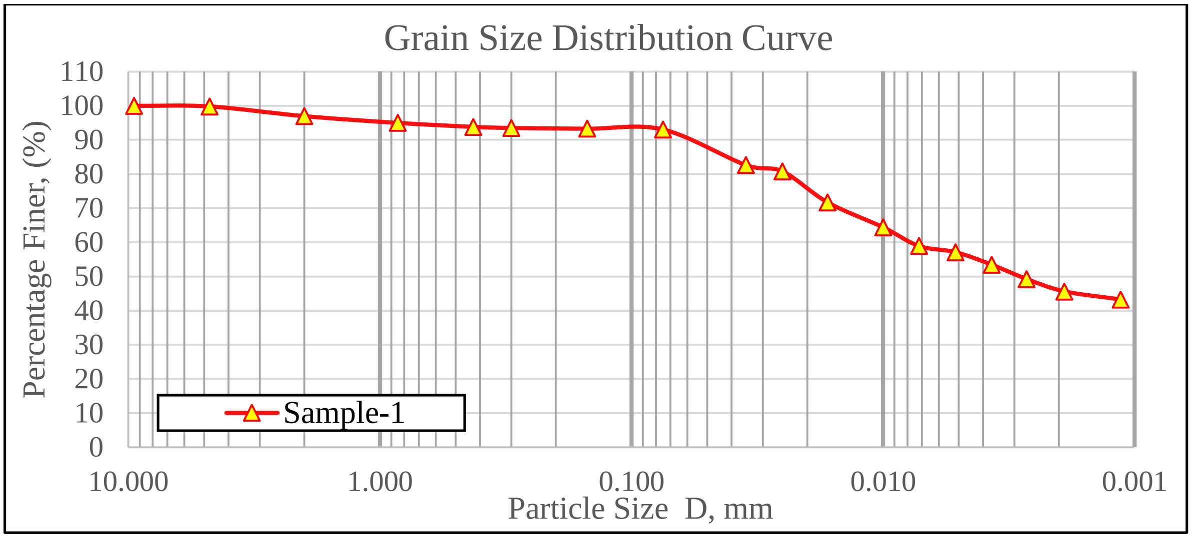


Figure 4.1: Grain size distribution Curve of sample -1

The soil sample from sample 1 was gray in color, and 93.08% of the soil is passing through No.200 sieve (75µm), this indicates that, almost the given soil sample was a clayey soil.

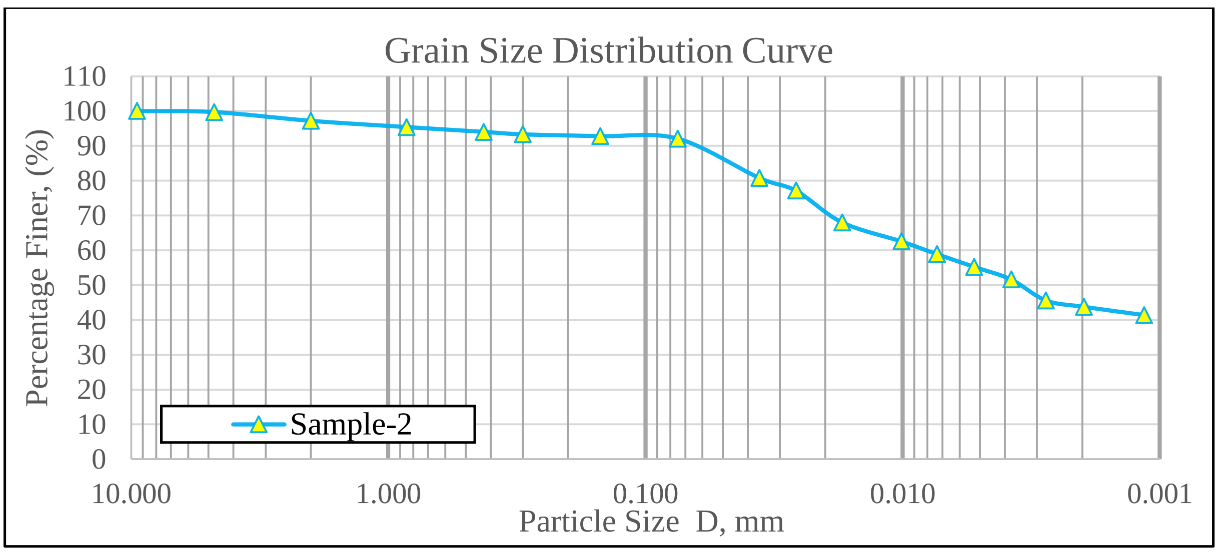


Figure 4.2: Grain size distribution Curve of sample-2

The soil sample from sample-2 was black in color, and 92.09 % of the soil is passing through No.200 sieve (75µm), this indicates that, almost the given soil sample was a clayey soil.

4.2.2 Atterberg limits

Atterberg limits (liquid limit and plastic limit) were determined according to AASHTO T89 and T90 standard test method. The result of the liquid limit, plastic limit and plasticity index were summarized in Table 4.2 and the detailed laboratory data analysis was attached in Appendix-D.

Table 4.2: Atterberg's limit test results

Sample name	Atterberg limits		
	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
Sample 1	108.4	41.3	67.1
Sample 2	98.1	36.9	61.2

Plasticity index represents the range in water content through which a soil is in plastic state. A high numerical value of plasticity index is an indication of the presence of high percentage of clay in the soil sample. As the result, both the natural sub-grade soil samples have poor for sub-grade material.

4.2.3 Soil Classification

4.2.3.1 AASHTO Classification System

The AASHTO System uses similar techniques as that of USCS but the dividing line has an equation of the form PI=LL−30. It generally classifies a soil broadly into granular material and silt-clay material.

From AASHTO Classification system results shown in Table 4.3 and Figure 4.3 it can be concluded that both sample1 and sample2 soil samples fall under A-7-5, which were clayey soils with group index of 76 and 67 respectively. Generally, the group index result indicate that the soils of the study area were very poor. The lower the GI value of a soil, the better as subgrade material. As GI value goes up to 20 and above it is not suitable as subgrade material. Thus, the natural subgrade material is unsuitable to be used as subgrade material unless otherwise employed some improvement methods.

Table4.3: Classification of soils based on AASHTO System

Sample name	Sieve analysis percentage of passing			LL (%)	PI (%)	LL-30	Group Index	Soil Group	material type
	No.10	No.40	No.200						
Sample-1	96.98	93.83	93.08	108.40	67.10	78.40	76	A-7-5	Clay
Sample-2	97.19	94.01	92.09	98.10	61.20	68.10	67	A-7-5	Clay

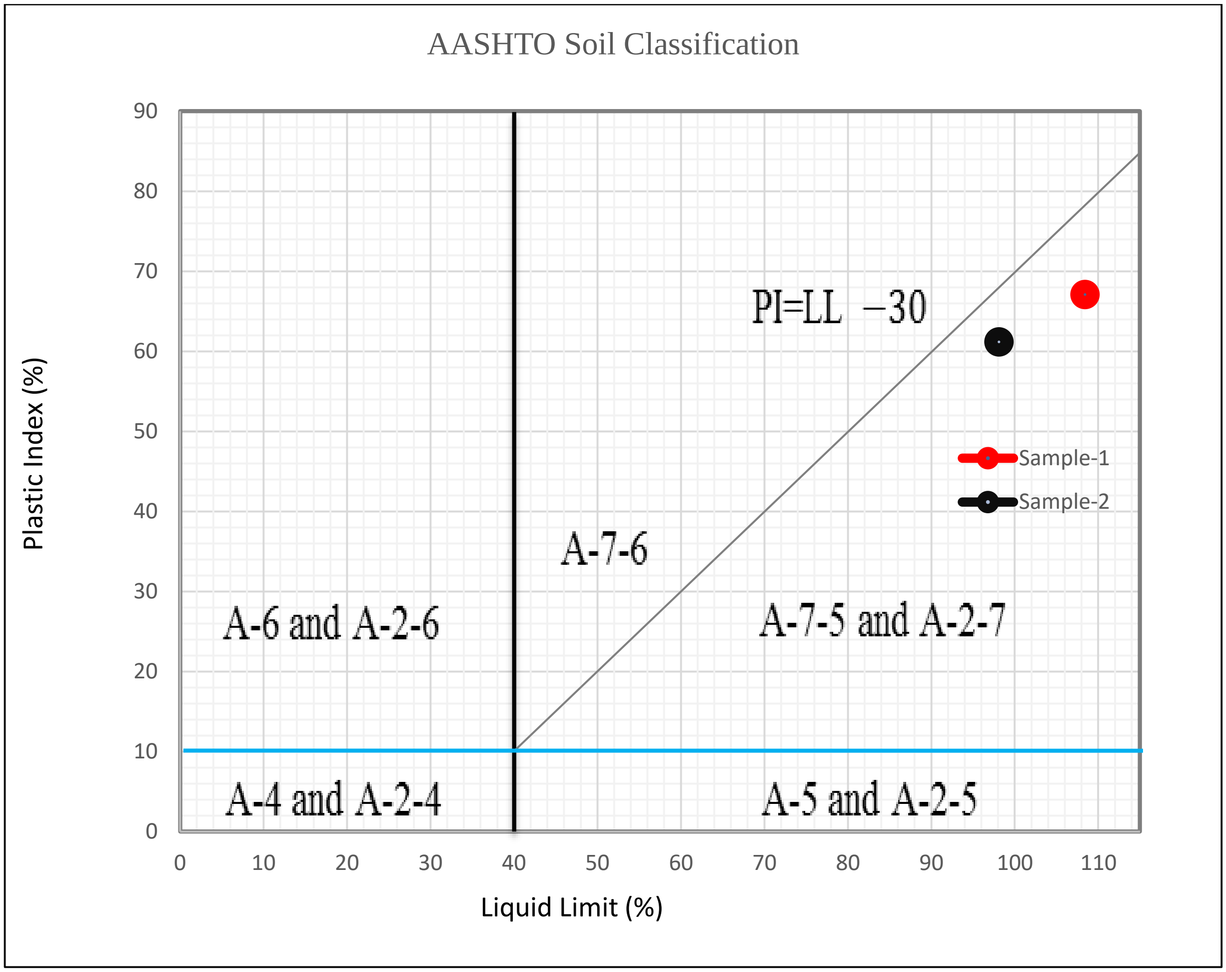


Figure 4.3: AASHTO Classification of natural soil

4.2.3.2 Unified Soil Classification System (USCS)

According to USCS, if the liquid limit are greater than or equal to 50% the soil can be clay, silt or organic depends on whether the soil coordinates plot above or below the A-line.

Since both soil samples have Liquid limit greater than 50% and lie above A-line in CH region, this shows a clayey soil with high plasticity. From USCS, results was shown in Table 4.4 and Figure 4.4 below.

Table 4.4: Classification of soils based on USCS

Sample name	Sample depth(m)	Quantity of grain size				LL (%)	PI (%)	USCS
		Gravel	Sand	Silt	Clay			
Sample-1	1.5	0.182	6.70	47.47	45.61	108.4	67.1	CH
Sample-2	1.5	0.303	7.605	48.3298	43.76	98.1	61.1	CH

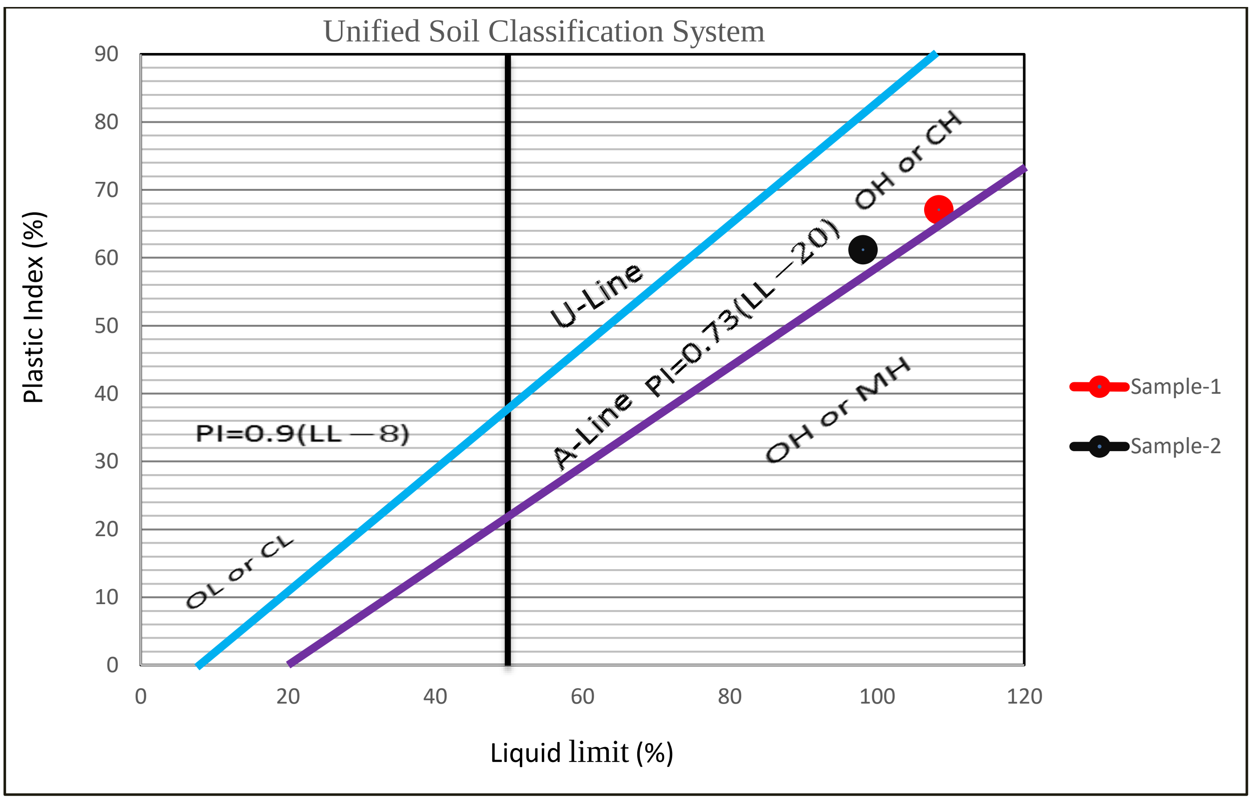


Figure 4.4: USCS Soil Classification of natural soil

4.2.4 Specific Gravity

Specific gravity, which is the measurement of the heaviness of the soil particles are determined for the natural soil by Pycnometer method using a soil sample passing No.10 sieves and oven dried at 105± 5°C for at least 16hours.The test was conducted with accordance of AASHTO T100−93 testing procedures. The laboratory test result of both soil samples were summarized in the Table 4.5 and the laboratory data analysis was attached in Appendix B.

Table 4.5: Specific Gravity

Sample location	Sample1			Sample 2		
Trial number	1	2	3	1	2	3
Pycnometer Code	P03	P07	P08	P07	P03	P08
Specific Gravity @20℃ ,Gs	2.74	2.78	2.73	2.68	2.72	2.70
Average Specific gravity @ 20℃, Gs	2.75			2.70		

As Table 4.5 shown sample 1 has an average specific gravity of 2.75 and 2.70 for sample 2. The specific gravity of solid particles of most soils varies from 2.5 to 2.9 .For most of the calculations specific gravity (Gs) can be assumed as 2.65 for cohesion less soils and 2.7 for clay. Therefore, as the Table 4.5 shown this results indicated that both samples are under clay soil.

4.2.5 Linear shrinkage Test

This test was conducted to determine the linear shrinkage of the drying soil. Linear shrinkage is the reduction in the length of the sample when completely dries. Results of the linear shrinkage test of the natural soil (untreated soil) sample was given in Table 4.6 and Appendix E.

Table 4.6: linear shrinkage

Sample location	Linear shrinkage (%)
Sample -1	20.36
Sample -2	18.61

As Table 4.6 shown the linear shrinkage of both soil samples are above 8% which means the degree of expansion is critical (Altmeyer, 1955). As the result, it is unsuitable for subgrade material unless improvement is done.

4.2.6 Free swell index test

The free swell index test is one of the most commonly used simple test for estimating soil swelling potential. Results of the free swell index tests of the soil was given in Table 4.7.

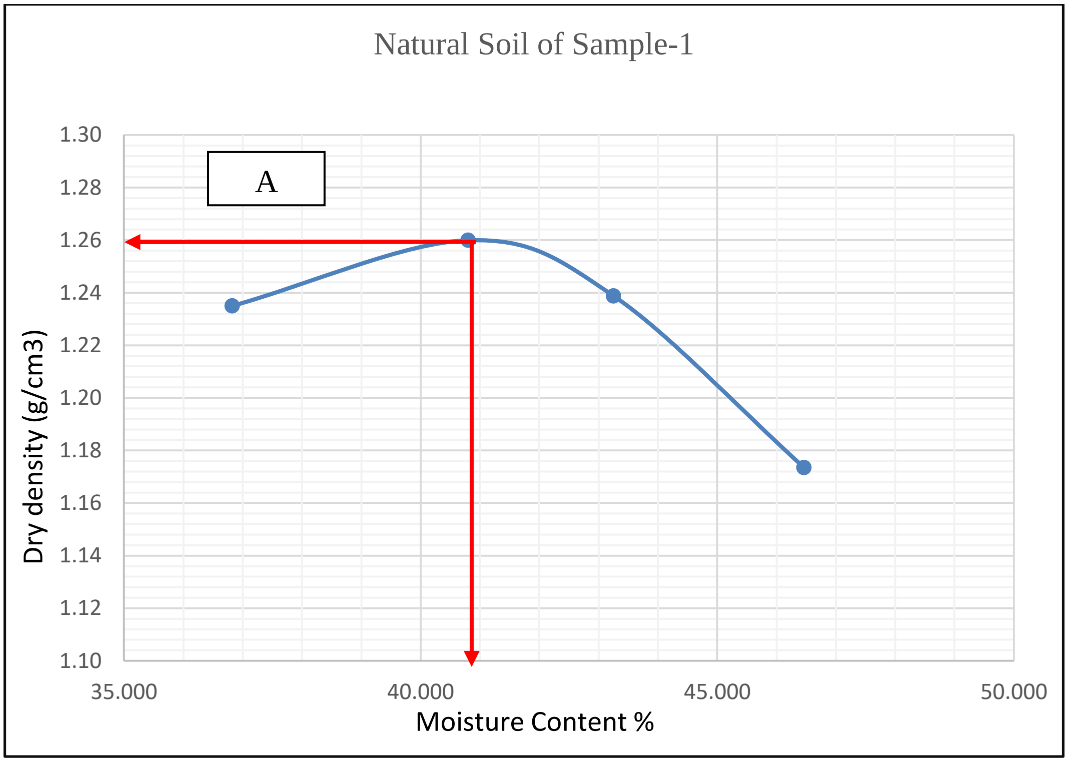
Table 4.7: Free swell test

Sample name	Free swell Index (%)
Sample-1	110
Sample-2	104

The free swell index value of both soil samples are above 50% which means the degree of expansive is high, and such soils undergo volumetric changes leading to pavement distortion and severe cracking due to seasonal wetting and drying.

4.2.7 Compaction test

To determine the maximum dry density and optimum moisture content of the untreated soil samples, standard proctor compaction test has been conducted according to AASHTO T-180.The sample 1 soil has a maximum dry density and optimum moisture content of 1.260g/cm^3 and 40.80%, respectively. Similarly, the sample 2 soil sample has a maximum dry density and optimum moisture content of 1.257g/cm^3 and 40.91 %, respectively. As shown in Figure 4.5 and a detailed laboratory data was attached as an Appendix F.



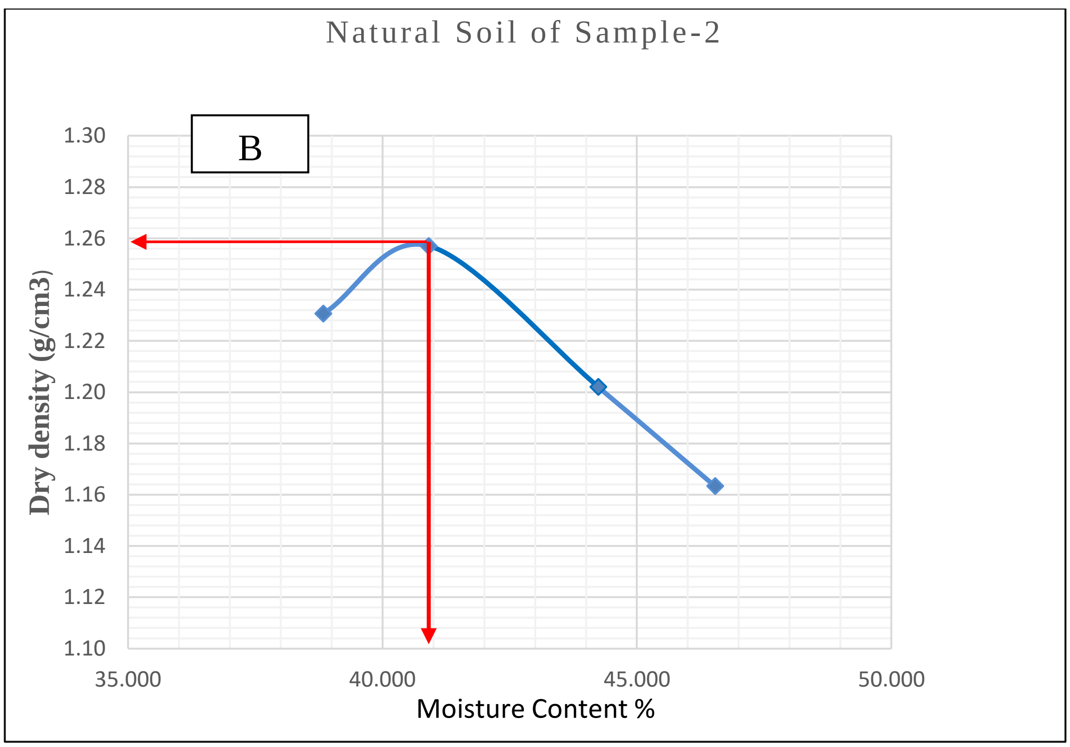


Figure 4.5: Density-moisture content Relationship for untreated soil samples (A) Sample 1 and (B) Sample 2

4.2.8 Soaked California Bearing Ratio (CBR) and CBR swell tests

The CBR value of both untreated soil samples 1 and 2 were summarized in Table 4.8 and shown in Figure 4.6 and 4.7, respectively. Also a detailed laboratory data analysis was attached in Appendix G.

Table 4.8: Summary of CBR Test sample 1 and 2

Description	Sample 1			Sample 2		
MMDD	1.260			1.257		
No. of blows	65	30	10	65	30	10
CBR values (%)	1.44	1.08	0.79	2.20	1.89	1.67
DDBS (g/cc)	1.23	1.18	1.12	1.23	1.18	1.12
Dry density @95% of MDD	1.211			1.188		
CBR @95% of MDD	1.21			1.96		
CBR swell (%)	5.03			4.21		

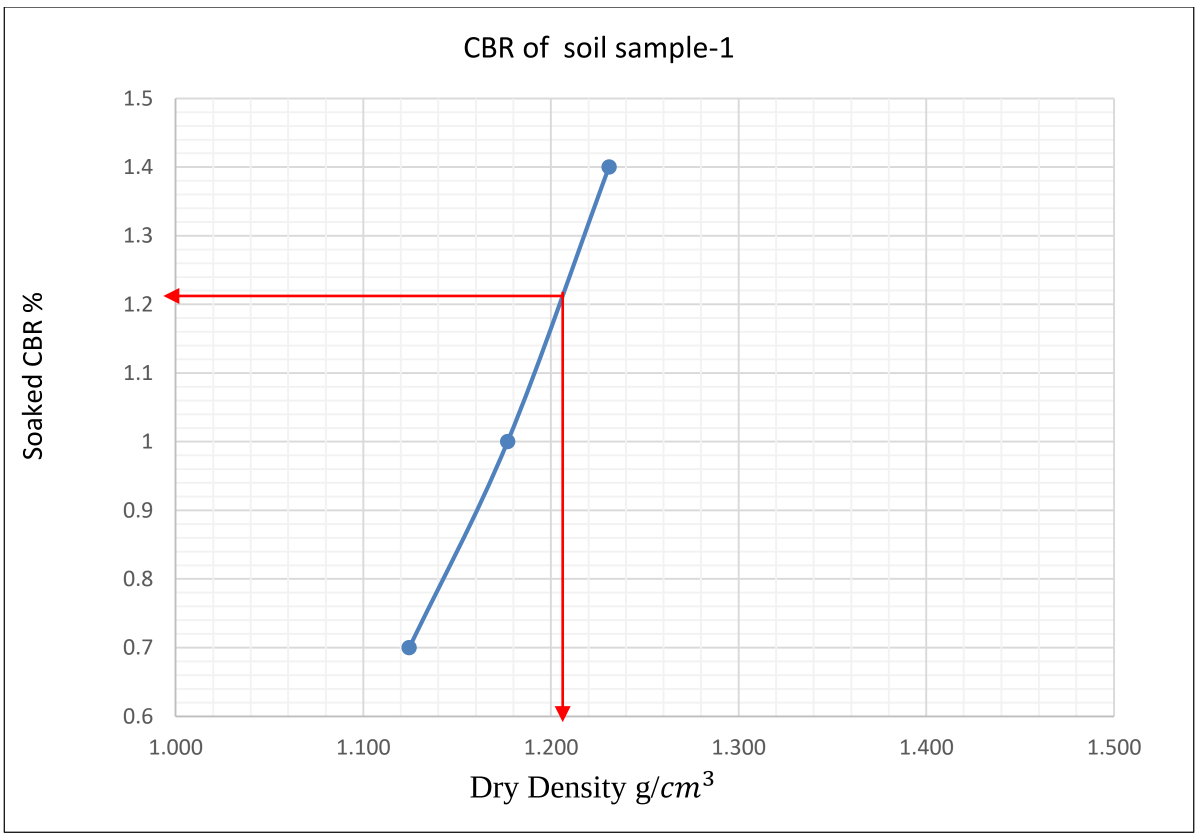


Figure 4.6: CBR test result of the soil sample1

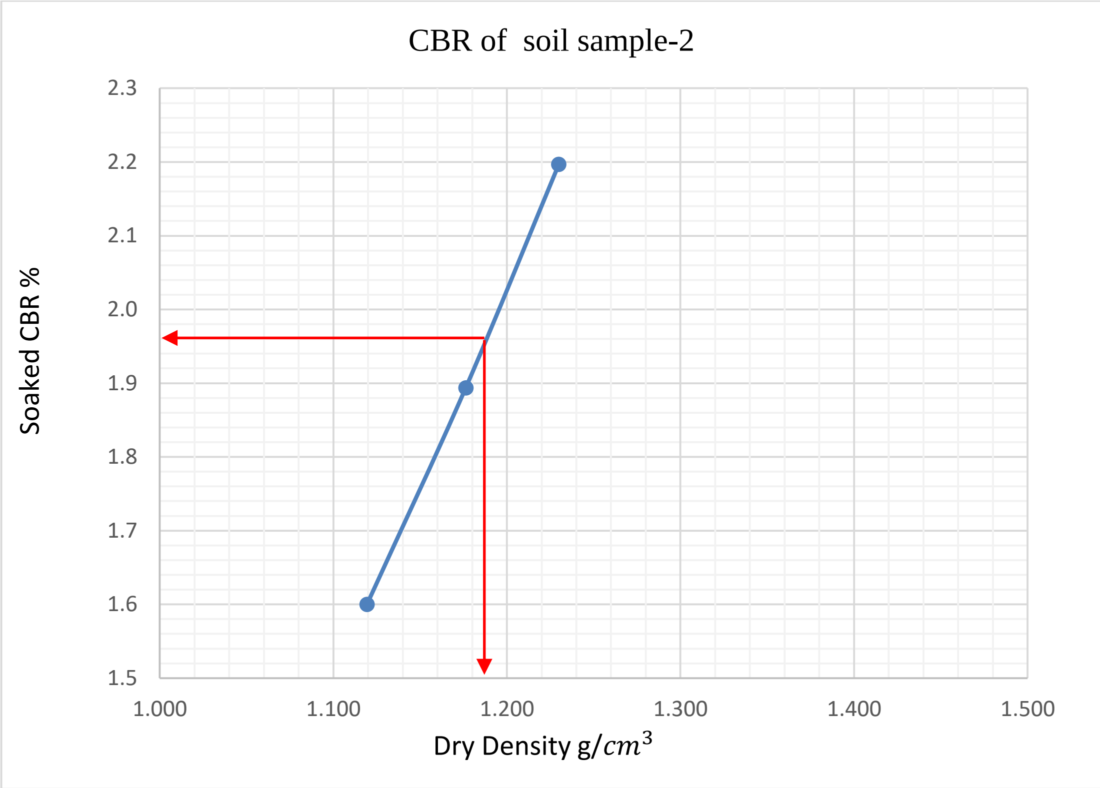


Figure 4.7: CBR test result of soil sample 2

As shown in the Figure 4.6 and 4.7, sample 1 had 1.21% CBR value at maximum dry density of 1.211g/cm^3 with 5.03% CBR swell and sample 2 had 1.96% CBR value at maximum dry density of 1.188g/cm^3 with 4.21% CBR swell.

The test showed that both soil samples has low CBR value, which doesn't satisfy the minimum requirements and also, CBR swell values are above the specified maximum value as sub-grade material. According to ERA standard specification a CBR value of less than 3% and CBR swell more than 2% special treatment is required.

4.3 Laboratory test results of stabilized clay soil

4.3.1 The effect of addition of Lime on Atterberg's Limits

The effect of lime addition in varying proportions with natural soil was studied. The result of the liquid limit, plastic limit and plasticity index were summarized in Table 4.9 and the detailed laboratory data analysis was attached in Appendix-D.

Table 4.9: Effect of Lime content on atterberg's limit

Atterberg Limits	Soil Sample-1			Soil sample-2		
Additives (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
Natural soil	108.4	41.3	67.1	98.1	36.9	61.2
Natural soil + 4% Lime	83.90	58.03	25.87	83.00	61.86	21.14
Natural soil + 6% Lime	75.60	60.63	14.97	73.60	61.68	11.92
Natural soil + 8% Lime	72.10	61.09	11.01	69.80	62.04	7.76

As shown in Table 4.9, it was found that as the percentage of lime content increases the liquid limit of both soil samples decreases on the other hand, the plastic limit increases compared to natural soil sample. The decrease of plasticity index indicates an improvement in the workability of the soil. This improvement was as the result of the ionic exchange of the lime and clay minerals of the soil. These led the flocculation and agglomeration of the clay particles which in turn reduces the plasticity of the treated soil.

4.3.2 The effect of addition of lime on linear shrinkage

According to (Altmeyer ,1955).Soils having linear shrinkage value above 8%, between 5% and 8%, and less than 5% possess critical, marginal, and non-critical degree of expansion, respectively. The laboratory result of linear shrinkage was presented in Table 4.10.

Table4.10: Effect of Lime on linear shrinkage

Linear shrinkage	Soil Sample-1		Soil Sample-2	
Additives (%)	Linear shrinkage (%)	Degree of expansion	Linear shrinkage (%)	Degree of expansion
Natural soil	20.36	Critical	18.61	Critical
Natural soil + 4% Lime	11.7	Critical	10.57	Critical
Natural soil + 6% Lime	7.07	Marginal	5.43	Marginal
Natural soil + 8% Lime	4.5	Non-critical	3.57	Non-critical

As shown in Table 4.10, the average linear shrinkage for both sample-1 and 2 natural soils were under critical degree of expansion with 20.36% and 18.61% respectively. The linear shrinkage was decreased as the percentage of lime increased. Both soil samples at 6% and 8% of lime content has significantly improved the natural soil sample into marginal and non-critical stage degree of expansion.

The cation exchange reaction results in flocculation of the clay particle thereby making the soil lose its plasticity and makes it behave more like silt. These reactions are responsible for the reduction in swelling and shrinkage characteristic of the soil as such improves its workability.

4.3.3 The effect of addition of Lime on Free Swell Index

According to Indian Standard (IS 1498). Soils having a free swell value above 100 can cause damage whereas free swell as low as 100 percent can cause considerable damage to light loaded structures and soils having a free swell value below 50 percent seldom exhibits appreciable volume change even under light loads. The effect of lime on the free swell index of the treated soil sample was tabulated in the Table 4.11.

Table 4.11: The effect of addition of lime on Free Swell Index

Free Swell Index	Sample-1		Sample-2	
Additives (%)	FSI (%)	IS 1498	(FSI %)	IS 1498
Natural soil	110	High	104	High
Kerosene	0	control	0	Control
Natural soil + 4% Lime	53	medium	49.2	Medium
Natural soil + 6% Lime	42.8	low	38.24	Low
Natural soil + 8% Lime	30.5	low	26.75	Low

For soil sample-1, the highest reduction was attained when the sample was treated with 6% and 8% Lime that means 42.8%, 30.5% reduction was observed from its natural state which was 110%.Similary, for sample-2 the maximum reduction of 38.24% and 26.75% was obtained at 6% and 8 % lime, respectively. This indicates that when increased the percentage content of lime the linear shrinkage decreases. Therefore, to safe cost 6% of lime is enough to stabilize the clay soil.

4.3.4 The effect of addition of lime and lime with Prosopis Juliflora fibers on Moisture-Density relationship

The values of the modified proctor compaction test for soil samples were presented and plotted in Figure 4.8, Figure 4.9 and a summary of the result were presented in Table 4.12. In addition to that further laboratory test analysis data was attached in Appendix- F

Table 4.12: Effect of Lime and Prosopis Juliflora fibers content on Moisture Density relation

Additive content (%)	Sample-1		Sample-2	
	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)
Natural soil	40.8	1.260	40.91	1.257
Natural soil + 4% Lime	41.41	1.244	41.32	1.238
Natural soil + 6% Lime	42.94	1.198	43.14	1.196
Natural soil + 8% Lime	44.95	1.185	44.37	1.162
5%Lime + 0.5% Fibers	41.32	1.241	41.68	1.208
5%Lime +1% Fibers	42.69	1.202	42.01	1.195
5%Lime +1.5% Fibers	43.61	1.199	44.32	1.193
5%Lime + 2% Fibers	44.8	1.189	44.14	1.175

As shown in Table 4.12, the addition of lime the OMC shows an increment and the MDD shows a slightly reduction in the treatment of both soil samples. In soil sample-1 the OMC increases from 40.80% to 44.95% while MDD decreases from 1.260g/cm^3 to 1.185g/cm^3 . Similarly, for addition of lime with Prosopis Juliflora fibers the OMC increases from 40.80% to 44.80% and the MDD decreases from 1.260g/cm^3 to 1.189g/cm^3.

For the sample-2, as shown in Table 4.12, the OMC increases from 40.91% to 44.37% while MDD decreases from 1.257g/cm^3 to 1.162g/cm^3 with an increase of lime Similarly, for addition of lime with Prosopis Juliflora fibers the OMC increases from 40.91% to 44.14% and the MDD decreases from 1.257g/cm^3 to 1.175g/cm^3.

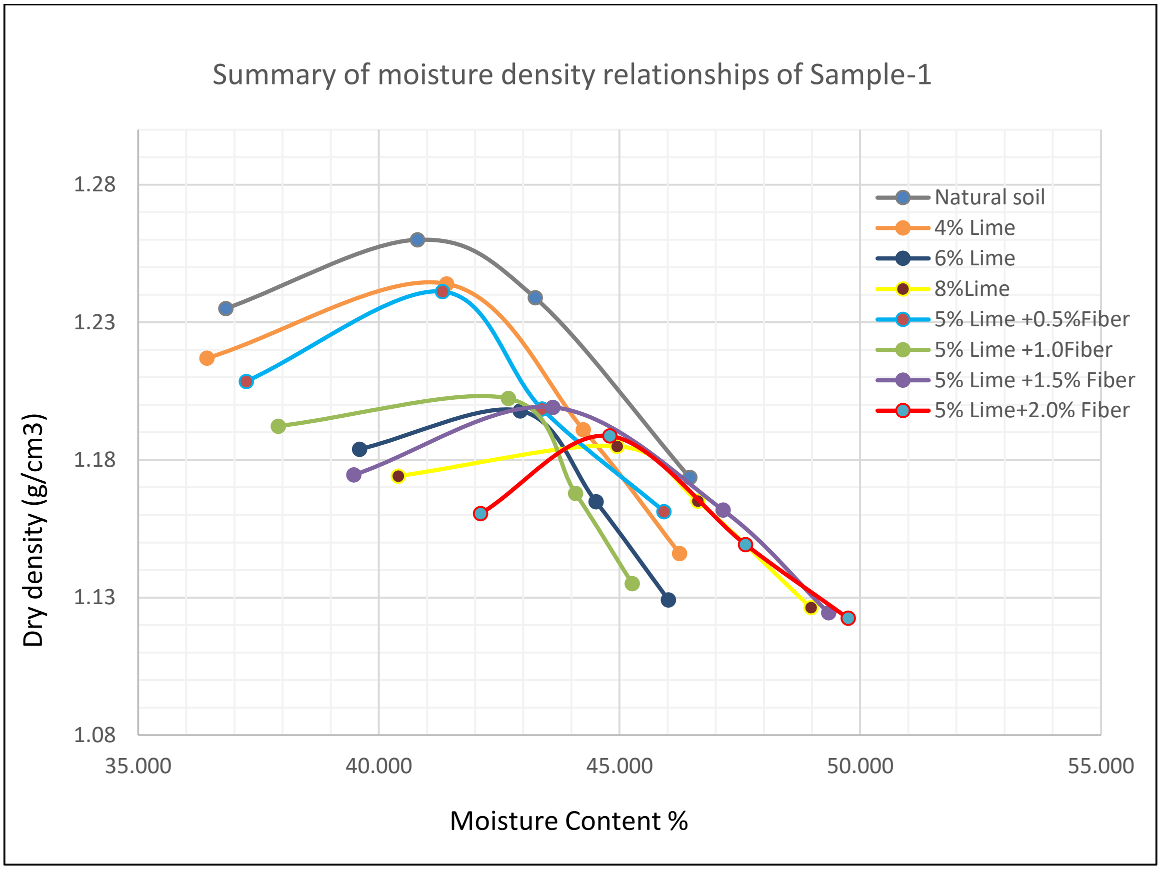


Figure 4.8: Summary of OMC and MDD of treated soil sample-1

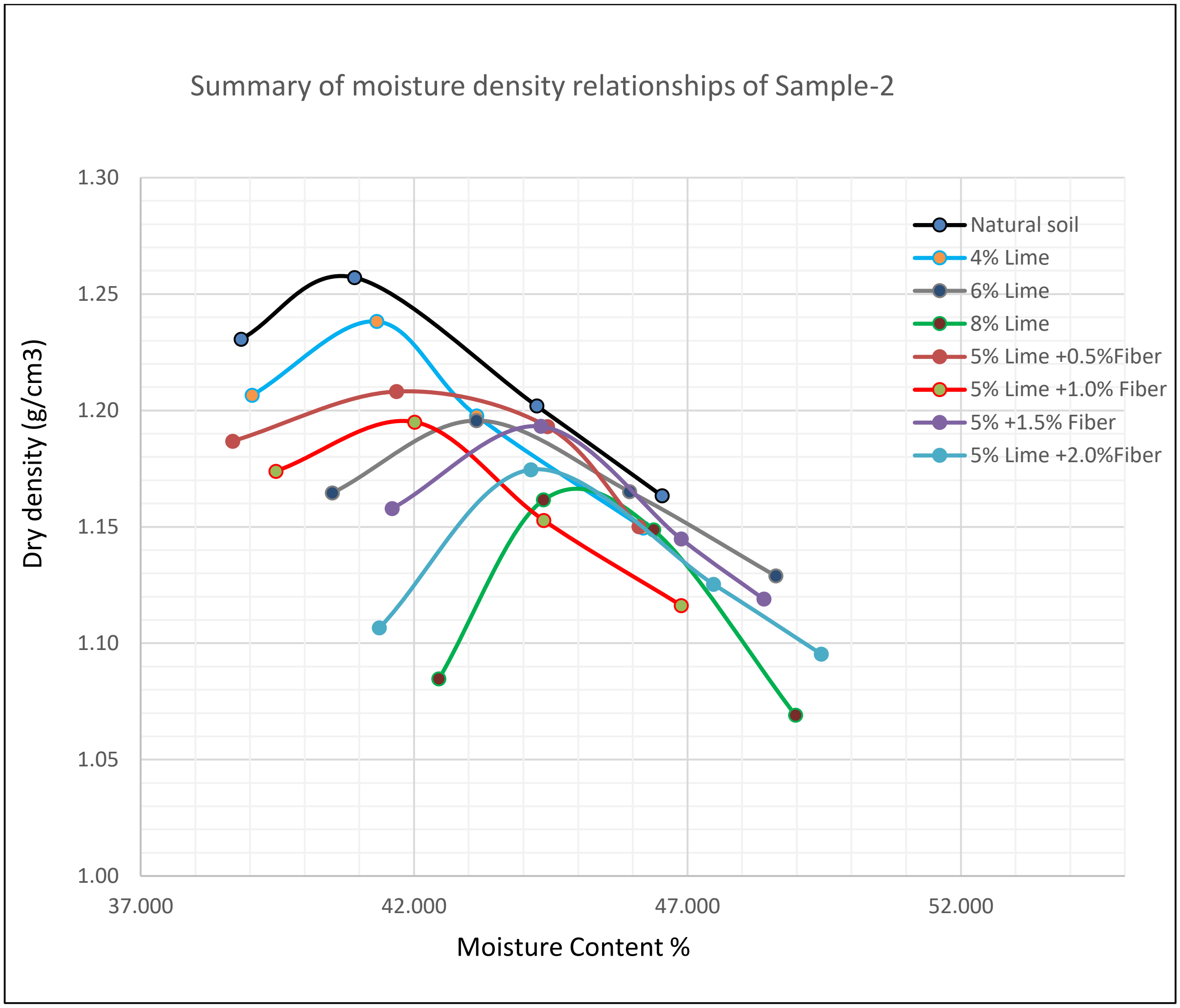


Figure 4.9: Summary of OMC and MDD of treated soil sample -2

The addition of Prosopis juliflora fibers and lime changes the optimum moisture content and maximum dry density of clayey soils because the effects of cation exchange and short-term pozzolonic reactions between lime and the soil results in flocculation and agglomeration of clay particles leading to texture changes. Furthermore, the decrease in density of all treated soils is mainly due to the partial replacement of comparatively heavy soil particles with the light weight of Prosopis juliflora fibers.The advantage of the increase in optimum moisture content and corresponding decrease maximum dry density is that it allowed compaction to be easily achieved with the wet soil. Any adverse effect on strength due to reduction in density is unlikely to occur due to the expected substantial gain in strength of treated soils due to the pozzolanic properties of Prosopis juliflora fiber and Lime.

4.3.5 The effect of addition of lime and lime with Prosopis Juliflora fibers on soaked CBR

CBR is the parameter which is used to measure the strength of sub-grade soil. Therefore, a California Bearing Ratio test has been conducted to determine the CBR values of stabilized soil. The CBR value was determined after soil samples were soaked in water for 96hours. That means if soil is stabilized using sufficient amount of stabilizer and hardening occurs. The soaking acts as an efficient means of curing providing hydration and prevents carbonation resulting in higher strength than can be achieved in the field.

The soaked CBR test result of both soil samples alongside ERA requirement was presented in Table 4.13 and 4.14 and Figure 4.10.Also a detailed test results are given Appendix- G. As shown in Table 4.13 and 4.14, the CBR values of natural sub-grade soils of the two samples did not fulfill the requirement of sub-grade soils as per ERA standard (CBR> 3%).However, the addition of lime alone increased the soaked CBR of all samples. The CBR of sample-1 increased from 1.21% to 8.93% and 10.53% at 6% and 8% of lime stabilization, respectively. Similarly, the CBR of sample-2 increased from 1.96% to 9.93% and 11.87% at 6% and 8% of lime stabilization, respectively. Therefore, all the samples fulfill the requirement of sub-grade soils as per ERA standard (CBR> 3%) adequate as sub-grade materials in highway construction.

The addition of lime with Prosopis juliflora fibers increased the soaked CBR of the samples up to addition of 5%lime with 1.5% Fibers and then decreased. The CBR value of sample-1 soil increased from 1.21% to a maximum of 8.28% at 5% lime and 1.5% prosopis juliflora fibers stabilization and then decreased to 7.69% at 5% lime with 2% fibers while that of sample-2 increased from 1.96% to maximum of 9.26% at 5% lime and 1.5% prosopis juliflora fibers stabilization and then decreased to 8.16% CBR for the addition of 5% lime with 2% Prosopis juliflora fibers. The stabilized subgrade strength was improved from class (S1) to class (S4) with addition of 6% lime alone and the addition of 5%lime with 1.5% Prosopis juliflora fibers for both soil samples as shows in Table 4.13 and 4.14.

Table 4.13: Summary of CBR and CBR swell test result of sample- 1

Soil Sample-1										
Additive content (%)	CBR (%)						CBR@ 95%MDD	CBR swell%	ERA requirement	Subgrade Class
	65-Blows		30-Blows		10-Blows					
	2.54	5.08	2.54	5.08	2.54	5.08				
Natural soil	1.44	1.15	1.08	0.95	0.79	0.76	1.21	5.03	CBR>3%	S1
Natural soil + 4% Lime	7.5	7.00	6.29	6.20	5.00	4.95	7.20	1.79		S3
Natural soil + 6% Lime	9.39	9.40	8.79	8.45	7.50	7.10	8.97	1.54		S4
Natural soil + 8% Lime	12.12	11.00	10.91	9.70	9.24	8.10	10.53	1.45		S4
5% Lime+ 0.5% Fibers	5.98	5.85	5.08	5.00	4.24	4.20	5.40	1.87		S3
5%Lime +1.0%Fibers	7.20	6.85	6.14	6.00	4.85	4.75	6.33	1.76		S3
5% Lime +1.5%Fibers	9.24	9.05	8.48	8.25	7.20	6.90	8.28	1.50		S4
5% Lime +2.0%Fibers	8.94	8.90	7.73	7.60	6.06	6.00	7.69	1.80		S3

Table 4.14: Summary of CBR and CBR swell test result of sample- 2

Soil sample -2										
Additive contents (%)	CBR Value (%)						CBR @95% MDD	CBR swell%	ERA requirement	Subgrade Class
	65-Blows		30-Blows		10-Blows					
	2.54	5.08	2.54	5.08	2.54	5.08				
Natural soil	2.20	2.00	1.89	1.80	1.67	1.65	1.96	4.21	CBR>3%	S1
Natural soil + 4% Lime	8.3	8.00	7.05	7.00	6.44	6.40	7.37	1.48		S3
Natural soil + 6% Lime	11.36	10.50	9.70	9.35	7.80	7.50	9.93	1.33		S4
Natural soil + 8% Lime	13.11	11.20	11.82	10.10	10.45	9.10	11.87	1.19		S4
5% Lime+ 0.5% Fibers	6.67	6.60	5.68	5.60	4.39	4.25	5.76	1.57		S3
5%Lime +1.0%Fibers	8.18	8.10	7.20	7.25	6.44	6.40	7.27	1.42		S3
5% Lime +1.5%Fibers	10.76	10.10	9.09	8.95	7.20	7.10	9.26	1.35		S4
5% Lime +2.0%Fibers	9.32	8.30	8.03	7.60	6.67	6.60	8.16	1.39		S4

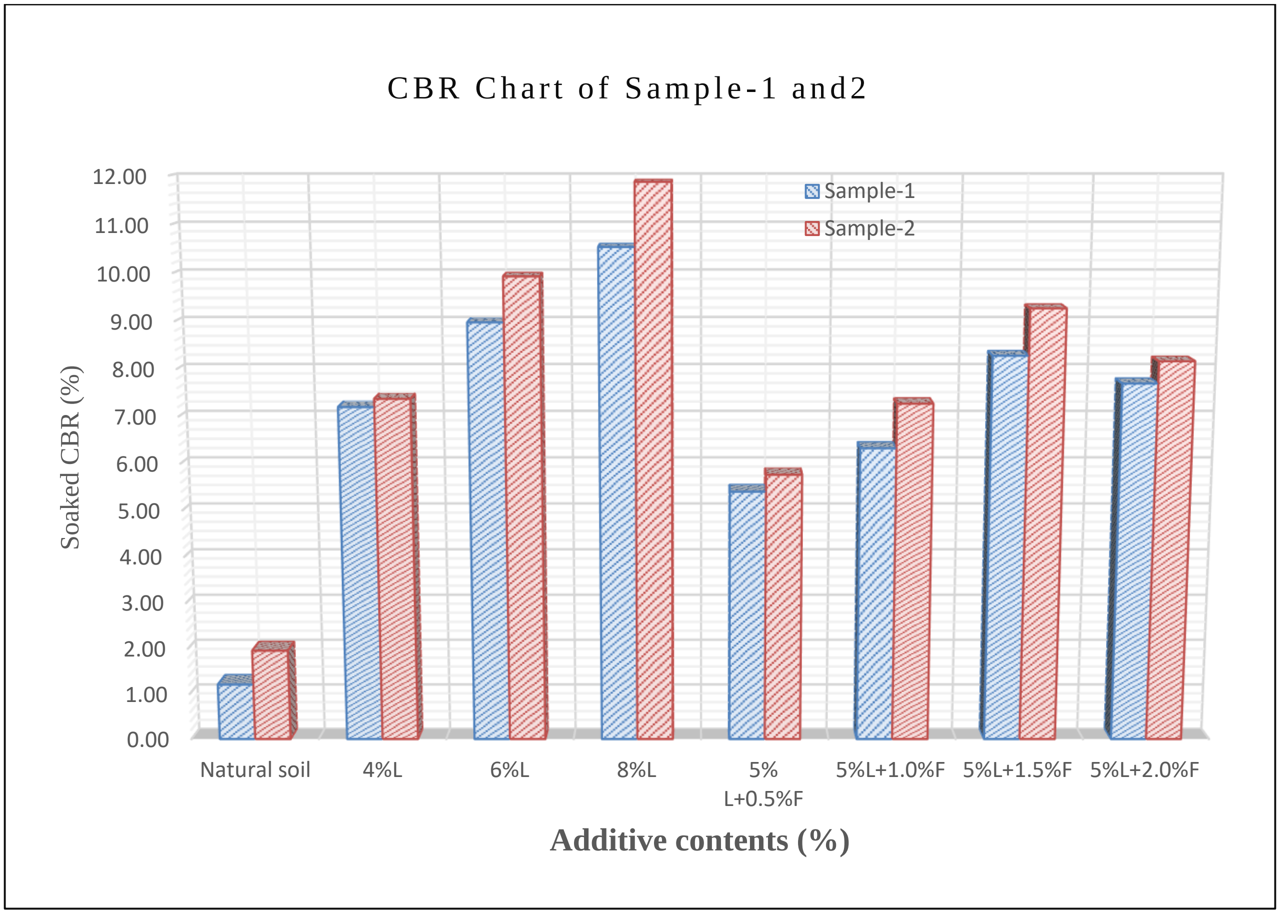


Figure 4.10: Summary of CBR test results of soil Sample-1 and 2

As shown in Figure 4.10, both soil samples of treated 6%, 8% lime alone and mixed of 5% lime and 1.5%Fibers showed more improvement. Furthermore, as shown from the graph the improvement of 6% of lime alone and mixed of 5% lime and1.5% fiber are more likely same improvement. Therefore, the result indicates that 1% lime can be partially replaced by 1.5% fibers to save cost of the lime .Because, this fulfilled the engineering properties of the sub-grade soil when compared with standard specifications.

The increase was as a result of the formation of cementitious compounds calcium-silicate-hydrates (CSH) and calcium-aluminate –hydrates (CAH), by calcium from lime and better interlocking of soil grains by Prosopis juliflora fibers contributed to the significant improvement in the properties of clayey soil.

4.3.6 The effect of addition of lime and lime with Prosopis Juliflora fibers on CBR swell.

The CBR swell was also conducted to determine the swelling properties of the soil. For the swell measurement was taken at the time of soaking and after for four days of soaking to evaluate the percent of swell. The test result at a different mix-ratio for both sample-1 and sample-2 was presented in Table 4.14 and Figure 4.11.

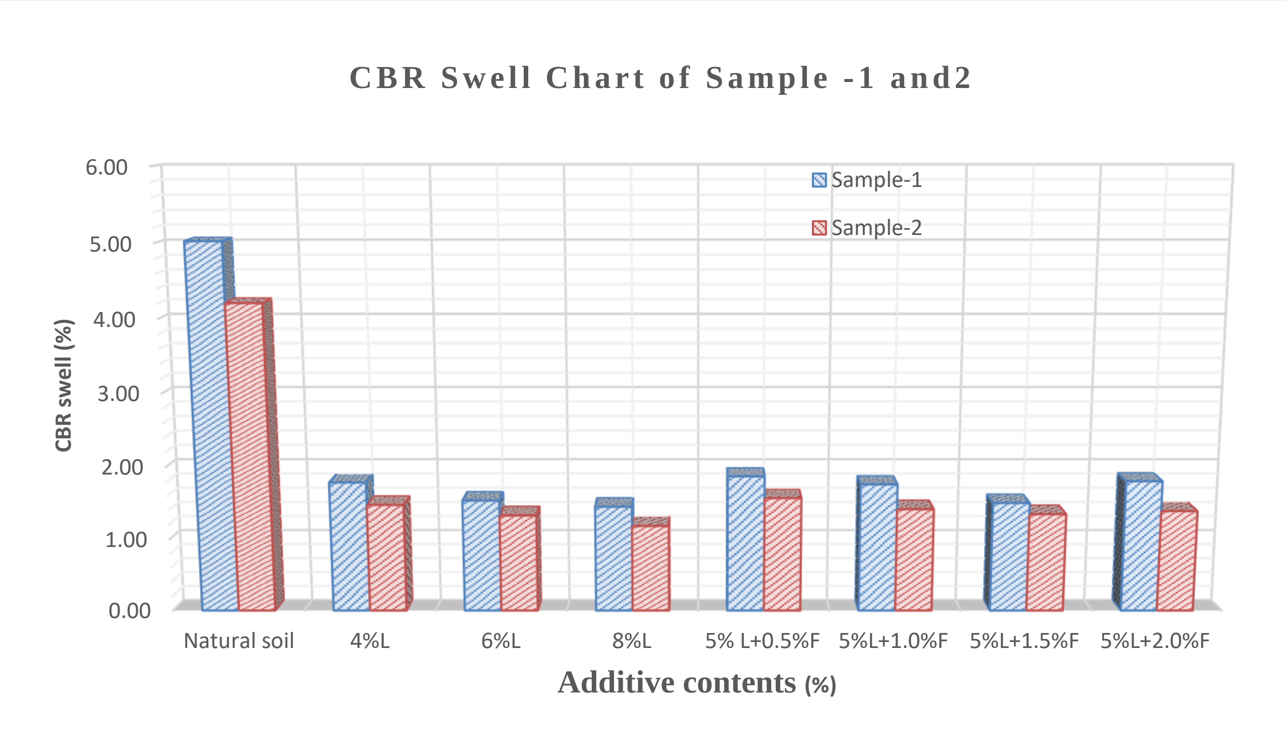


Figure 4.11: Summary of CBR Swell results of soil sample 1 and 2

Results presented Figure 4.11, shows that both the untreated soil samples have the properties of swelling and potentially expansive soil since it is above the recommended value of CBR Swell. ERA recommended that value of CBR Swell <2% .However, it was observed that the swelling capacity, of the expansive soil decreased considerably with addition of lime alone and lime with Prosopis juliflora fibers. The decrease in CBR swell of clayey soil is due to cation exchange and flocculation and agglomeration of the soil particles. This is also due to replacement of some of the volume that was occupied by expansive clay minerals (Montomorillite and illite clay minerals) by Prosopis Juliflora fibers.

4.3.7 Summary of results and analysis

The natural soil sample used in this study were identified and taken from two pits Kitto furdisa (sample1) and Merkato (sample2) the color of the soil samples are gray and black, respectively. From sieve analysis, percentage passing through sieve No.200 (0.075 mm sieve size) of sample1 and sample2 are 93.08% and 92.09% respectively. While from the atterberg's limit test results, the soil sample contains a liquid limit of 108.4% and 98.1%, a plastic limit of 41.3% and 36.9% and plasticity index of 67.1 % and 61.2%, respectively.

According to (Whitlow, R., 1995), Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity. Hence, these values indicate that both soil samples are highly plastic clay.

According to AASHTO soil classification system the soils are under the A-7-5 soil and CH (fat clay) according to ASTM soil class. This class are generally classified as a material of poor engineering property to be used as sub-grade material.

The results from free swell test indicated that the soil is highly expansive clay with a free swell of about 110% and 104% for sample 1 and sample 2, respectively. The soil samples have a maximum dry density of 1.260g/cm^3 and 1.257g/cm^3, the optimum moisture content of 40.80% and 40.91%, natural moisture content of 45.48% and 40.69% and soaked CBR value of 1.44% and 2.20% for sample-1 and sample-2, respectively. This was indicated that the soil has a low load bearing capacity when compared to ERA's specifications of CBR$\geq$ 3%.

The effect of lime addition in varying proportions with natural soil was studied. As shown in Table 4.9, it was found that as the percentage of lime content increases the liquid limit of both soil samples decreases on the other hand, the plastic limit increases compared to natural soil sample. The decrease of plasticity index indicates an improvement in the workability of the soil. This improvement was as the result of the ionic exchange of the lime and clay minerals of the soil. These led the flocculation and agglomeration of the clay particles which in turn reduces the plasticity of the treated soil.

As shown in Table 4.10, the average linear shrinkage for both sample-1 and 2 natural soils were under critical degree of expansion with 20.36% and 18.61%, respectively. The linear shrinkage was decreased as the percentage of lime increased. Both soil samples at 6% and

8% of lime content has significantly improved the natural soil sample into marginal and non-critical stage degree of expansion, respectively. According to (Altmeyer, 1955).Soils having linear shrinkage value above 8% possess critical degree of expansion.

The cation exchange reaction results in flocculation of the clay particle thereby making the soil lose its plasticity and makes it behave more like silt. These reactions are responsible for the reduction in swelling and shrinkage characteristic of the soil as such improves its workability.

As shown in Table 4.12, the addition of lime the OMC shows an increment and the MDD shows a slightly reduction in the treatment of both soil samples. In soil sample-1 the OMC increases from 40.80% to 44.95% while MDD decreases from 1.260g/cm^3 to 1.185g/cm^3.Similarly, for addition of lime with Prosopis Juliflora fibers the OMC increases from 40.80% to 44.80% and the MDD decreases from 1.260g/cm^3 to 1.189g/cm^3.

For the sample-2, as shown in Table 4.12, the OMC increases from 40.91% to 44.37% while MDD decreases from 1.257g/cm^3 to 1.162g/cm^3 with an increase of lime Similarly, for addition of lime with Prosopis Juliflora fibers the OMC increases from 40.91% to 44.14% and the MDD decreases from 1.257g/cm^3 to 1.175g/cm^3.

The addition of Prosopis juliflora fibers and lime changes the optimum moisture content and maximum dry density of clayey soils because the effects of cation exchange and short- term pozzolonic reactions between lime and the soil results in flocculation and agglomeration of clay particles leading to texture changes. Furthermore, the decrease in density of all treated soils is mainly due to the partial replacement of comparatively heavy soil particles with the light weight of Prosopis juliflora fibers.

As shown in Table 4.13 and 4.14, the CBR values of natural sub-grade soils of the two samples did not fulfill the requirement of sub-grade soils as per ERA standard (CBR> 3%).However, the addition of lime alone increased the soaked CBR of all samples. The CBR of Sample-1 increased from 1.21% to 8.93% and 10.53% at 6% and 8% of lime alone stabilization, respectively. Similarly, the CBR of sample-2 increased from 1.96% to 9.93% and 11.87% at 6% and 8% of lime stabilization respectively. Therefore, all the samples fulfill the requirement of sub-grade soils as per ERA standard (CBR> 3%) adequate as sub-grade materials in highway construction.

The addition of lime with Prosopis juliflora fibers increased the soaked CBR of the samples up to addition of 5%lime with 1.5%Fibers and then decreased. The CBR value of sample-1 soil increased from 1.21% to a maximum of 8.28% at 5% lime and 1.5% prosopis juliflora fibers stabilization and then decreased to 7.69% at 5% lime with 2% fibers while that of sample-2 increased from 1.96% to maximum of 9.26% at 5% lime and 1.5% prosopis juliflora fibers stabilization and then decreased to 8.16% CBR for the addition of 5% lime with 2% Prosopis juliflora fibers. The stabilized subgrade strength was improved from class (S1) to class (S4) with addition of 6% lime alone and the addition of 5%lime with 1.5% Prosopis juliflora fibers for both samples as shows Table 4.13 and 4.14.

As shown in Figure 4.10, both soil samples of treated 6% lime alone and mixed of 5% lime with 1.5%Fibers showed more improvement. Furthermore, the improvement of 6% of lime alone and mixed of 5% lime and1.5% fibers are more likely same improvement. Therefore, the result indicates that 1% lime can be partially replaced by 1.5% fibers to save cost of the lime. Because, this fulfilled the engineering properties of the subgrade soil when compared with standard specifications.

Results presented Figure 4.11, shows that both the untreated soil samples have the properties of swelling and potentially expansive soil since it is above the recommended value of CBR Swell. ERA recommended that value of CBR Swell <2% .However, it was observed that the swelling capacity of the expansive soil decreased considerably with addition of lime alone and Prosopis juliflora fibers and lime together. The decrease in CBR swell of expansive soil is due to cation exchange and flocculation and agglomeration of the soil particles. This is also due to replacement of some of the volume that was occupied by expansive clay minerals (Montomorillite and illite clay minerals) by Prosopis Juliflora fibers**.**

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1Conclusions

Based on the results of the laboratory investigation, the following conclusions have been drawn.

- Based on observation and free swell test, clayey soil samples were selected from the study area of Jimma town .Two soil samples Kitto furdisa (sample-1) and Merkato (sample-2) with high free swell value were selected, and all the tests were performed.
- Sample1 and 2 have a maximum dry density of 1.260g/cm^3 and 1.257g/cm^3, the optimum moisture content of 40.8% and 40.91%, natural moisture content of 45.48% and 40.69% and soaked CBR value of 1.44% and 2.20%, respectively.
- According to AASHTO soil classification system, the soils are under the A-7-5 soil and CH (fat clay) according to ASTM soil class. This class are generally classified as a material of poor engineering property to be used as sub-grade.
- Laboratory test results indicated that the natural sub-grade soil of the selected area has a low load bearing capacity and unsuitable for use as sub-grade material unless otherwise modification and stabilization is applied to improve its workability and engineering property.
- Hence, to improve the engineering properties of the soil a stabilization techniques was used by adding different percentages of 4%, 6% and 8% lime alone and mixture of 5% lime with different percentage of 0.5% ,1% ,1.5% and 2% Prosopis juliflora fibers.
- The CBR of Sample-1 increased from 1.21% to 8.93% with the addition of 6% lime alone .Similarly, the CBR of sample-2 increased from 1.96% to 9.93%.
- The CBR value of sample-1 soil increased from 1.21% to a maximum of 8.28% with the addition of 5% lime and 1.5% prosopis juliflora fibers stabilization while that of sample-2 increased from 1.96% to maximum of 9.26%.

- The values for the maximum moisture content were noted to increase with the addition of lime and mixture of lime and Prosopis juliflora fibers content while maximum dry density decrease.
- The addition of lime the OMC shows an increment and the MDD shows a slightly reduction in the treatment of both soil samples. The OMC increases from 40.80% to 44.95% and 40.91% to 44.37 while MDD decreases from 1.260g/cm^3 to 1.185g/cm^3 and1.257g/cm^3 to 1.162g/cm^3 in sample-1 and 2, respectively. Similarly, for addition of lime with Prosopis Juliflora fibers the OMC increases from 40.80% to 44.80% and 40.91% to 44.14% and the MDD decreases from 1.260g/cm^3 to 1.189g/$cm^3$and from 1.257g/cm^3 to 1.175g/cm^3in sample -1 and 2, respectively. The laboratory test results, shows that the treated soil fulfilled the required sub-grade when compared to specifications.
- From test results, it was inferred that the optimum content of lime and lime with Prosopis Juliflora fibers required to achieve superior improvement of engineering properties of clayey soil was found to be 6% lime alone and mixture of 5%lime and 1.5% Prosopis Juliflora fibers.
- Furthermore, the result shows that the improvement of 6% of lime alone and mixture of 5% lime with 1.5% Prosopis Juliflora fibers are more likely same improvement. Therefore, the result indicates that 1% lime can be partially replaced by 1.5% fibers to reduce the cost of lime.
- Finally, the laboratory test results was compared with standard specifications by comparing the value obtained from the laboratory tests with the required value on the standard specifications. Hence, the obtained value from the test results fulfilled the required value on the standard specifications. Therefore, it is recommended to use 6% lime alone and mixture of 5%lime and 1.5% Prosopis Juliflora fibers for clayey soil stabilization.

5.2 Recommendations

Based on the findings of this research, the following recommendations were forwarded:

- This research is show that lime with Prosopis Juliflora fibers, can be used as a stabilizer of clay sub-grade soil.
- It is found to be effective for 6% lime alone and mixture of 5%Lime and 1.5% Prosopis juliflora fibers and can be taken as a weak subgrade stabilizer.
- According to assessment made by Ethiopia Institute of Agricultural Research (EIAR) and other national and international organizations, Prosopis juliflora tree is number one priority invasive weeds in Ethiopia .As the result, it is important to make use this type of plants as innovative stabilizers for soil stabilization to minimize its problems from the environment.
- This study was done for specific area and specific stabilizers, it is recommended as more investigation shall be performed on different parts of the country by mixing with other stabilizers such as cement with prosopis julilfora fibers
- In this research, it was considered the different percentages of the Prosopis juliflora fibers. Therefore, it is recommended to conduct further study by considering both percentages and length of the Prosopis juliflora fibers.
- To know more about the ageing (durability) of the prosopis juliflora fibers, it is recommended to conduct further study for the future.
- The present study was conducted by taking limited parameter such as moisture density relationship, CBR and CBR swell potential on stabilization by lime alone and lime with Prosopis juliflora fibers. Hence, it is recommended to test additional parameters for future like unconfined compressive strength and mineralogical tests should also be performed.

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APPENDIX

APPENDIX A: NATURAL MOISTURE CONTENT

Sample location	Soil sample-1		
Can number	A	B	C
Mass of moisture can(MC)	17.1	17.61	17.65
Mass of moisture can+ mass moist soil (McMs)	99.5	81.73	89.67
Mass of moisture can + Mass of oven dried soil (McMds	74.08	61.79	66.67
Mass of water (Mw)	25.42	19.94	22.89
Mass of dry soil (Mds)	56.98	44.18	49.02
Water content (Wc) in %	44.61	45.13	46.7
Average water content (%)	45.48		

Sample location	Soil sample-2		
Can number	A	B	C
Mass of moisture can(MC)	18.05	17.44	17.76
Mass of moisture can+ mass moist soil (McMs)	94.52	104.28	97.44
Mass of moisture can + Mass of oven dried soil (McMds	76.62	75.28	79.1
Mass of water (Mw)	22.9	25.18	22.16
Mass of dry soil (Mds)	53.75	61.66	57.52
Water content (Wc) in %	42.75	40.8	38.53
Average water content (%)	40.69		

APPENDIX B: SPECIFIC GRAVITY TEST ANALYSIS DATA

Sample location	Soil Sample-1		
Trial Number	1	2	3
Determination Code	L	N	P
Mass of dry, clean Calibrated pycnometer, Mp, in g	28.2340	29.5430	29.64
A. Mass of oven dry sample(gm)	25.000	25.000	25.00
B. Mass of Pycnometer + water(g)	79.231	77.980	81.85
C. Mass of Pycnometer + water + sample(g)	95.12	93.99	97.71
Observed temperature of water,Ti	24.00	23.00	23.00
Temperature of contents of pycnometer when Mpsw was taken, Tx, in °C	25.00	25.00	25.00
Temperature correction factor,K	0.9990	0.9990	0.9990
Specific Gravity @20°C , Gs=A*k/(A+B-C)	2.74	2.78	2.73
Average Specific gravity @ 20°C, Gs	2.75		

Sample location	Soils Sample-2		
Trial Nummber	1	2	3
Determination Code	B1	C4	M
Mass of dry, clean Calibrated pycnometer, Mp, in g	31.20	31.12	30.64
A. Mass of oven dry sample(gm)	25	25.00	25.00
B. Mass of Pycnometer + water(g)	107.85	104.50	114.45
C. Mass of Pycnometer + water + sample(g)	123.54	120.31	130.20
Observed temperature of water,Ti	25.00	24.00	25.00
Temperature of contents of pycnometer when Mpsw was taken, Tx, in °C	25.00	25.00	25.00
Temperature correction factor,K	0.9990	1.00	0.9990
Specific Gravity @20°C , Gs=A*k/(A+B-C)	2.68	2.72	2.70
Average Specific gravity @ 20°C, Gs	2.70		

APPENDIX C: GRAIN SIZE DISTRIBUTION TEST ANALYSIS DATA

Wet sieve analysis and Hydrometer analysis

Soil sample-1					
Sieve number	Sieve size (mm)	Mass of retain on each sieve (g)	Percentage of retained soil	Percentage of cumulative of retain soil	Percentage of passing fine particle
4	4.75	1.82	0.182	0.1820	99.8180
10	2	28.41	2.84	3.023	96.9769
20	0.85	19.82	1.98	5.005	94.9949
40	0.425	11.62	1.16	6.167	93.8329
60	0.3	3.214	0.321	6.489	93.5115
140	0.15	2.311	0.231	6.720	93.2804
200	0.075	2.033	0.203	6.923	93.0771
	Pan	930.776	93.0776	100.00	0.00
	Total	1000.00			

Soil sample -1											
Time	Elapse time (min)	Hydro reading ,R	Temperature (°C)	Ct	L	Factor(K)	D(mm)	Correction factor (a)	Corrected hyro.Reading (Rc)	Percentag of fine (P)	Corrected (PA)
8:45	1	51	25	1.30	7.9	0.01249	0.035	0.98	45.30	88.79	82.64
8:46	2	50	25	1.30	8.1	0.01249	0.025	0.98	44.30	86.83	80.82
8:49	5	45	25	1.30	8.9	0.01249	0.017	0.98	39.30	77.03	71.70
8:59	15	41	25	1.30	9.6	0.01249	0.010	0.98	35.30	69.19	64.40
9:14	30	38	25	1.30	10.1	0.01249	0.007	0.98	32.30	63.31	58.93
9:44	60	37	25	1.30	10.2	0.01249	0.005	0.98	31.30	61.35	57.10
10:44	120	35	25	1.30	10.6	0.01249	0.004	0.98	29.30	57.43	53.45
12:44	240	33	24	1.00	10.9	0.01264	0.003	0.98	27.00	52.92	49.26
4:44	480	31	24	1.00	11.2	0.01264	0.002	0.98	25.00	49.00	45.61
8:45	1440	30	23	0.7	11.4	0.01279	0.001	0.98	23.7	46.45	43.24

Soil sample-2					
Sieve number	Sieve size (mm)	Mass of retain on each sieve (g)	Percentage of retained soil	Cumulative % of retain soil	Percentage of passing particle
4	4.75	3.030	0.303	0.303	99.697
10	2	25.080	2.508	2.811	97.189
20	0.85	17.910	1.791	4.602	95.398
40	0.425	13.870	1.387	5.989	94.011
60	0.3	7.100	0.710	6.699	93.301
140	0.15	5.308	0.531	7.230	92.770
200	0.075	6.780	0.678	7.908	92.092
	pan	92.922	92.092	100.00	0.000
	Total	1000.0			

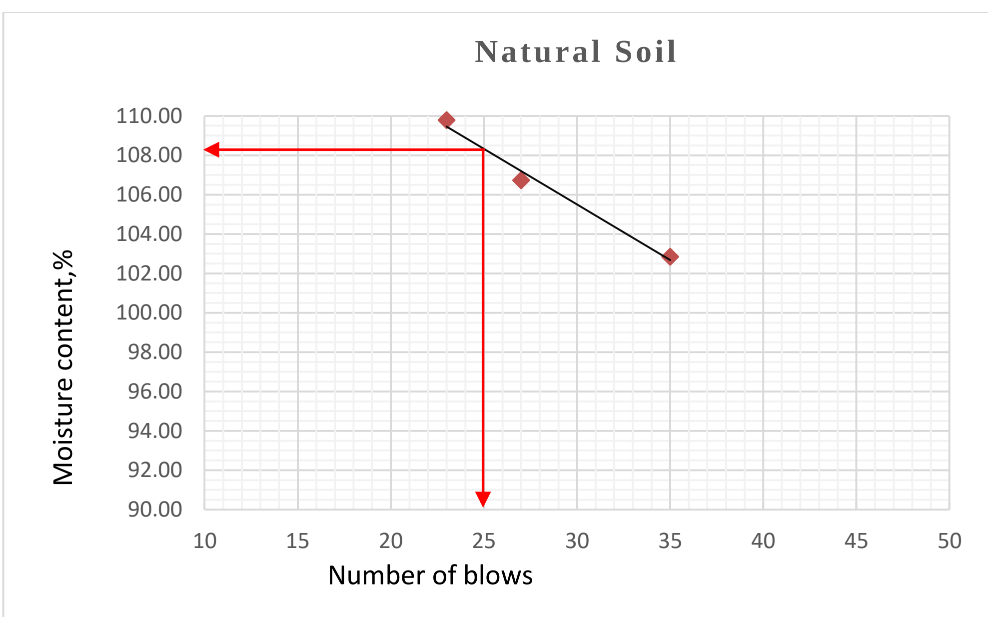
Soil Sample -2											
Time	Elapsed time (min)	Hydro reading ,R	Temperature(°C)	Ct	L	Factor(K)	D(mm)	Correction factor (a)	Corrected hyro.Reading(RC)	Percentage of fine (P)	Corrected (PA)
8:50	1	50	25	1.30	8.1	0.01267	0.036	0.99	44.30	87.71	80.78
8:51	2	48	25	1.30	8.4	0.01267	0.026	0.99	42.30	83.75	77.13
8:54	5	43	25	1.30	9.2	0.01267	0.017	0.99	37.30	73.85	68.01
9:04	15	40	25	1.30	9.7	0.01267	0.010	0.99	34.30	67.91	62.54
9:19	30	38	25	1.30	10.1	0.01267	0.007	0.99	32.30	63.95	58.90
9:49	60	36	25	1.30	10.4	0.01267	0.005	0.99	30.30	59.99	55.25
10:49	120	34	25	1.30	10.7	0.01267	0.004	0.99	28.30	56.03	51.60
12:49	240	31	24	1.00	11.2	0.01282	0.003	0.99	25.00	49.50	45.59
4:49	480	30	24	1.00	11.4	0.01282	0.002	0.99	24.00	47.52	43.76
8:50	1440	29	23	0.70	11.5	0.01297	0.001	0.990	22.70	44.95	41.39

Sieve analysis and hydrometer analysis combined

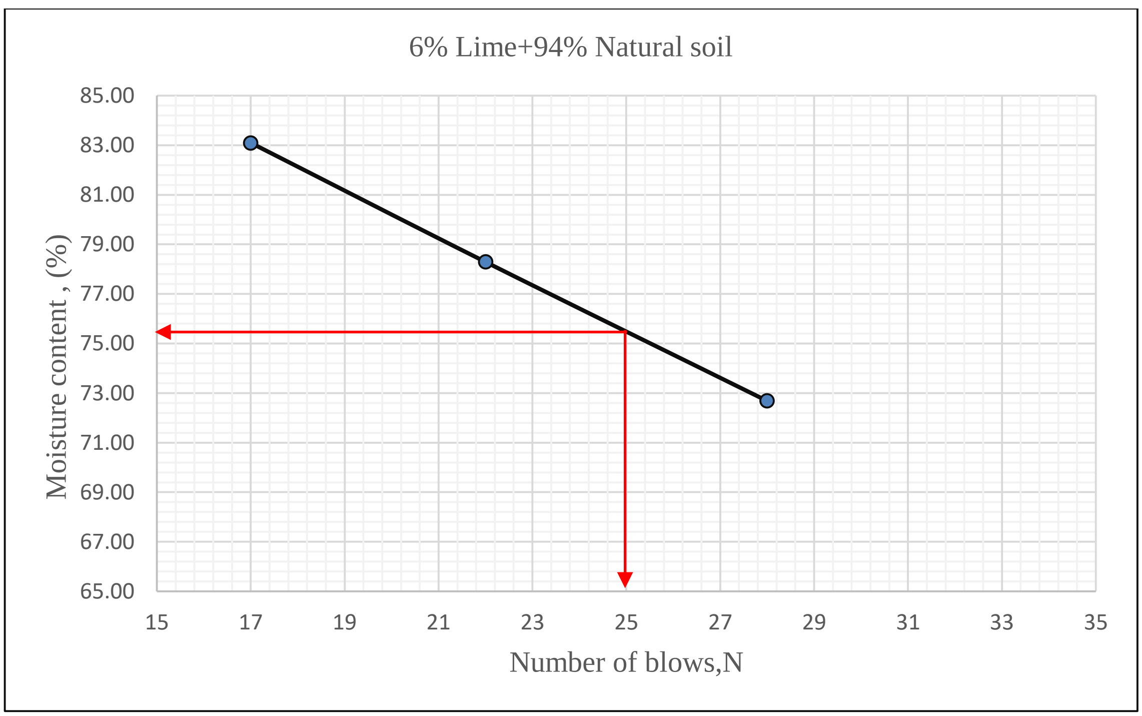
Diameter (mm)	Sample-1	sample-2
	Percentage passing	Percentage passing
9.5	100	100
4.75	99.8180	99.6970
2	96.9769	97.1890
0.85	94.9949	95.3980
0.425	93.8329	94.0110
0.3	93.5115	93.3010
0.15	93.2804	92.7700
0.075	93.0771	92.0920
0.035	82.64	80.78
0.025	80.82	77.13
0.017	71.70	68.01
0.010	64.40	62.54
0.007	58.93	58.90
0.005	57.10	55.25
0.004	53.45	51.60
0.003	49.26	45.59
0.002	45.61	43.76
0.001	43.24	41.39

APPENDIX D: ATTERBERG'S LIMIT TEST ANALYSIS DATA

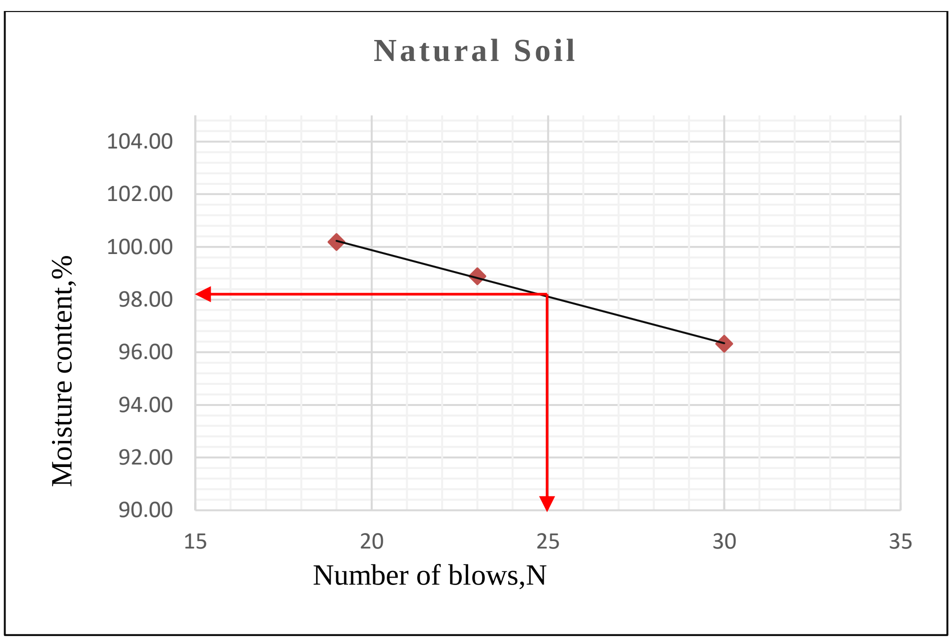
Sample-1	Natural soil				
Determination	Liquid limit			Plastic limit	
Trials	**1**	**2**	**3**	**1**	**2**
Number of blows	35	27	23		
Container code	4	3.3	B9	A4	A7
Wt. of container + wet soil(g)	36.72	42.41	46.28	22.30	23.45
Wt. of container + dry soil(g)	26.24	29.40	32.14	20.77	21.56
Wt. of container,(g)	16.05	17.21	19.26	17.01	17.05
Wt. of water,(g)	10.48	13.01	14.14	1.53	1.89
Wt. of dry soil,(g)	10.19	12.19	12.88	3.76	4.51
Moisture content,%	102.85	106.73	109.78	40.69	41.91
Av.Plastic limit (%)				41.30	
Plasticity Index (%)					
Liquid limit(%) @25blows from the graph		108.40			
Av.plastic limit (%)	41.30				
Plasticity index (%)	67.10				



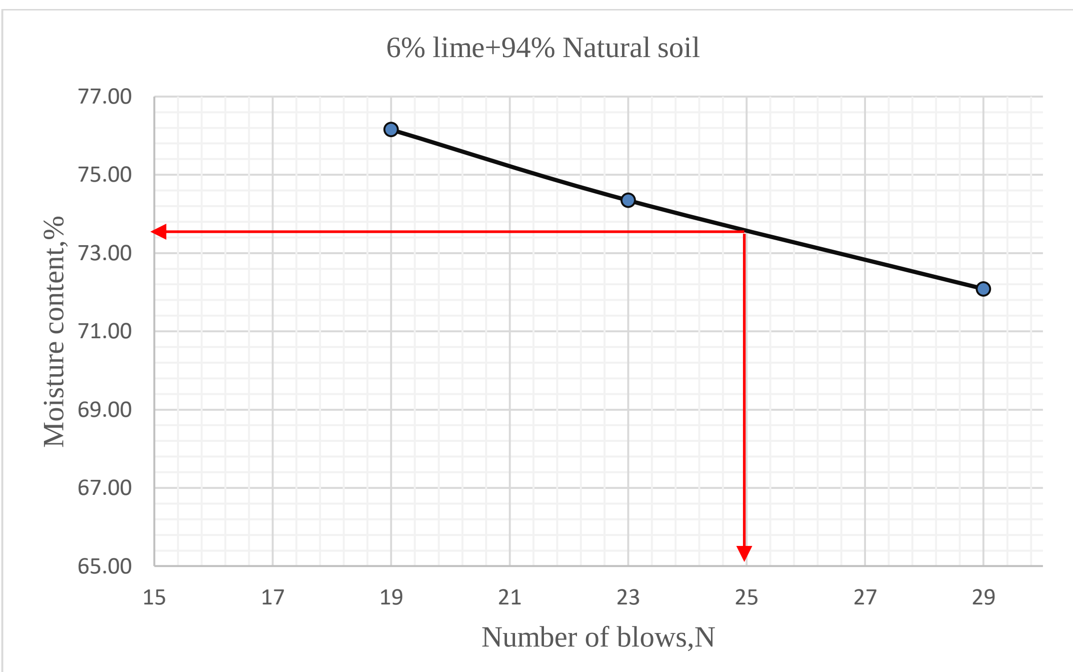
Sample 1	6% lime+94% Natural soil				
Determination	Liquid limit			Plastic limit	
Trials	**1**	**2**	**3**	**1**	**2**
Number of blows	28	22	17		
Container code	B4	C1	F5	A	G8
Wt. of container + wet soil,(g)	33.10	33.25	33.62	25.52	12.33
Wt. of container + dry soil,(g)	26.82	27.84	26.10	23.39	9.85
Wt. of container,(g)	18.18	20.93	17.05	19.62	6.02
Wt. of water,(g)	6.28	5.41	7.52	2.13	2.48
Wt. of dry soil,(g)	8.64	6.91	9.05	3.77	3.83
Moisture content,%	72.69	78.29	83.09	56.50	64.75
Av.Plastic limit (%)				60.63	
Plasticity Index (%)					
Liqud limit(%) @25blows from the graph		75.60			
Av.plastic limit (%)	60.63				
Plasticity index (%)	14.97				



Sample-2	Natural soil				
Determination	Liquid limit			Plastic limit	
Trials	**1**	**2**	**3**	**1**	**2**
Number of blows	30	23	19		
Container code	P15	A	C2	A1	B3
Wt. of container + wet soil,(g)	40.41	42.89	39.77	22.07	23.00
Wt. of container + dry soil,(g)	28.89	30.46	28.91	20.78	21.31
Wt. of container,(g)	16.93	17.89	18.07	17.00	17.05
Wt. of water,(g)	11.52	12.43	10.86	1.29	1.69
Wt. of dry soil,(g)	11.96	12.57	10.84	3.78	4.26
Moisture content,%	96.32	98.89	100.18	34.13	39.67
Av.Plastic limit (%)				36.90	
Plasticity index (%)					
Liqud limit(%) @25blows from the graph		98.10			
Av.plastic limit (%)		36.90			
Plasticity index (%)		61.20			



Sample -2	6% lime+94% Natural soil				
Determination	Liquid limit			Plastic limit	
Trials	**1**	**2**	**3**	**1**	**2**
Number of blows	29	23	19		
Container code	A4	G8	F5	T65	T1
Wt. of container + wet soil,(g)	32.62	30.96	31.20	13.20	14.65
Wt. of container + dry soil,(g)	26.81	24.99	25.58	10.49	11.61
Wt. of container,(g)	18.75	16.96	18.20	6.30	6.43
Wt. of water,(g)	5.81	5.97	5.62	2.71	3.04
Wt. of dry soil,(g)	8.06	8.03	7.38	4.19	5.18
Moisture content,%	72.08	74.35	76.15	64.68	58.69
Av.plastic limit (%)				61.68	
Plasticity Index (%)					
Liqud limit(%) @25blows from the graph		73.60			
Av.plastic limit (%)	61.68				
Plasticity index (%)	11.92				



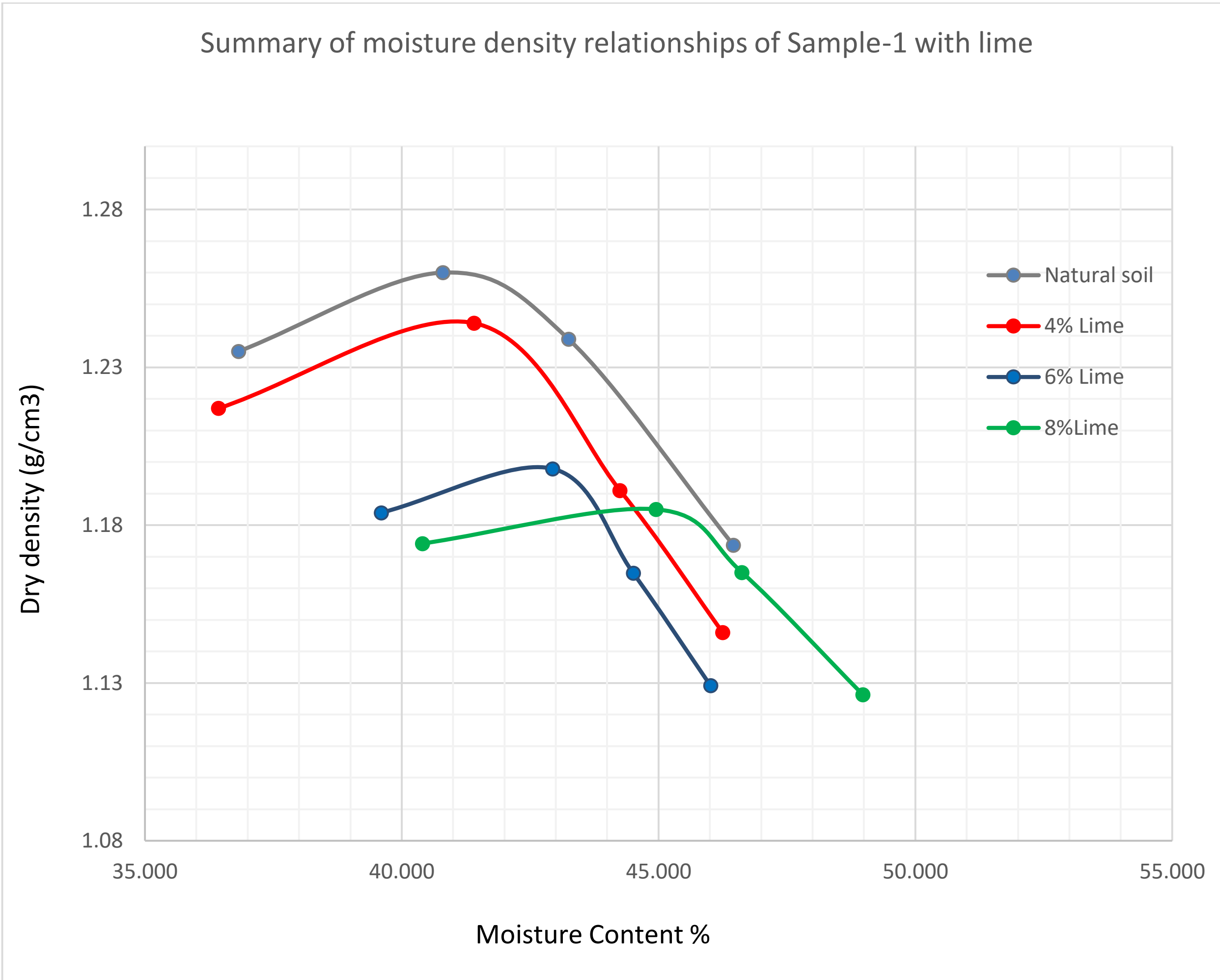
APPENDIX E: LINEAR SHRINKAGE ANALYSIS DATA

Linear shrinkage		Soil Sample-1		Soil Sample-2	
Additives %	Length of mold (cm)	Oven dry length (cm)	Linear shrinkage %	Oven dry length (cm)	Linear shrinkage %
Natural soil	14	11.4	20.36	11.39	18.61
Natural soil + 4 %Lime	14	12.35	11.7	12.52	10.57
Natural soil + 6 %Lime	14	13.01	7.07	13.24	5.43
Natural soil + 8 %Lime	14	13.55	4.5	13.5	3.57

APPENDIX F: COMPACTION TEST ANALYSIS DATA

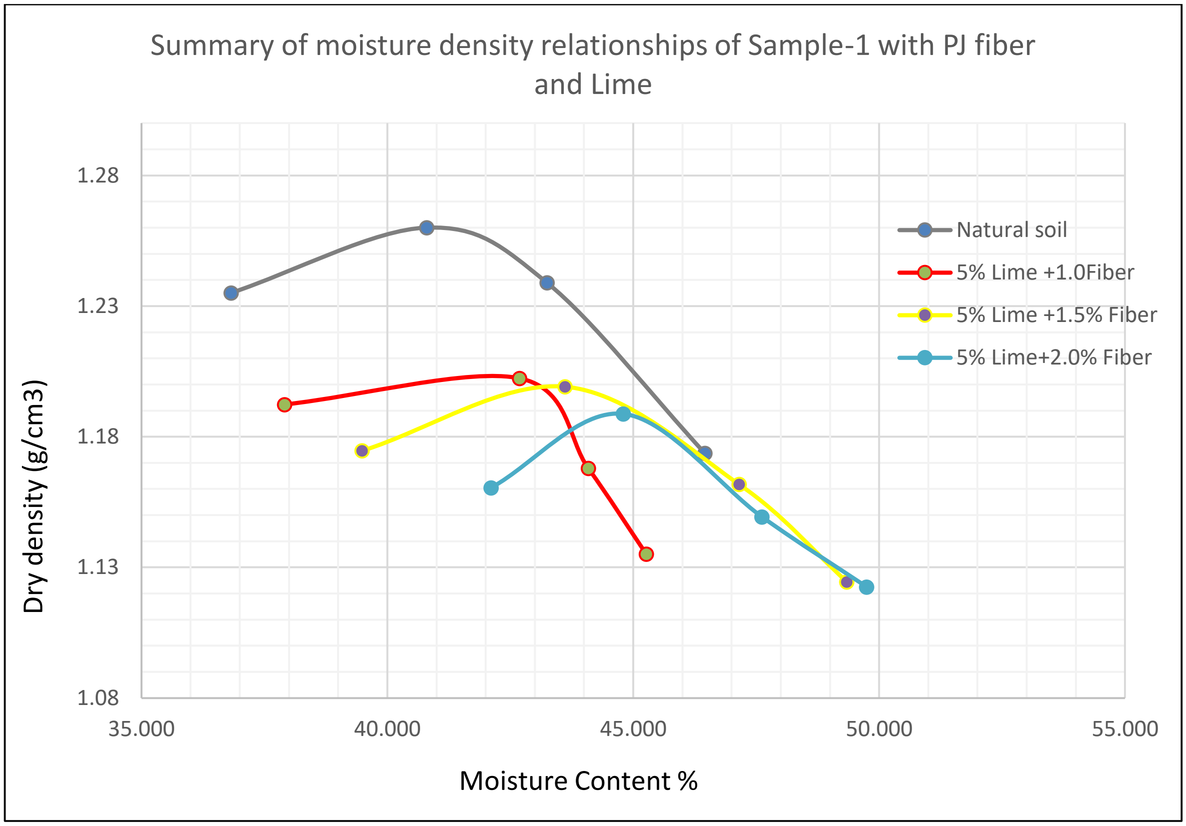
Sample-1	Natural soil							
Density Determination								
Test No.	1	2	3	4				
Mass of sample (gm)	4500	4500	4500	4500				
Mass of Mold+Wet soil(gm) (A)	6310.1	6488.78	6478	6371				
Mass of Mold (gm) (B)	2720.98	2720.1	2708.5	2720.1				
Mass of Wet Soil(gm)A-B=C	3589.12	3768.68	3769.5	3650.9				
Volume of Mold cm^3(D)	2124	2124	2124	2124				
Bulk Density gm/cm^3 C/D=(E)	1.69	1.77	1.77	1.72				
Moisture Content Determination								
Container Code.	A1	C2	J	K	X	T1	C	P65
Mass of Wet soil+ Container (gm)(F)	127.8	124.1	132.5	137	125.2	135.4	135.1	132.09
Mass of dry soil+container (gm)(G)	99.32	96.25	102.6	106.22	96.65	103.27	102.6	100.8
Mass of container(gm)(H)	20.4	22.1	25.2	34.59	28.1	31.63	29.4	33.59
Mass of moisture(gm)F-G=(I)	28.48	27.85	29.9	30.78	28.55	32.13	32.5	31.29
Mass of Dry soil(gm)G-H=(J)	78.92	74.15	77.4	71.63	68.55	71.64	70.1	67.21
Moisture content % (I/J)*100=K	36.09	37.56	38.63	42.97	41.65	44.85	46.36	46.56
Av. Moisture content%(L)	36.823		40.801		43.249		46.459	
Dry Density gm/cm^3 E/(100+L)*100	1.24		1.260		1.24		1.17	

Sample-1	Additive content: 6%Lime+94%Natural soil							
Density Determination								
Test No.	1	2	3	4				
Mass of sample (gm)	4500	4500	4500	4500				
Mass of Mold+Wet soil(gm)(A)	6235.8	6358.95	6299.3	6227.2				
Mass of Mold(gm)(B)	2725.3	2722.2	2724.1	2725.3				
Mass of Wet Soil(gm)A-B=C	3510.5	3636.75	3575.2	3501.9				
Volume of Mold cm^3(D)	2124	2124	2124	2124				
Bulk Density gm/cm^3 C/D=(E)	1.65	1.71	1.68	1.65				
Moisture Content Determination								
Container Code.	A3	G19	N	P65	P165	A-16	E-3	K23
Mass of Wet soil+ Container(gm)(F)	166.87	169.30	180.64	175.00	150.50	162.80	169.55	166.78
Mass of dry soil+container (gm)(G)	128.88	131.98	137.05	134.39	112.82	123.68	126.00	120.49
Mass of container (gm)(H)	34.60	36.06	38.12	37.28	30.81	32.86	28.51	22.75
Mass of moisture (gm)F-G=(I)	37.99	37.32	43.59	40.61	37.68	39.12	43.55	46.29
Mass of Dry soil (gm)G-H=(J)	94.28	95.92	98.93	97.11	82.01	90.82	97.49	97.74
Moisture content % (I/J)*100=K	40.29	38.91	44.06	41.82	45.95	43.07	44.67	47.36
Av. Moisture content%(L)	39.60		42.94		44.51		46.02	
Dry Density gm/cm^3 E/(100+L)*100	1.184		1.198		1.165		1.129	


Summary of moisture density relationships of Sample-1 with lime
Dry density (g/cm3)
1.28
1.23
1.18
1.13
1.08
35.000
40.000
45.000
50.000
55.000
Moisture Content %
Natural soil
4% Lime
6% Lime
8%Lime

Sample-1	Additive content: 1.0%PJ Fiber+ 5% Lime							
Density Determination								
Test No.	1	2	3	4				
Mass of sample (gm)	4500	4500	4500	4500				
Mass of Mold+Wet soil(gm)(A)	6217.9	6366.1	6298.2	6227.5				
Mass of Mold(gm)(B)	2725.3	2722.2	2724.1	2725.3				
Mass of Wet Soil(gm)A-B=C	3492.6	3643.9	3574.1	3502.2				
Volume of Mold cm^3(D)	2124	2124	2124	2124				
Bulk Density gm/cm^3 C/D=(E)	1.64	1.72	1.68	1.65				
Moisture Content Determination								
Container Code.	A3	G19	N	P65	P165	A-16	E-3	K23
Mass of Wet soil+Container (gm)(F)	161.51	170.30	175.86	177.10	149.60	162.80	169.15	165.23
Mass of dry soil+container (gm)(G)	128.00	131.98	136.12	134.10	112.58	123.79	125.85	120.25
Mass of container(gm)(H)	34.60	36.06	38.54	37.81	30.81	32.86	28.51	22.56
Mass of moisture(gm)F-G=(I)	33.51	38.32	39.74	43.00	37.02	39.01	43.30	44.98
Mass of Dry soil(gm)G-H=(J)	93.40	95.92	97.58	96.29	81.77	90.93	97.34	97.69
Moisture content % (I/J)*100=K	35.88	39.95	40.73	44.66	45.27	42.90	44.48	46.04
Av. Moisture content%(L)	37.91		42.69		44.09		45.26	
Dry Density gm/cm^3 E/(100+L)*100	1.192		1.202		1.17		1.14	

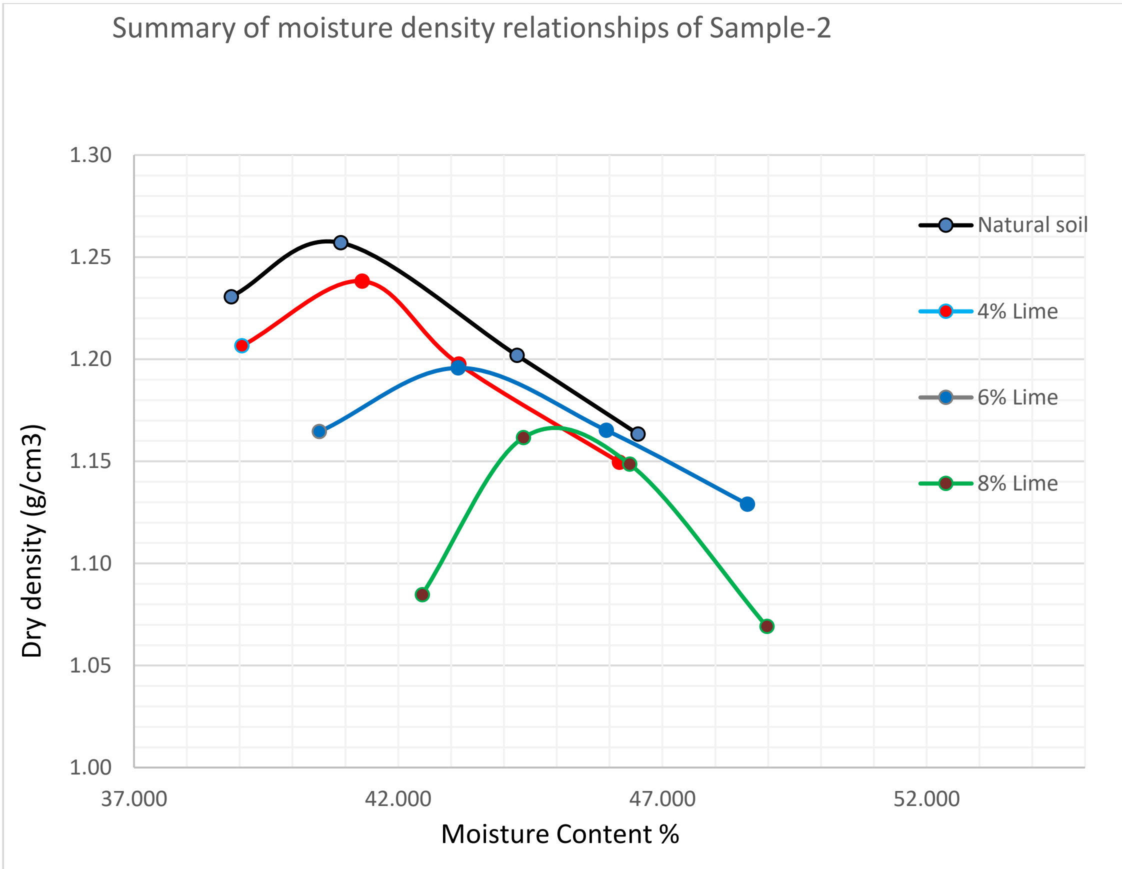
Sample-1	Additive content: 1.5%PJ Fiber+ 5% Lime							
Density Determination								
Test No.	1	2	3	4				
Mass of sample (gm)	4500	4500	4500	4500				
Mass of Mold +Wet soil(g m)(A)	6205.1	6380	6355.2	6292.2				
Mass of Mold(gm)(B)	2725.3	2722.2	2724.1	2725.3				
Mass of Wet Soil(g m)A-B=C	3479.8	3657.8	3631.1	3566.9				
Volume of Mold cm^3(D)	2124	2124	2124	2124				
Bulk Density gm/cm^3 C/D=(E)	1.64	1.72	1.71	1.68				
Moisture Content Determination								
Container Code.	C2	G19	G	G3T2	A-12	E-12	K23	M
Mass of Wet soil Container (gm)(F)	165.22	159.61	179.12	189.88	158.02	161.9	174.24	167.56
Mass of dry soil+container(gm)(G)	128.85	124.12	136.13	142.1	118.85	124.25	126.26	122.45
Mass of container(gm)(H)	34.96	35.9	35.45	34.8	39.56	40.4	30.56	29.54
Mass of moisture(gm)F-G=(I)	36.37	35.49	42.99	47.78	39.17	37.65	47.98	45.11
Mass of Dry soil(gm)G-H=(J)	93.89	88.22	100.68	107.3	79.29	83.85	95.7	92.91
Moisture content % (I/J)*100=K	38.74	40.23	42.70	44.53	49.40	44.90	50.14	48.55
Av.Moisture content%(L)	39.48		43.61		47.15		49.34	
Dry Density gm/cm^3 E/(100+L)*100	1.175		1.199		1.16		1.12	


Summary of moisture density relationships of Sample-1 with PJ fiber and Lime
Dry density (g/cm3)
1.28
1.23
1.18
1.13
1.08
35.000
40.000
45.000
50.000
55.000
Moisture Content %
Natural soil
5% Lime +1.0Fiber
5% Lime +1.5% Fiber
5% Lime+2.0% Fiber

Sample-2	Natural soil							
Density Determination								
Test No.	1		2		3		4	
Mass of sample (gm)	4500		4500		4500		4500	
Mass of Mold+Wet soil(gm)(A)	6350.1		6482.4		6391		6341	
Mass of Mold(gm)(B)	2720.98		2720.1		2708.5		2720.1	
Mass of Wet Soil(gm)A-B=C	3629.12		3762.3		3682.5		3620.9	
Volume of Mold cm^3(D)	2124		2124		2124		2124	
Bulk Density gm/cm^3 C/D=(E)	1.71		1.77		1.73		1.70	
Moisture Content Determination								
Container Code.	B3	A2	R	K	X	T1	C	P15
Mass of Wet soil+Container(gm)(F)	134	125.6	143.5	145.2	128.2	135.4	134.1	140.09
Mass of dry soil+container(gm)(G)	106.8	98.8	110.6	112.22	97.65	105.27	101.9	106.1
Mass of container(gm)(H)	35.4	31.1	30.2	31.59	30.1	35.63	30.5	33.59
Mass of moisture(gm)F-G=(I)	27.2	26.8	32.9	32.98	30.55	30.13	32.2	33.99
Mass of Dry soil(gm)G-H=(J)	71.4	67.7	80.4	80.63	67.55	69.64	69.7	72.51
Moisture content % (I/J)*100=K	38.10	39.59	40.92	40.90	45.23	43.27	46.20	46.88
Av.Moisture content%(L)	38.841		40.912		44.246		46.537	
Dry Density gm/cm^3 E/(100+L)*100	1.23		1.257		1.20		1.16	

Sample-2	Additive content :6% Lime +94%Natural soil			
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Mass of Mold+Wet soil(gm)(A)	6200.86	6357.45	6335.87	6288.78
Mass of Mold(gm)(B)	2725.3	2722.2	2724.15	2725.3
Mass of Wet Soil(gm)A-B=C	3475.56	3635.25	3611.72	3563.48
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.64	1.71	1.70	1.68

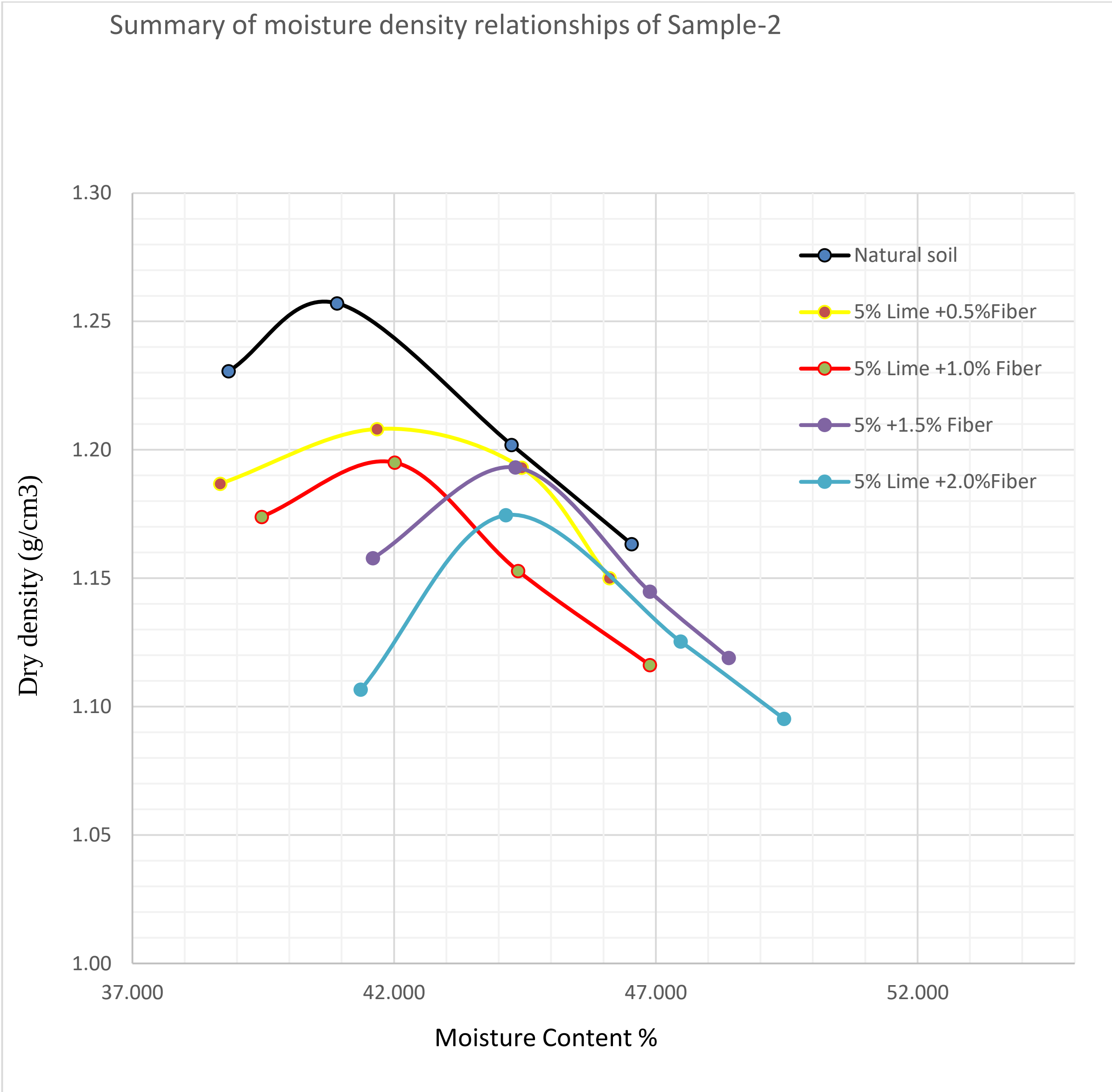
Moisture Content Determination								
Container Code.	G3	P65	P65	M	Z2	A-6	E-3	B4
Mass of Wet soil+Container (gm) (F)	160.28	164.70	178.98	180.89	149.61	163.15	168.48	165.56
Mass of dry soil+container(gm) (G)	118.78	131.28	136.02	137.12	112.25	122.87	121.85	119.56
Mass of container(gm) (H)	30.15	33.53	35.35	36.74	32.96	32.89	28.51	22.25
Mass of moisture(gm)F-G=(I)	41.50	33.42	42.96	43.77	37.36	40.28	46.63	46.00
Mass of Dry soil(gm)G-H=(J)	88.63	97.75	100.67	100.38	79.29	89.98	93.34	97.31
Moisture content % (I/J)*100=K	46.82	34.19	42.67	43.60	47.12	44.77	49.96	47.27
Av. Moisture content%(L)	40.51		43.14		45.94		48.61	
Dry Density gm/cm^3 E/(100+L)*100	1.165		1.196		1.165		1.129	


Summary of moisture density relationships of Sample-2
Dry density (g/cm3)
1.30
1.25
1.20
1.15
1.10
1.05
1.00
37.000
42.000
47.000
52.000
Moisture Content %
Natural soil
4% Lime
6% Lime
8% Lime

Sample-2	Additive content: 1.0%PJ Fiber+ 5% Lime			
Density Determination				
Test No.	1	2	3	4
Mass of sample (gm)	4500	4500	4500	4500
Mass of Mold+Wet soil(gm)(A)	6202.82	6326.82	6259.2	6207.78
Mass of Mold(gm)(B)	2725.3	2722.2	2724.15	2725.3
Mass of Wet Soil(gm)A-B=C	3477.52	3604.62	3535.05	3482.48
Volume of Mold cm^3(D)	2124	2124	2124	2124
Bulk Density gm/cm^3 C/D=(E)	1.64	1.70	1.66	1.64

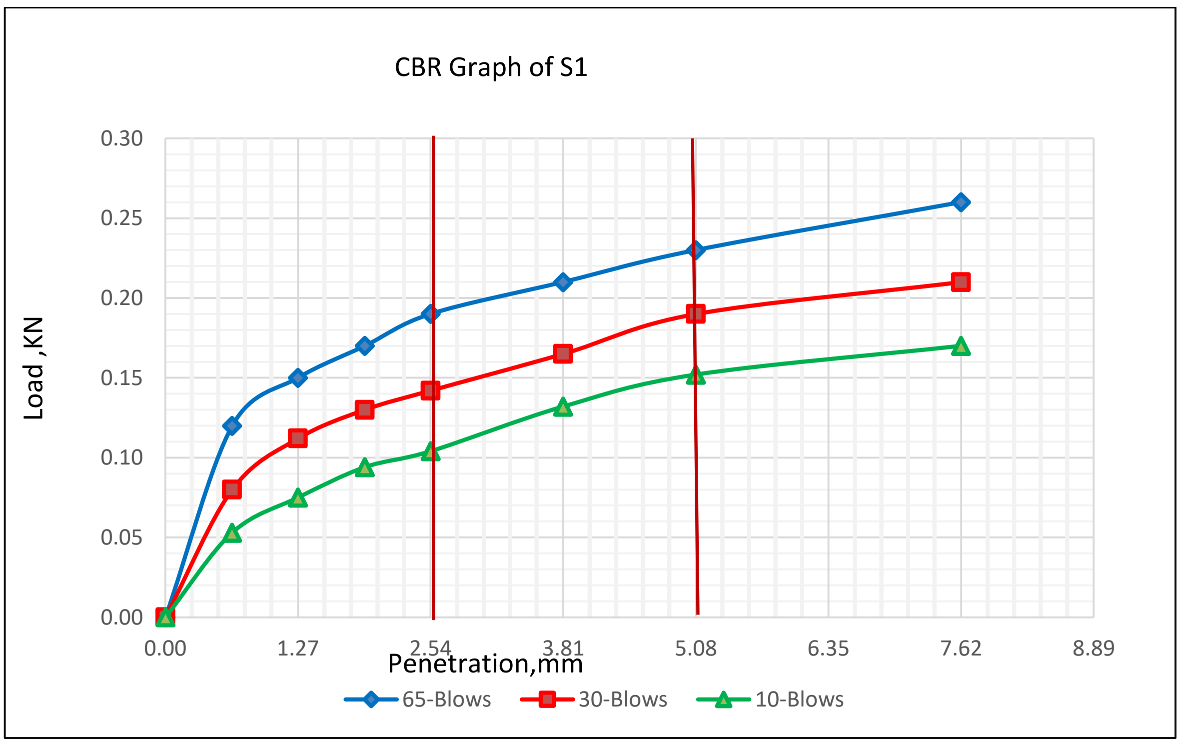
Moisture Content Determination								
Container Code.	G	G3	P65	M	A-16	J	E-3	G3T2
Mass of Wet soil+Container(gm)(F)	159.98	162.80	178.25	179.45	146.60	162.80	165.48	165.23
Mass of dry soil+container(gm)(G)	118.00	131.99	136.12	137.10	111.65	122.90	121.80	119.52
Mass of container(gm)(H)	30.15	33.11	35.25	36.88	32.96	32.89	28.51	22.16
Mass of moisture(gm)F-G=(I)	41.98	30.81	42.13	42.35	34.95	39.90	43.68	45.71
Mass of Dry soil(gm)G-H=(J)	87.85	98.88	100.87	100.22	78.69	90.01	93.29	97.36
Moisture content % (I/J)*100=K	47.79	31.16	41.77	42.26	44.41	44.33	46.82	46.95
Av. Moisture content%(L)	39.47		42.01		44.37		46.89	
Dry Density gm/cm^3 E/(100+L)*100	1.17		1.195		1.15		1.116	

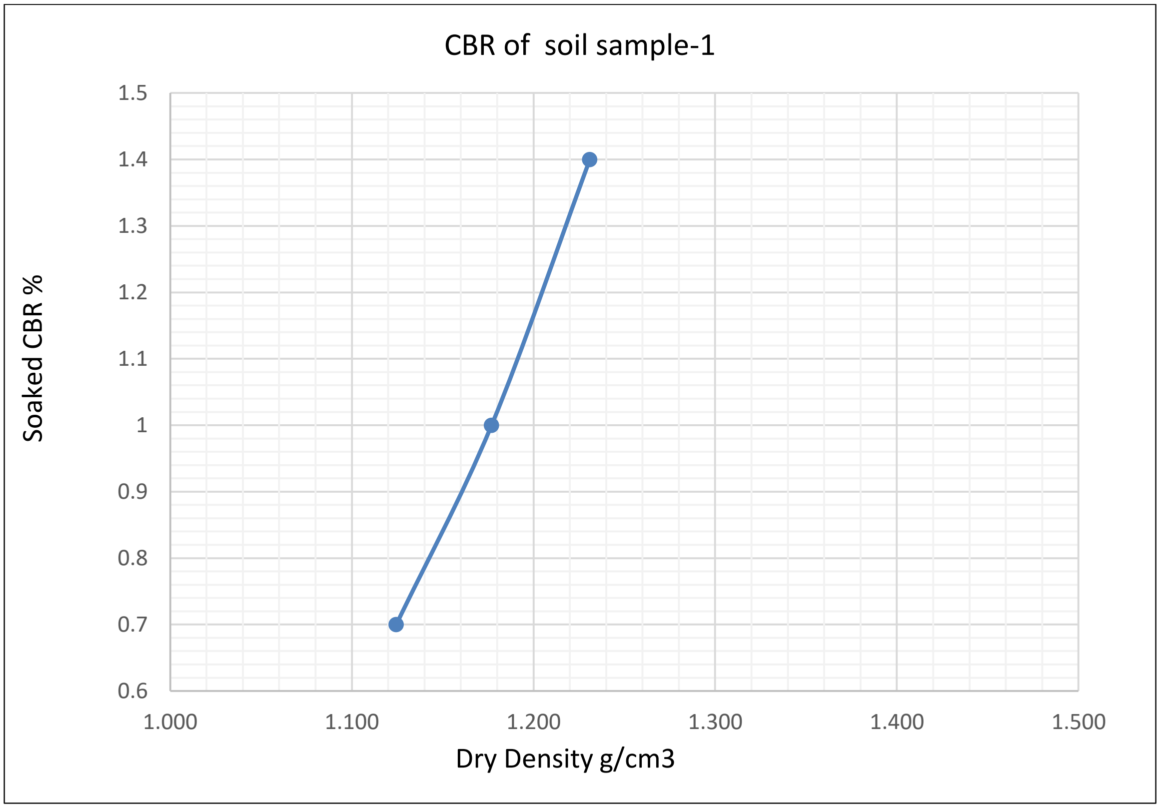
Sample-2	Additive content: 1.5%PJ Fiber+ 5% Lime							
Density Determination								
Test No.	1	2	3	4				
Mass of sample (gm)	4500	4500	4500	4500				
Mass of Mold+Wet soil(gm)(A)	6207.52	6379.76	6295.7	6252.25				
Mass of Mold(gm)(B)	2725.3	2722.2	2724.1	2725.3				
Mass of Wet Soil(gm)A-B=C	3482.22	3657.56	3571.6	3526.95				
Volume of Mold cm^3(D)	2124	2124	2124	2124				
Bulk Density gm/cm^3 C/D=(E)	1.64	1.72	1.68	1.66				
Moisture Content Determination								
Container Code.	G	A-3	G19	N	J	E-12	P65	E-3
Mass of Wet soil+Container (gm)(F)	158.27	160.41	161.14	164.1	158.45	164.98	169	154.18
Mass of dry soil+container (gm)(G)	121.5	124.12	122.85	123.17	120.85	124.85	125.2	112.18
Mass of container(gm)(H)	35.41	34.48	35.45	31.87	39.56	40.4	29.13	30.15
Mass of moisture(gm)F-G=(I)	36.77	36.29	38.29	40.93	37.6	40.13	43.8	42
Mass of Dry soil(gm)G-H=(J)	86.09	89.64	87.4	91.3	81.29	84.45	96.07	82.03
Moisture content % (I/J)*100=K	42.71	40.48	43.81	44.83	46.25	47.52	45.59	51.20
Av.Moisture content%(L)	41.60		44.32		46.89		48.40	
Dry Density gm/cm^3 E/(100+L)*100	1.16		1.193		1.145		1.12	


Summary of moisture density relationships of Sample-2
1.30
1.25
1.20
1.15
1.10
1.05
1.00
Dry density (g/cm3)
37.000
42.000
47.000
52.000
Moisture Content %
Natural soil
5% Lime +0.5%Fiber
5% Lime +1.0% Fiber
5% +1.5% Fiber
5% Lime +2.0%Fiber

APPENDIX G: CALIFORNIA BEARING RATIO (CBR) TEST ANALYSIS DATA

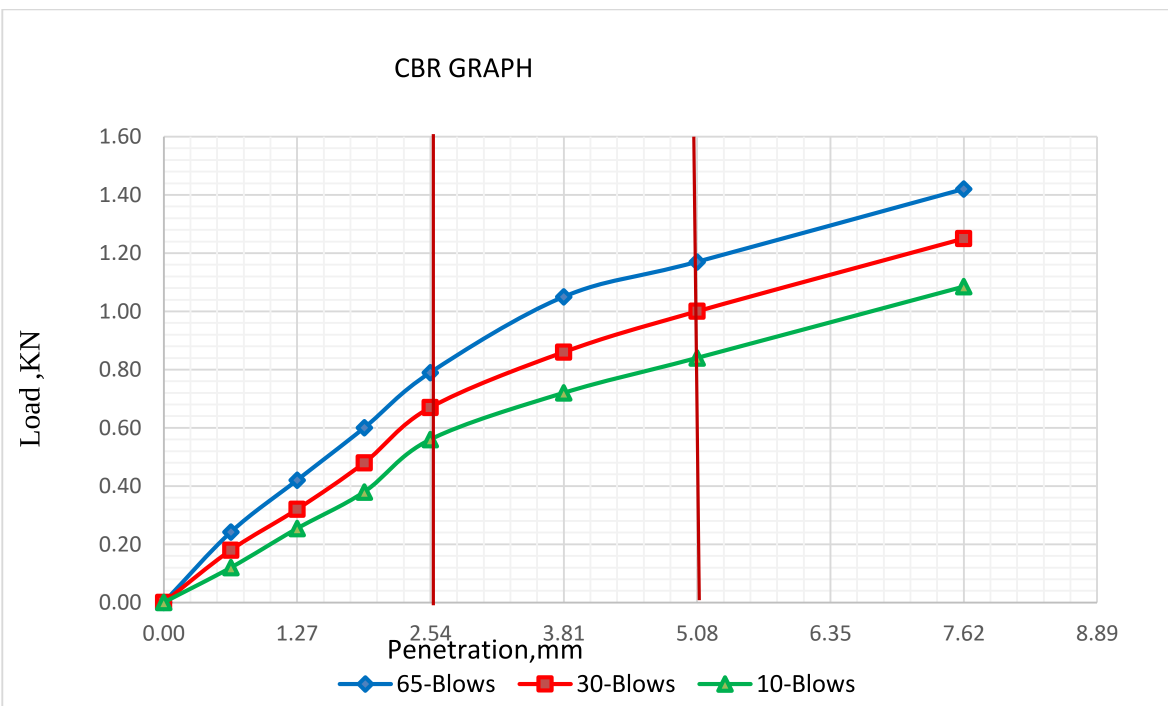
Penetration and load determination of natural soil of sample-1						
Penetration data after 96-hrs soaking						
	65-Blows		30-Blows		10-Blows	
Penetration (mm)	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.19	1.44	0.14	1.08	0.10	0.79
5.08	0.23	1.15	0.19	0.95	0.15	0.76
CBR Result summary of natural soil of sample-1						
MMDD	1.26					
Dry density @95% of MDD	1.211					
No. of blows	65	30	10			
CBR values (%)	1.44	1.08	0.79			
DDBS (g/cc)	1.23	1.18	1.12			
CBR @95% of MDD (%)	1.21					
CBR swell (%)	5.03					

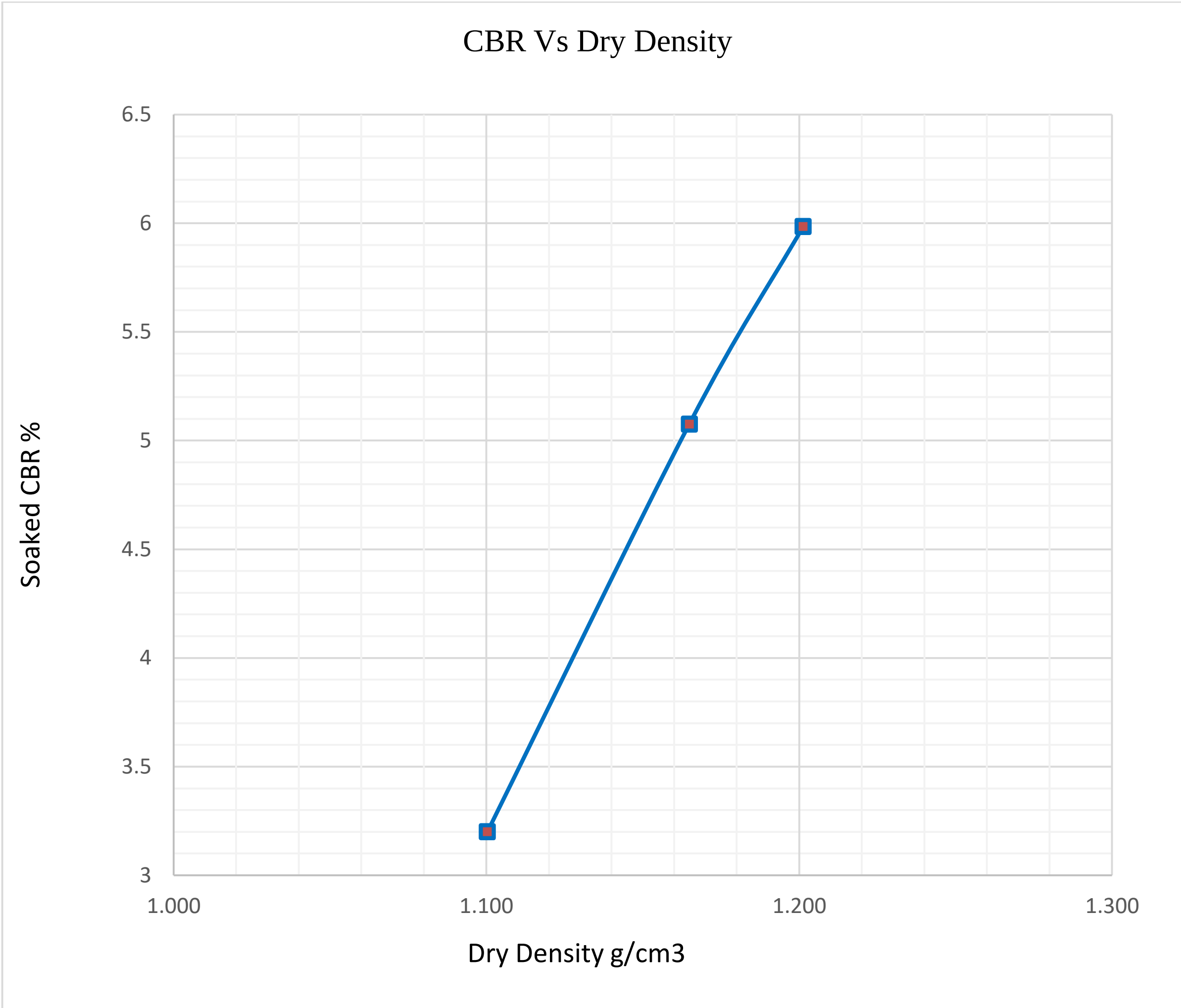



CBR of soil sample-1
Soaked CBR %
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
1.000
1.100
1.200
1.300
1.400
1.500
Dry Density g/cm3

Penetration and load determination of 5% Lime with 0.5% fiber for sample-1						
Penetration data after 96-hrs soaking						
	65-Blows		30-Blows		10-Blows	
Penetration (mm)	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.79	5.98	0.67	5.08	0.56	4.24
5.08	1.17	5.85	1.00	5.00	0.84	4.20

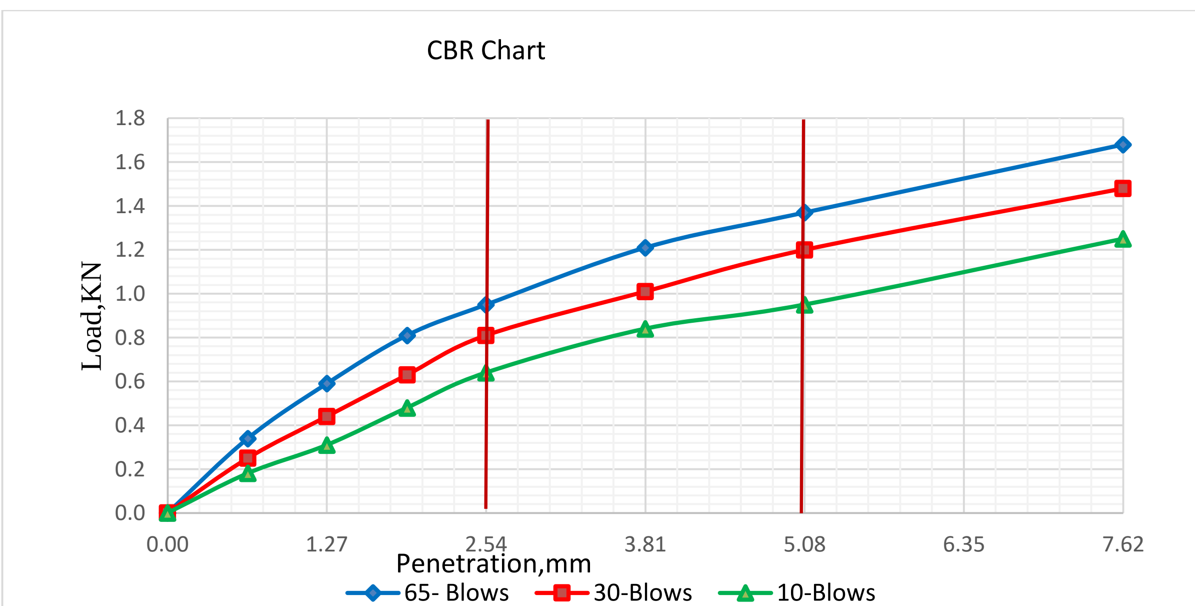
CBR Result summary of 5% Lime with 0.5% Fiber soil sample-1			
MMDD	1.24		
Dry density @95% of MDD	1.18		
No. of blows	65	30	10
CBR values (%)	6.0	5.1	4.2
DDBS (g/cc)	1.201	1.165	1.100
CBR @95% of MDD (%)	5.4		
CBR swell (%)	1.87		

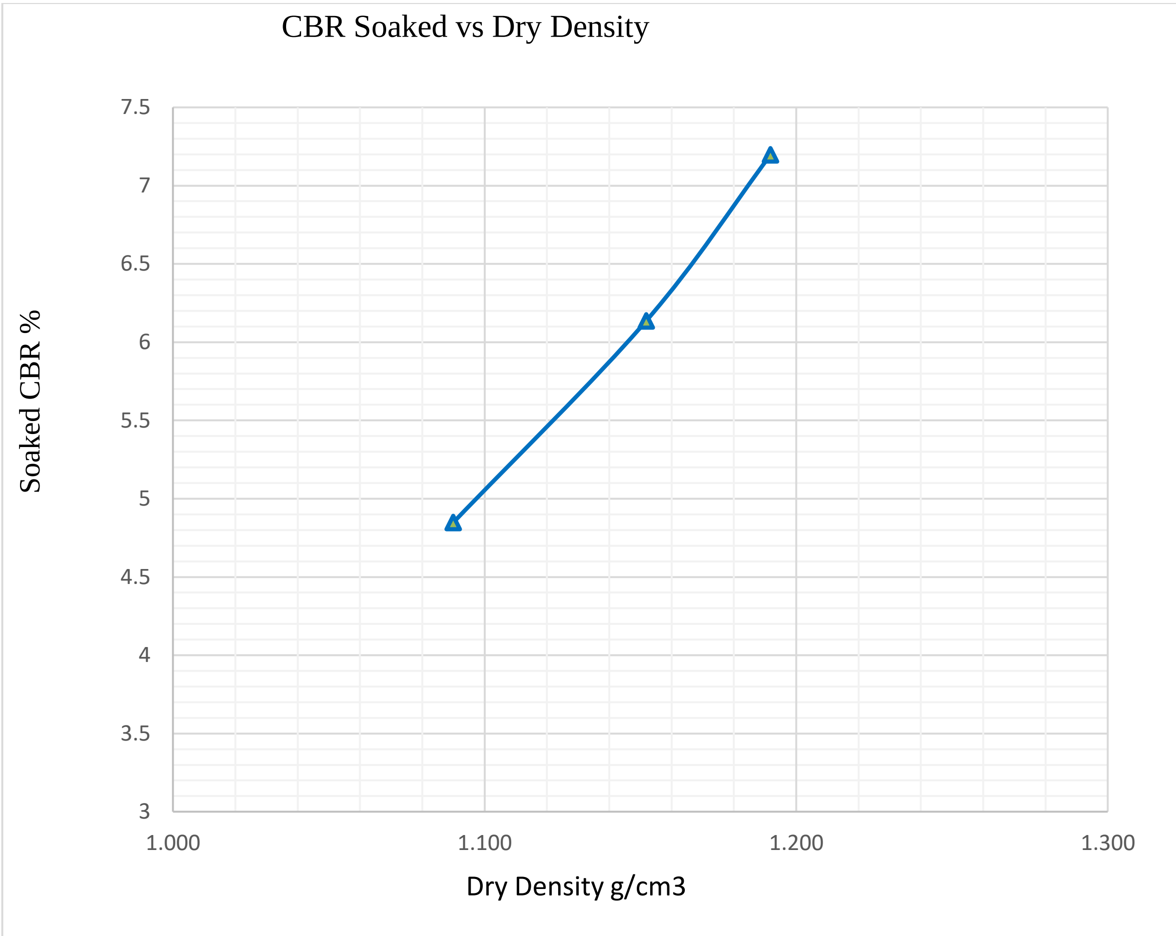



CBR Vs Dry Density
6.5
6
5.5
5
4.5
4
3.5
3
1.000
1.100
1.200
1.300
Soaked CBR %
Dry Density g/cm3

Penetration and load determination of 5% Lime with 1.0% Fiber of soil sample-1						
Penetration data after 96-hrs soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.95	7.20	0.81	6.14	0.64	4.85
5.08	1.37	6.85	1.20	6.00	0.95	4.75

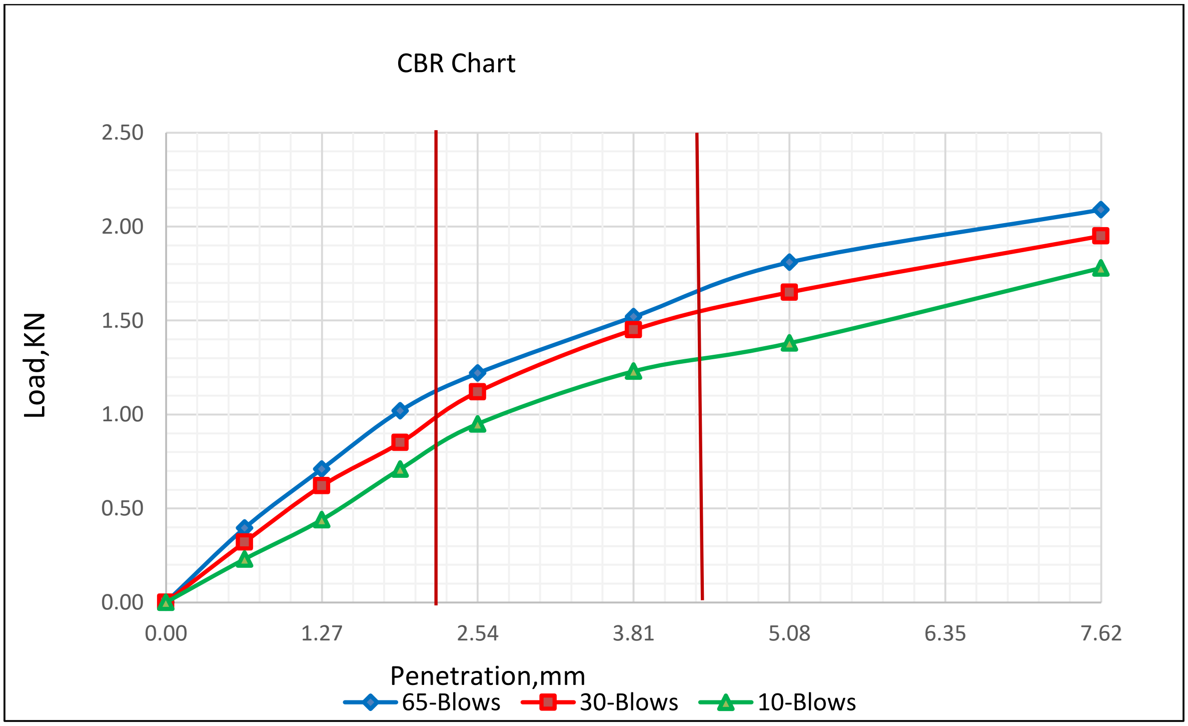
CBR Result summary of 5% Lime with 1.0% Fiber of soil sample-1			
MMDD	1.22		
Dry density @95% of MDD	1.159		
No. of blows	65	30	10
CBR values (%)	7.2	6.1	4.8
DDBS (g/cc)	1.192	1.152	1.090
CBR @95% of MDD (%)	6.3		
CBR swell (%)	1.76		

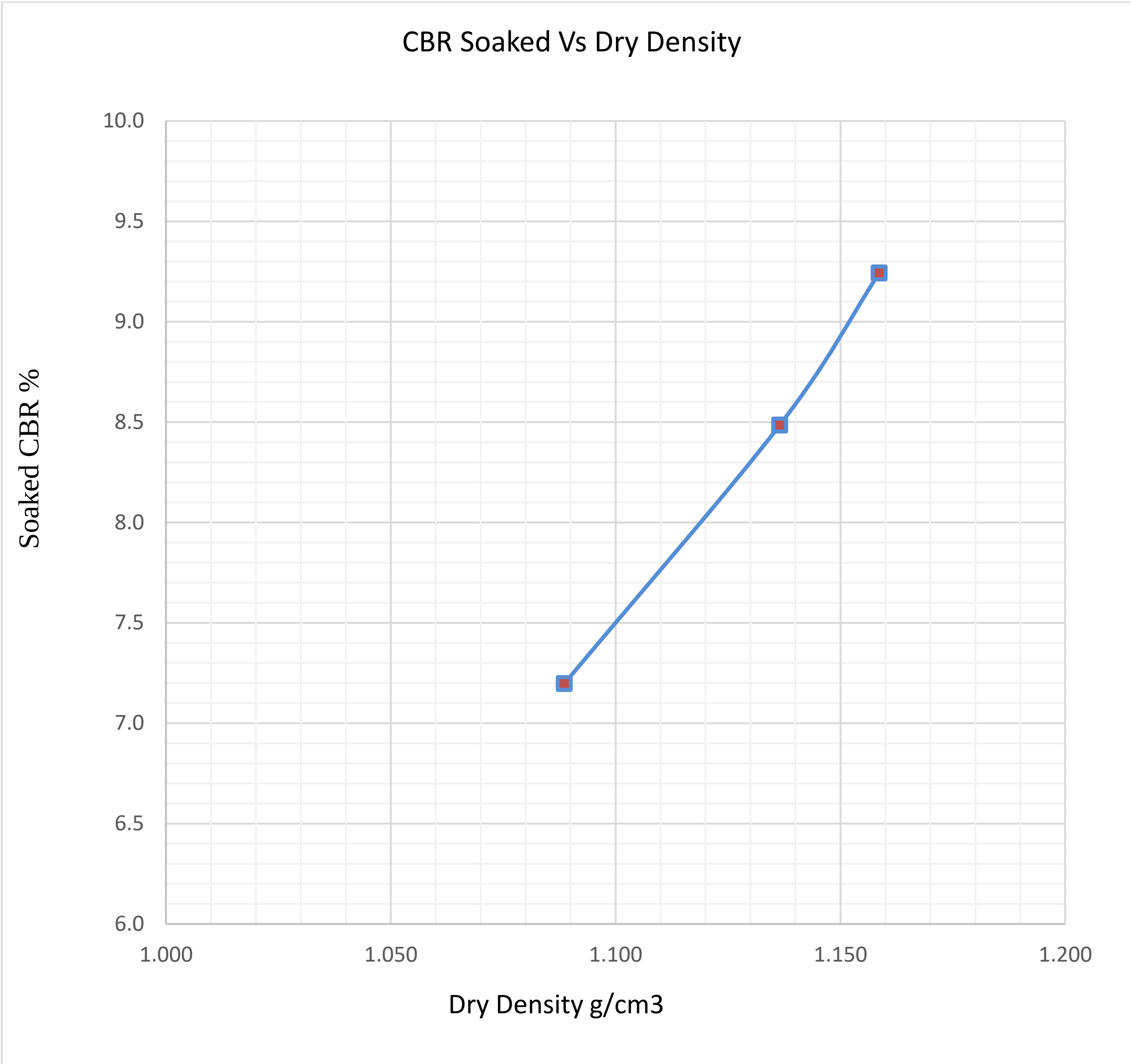



CBR Soaked vs Dry Density
Soaked CBR %
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1.000
1.100
1.200
1.300
Dry Density g/cm3

Penetration and load determination of 5% Lime with 1.5% fiber soil sample-1						
Penetration data after 96-hrs soaking						
	65-Blows		30-Blows		10-Blows	
Penetration (mm)	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.22	9.24	1.12	8.48	0.95	7.20
5.08	1.81	9.05	1.65	8.25	1.38	6.90

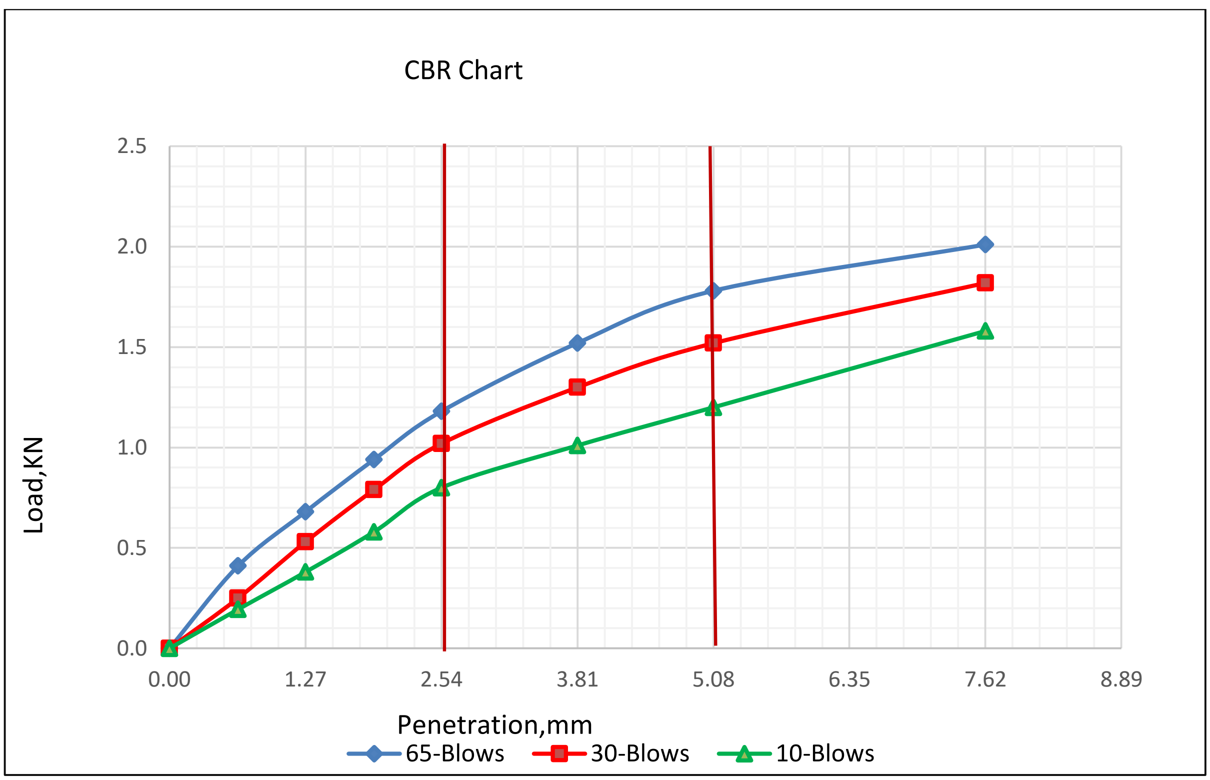
CBR Result summary of 5% Lime with 1.5% fiber soil sample-1			
MMDD	1.19		
Dry density @95% of MDD	1.131		
No. of blows	65	30	10
CBR values (%)	9.2	8.5	7.2
DDBS (g/cc)	1.159	1.137	1.089
CBR @95% of MDD (%)	8.3		
CBR swell (%)	1.50		




CBR Soaked Vs Dry Density
Soaked CBR %
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
1.000
1.050
1.100
1.150
1.200
Dry Density g/cm3

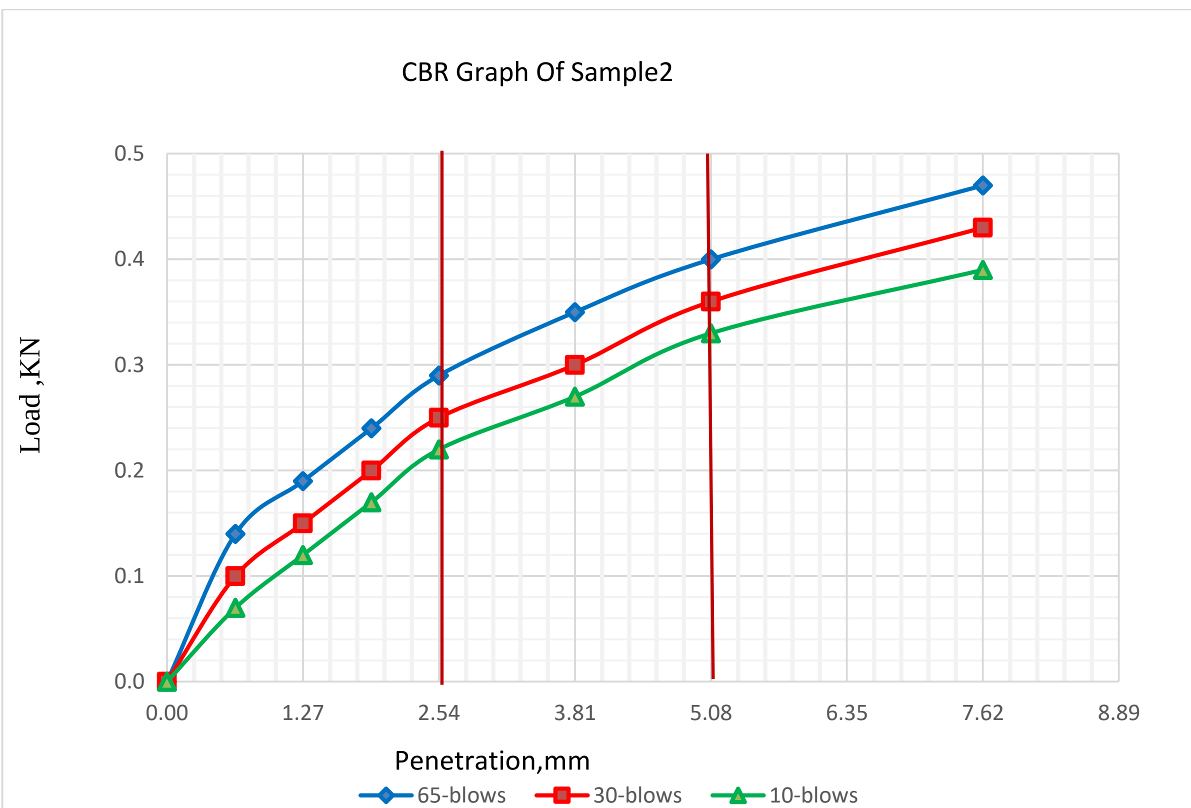
Penetration and load determination of 5% Lime with 2% Fiber of soil sample-1						
Penetration data after 96-hrs soaking						
Penetration(mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.18	8.94	1.02	7.73	0.80	6.06
5.08	1.78	8.90	1.52	7.60	1.20	6.00

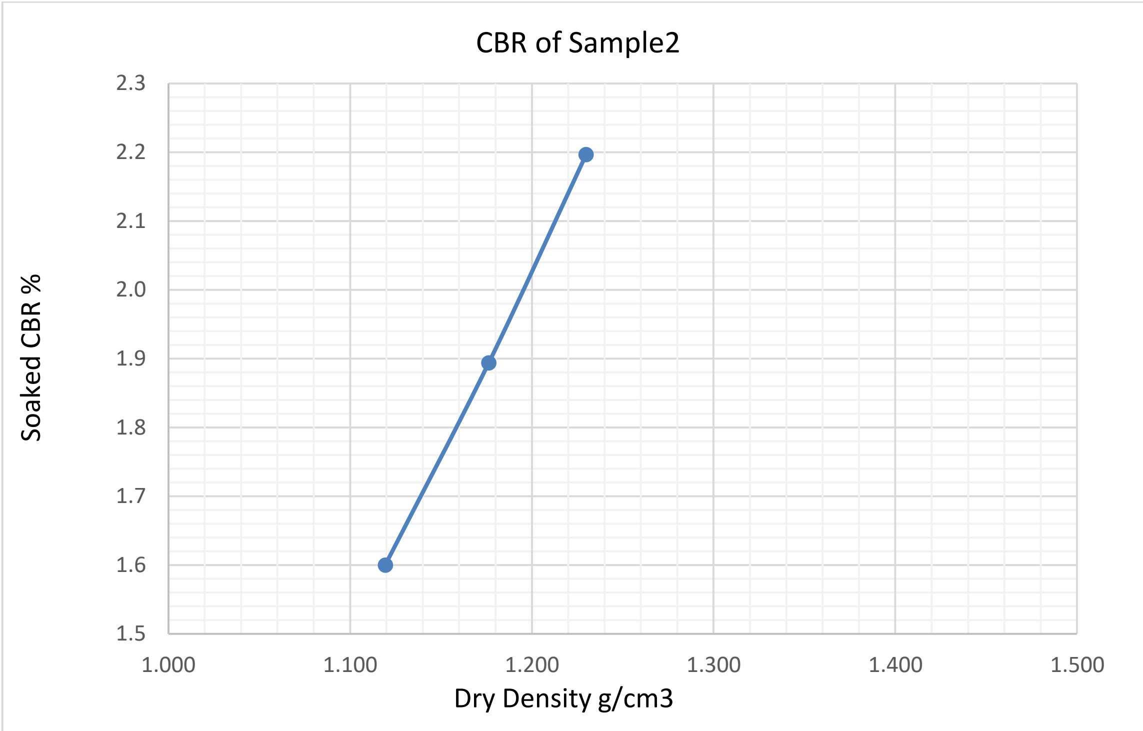
CBR Result summary of 5% Lime with 2% Fiber of soil sample-1			
MMDD	1.19		
Dry density @95% of MDD	1.130		
No. of blows	65	30	10
CBR values (%)	8.9	7.7	6.1
DDBS (g/cc)	1.211	1.132	1.095
CBR @95% of MDD (%)	7.7		
CBR swell (%)	1.80		



Penetration and load determination of natural soil of sample-2						
Penetration data after 96-hrs soaking						
Penetration(mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.29	2.20	0.25	1.89	0.22	1.67
5.08	0.40	2.0	0.36	1.80	0.33	1.65

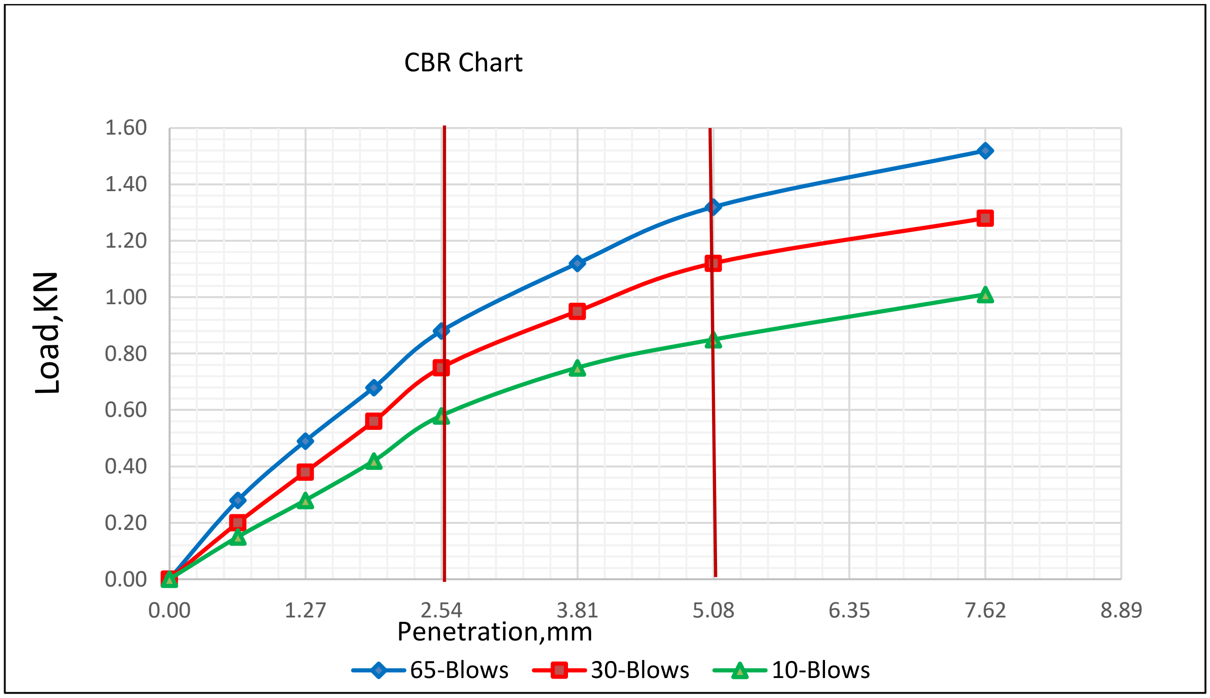
CBR Result summary of natural soil of sample-2			
MMDD	1.25		
Dry density @95% of MDD	1.188		
No. of blows	65	30	10
CBR values (%)	2.20	1.89	1.67
DDBS (g/cc)	1.23	1.18	1.12
CBR @95% of MDD (%)	1.96		
CBR swell (%)	4.21		




CBR of Sample2
Soaked CBR %
Dry Density g/cm3
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.000
1.100
1.200
1.300
1.400
1.500

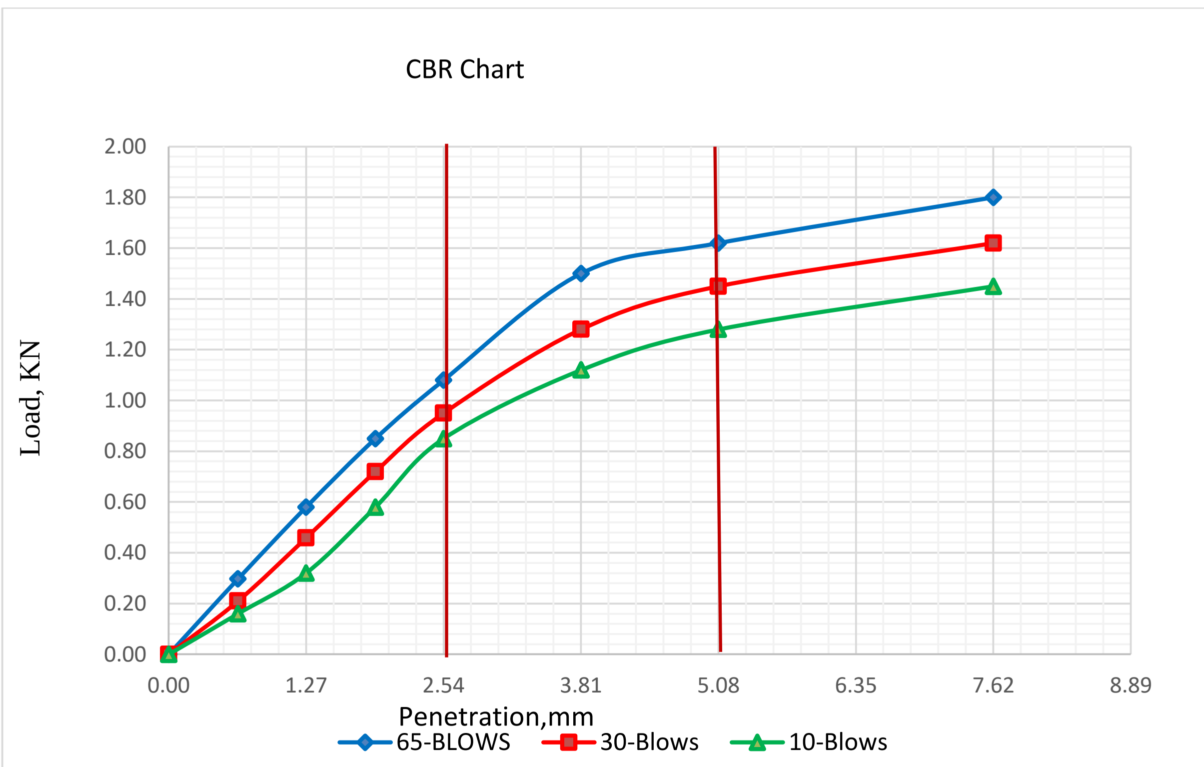
Penetration and load determination of 5% Lime with 0.5% Fiber of soil sample-2						
Penetration data after 96-hrs soaking						
Penetration(mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	0.88	6.67	0.75	5.68	0.58	4.39
5.08	1.32	6.60	1.120	5.60	0.85	4.25

CBR Result summary of 5% Lime with 0.5% Fiber of soil sample-2			
MMDD	1.208		
Dry density @95% of MDD	1.148		
No. of blows	65	30	10
CBR values (%)	6.7	5.7	4.4
DDBS (g/cc)	1.289	1.135	1.099
CBR @95% of MDD (%)	5.8		
CBR swell (%)	1.57		



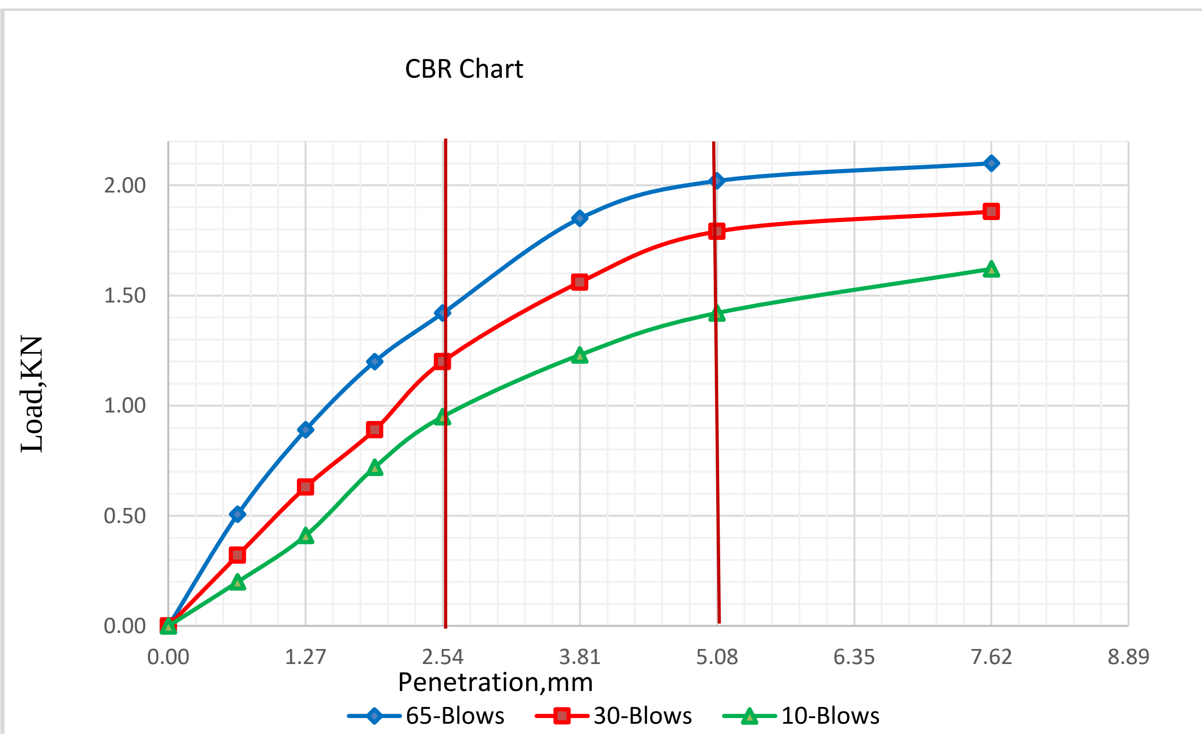
Penetration and load determination of 5% Lime with 1% Fiber of soil sample-2						
Penetration data after 96-hrs soaking						
Penetration(mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.08	8.18	0.95	7.20	0.85	6.44
5.08	1.62	8.10	1.45	7.25	1.28	6.40

CBR Result summary of 5% Lime with 1% Fiber of soil sample-2			
MMDD	1.20		
Dry density @95% of MDD	1.135		
No. of blows	65	30	10
CBR values (%)	8.2	7.3	6.4
DDBS (g/cc)	1.288	1.132	1.053
CBR @95% of MDD (%)	7.3		
CBR swell (%)	1.42		



Penetration and load determination of 5% Lime with 1.5% fiber of soil sample-2						
Penetration data after 96-hrs soaking						
Penetration (mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.42	10.76	1.20	9.09	0.95	7.20
5.08	2.02	10.10	1.79	8.95	1.42	7.10

CBR Result summary of 5% Lime with 1.5% fiber of soil sample-2			
MMDD	1.19		
Dry density @95% of MDD	1.132		
No. of blows	65	30	10
CBR values (%)	10.8	9.1	7.2
DDBS (g/cc)	1.282	1.115	1.044
CBR @95% of MDD (%)	9.3		
CBR swell (%)	1.35		



Penetration and load determination of 5% Lime with 2% Fiber of soil sample-2						
Penetration data after 96-hrs soaking						
Penetration(mm)	65-Blows		30-Blows		10-Blows	
	Load (KN)	CBR (%)	Load (KN)	CBR (%)	Load (KN)	CBR (%)
2.54	1.23	9.32	1.06	8.03	0.88	6.67
5.08	1.66	8.30	1.520	7.60	1.32	6.60

CBR Result summary of 5% Lime with 2% Fiber of soil sample-2			
MMDD	1.18		
Dry density @95% of MDD	1.116		
No. of blows	65	30	10
CBR values (%)	9.3	8.0	6.7
DDBS (g/cc)	1.283	1.097	1.0
CBR @95% of MDD (%)	8.2		
CBR swell (%)	1.39