JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Stabilization of expansive subgrade soil using Sisal fiber mixed with lime. A case of Tarcha Town, Dawro Zone, Ethiopia

A Research 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: Abel Shibru

May, 2022

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By: Abel Shibru

Main Advisor: Dr. Jemal Jibril (PhD)

Co-Advisor: Eng. Mesfin Dinku (MSc)

May, 2022

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that this thesis entitled: "Stabilization of expansive subgrade soil using Sisal fiber mixed with lime. A case of Tarcha Town, Dawro Zone, Ethiopia" is my original work, and has not been presented for a degree in this or any other university and that all sources of materials used for the thesis have been fully acknowledged.

Candidate:

Mr. Abel Shibru	________________________	________________________
Name	Signature	Date

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ABSTRACT

Expansive soils are one of the most abundant and problematic soils in the world, as well as in Ethiopia, which mostly causes significant damage to structures such as buildings, pavements, bridges and other civil engineering structures which constructed over it due to its considerable volume change with the existence of moisture variations. To reduce such unsuitable behavior of expansive soil, soil stabilization is required. From a number of techniques like chemical stabilization, mechanical stabilization, soil reinforcement by artificial and natural materials and others to treat this types of soil; the technique which is effective, economical and environmentally friendly be the best solution. The general objective of this research was to stabilize the expansive subgrade soil by using Sisal fiber mixed with lime. This research followed the experimental type of study and purposive sampling technique. In this study FSI, NMC, G_s, Atterburg limits (LL, PL and PI), Particle size distribution, Moisture absorption rate of sisal fiber, Moisture releasing rate of sisal fiber, Decomposition rate of sisal fiber, Compaction (moisture – density relationship), CBR and CBR swell, UCS were determined. The soil sample was collected from three test pits from adequate depth (1.5m – 2m) to avoid the intrusion of organic matter. Lime and sisal fiber collected from local market. The engineering properties of the sample from all the three sources were determined and stabilization held on relatively the weakest soil sample based on the CBR values. The stabilizing agents (lime and sisal fiber) mixed to soil sample separately and then combined to determine the combined effect at a point where maximum CBR values recorded by separate testing. The varying proportion of randomly distributed sisal fiber of 0.5%, 0.8% and 1.1% by dry mass of soil sample with a varying length of sisal fiber 5cm, 8cm and 11cm were added to expansive soil. And lime added at 1.5%, 2.5%, 3.5% and 4.5% by dry mass of soil sample were added and tested separately. 3.5% of lime was added to 0.8% of sisal fiber at varying length (5cm, 8cm, and 11cm) of the fiber and mixed to soil sample to determine the combined effect. The engineering properties of untreated soil sample from laboratory tests were determined as FSI, NMC, G_s, LL, PI, MDD, OMC, CBR, CBR swell and UCS were 94%, 41.77%, 2.73, 94.3%, 61.88%, 1.395g/cc, 29.7%, 1.035%, 8.45% and 149kPa respectively. Based on the test results the soil was classified as CH according to USCS and A-7-5(45) according to AASHTO soil classification system. At optimum combination of lime and SF (3.5% of lime, and 0.8% of SF at 8cm length), MDD determined as 1.387g/cc and OMC equals to 30.95%. CBR of treated sample were improved by 607.25% and CBR swell decreased from 8.45% to 0.72%. The uncured UCS of S1 was improved by 31.62% and by 83.72% and 151.62% for 7 and 21 days cured.

Keywords: *CBR; FSI; Decomposition rate; Expansive soil; lime; Sisal fiber; Soil stabilization*

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ACRONYMS

AS	Acetylation
MAS	Alkaline treatment followed by acetylation
AASHTO	American Association State Highway and Transport Organization
ASTM	American Society Test Material
CBR	California Bearing Ratio
DD	Dry density
DMSS	Dry mass of the soil sample
ERA	Ethiopian Road Authority
FSI	Free Swell Index
LC	Lime Content
LL	Liquid Limit
MAR	Moisture Absorption Rate
MDD	Maximum Dry Density
NF’s	Raw Sisal
NMC	Natural Moisture Content
NS	Natural Soil
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
SF	Sisal Fiber
S1	Soil Sample collected from Adventist Sefer
S2	Soil Sample collected from Stadium Sefer
S3	Soil Sample collected from Bahil Adarash Sefer
UCS	Unconfined Compressive Strength
UTM	Universal Transverse Mercator

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Safety and stability are the primary concern of engineers to design and construct any civil engineering structures. To attain this safety and stability requirements the engineering properties of the soil beneath the structure or on the structure must be identified. According to [1] Construction civil engineering structures such as highways, bridges, airports, seaports on expansive soil is highly risky in that such soil is susceptible to cycles of drying and wetting, inducing shrinkage and swelling behavior under foundations, which results in cracking to structural and none structural elements of those structures. Designing and constructing civil engineering structures on expansive soil is the most challenging task throughout the time.

Expansive soils are fine grained soil or decomposed rocks that show huge volume change when exposed to the fluctuations of moisture content. Swelling-shrinkage behavior is likely to take place near ground surface where it is directly subjected to seasonal and environmental variations. The expansive soils are most likely to be unsaturated and have dominantly montmorillonite clay minerals [2]. Expansive soil is one of the weak sub grade soils that is not favorable for road construction. Those soils are one of the most abundant soils in Ethiopia, which mostly creates problems on built of structure. This damage is due to moisture fluctuation caused by seasonal variation [3].

These problems need wider application of cost effective and environmentally friendly technology of improving soil properties to be customized or adopted to the current road construction trend in Ethiopia. According to, ERA manual proposes: Alignment improvement (avoiding the area of expansive soil), Excavation/soil replacement (replacing expansive soil with good quality material along the road route), Stabilization with stabilizing agent and Minimizing of water content change (implementing measure to prevent water infiltration) [3]. According to [4] there are many alternate methods available to handle the problem of expansive soils that include complete or part replacement of subgrade soil, in-place mechanical modification of soil with better soil, treatment with chemical or cementitious or polymeric stabilizers, providing geotextiles and recently mixing with synthetic and natural fibers.

Treating expansive soil using lime and Natural fiber (sisal fiber) reinforcement is the effective method to reduce swelling and plasticity and improve the strength.

Lime stabilization is the most commonly used method for controlling shrink-swell behavior of expansive soil due to seasonal variations. Lime reacts with expansive clay in the presence of water and changes the physio-chemical properties of expansive soil, which in turn alters the engineering properties of treated soil [2].

The natural fiber composites have attained a considerable attention for wide purposes in construction. Many cellulosic fibers like jute, banana, hemp, sisal, kenaf, bamboo etc were used for reinforcement because they have excellent strength, cheaper, low specific weight and also abundantly available in nature. Out of various bio fibers, sisal fiber is moderately inflexible, possess high specific strength, stiffness, ability to stretch, durability and offers resistance to deterioration in salt water. Sisal fiber is one of the least experimented natural fibers for soil reinforcement. Fiber reinforcement can be termed as a mechanical form of soil reinforcement. A soil may be referred as a fiber-reinforced soil, if it consists of discrete elements of fibers of specified lengths, randomly yet uniformly distributed through it, to improve its properties [5].

Soil treatment using Sisal fiber mixed with lime is an effective and economical method since both sisal fiber and lime are locally available and environmentally friendly materials. This paper focused on stabilization of expansive subgrade soil using sisal fiber mixed with lime.

1.2. Statements of the Problem

In worldwide it is headache for engineers to design and construct civil engineering structures on weak (expansive) soil. Expansive clays are characterized by excessive compression, collapse, low shear strength, low bearing capacity and high swell potential; [6], due to its volume change depending upon seasonal moisture variation. Such soils are unsuitable for road subgrade layer construction. It results in the failure of structures which built over it.

As weak (expansive) soil affect a large area in most part of Ethiopia, in case of Tarcha town, the problem is also common. One of the difficult challenges in construction of road project is constructing a road on weak sub grade/expansive soils. The pavement distresses like longitudinal cracking and failure, transverse cracking, high and low severity alligator cracking, rutting, depression and other types may be due to expansive soils exist in subgrade layer which make subgrade layer weak [3].

There are a number of techniques like mechanical stabilizations or chemical stabilization are available to improve the Engineering properties of expansive soil to make it suitable for construction. Researches on lime stabilization fails to improve the tensile resistance of the subgrade and rarely available researches on sisal fiber stabilization fails to improve the compressive resistance of the subgrade; the combined effect of lime mixed with sisal fiber fills this gap. This study attempts on the experimental result carried out to stabilize or improve the engineering property of the expansive soil by using Sisal fiber mixed with lime, which are locally available, environmentally friendly and economically feasible materials.

1.3. Research Questions

The major research questions are:

1. What are the engineering properties of expansive subgrade soil and physical properties of Sisal fiber?
2. What are the effects of Sisal fiber and lime on the strength of expansive subgrade soil?
3. What are the optimum amount of stabilizing agents compared to standard specifications?

1.4. Objectives

1.4.1. General objective

The general objective of this study is to stabilize the expansive subgrade soil by using Sisal fiber mixed with lime.

1.4.2. Specific objectives

1. To identify the engineering properties of expansive subgrade soil and physical properties of Sisal fiber.

2. To determine the effects of Sisal fiber and lime on the strength of expansive subgrade soil.
3. To determine the optimum amount of stabilizing agents compared to standard specifications.

1.5. Scope of the study

The scope of study is to stabilize expansive subgrade soil by using Sisal fiber mixed with lime depending on laboratory test. The laboratory tests conducted were; NMC, FSI, particle size distribution, Atterberg limits, Compaction test, CBR and CBR swell, UCS, moisture absorption rate of sisal fiber, moisture releasing rate of sisal fiber and decomposition rate of sisal fiber. The finding of the research is limited on selected expansive subgrade soil from Tarcha town, Dawro zone, Ethiopia. The soil samples were taken from three test pits at a bore depth of 1.5m-2m to avoid the intrusion of organic matters. Hydrated lime and sisal fiber were the stabilizing agents used in this investigation. The soil sample stabilized with lime and sisal fiber separately and the final stabilization was held on by mixing lime with sisal fiber. Based on previous literatures lime was added at 1.5%, 2.5%, 3.5% and 4.5% by DMSS and sisal fiber at 0.5%, 0.8% and 1.1% by DMSS at each sisal fiber length of 5cm, 8cm and 11cm. The combined effects of stabilizing agents were tested at 3.5% of lime mixed with 0.8% of sisal fiber at 5cm, 8cm and 11cm length of the sisal fiber which were the points where maximum CBR value was recorded at separate testing.

1.6. Significance of the study

The result of this research can be utilized by the road contractors willing to stabilize expansive subgrade soil by sisal fiber mixed with lime can use it simply by spreading the amount identified in this research paper and mixing with the expansive soil. Stabilizing expansive soil by sisal fiber mixed with lime is easier to apply and environmentally friendly. As sisal fiber is natural fiber and biodegradable and also lime is a natural material, there is no negative effect on the environment. The existence of sisal plant in excess amount and easier production of sisal fiber and local availability of lime makes the stabilizing agent economically feasible. And on the other hand, this research can be reference for those who wants to carry out further study with respect to expansive soil stabilization.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

The movement of people and goods throughout the world is primarily dependent upon a transportation network consisting of roadways. Most, if not all, business economies, personal economies, and public economies are the result of this transportation system. The surface of these roadways, the pavement, must have sufficient smoothness to allow a reasonable speed of travel, as well as ensure the safety of people and cargo [7].

Highway pavements are constructed of either asphalt or concrete and ultimately rest on native soil. The engineer must be familiar with the properties and structural characteristics of materials that will be used in constructing or rehabilitating a roadway segment. The engineer must also be familiar with methods and theories for the design of heavy-duty asphaltic and concrete pavements, as well as various treatment strategies for low-volume roads. Highway engineers are interested in the basic engineering properties of soils because soils are used extensively in highway construction. Soil properties are of significant importance when a highway is to carry high traffic volumes with a large percentage of trucks. They are also of importance when high embankments are to be constructed and when the soil is to be strengthened and used as intermediate support for the highway pavement. Thus, several transportation agencies have developed detailed procedures for investigating soil materials used in highway construction [8].

2.2. Expansive soil

Expansive soils, also known as black cotton soils, undergo swelling by absorbing water and shrinking by loss of moisture. Therefore, during summer when evaporation from the ground and transpiration due to vegetation exceeds the rainfall, the expansive soil dries up and moisture deficiency develops in the soil, giving rise to soil shrinkage. During the rainy season, the soil absorbs moisture and swells. Soils possessing the clay mineral Montmorillonite generally exhibit these properties. Expansive soils where necessarily cannot be used as a construction material without altering their properties suitably by some means [9].

Expansive soils contain minerals that are capable of absorbing water. They undergo severe volume changes corresponding to changes in moisture content. They swell or increase in their volume when they imbibe water and shrink or reduce in their volume on evaporation of water. Because of their alternate swelling and shrinkage, they result in detrimental cracking of lightly loaded civil engineering structures such as foundations, retaining walls, pavements, airports, side -walks, canal beds and linings. Due to these reasons expansive soils are generally poor material for construction. So to improve the engineering properties of soil, stabilization or reinforcement is done. Soil stabilization is the process of blending and mixing materials to improve engineering properties of soil like increasing shear strength, compressibility and permeability, thus improving load bearing capacity of a sub-grade to support pavements and foundations [10].

2.3. Distribution of expansive soil in Ethiopia

Expansive soils are found in the central, north western and eastern highlands of Ethiopia. In western lowlands around Gambella, and in some parts of the rift valley. Local deposits of these soils are also present throughout the country near rivers, water logged areas, and in drainage restricted localities. Damage caused by expansive clays is particularly prevalent around Addis Abeba [3].

2.4. Road Subgrade

The type of subgrade soil is largely determined by the location of the road. However, where the soils within the possible corridor for the road vary significantly in strength from place to place, it is clearly desirable to locate the pavement on the stronger soils if this does not conflict with other constraints. For this reason, the pavement engineer should be involved in the route corridor selection process when choices made in this regard influence the pavement structure and the construction costs. The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. Direct assessment of the likely strength or CBR of the subgrade soil under the completed road pavement is often difficult to make. Its value, however, can be inferred from an estimate of the density and equilibrium (or ultimate) moisture content of the subgrade together with knowledge of the relationship between strength, density and moisture content for the soil in question. This relationship must be determined in the laboratory. The density of the subgrade soil can be controlled within limits by compaction at a suitable moisture content at the time of construction. The moisture content of the subgrade soil is governed by the local climate and the depth of the water table below the road surface [11].

Road performance and its service life very much depend on the quality of its subgrade. Subgrade acts as foundation layer under all traffic and weather condition and assures uniform distribution traffic load in depth. For low-traffic volume roads, subgrade plays an important role, as stress magnitude from the vehicles is mainly distributed at the subgrade level. Weak subgrade subjected to swelling while contact with water and shows shrinkage cracks in dry condition. Unpaved low volume roads such as rural roads, access roads, and haul roads when constructed on weaker subgrade soils suffer problems like excessive rutting and mud pumping. Longitudinal ruts, waves, and undulation formed along the wheel path inflexible pavements are primarily due to the stresses from the heavy vehicles that are repeatedly transferred to the poor subgrade. These problems are also intensified by poor compaction quality of subgrade, unsatisfactory pavement thickness, and weak asphalt mixtures. Road structures built on soft subgrade also possess the low bearing capacity, slope instability, excessive lateral movement and settlement problem under imposed traffic load. These adverse effects of weak subgrade together with poor compaction quality make the road unusable for the traffic and if paved roads are built over it then higher pavement thickness is required [12].

2.5. Determining the Subgrade Strength

The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. Direct assessment of the likely strength or CBR of the subgrade soil under the completed road pavement is often difficult to make. Its value, however, can be inferred from an estimate of the density and equilibrium (or ultimate) moisture content of the subgrade together with knowledge of the relationship between strength, density and moisture content for the soil in question. This relationship must be determined in the laboratory. The density of the subgrade soil can be controlled within limits by compaction at a suitable moisture content at the time of construction. The eventual moisture content of the subgrade soil is governed by the local climate, the depth of the water table below the road surface, and the provisions that are made for both internal and external drainage [13].

The structural catalogue given in this manual requires that the subgrade strength for design be assigned to one of six strength classes reflecting the sensitivity of thickness design to subgrade strength. The classes are defined in table below. For subgrades with CBRs less than 2, special treatment is required.

Table 2. 1: Subgrade Strength Classes [13]

Class	CBR Range (%)
S1	<3
S2	3,4
S3	5,6,7
S4	8-14
S5	15-30
S6	>30

2.6. Stabilizing expansive (weak) subgrade soil

The stabilizing process involves the addition of a stabilizing agent to the soil, mixing with sufficient water to achieve the optimum moisture content, compaction of the mixture, and final curing to ensure that the strength potential is realized. Stabilization can enhance the properties of road materials and pavement layers in the following ways [13]:

i. A substantial proportion of their strength is retained when they become saturated with water. Surface deflections are reduced.
ii. Materials in the supporting layer cannot contaminate the stabilized layer.
iii. Layers above a stabilized layer can be compacted more effectively and thereby possess enhanced strength and elastic properties.
iv. Resistance to erosion is increased.
v. Lime-stabilized material is suitable for use as a capping layer or working platform when the in situ material is excessively wet or weak and removal is not economical.

Soil stabilization is used to reduce permeability and compressibility of the soil mass in earth structures and to increase its shear strength. Stabilization and its effect on soil indicate the reaction mechanism with additives, effect on its strength, improve and maintain soil moisture content and suggestion for construction systems. Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely mechanical stabilization and chemical stabilization. Mechanical Stabilization is the process of improving the properties of the soil by changing its gradation and chemical stabilization of expansive soil comprises of changing the physico-synthetic around and within clay particles where by the earth obliges less water to fulfill the static imbalance and making it troublesome for water that moves into and out of the framework so as to fulfill particular designing road ventures. In road construction projects, soil or gravelly material is used as the road main body in pavement layers. To have required strength against tensile stresses and strains spectrum, the soil used for constructing pavement should have special specification. Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil [14].

2.6.1. Subgrade stabilization methods

Soil stabilization can be achieved by crushing the natural soil, and mixing it with a particular chemical additive, then compacting the mixture. Under this process, soil stabilization depends mainly on the chemical reactions between the additive (i.e. lime, cement, fly ash, bitumen) and the soil to achieve the desired change [15].

The subgrade stabilization approaches include mechanical, cementitious and asphalt methods [16].

A. Mechanical Stabilization: Mechanical stabilization is used to enhance soil–particle interlock through
    - ✓ Compaction
    - ✓ Blending
    - ✓ Geo-synthetics

B. Cementitious Stabilization
    - ✓ Cement
    - ✓ Lime
    - ✓ Other Cementitious Stabilizers like Fly ash, cement kiln dust, lime kiln dust

2.7. Lime as soil stabilizing material

Lime-treated soils have been used as materials in pavement and sub-base construction. The stabilization of expansive soils by lime has been widely used to improve the mechanical and physical properties of the soil. For the improvement of the mechanical properties of expansive soils, the use of lime with sea water as a stabilizer has given good results [17].

Lime provides an economical way of soil stabilization. The method of soil improvement in which lime is added to the soil to improve its properties is known as lime stabilization. The types of lime used to the soil are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, dolomite lime. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction. In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes. Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds. The effect can be brought by either quicklime, CaO or hydrated lime, Ca(OH) [14].

Lime addition shows many advantageous effects on the engineering properties of clayey soil that included strength improvement via long-term pozzolanic reactions, preventing the swelling and shrinkage problems associated with clayey soil, workability improvement etc. An additional benefit of using lime is its low cost and simplicity of construction, full-scale utilization unsuitable in situ soil [12].

2.8. Sisal fiber as soil reinforcement

Sisal is a fiber obtained from the leaves of the plant Agave Sisalana. A native of Mexico, it is now maintained and cultivated in East Africa, Brazil, Haiti, India mainly in Assam and Indonesia [18].

Sisal fiber is a natural biodegradable waste, it is available in abundance and at very low cost so it can be used as a reinforcing material that will increase the soil properties and reduces the disposal problem. The exceptional properties of Sisal such as its unique chemical composition, slow degradation rate, high tensile strength, thermal insulation, elastic recovery, scaly surface, and unique interactions with water and oils, has led to many diverse uses. Recently soil reinforcement with short, discrete, randomly oriented fibers is getting more attention from many researchers around the world [19]. The major reasons trailing for the use of natural fibers (NF's) as a reinforcement are low cost, medium or high strength, great adaptability, high stiffness, recyclability, high degree of flexibility, less energy expenditure, low health risk and low abrasiveness as compared to synthetic fibers. Natural fibers suffer some limitations such as being hydrophilic in nature [20].

Sisal is the lignocellulosic plant which is found in America, Africa, and Asia. A sisal plant produces 200-250 leaves before flowering and its leaves contain approximately 700-1400 fiber bundles which are about 0.5-1.0m. The sisal fiber constitutes of 65.8% cellulose, 12% hemicellulose, 9.9% lignin, 0.3% wax, and some water soluble compounds. In recent years the sisal fiber are used in many applications like making ropes, carpet, twines, mats, and handicraft articles beside this it is also used in making composites and in biogas production. Due to its good tensile strength, it is used to make composite with different polymers which increase the strength of the polymers. As the sisal fiber is cheap, biodegradable and eco-friendly; in present days it is used in many areas. Currently, plenty of research focused on the potential of sisal fibers reinforced composites. For using the fiber composites in many applications it is necessary that it had some mechanical properties like it should have flexibility, good tensile strength, and should have less wear property. As from the previous research it had been shown that the fiber increases the toughness of polymer than increasing the strength and modulus, and it is noted that sisal fiber composite had maximum toughness than other fiber i.e., approximately 1250 MN/$m^2$and its strength is 580 MN/m^2 [21].

Figure 2. 1: Photos of Sisal Plant and Sisal fiber [22].

Table 2. 2: Physical properties of Sisal Fiber (Extraweave Company, Alappuzha) [22].

Physical property of Fiber	**Value**
Color	White
Average diameter (mm)	0.25
Average tensile strength (N/mm^2)	405.9
Density (g/cc)	1.45
Unit weight (Kg/m^3)	962
Specific gravity	0.962

Table 2. 3: Chemical composition of Sisal fiber [22]

The components of sisal fiber	% by weight
Cellulose	55-65
Hemi-cellulose	10-15
Pectin	2-4
Lignin	10-20
Water soluble materials	1-4
Fat and wax	0.15-0.3
Ash	0.7-1.5

2.9. Surface Treatments on Sisal fiber

Due to their hydrophilic nature of natural fibers, natural fibers have high moisture absorption. Sisal fibers are characterized by low density, high tenacity, and high moisture absorbency. The moisture absorption of sisal is profoundly subject to the chemical constituents of the fibrils [18]. Listed the major chemical components of some of the natural fibers. Accordingly, sisal fiber is mainly composed of 65% cellulose, 12% hemicellulose, 9.9% lignin, and 2% waxes. The main drawback of natural fibers as reinforcement is their higher water absorption due to its hydrophilic properties. Cellulose and hemicellulose are the primary components responsible for high moisture absorption. Cellulose is a linear polysaccharide with long chains containing primary hydroxyl in a methyl group (–CH2OH) and secondary hydroxyl groups (–OH) both of which are hydrophilic and are capable of forming hydrogen bonding with other cellulose units and water molecules. There are several chemical and physical modification techniques to enhance physical, mechanical, and process performance properties. Selective removal of non-cellulosic compounds constitutes the main objective of all fiber chemical treatment methods. Among modifications is alkaline treatment. Alkali treatment is the treatment of natural cellulosic fibers with hydroxides such as NaOH or KOH to improve surface roughness, strength, and wettability. It is capable of making the hydroxyl groups of cellulose more reactive by removing impurities and making hydroxyl groups more accessible. Alkaline treatment improves the fiber surface adhesive characteristics by removing the natural and artificial impurities from the surface of natural fibers. As a result of the removal of impurities, the fiber surface becomes more uniform and thus stress transfer capacity between the ultimate cells improves. In addition to this, it reduces the fiber diameter and thereby increases aspect ratio, which results in better fiber interfacial adhesion. Acetylation is another fundamental surface modification technique. It involves surface treatment of natural fibers with acetic anhydride, which assumes the substitution of the hydroxyl group of cellulose with acetyl groups and makes the fibers more hydrophobic. During acetylation, full esterification of all the hydroxyl groups takes place, which results in the substitution of hydroxyl groups of cellulose by acetyl ones, removal of non-crystalline constituents and alteration of surface topology all of which contribute to an improved stress transfer at the fiber–matrix interface. The AS (Acetylation) had a decreased moisture absorption by about 42%, and MAS (Alkaline treatment followed by acetylation) by 28%, in comparison to RS (raw sisal). This confirms the enhancement of hydrophobicity of sisal fiber due to the replacement of hydroxyl groups of the cellulose by hydrophobic acetyl components as a result of acetylation [23].

The alkali treatment removed most of the non-cellulosic components like pectin and hemicelluloses, and the chemical treatment using potassium hydroxide (KOH) exhibited higher tensile strength than those of sodium hydroxide (NaOH) treated ones. The potassium permanganate (KMnO4) treatment of many fibers imparted improved mechanical properties [20].

2.9.1. Tensile strength of treated and untreated sisal fiber

The plot of tensile strength with number of days (using 3 strands sisal fiber) on the natural and treated sisal fiber is shown in Fig. below. The untreated SF recorded higher strength than the treated sisal fiber after been buried in lateritic soil for a period of 28 days beyond which the difference is marginal. The possible reason for the differences in strength could be due to the removal of the cellulose present in the sisal fiber by Sodium Borohydride. The tensile strength for the untreated SF decreased from it natural value of 30.60 $^{N}/_{mm^2}$ to 15.57 $^{N}/_{mm^2}$ after 7 days and 5.03 $^{N}/_{mm^2}$ after 90 days. The tensile strength for the treated sisal fiber on the other hand decreased from 27.31 $^{N}/_{mm^2}$ to 13.25 $^{N}/_{mm^2}$ after 7 days and maintains its steady strength for the next 60 days before it decreased to a value of 3.15 $^{N}/_{mm^2}$ after 90 days. Result shows that the sisal fiber maintained a steady strength for long time as a result of treatment with Sodium Borohydride [24].

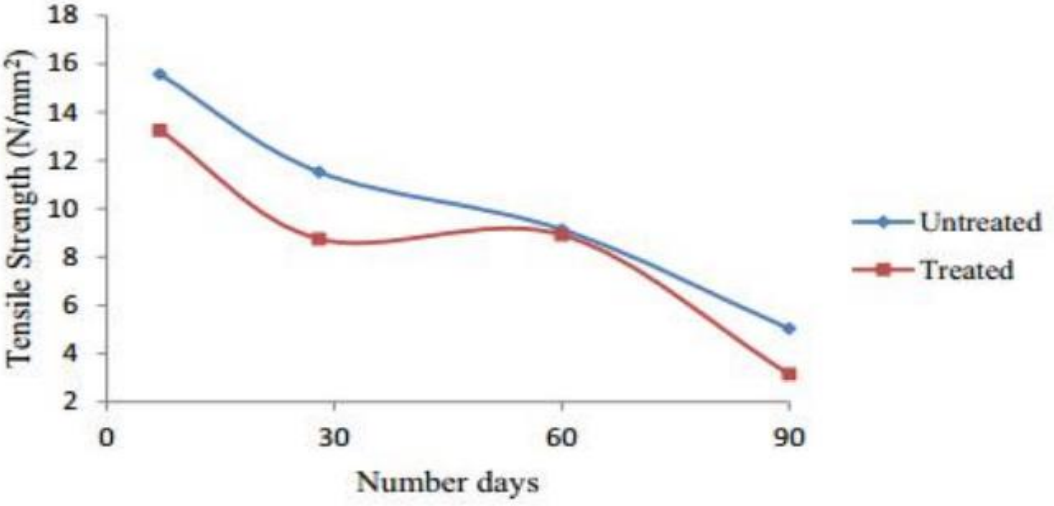

Figure 2. 2: Variation of tensile strength with days for untreated and treated SF [24].

Soil stabilization is the most common ground improvement technique adopted to improve problematic soil properties. Soil stabilization is the most common ground improvement technique adopted to improve problematic soil properties.

CHAPTER THREE

METHODOLOGY

3.1. Study Area

The soil sample was took from Tarcha town which is the administrative center of Dawro zone. Dawro (or Dawuro) is a zone in the South West Region of Ethiopia. It is located between 6°35’ to 7°34’ N latitude and 36°04’ to 37°53’ E longitudes. Dawro belongs to Northern Ometo cluster in the Omotic family [20]. Dawro is located at about 500km southwest of Addis Ababa, the capital of Ethiopia. Dawuro is bordered on the south by Gamo Gofa Zone, on the west by the Konta zone, on the north by the Gojeb River which defines its boundary with the Oromia Region, Jimma zone, on the northeast by Hadiya and Kembata Tembaro Zones, and on the east by Wolayita Zone; the Omo River defines its eastern and southern boundaries. The administrative center of Dawuro was Waka before it was transferred to Tarcha [26].

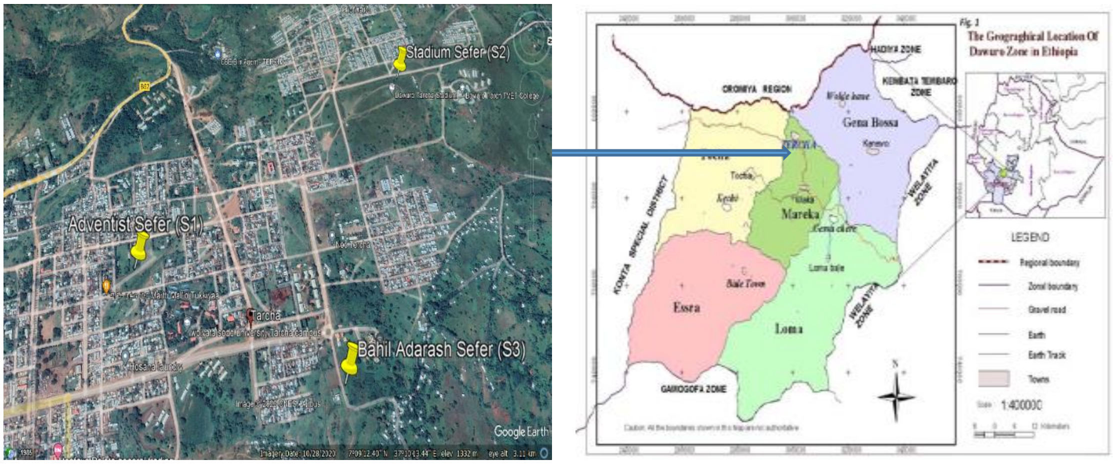

Figure 3. 1: Administrative map of Dawuro [27].

3.2. Study Design

The study followed the experimental type of study which begun with collecting samples, preparation of samples for each laboratory tests, finding out maximum replacement amount of sisal fiber mixed with lime that satisfies requirement of the standard specification and stabilization of the expansive soil by improving its engineering properties.

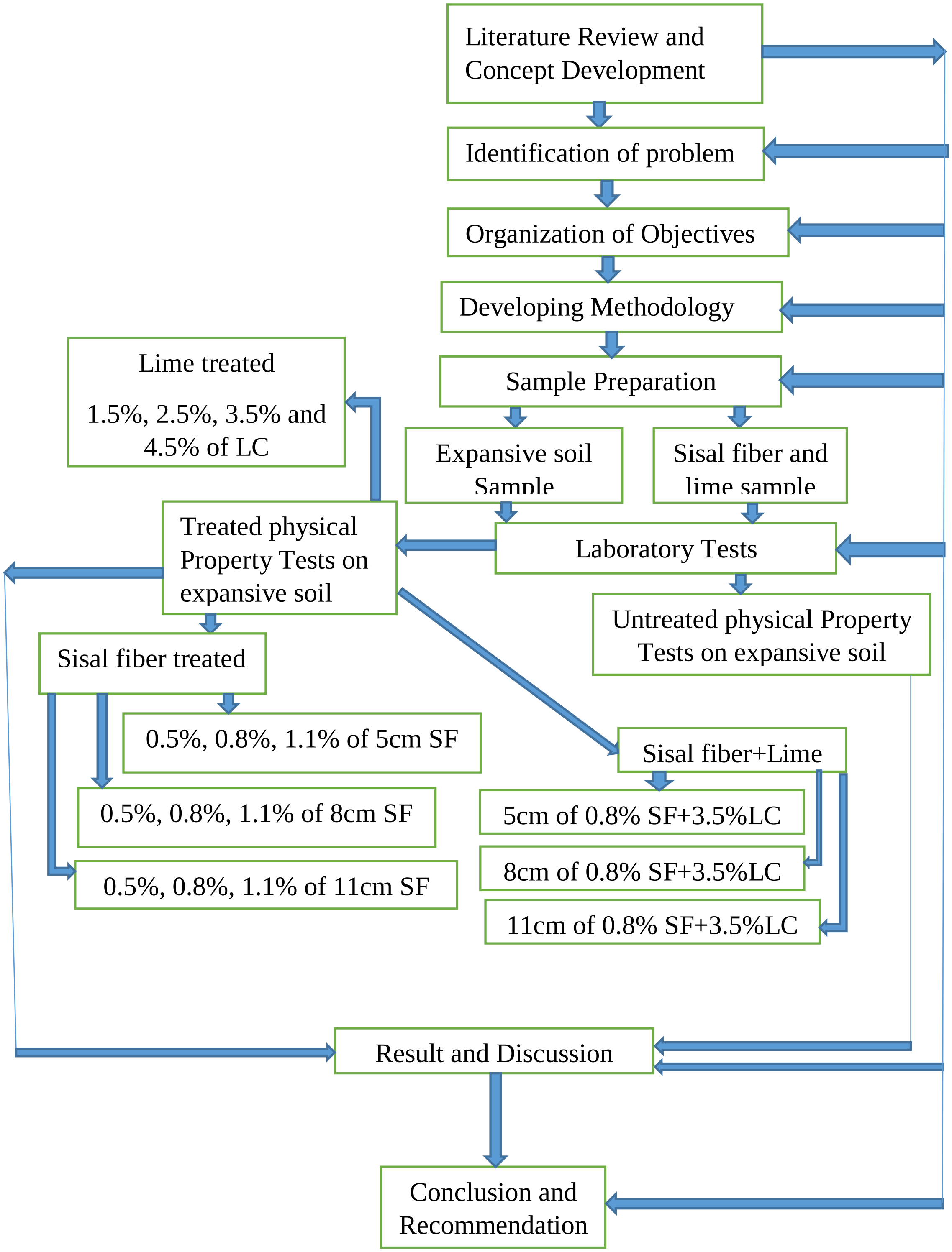

Figure 3. 2: Study Flow Chart

3.3. Materials

3.3.1. Expansive soil

The expansive soil sample for this study was collected from Tarcha town from three test pits (Adventist Sefer (S1), Stadium Sefer (S2) and Bahil Adarash Sefer (S3)). The sampling area for expansive soil was identified by the recommendation of "Transnational Engineers Plc"; consultant of "Design and Build of Tercha-Weldehane-Omonada Junction Road Project". S1 was collected from UTM zone 37, Easting=298125, Northing=790557, altitude=1353m; S2 from UTM zone 37, Easting=297192, Northing=791737, Altitude=1333m and S3 from UTM zone 37, Easting=298287, Northing=791387, Altitude=1309m. The disturbed sample was picked along the soil profile at the depth of 1.5m-2m to avoid the intrusion of organic matter. Preliminary checks indicated that the soil was grayish black in color and high cracks are observed.

(a) Photo captured by cell phone (b) Photo captured by cell phone

Figure 3. 3: (a) and (b) shows the site appearance of the soil

(a) Digging the soil sample (b) The bore depth

Figure 3. 4: (a) and (b) shows the depth of test pit

The soil sample is damp when received from the field. It left to air dry until it comes friable under a trowel. Then thoroughly braked up the aggregation in such a manner as to avoid reducing the natural size of individual particles. The representative pulverized sample was sieved over 4.75mm sieve in adequate quantity according to AASHTO designation.

3.3.2. Lime

Hydrated lime was collected from local market. The lime sample was prepared by sieving the representative sample over no_200 sieve with due care to avoid flocs formed if there exist any. Lime added to an expansive soil at ranges of 1–10% [28]. The potential of lime at different lime percentages (3, 5, 7 and 9%) was checked on strength and bearing capacity improvement of subgrade soil [12], lime needed for maximum modification of the soil is normally between 1% and 3% lime by weight However, other studies reported the use of lime between 2% and 8% in soil stabilization [29]. Based on previous literature hydrated lime added by 1.5%, 2.5%, 3.5% and 4.5% of dry mass of soil sample and mixed to have uniform mixture.

3.3.3. Sisal fiber

Sisal fiber used in this study was collected from local market. The fiber sample was washed and air dried to avoid surface impurities and prepared by chopping it in to 5cm, 8cm and 11cm in required quantity. According to [30] Soil stabilization was done with the addition of sisal fiber with varying percentages of sisal fiber are 0.2%, 0.5%, 0.9% and 1.2% with varying lengths of sisal fiber are 3cm, 3.2cm and 3.4cm length at the interval of 0.2cm. According to previous scholars; 0.25%, 0.5%, 0.75% and 1% of sisal fibers by weight of raw soil with four different lengths of 10, 15, 20 and 25 mm to reinforce a local problematic soil [31]. Sisal fibers were cut into different lengths (0.5, 1 and 1.5 cm) and mixed with the soils at different percentages (0.25, 0.5, 0.75, 1, and 1.25%) [5]. The sisal fiber content increased from 0.25 to 0.5, 0.75 and 1.0% by dry weight of soil [24]. Based on the previous literature sisal fiber is chopped in 5cm, 8cm and 11cm in length and mixed with soil sample by 0.5%, 0.8% and 1.1% of dry mass of soil sample.

3.4. Study Variables

There are two type of study variables. Which are dependent variables and independent variables.

3.4.1. Dependent Variable

Dependent variable is the engineering properties of expansive subgrade soil treated (stabilized) with sisal fiber mixed with lime.

3.4.2. Independent variable

The independent variable of this research is engineering properties of untreated subgrade Soil (particle size distribution test, free well potential, Water content, LL, PL, PI, MDD, OMC, CBR, and UCS) and percentage of Sisal fiber and lime.

3.5. Sampling technique

The samples are collected by following purposive sampling technique. Test pits were taken based on visual inspection. The disturbed sample were collected at desired amount from adequate depth (1.5m-2m) to avoid the intrusion of organic matter in to a soil sample. Lime and sisal fiber sample were collected based on desired amount from local market.

3.6. Laboratory tests

The tests were performed on expansive subgrade soil before and after treating it with Sisal fiber mixed with lime.

3.6.1. Untreated engineering property tests on soil sample

a. Natural Moisture content

According to the standard test procedure of AASHTO T265 natural moisture content test was conducted for natural soil.

b. Differential Swell index

Differential swell index measures the expansive potential of cohesive soils. The test conducted by pouring 10 cubic centimeters of the dry soil sample passing sieve No. 40 into a 100 cubic centimeters graduated measuring cylinder and pouring water in first cylinder and kerosene in second cylinder to the level of 100 cubic centimeter and letting the content stand for approximately 24 hours until all the soil ultimately settles on the bottom of the graduating cylinders. Then the final volume of the soil is noted.

The free swell value is calculated as:

Free swell (%) =$\frac{V_w - V_k}{V_k} * 100$……………………………..Equation 3.1

Where $V_w = final\ reading\ after\ 24\ hours, V_k = intial\ reading$

Figure 3. 5: Photo of Differential swell index

c. Specific gravity

Specific gravity is defined as the ratio of the unit weight of a given material to the unit weight of water. Most of the values fall within a range of 2.6 to 2.9 [32]. The test is conducted by Test method- ASTM D 854-83 testing procedure.

Figure 3. 6: Specific gravity test

d. Textural classification

Texture of soil refers to its surface appearance. Soil texture is affected by the size of the individual particles present in it. Natural soils are combinations of particles from several size groups. In the textural classification system, the soils are named after their principal components, such as sandy, clay, silty clay, and so forth.

i. Wet sieve analysis

Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings. When cohesive soils are analyzed, breaking all the lumps into individual particles may be difficult. Therefor the soil mixed with water to make a slurry and then washed through the sieve. Portions retained on sieve are collected and oven-dried before the mass retained on each sieve is measured [32]. The test is conducted by the following procedure of Test Method- ASTM D 422 on natural soil sample.

Figure 3. 7: Soil sample soaked for wet sieve analysis

e. Atterberg Limit

When clay minerals are there in fine-grained soil, the soil can be remolded in the presence of some moisture without crumbling. This cohesive character is caused by the adsorbed water surrounding the clay particles. In the early 1900s, a Swedish scientist Atterburg developed a method to describe the consistency of fine-grained soils with varying moisture contents. At very low moisture content, soil act as more like a solid. When the moisture content is extremely high, the soil and water may flow like a liquid. Hence, depending on the moisture content, the behavior of soil can be divided into four basic states solid, semisolid, plastic and liquid. The moisture content, in percent, at which the transition from solid to semisolid state takes place, is defined as the shrinkage limit. The moisture content at the position of transition from semisolid to plastic state is the plastic limit, and from plastic to liquid state is the liquid limit. These parameters are also known as Atterburg limits. This limit describes the plasticity and consistency of fine grained soils with varying degrees of water content. For the portion of soil passing 425mm (no 40) sieve, the moisture content is varied to determine the three stages of soil behavior in terms of consistency. These stages are generally known as liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) of soils.

i. Liquid Limit

The transition state from the liquid state to a plastic state is called the liquid limit. At this stage all soils possess a certain small shear strength [33]. The test is conducted based on test procedures of AASHTO T 89-96.

Figure 3. 8: Soaking and mixing soil sample respectively for LL and PL

ii. Plastic Limit

The transition from the plastic state to the semi solid state is termed as the plastic limit. The plastic limit is defined as the moisture content in percent, at which the soil crumbles when rolled into threads of 3.2mm (1/8 in.) in diameter. The plastic limit is the lower limit of the plastic stage of the soil [32, 33]. Test is conducted by the following procedure of AASHTO T90-96 Test Method.

Table 3. 1: The plasticity index in a qualitative manner classified as follows by [32].

PI	**Description**
0	Non-plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
>40	Very high plasticity

Figure 3. 9: PL test and data recording

iii. Plastic Index

Plasticity index indicates the degree of plasticity of a soil. The greater the difference between Liquid and plastic limits, the greater is the plasticity of the soil. Clays are highly plastic and possess a high Plasticity index. The greater the plasticity index means that the soil is more plastic, compressible and the greater volume change characteristic of the soil [33].

f. Moisture Density Relationship

Compaction is the densification of a soil by the expulsion of air and the rearrangement of soil particles. Compaction increases the strength, lowers the compressibility, and reduces the permeability of a soil by rearranging its fabrics. The soil fabric is forced into denser configurations by the mechanical effort used in the compaction [34]. The test is conducted by AASHTO T99-95 testing procedures.

Figure 3. 10: Compacting and trimming soil sample

g. California Bearing Ratio

Test is conducted according to AASHTO T193 procedure. The CBR test taken in this research is socked CBR test.

Figure 3. 11: Sample prepared for soaking and penetration reading

h. Unconfined compression test

The unconfined compression test is a special case of a triaxial compression test which carried out only on saturated samples which can stand without any lateral support. The test, is therefore, applicable to cohesive soils only. The UCS is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils [33]. The test was carried out by AASHTO T208-92.

Figure 3. 12: Unconfined compression test

3.6.2. Physical property test on sisal fiber

a. Water absorption rate

Water sorption during soil burial was determined gravimetrically [35]. Gravimetry is a method that consists in doing measurements relating of the weight intensity [36].

Figure 3. 13: Measuring and soaking the sample to determine absorption rate

b. Decomposition rate of sisal fiber

The biodegradation rate of sisal fiber composites was found by evaluating the weight loss before and after soil burial test. Out of various bio fibers, sisal fiber is moderately possess high specific strength, stiffness, ability to stretch, durability and offers resistance to deterioration in salt water [37]. The degradation of sisal fiber was calculated as;

% of weight loss = $\frac{W_f - W_i}{W_i} * 100$ where $W_f = final\ weight\ after\ burial\ and\ W_i = intial\ weight\ before\ burial$

Figure 3. 14: Burying the sample to determine decomposition rate

3.6.3. Treated engineering property of soil sample

a. Moisture density relationship

The test is conducted by AASHTO T99-95 testing procedures.

Sisal fibers were cut into different lengths (0.5, 1 and 1.5 cm) and mixed with the soils at different percentages (0.25, 0.5, 0.75, 1, and 1.25%) [5]. The sisal fiber content increased from 0.25 to 0.5, 0.75 and 1.0% by dry weight of soil [24]. Based on the previous literature sisal fiber is chopped in 5cm, 8cm and 11cm in length and mixed with soil sample by 0.5%, 0.8% and 1.1% of dry mass of soil sample.

Lime added to an expansive soil at ranges of 1–10% [28]. The potential of lime at different lime percentages (3, 5, 7 and 9%) was checked on strength and bearing capacity improvement of subgrade soil [12], lime needed for maximum modification of the soil is normally between 1% and 3% lime by weight However, other studies reported the use of lime between 2% and 8% in soil stabilization [29]. Based on previous literature hydrated lime added by 1.5%, 2.5%, 3.5% and 4.5% of dry mass of soil sample and mixed to have uniform mixture.

Figure 3. 15: Sisal fiber chopped in 5cm, 8cm and 11cm

Figure 3. 16: Mixing samples uniformily

b. California bearing ratio

Test is conducted according to AASHTO T193 procedure. The length of sisal fiber and ratio of sisal fiber and lime is similar to that explained in moisture density relationship.

Figure 3. 17: Recording swell and penetration data

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

In this chapter; the result of laboratory tests on natural soil sample; sisal fiber; as well as stabilized soil sample and discussion to the result of the laboratory tests are presented.

4.2. Laboratory test results on natural soil

The soil samples were collected from three pits; Adventist Sefer (S_1), Stadium Sefer (S_2), Bahil Adarash Sefer (S_3). Here S_i assigned to show the locations of the samples for ease calculation. "S" stands for "soil sample" and "i" for locations from which the soil samples were collected. The experimental data and analysis results of laboratory tests were presented in Appendix A in tabular and graphical presentation. The summary of test results and explanations are shown as follow.

Table 4. 1: Summary of engineering properties of untreated soil samples

SL.N0	Properties	source of sample		
		S1	S2	S3
1	Natural moisture content (%)	41.77	36.75	34.15
2	Specific gravity	2.73	2.71	2.70
3	Free swell index (%)	94	83	71
4	% finer than 0.075mm	97.95	95.43	91.38
5	Liquid limit (%)	93.20	88.00	84.80
6	Plastic limit (%)	31.32	30.11	29.35
7	Plasticity index	61.88	57.89	55.45
8	**Classification** AASHTO USCS	 A-7-5(45) CH	 A-7-5(43) CH	 A-7-5(39) CH
9	Maximum dry density(g/cc)	1.395	1.46	1.4955
10	Optimum moisture content (%)	29.7	27.71	24
11	CBR (%)	1.035	1.49	1.66

12	CBR swell (%)	8.45	6.60	5.83
13	UCS (kPa)	149	-	-
14	Color	Black	Black	Black
15	Rating as subgrade material	Very poor	Very poor	Very poor

The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content [13]. From table 4.1 the CBR values of soil sample from three test pits were less than 3% and CBR swell of three soil samples were greater than 3%. Therefore the material (soil sample) was rated as very poor subgrade material which needs stabilization to improve its engineering properties.

4.2.1. Particle size distribution

In this study, wet sieve analysis for coarse grained soils and hydrometer analysis for fine-grained soils was used.

Table 4. 2 : Particle size distribution

Grain size		Soil samples		
		S1	S2	S3
Coarser material	Gravel (75mm-2mm) in %	0	0	0
	Sand (2mm-0.075) in %	2.05	4.57	8.62
Finer material	Silt (0.075mm-0.002mm) in %	30.48	31.58	26.64
	Clay (<0.002mm) in %	67.47	63.85	64.74

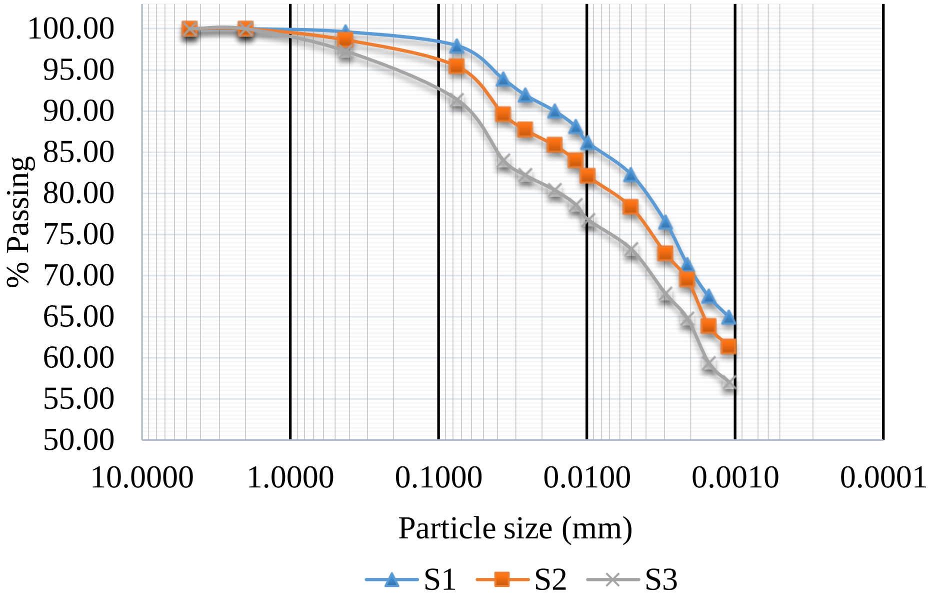

Figure 4. 1: Particle size distribution curve of samples S1, S2 and S3

From the wet sieve analysis test 97.95%, 95.43% and 91.38% of S1, S2 and S3 soil samples respectively were identified finer than sieve no_200 and the clay content of the soil sample from the three test pits were identified greater than 50% from hydrometer analysis. Therefore the soil samples were clayey soil.

4.2.2. Atterberg limits

The water contents at which the soil changes from one state to the other are known as consistency limits or Atterberg's limits. The consistency limits are very important properties of fine grained soils. LL is the water content at which the soil changes from liquid state to plastic state at which clay possesses small shearing strength. PL is the water content below which the soil stops behaving as a plastic material; at this water content the soil loses its plasticity and passes to a semi-solid state. PI is the range of water content over which the soil remains in the plastic state [38].

Table 4. 3: Atterberg limits

Atterberg limits	Soil samples		
	S1	S2	S3
LL	93.2	88	84.8

PL	31.32	30.11	29.35
PI	61.88	57.89	55.45

From the Atterberg limits test, the soil samples from all the three sources possesses the plasticity index value greater than 50%. Therefore the soil samples were identified as highly plastic.

4.2.3. Soil classification

A. Unified soil classification system (USCS)

USCS uses both particle size analysis and plasticity characteristics of soil to classify the soil. If more than 50% of the soil is retained on no_200 sieve, it is designated as coarse grained soil unless fine grained soil [38]. Here the plasticity chart was used to determine the type of soil.

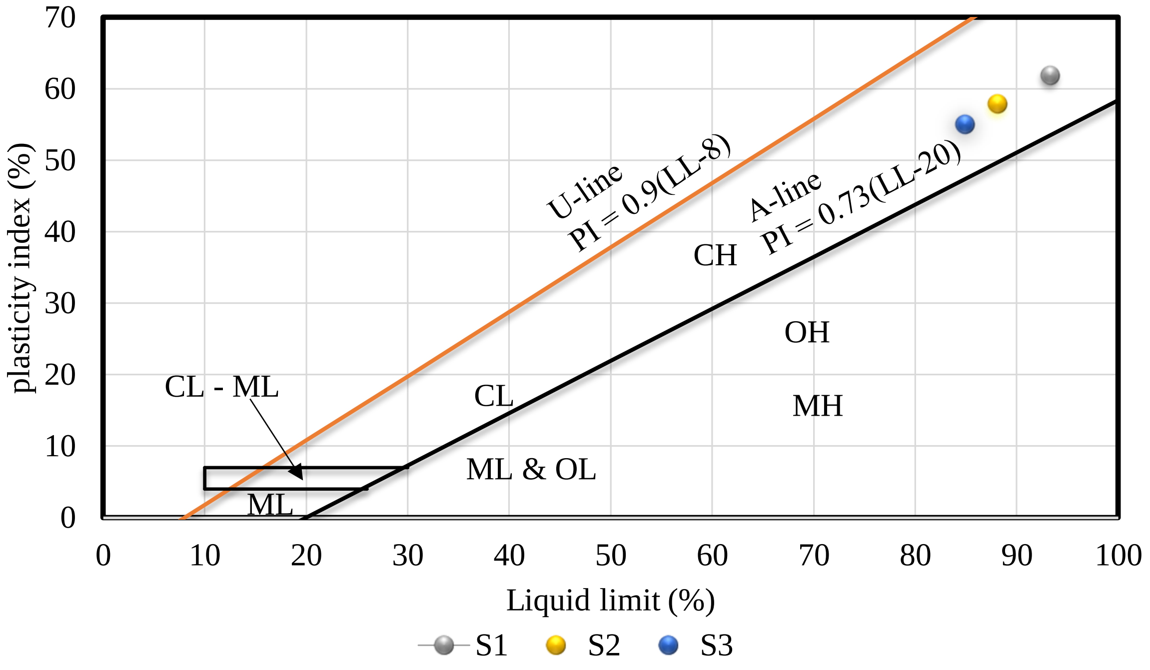

Figure 4. 2: Soil classification according to USCS

The figure 4.2 shows that all the samples from three test pit lies above A-Line; that shows all the samples are classified as high plasticity clay (CH).

B. AASHTO soil classification system

To classify a soil, its particle size analysis is done, and the plasticity index and liquid limit are determined.

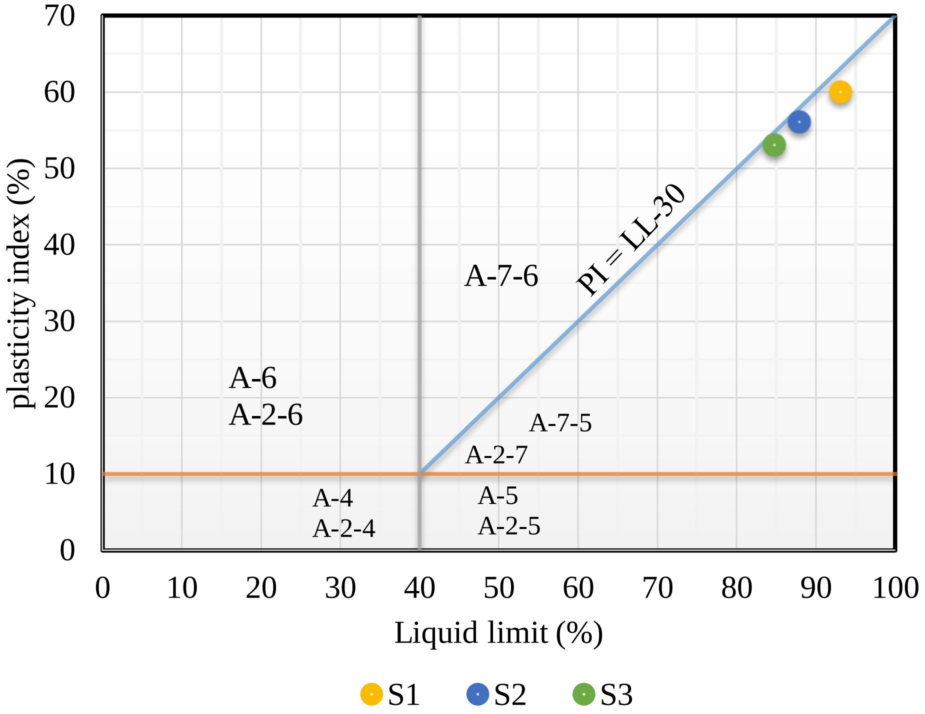

Figure 4. 3: Soil classification according to AASHTO

From laboratory test data analysis the soil samples from all the three test pits are classified as A-7-5 according to AASHTO soil classification by using plasticity chart.

97.95% of the soil sample S1 is finer than 0.075mm with LL of 93.2% and GI of 45, 95.43% of the soil sample S2 is finer than 0.075mm with LL of 88% and GI of 43 and 91.38% of the soil sample S3 is finer than 0.075mm with LL of 84.8% and GI of 39. According to Muni Budhu [34], the particle finer than sieve no. 200 is more than 50% and also LL is greater than 50%. Based on USCS, all the soil samples S1, S2 and S3 were classified as CH. Based on AASHTO soil classification system the sample S1 is classified as A-7-5(45), S2 classified as A-7-5(43) and S3 classified as A-7-5(39). Therefore all the materials S1, S2 and S3 were rated as poor to use as subgrade material and needs treatment to improve their engineering property.

4.2.4. Specific Gravity

Specific gravity is defined as the ratio of the unit weight of a given material to the unit weight of water. The specific gravity of soil solid values fall within a range of 2.6 to 2.9 [32].

Table 4. 4: Specific Gravity

Soil samples	S1	S2	S3
Average specific gravity	2.73	2.71	2.70

4.2.5. Free swell index

Free swell tests were conducted for all soil samples from three test pits and detected that all the samples were highly expansive. Sample S1 was recorded as more expansive relative to the others.

Table 4. 5: Free swell index

Soil samples	S1	S2	S3
Free swell index (%)	94	83	71

4.2.6. Natural moisture content

Disturbed soil samples were collected with due care in plastic bags not to lose natural moisture and tests were conducted.

Table 4. 6: Natural moisture content

Soil samples	S1	S2	S3
Natural moisture content (%)	41.77	36.75	34.15

4.2.7. Compaction test

Compaction is the densification of soil by removal of air. The laboratory test result of the soil samples are shown in the chart below.

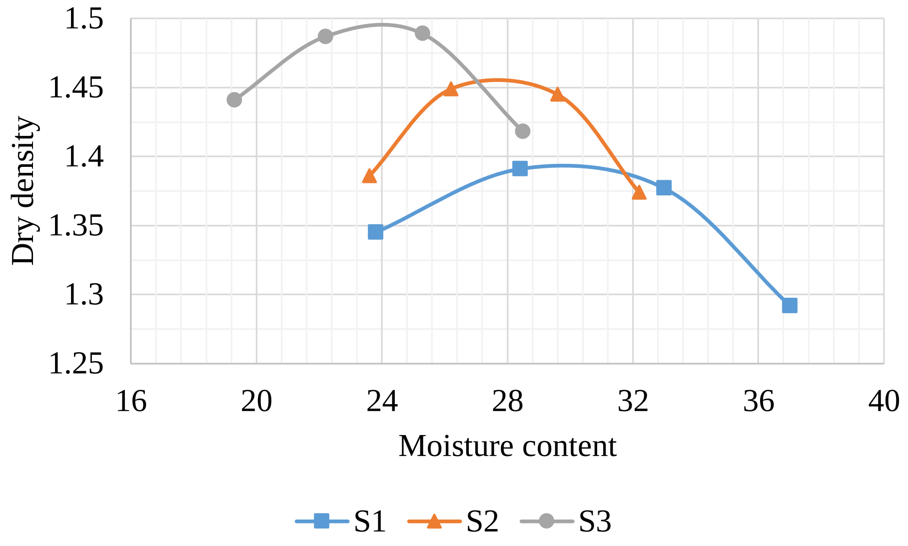

Figure 4. 4: Moisture density relationship

From the figure 4.4, soil sample S1 possesses relatively the smallest value of maximum dry density with the highest optimum moisture content. As maximum dry density increases, the materials ability to resist the overcoming load. Therefore sample S1 was relatively the weakest material.

4.2.8. CBR test

California bearing ratio test is a test from which the subgrade class of the material could be detected. As the value of CBR increase the quality of the material also increase.

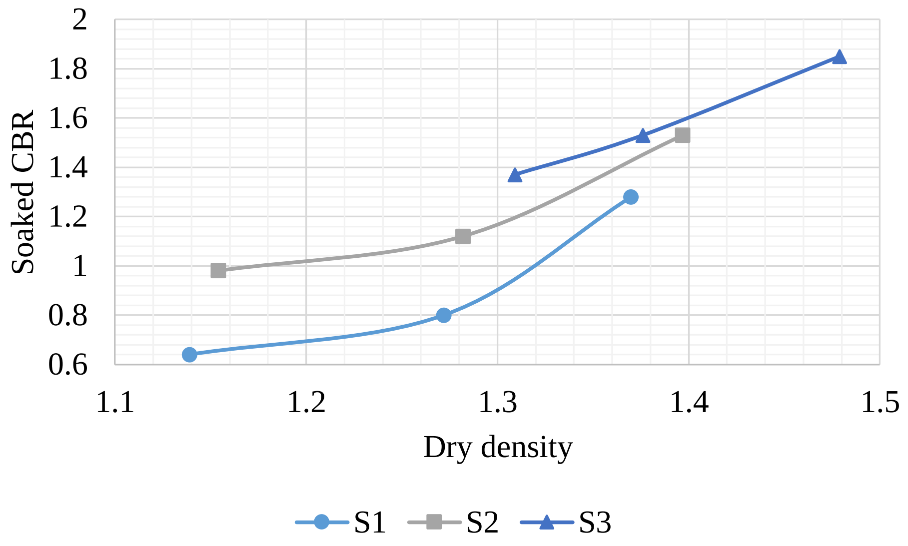

Figure 4. 5: Dry density Vs Soaked CBR

At 95% of maximum dry density the CBR Value of sample S1, S2 and S3 was recorded as 1.035%, 1.46% and 1.57% respectively. All the samples were very weak and not recommended as subgrade material as their CBR values were less than 3%. The materials were graded as very poor material. From the three samples, sample S1 was relatively the weakest material.

4.2.9. CBR swell test

The values of CBR swell shows the expansiveness of the soil material and poor quality. If CBR swell value exceeds 3%, the material is not recommended as subgrade material.

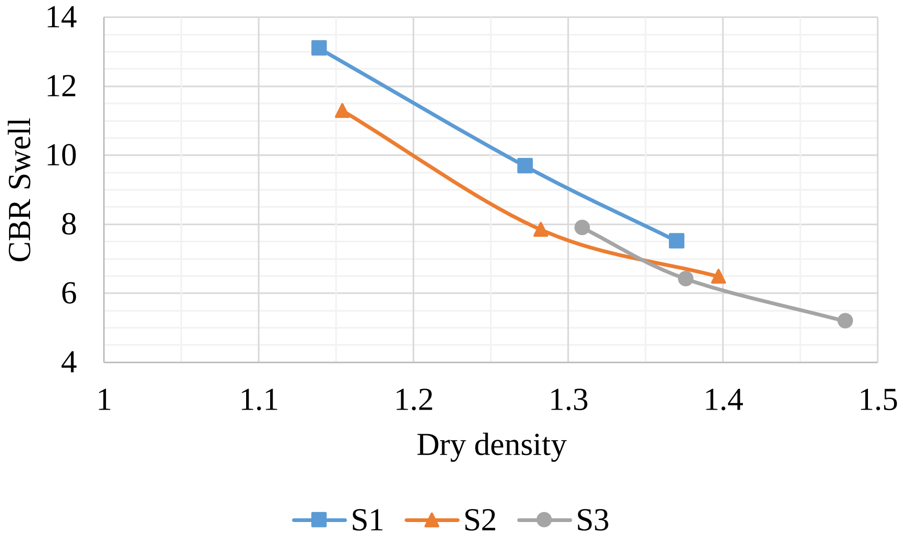

Figure 4. 6: Dry density Vs CBR swell curve

At 95% of MDD, the CBR swell value of sample S1, S2 and S3 was recorded as 8.47%, 6.7% and 6.22% respectively. All the values were greater than 3%. This shows that the materials were highly expansive material with poor quality to use as subgrade material. Relatively sample S1 was the poorest material.

4.3. Laboratory test result on physical properties of sisal fiber

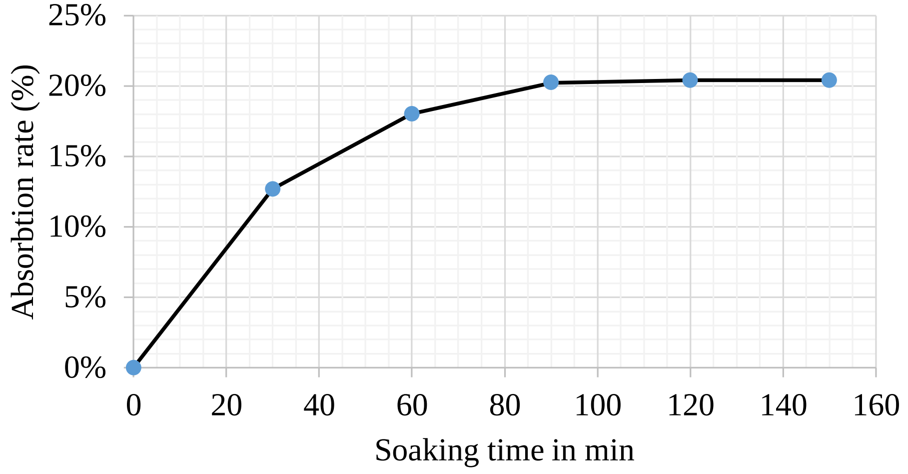

Figure 4. 7: Moisture absorption rate of sisal fiber

The SF was soaked for 150 minutes. The weight of sample was recorded at every 30 minutes interval till the sample became fully saturated. The absorption rate of SF increased to 20.40% for the first 120 minutes and then remain constant (20.40%). This shows that the absorption rate of sisal fiber fully submerged in water for 120 minutes is 20.40%.

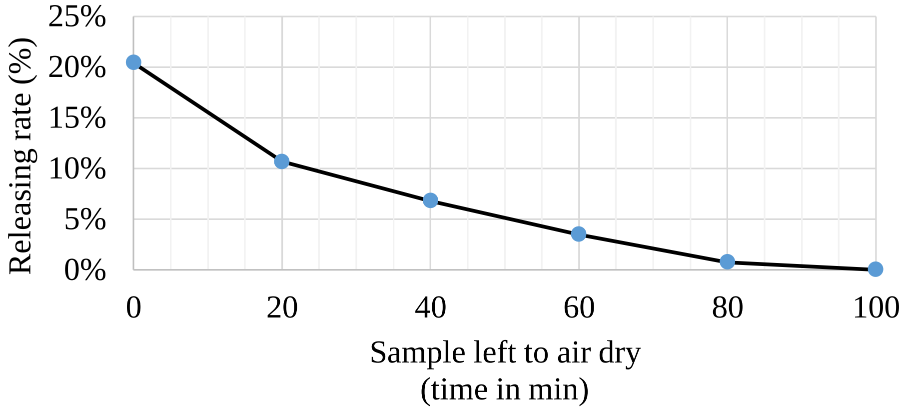

Figure 4. 8: Moisture releasing rate of sisal fiber

The fully saturated sisal fiber was left to air dry for 120 minutes and weight of the sample was recorded at every 20 minutes interval. The sample released the moisture for the first 100 minutes and then remain constant. This shows that the time required for fully saturated sample to fully release the moisture is 100 minutes. From this result it is concluded that the moisture releasing rate of SF is more rapid than its absorption rate.

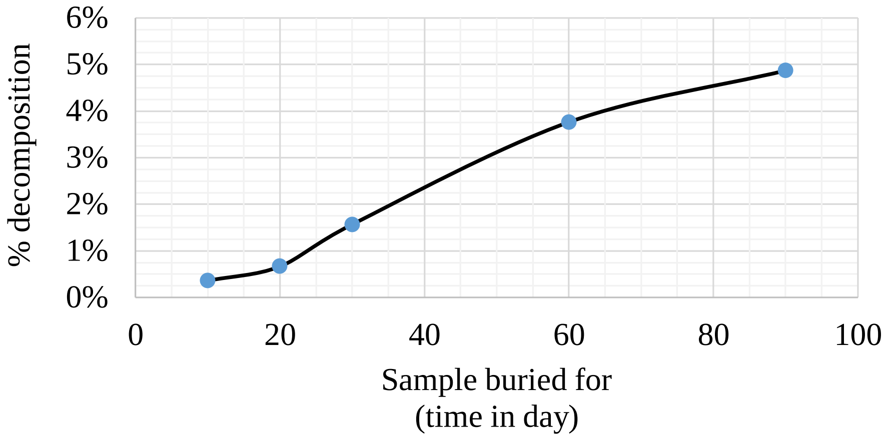

Figure 4. 9: Decomposition rate of sisal fiber

The SF sample buried for 90 days in the soil and data recorded at 10, 20, 30, 60 and 90 days. The decomposition rate of SF after 90 days was recorded as 4.87%.

4.4. The effect of lime on soil sample

Lime addition shows many advantageous effects on the engineering properties of clayey soil that included strength improvement, preventing the swelling and shrinkage problems associated with clayey soil and workability improvement. An additional benefit of using lime is its low cost, simplicity of construction and full-scale utilization of unsuitable in situ soil [12]. In this study soil sample S1 was selected for stabilization as it was relatively the weakest sample. Hydrated lime added at 1.5%, 2.5%, 3.5% and 4.5% of dry mass of the soil sample and tests were conducted.

Table 4. 7: Summary of the effect of lime on soil sample S1

lime content in %	MDD (g/cc)	OMC %	CBR %	Swell %	Cured UCS (kPa)		
					0 days	7 days	21days
0	1.395	29.7	1.035	8.45	149		

1.5	1.415	26.75	2.835	4.53			
2.5	1.444	22.5	3.42	3.72			
3.5	1.489	22.39	4.4	2.58	301.7	428.9	588.3
4.5	1.464	22.5	4.04	2.94			

The UCS of lime treated soil increases with increase in the curing period which is due to the time-dependent pozzolanic reaction which increases with increase in curing time. During the pozzolanic reaction, lime is used up to form cementitious gel products i.e. CSH and CAH. The improvement is even observed at 0 days curing because the strength increases rapidly at first [12]. The UCS of soil sample S1 was tested at 3.5% LC which was the point where maximum CBR value was recorded. The UCS value of untreated soil sample was recorded as 149kPa and which improved to 301.7kPa, 428.9kPa and 588.3kPa at 0 day, 7days and 21 days curing time respectively.

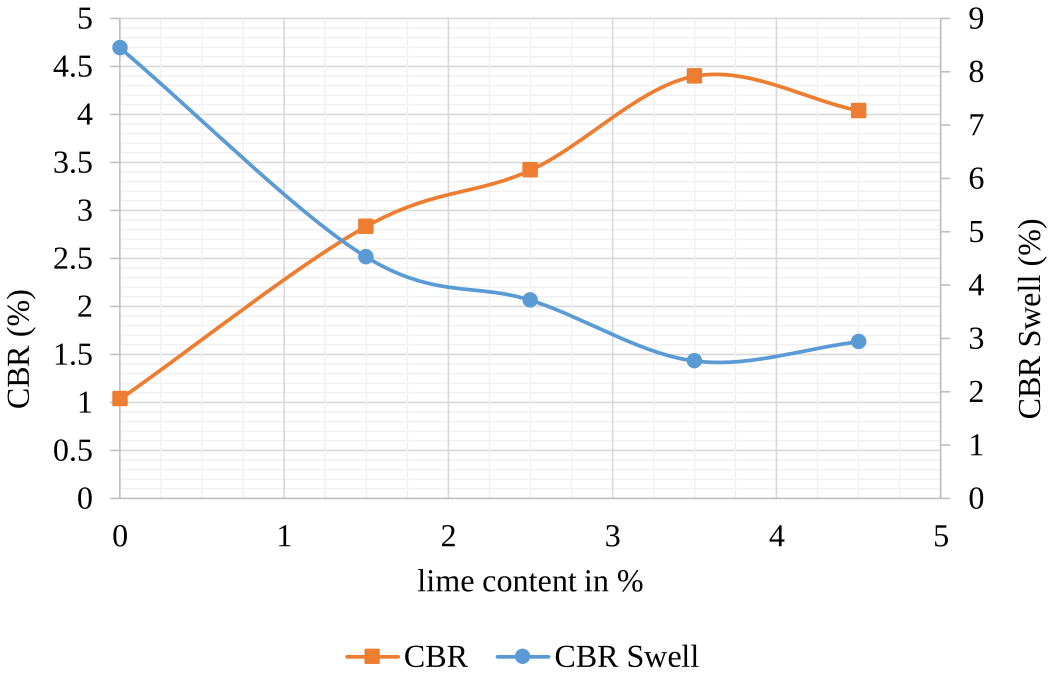

Figure 4. 10: The effect of lime content on sample S1

1.035% of untreated soil CBR increased to 2.835%, 3.42%, 4.4% and 4.04% at 1.5, 2.5, 3.5 and 4.5% LC respectively. Also CBR swell decreased from 8.45% to 4.53%, 3.72%, 2.58% and 2.92% at 1.5, 2.5, 3.5 and 4.5% of LC. Increasing the lime content improved the CBR value from 1.035% to 4.4% and CBR swell from 8.45% to 2.58% and failed to improve beyond 3.5% of lime content. From this the optimum amount of lime was identified as 3.5%. So that 3.5% of LC was selected as a point at which UCS was tested.

4.4.1. Compaction test

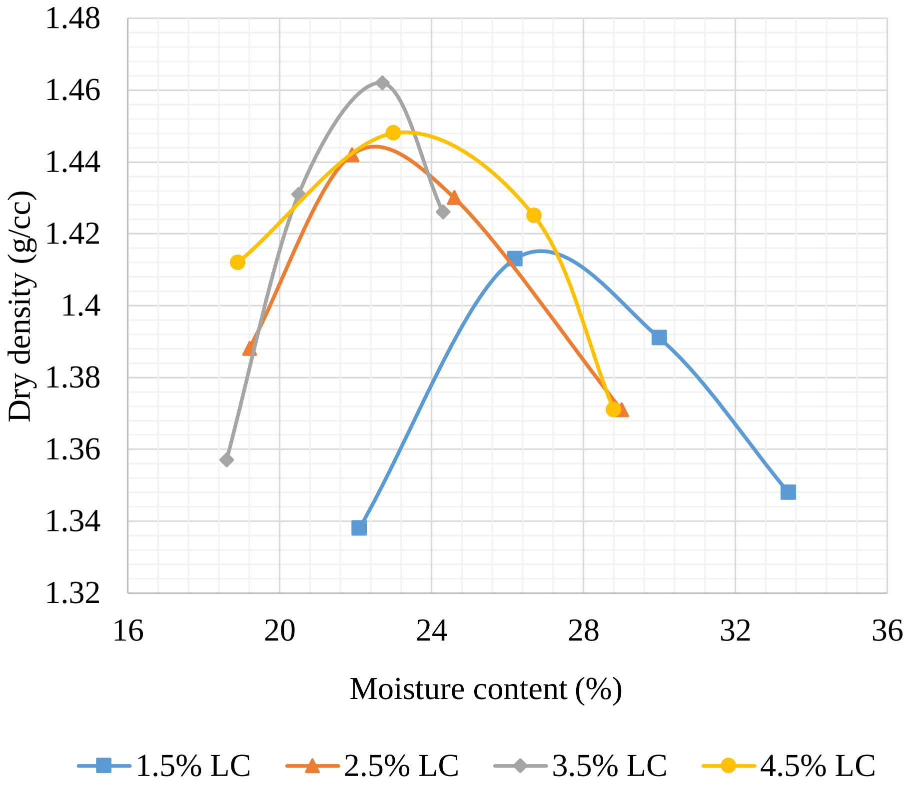

Figure 4. 11: The effect of lime content on dry density and moisture content

Dry density increased with increasing lime content and failed beyond the optimum lime content. Floc formation due to the addition of lime content is the reason for increment of dry density and high increment of lime content beyond the optimum amount is the reason for the failure of dry density since lime is relatively lighter than soil sample.

4.4.2. CBR test

CBR test is mainly applicable during pavement construction to determine the bearing capacity of subgrade material. For the pavement design of new roads, the subgrade strength and bearing capacity need to be evaluated so that it can withstand the repetitive traffic load

[12]. The natural soil with CBR value of 1.035% was very weak and not recommended as subgrade material. The following graph shows the CBR values of lime stabilized soil.

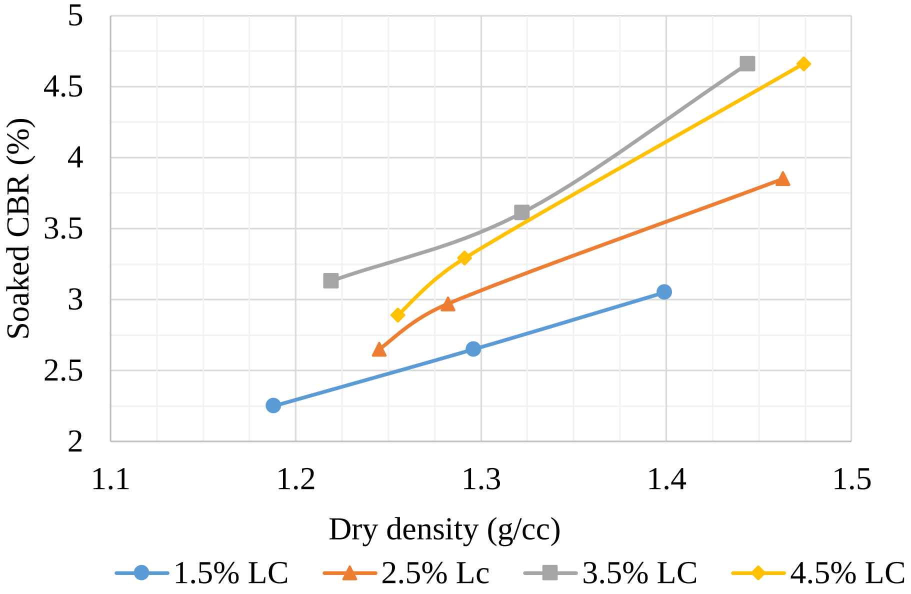

Figure 4. 12: The effect of lime on CBR value of soil sample S1

The CBR value of soil sample S1 was recorded as 2.835%, 3.42%, 4.4% and 4.04% at 1.5%, 2.5%, 3.5% and 4.5% of lime content respectively. Based on the data 3.5% of lime content became the optimum content of lime.

4.4.3. CBR swell test

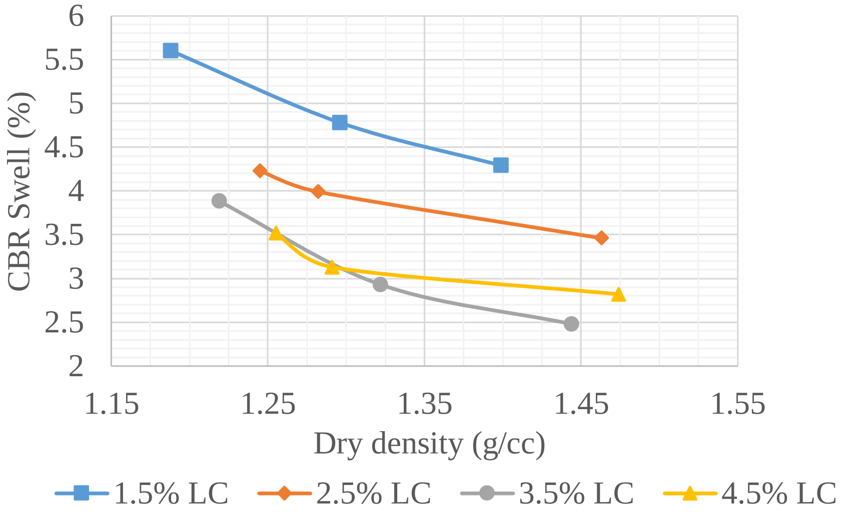

Figure 4. 13: The effect of lime on CBR swell of soil sample S1

The CBR swell value of soil sample S1 was recorded as 4.53%, 3.72%, 2.58% and 2.94% at 1.5%, 2.5%, 3.5% and 4.5% of lime content respectively. Increasing lime content up to optimum lime content could improve the CBR swell and failed beyond optimum lime content.

4.4.4. UCS test

UCS test was conducted at optimum lime content. The UCS value was improved with increasing lime content and curing time.

4.5. The effect of sisal fiber on soil sample S1

Sisal fiber improves the engineering properties of soil sample by interlocking the soil particles together without changing the chemical properties of the soil. Here 5cm, 8cm and 11cm length of sisal fiber was used at 0.5%, 0.8% and 1.1% of dry mass of soil sample at each length class and tests were conducted.

Table 4. 8: Summary of the effect of SF on the properties of soil sample S1

Length of sisal fiber (cm)	Sisal fiber content (%)	MDD	OMC	CBR at 95% of MDD	Swell at 95% of MDD	UCS (kPa)		
						Curing days		
						0	7	21
5	0.5	1.358	31.4	2.89	4.72			
	0.8	1.336	31.55	4.2	3.33			
	1.1	1.311	31.75	2.775	3.24			
8	0.5	1.354	31.42	3.63	2.68			
	0.8	1.334	31.58	5.73	1.69	127.3	165.1	239.2
	1.1	1.309	31.83	4.52	1.58			
11	0.5	1.353	31.5	3.465	1.99			
	0.8	1.333	31.63	4.33	1.17			
	1.1	1.308	31.85	3.55	0.89			

4.5.1. Compaction test

The main reason for soil compaction is to enhance the shear resistance and the bearing capacity of the soil material, reduce settlement of soil material under live loads and reduction in permeability [39]. Compaction was conducted by mixing soil sample with 0.5%, 0.8% and 1.1% of SF at every 5cm, 8cm and 11cm sisal fiber length. The maximum dry density and optimum moisture content was determined and graphically presented as follow.

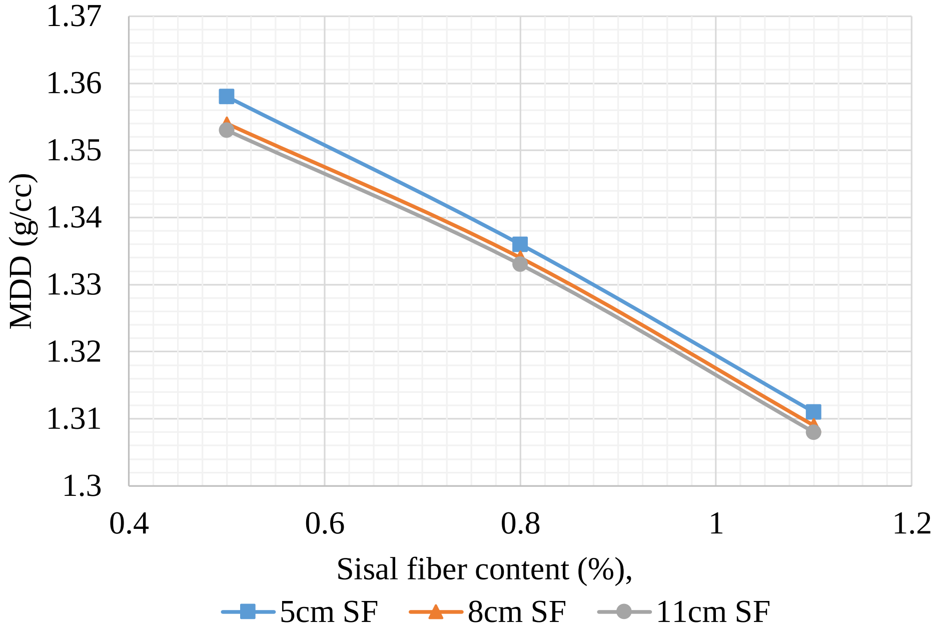

Figure 4. 14: The effect of sisal fiber on MDD of the sample S1

Adding more amount of sisal fiber to the soil sample decreased the maximum dry density of the soil. This was because sisal fiber was light weight material relative to the soil and replacing denser material by relatively lighter material decreased the MDD of the soil.

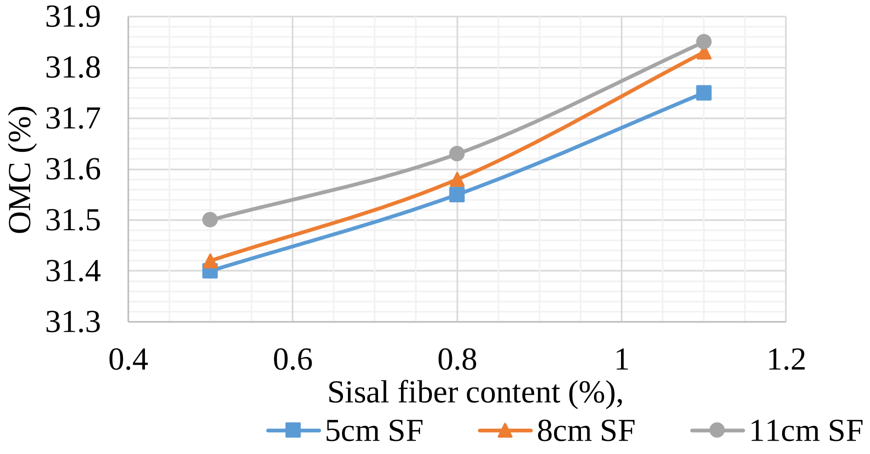

Figure 4. 15: The effect of sisal fiber on OMC of the sample S1

Adding more amount of sisal fiber to the soil sample increased the optimum moisture content of the soil. This was because the high moisture absorption rate of sisal fiber. As the amount of sisal fiber increased the absorbed moisture also increased.

4.5.2. CBR test

CBR test is mainly applicable during pavement construction to determine the bearing capacity of subgrade material. For the pavement design of new roads, the subgrade strength and bearing capacity need to be evaluated so that it can withstand the repetitive traffic load. In transportation geotechnics, the CBR is considered as the most common indentation test to check the quality of subgrade and base material [12]. CBR was conducted by mixing soil sample with 0.5%, 0.8% and 1.1% of SF at every 5cm, 8cm and 11cm sisal fiber length. The CBR values with varying amount of SF content at each fiber length was determined and graphically presented as follow.

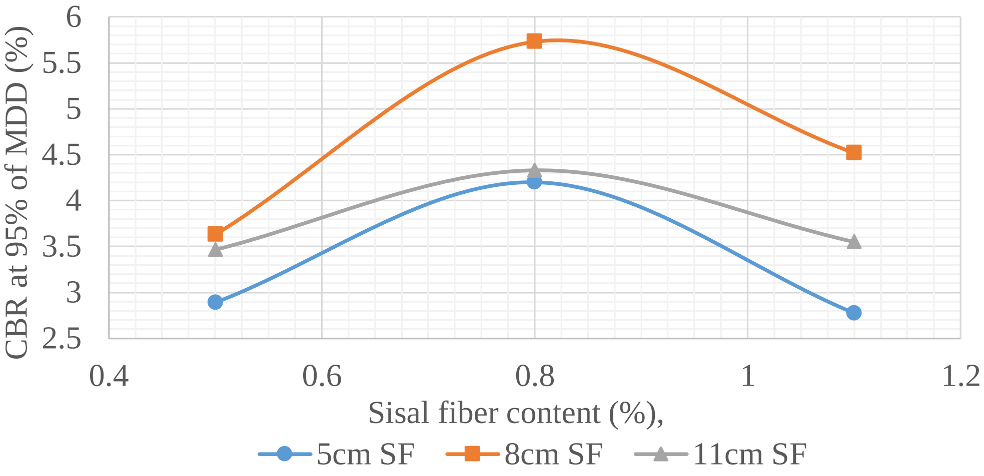

Figure 4. 16: The effect of sisal fiber on CBR of the sample S1

The CBR value get maximum at 0.8% for each length class. Therefore 0.8% became the optimum amount of sisal fiber to treat the expansive soil sample S1. From the length group 8cm long sisal fiber at 0.8% by dry mass of soil sample possessed maximum CBR value and which became the optimum lime content.

4.5.3. CBR swell test

Fiber is effective in controlling the heave of the expansive soil. Heave reduces when the fiber content was increased. The reduction in heave is mainly due to two reasons, one is due to the increase in the fiber content which replaces the expansive soil and the other is due to the reinforcing affect which binds the soil together and does not allow to swell [40]. CBR swell was conducted by mixing soil sample with 0.5%, 0.8% and 1.1% of SF at every 5cm, 8cm and 11cm sisal fiber length. The CBR swell values with varying amount of SF content at each fiber length was determined and graphically presented as follow.

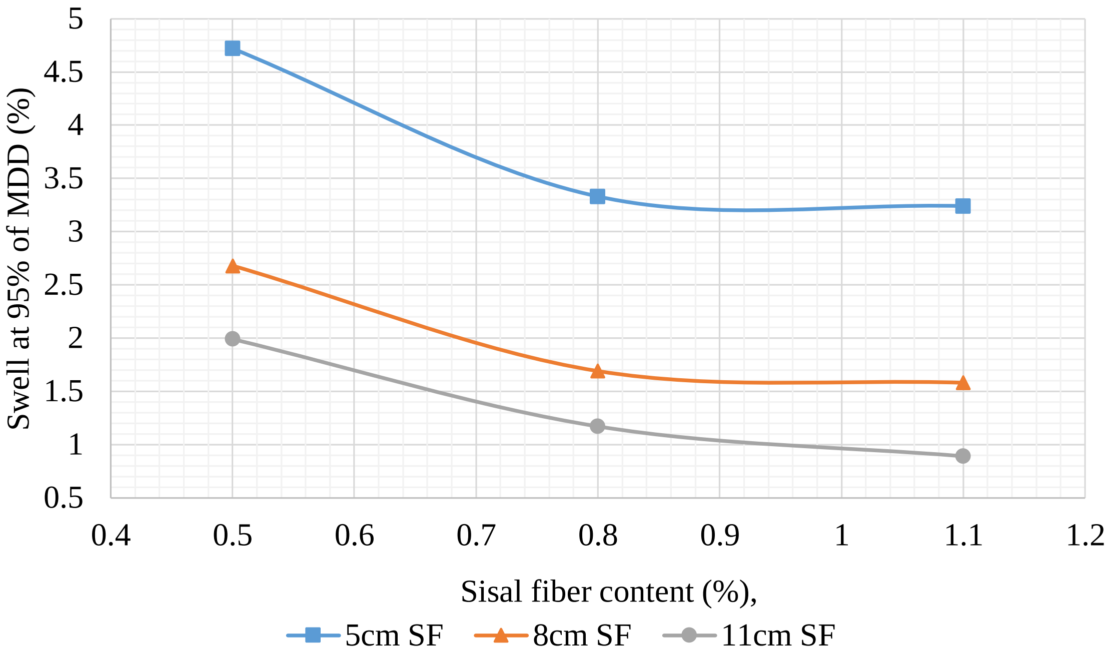

Figure 4. 17: The effect of sisal fiber on Swell of the sample S1

The CBR swell value get minimum (improved) as sisal fiber content increased. This was because the addition of high amount of sisal fiber stick the soil particles together and prevent the further movements of soil particles in the presence of moisture.

4.5.4. UCS test

UCS test was conducted at optimum sisal fiber content. The UCS value was improved with the increasing curing time. The UCS value of zero day curing time was recorded minimum; this was due to the loss of density of the soil mass with the addition of relatively light weight sisal fiber.

4.6. The effect of lime mixed with sisal fiber on soil sample

Previous literature shows that soil stabilization was done by fixing one or two of the stabilizer with varying the other when two or more stabilizing agents used as soil stabilizer. Stabilization was done according to [28] by fixing Lime percentage with varying amount of Sisal fiber; [24] by fixing the percentage Rice Husk ash with varying amount of sisal fiber; [6] by fixing Natural Lime with varying amount of Rice Husk Ash; [4] by fixing the amount of lime with varying Coir waste. Based on the literature, the optimum lime content was fixed to 3.5% which was detected from section 4.4 and optimum sisal fiber content was fixed to 0.8% which was detected from section 4.5. For every sisal fiber length subdivision, Therefore laboratory tests were conducted to determine the effect of lime (at 3.5%) mixed with sisal fiber (at 0.8%) at 5cm, 8cm and 11cm sisal fiber length.

Table 4. 9: Summary of the combined effects of Stabilizers on S1

Combination of stabilizing agents	MDD (g/cc)	OMC (%)	CBR at 95% Of MDD (%)	Swell at 95% of MDD (%)	Cured UCS in kPa		
					0 days cured	7 days cured	21 days cured
Untreated S1	1.395	29.7	1.035	8.45	149		
5cm of 0.8% SF+3.5% LC	1.401	28.75	5.47	1.47			
8cm of 0.8% SF+3.5% LC	1.387	30.95	7.32	0.72	196.1	273.7	374.9
11cm of 0.8% SF+3.5%LC	1.36	32.75	5.72	0.57			

4.6.1. Compaction test

The main reason for soil compaction is to enhance the shear resistance and the bearing capacity of the soil material, reduce settlement of soil material under live loads and reduction in permeability [39]. Compaction was conducted by mixing soil sample with 5cm of 0.5% SF+3.5% LC, 8cm of 0.8% SF+3.5% LC and 11cm of 1.1% SF+3.5% LC. The maximum dry density and OMC versus fiber length was graphically presented as follow.

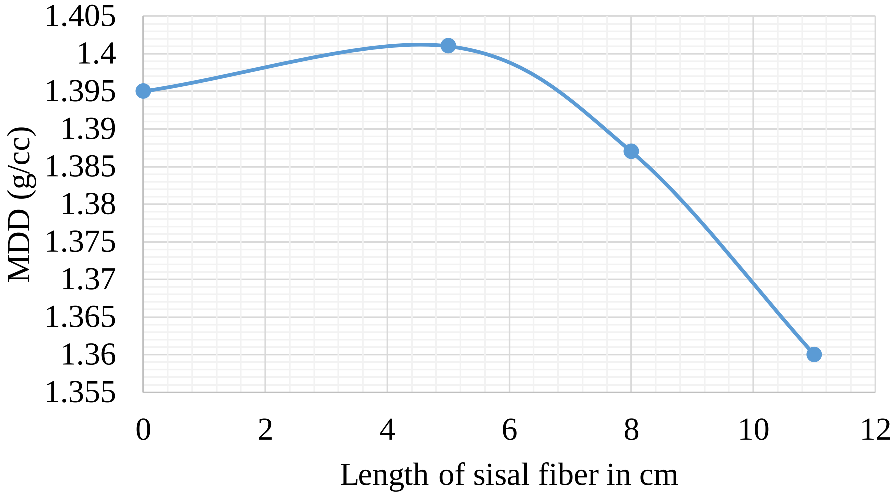

Figure 4. 18: Length of SF Vs MDD curve at constant content of lime and SF

Maximum dry density of the soil sample S1 showed slight decrement at 3.5% of lime and 0.8% of sisal fiber content with varying fiber length due to the replacement of relatively heavier material by lighter material.

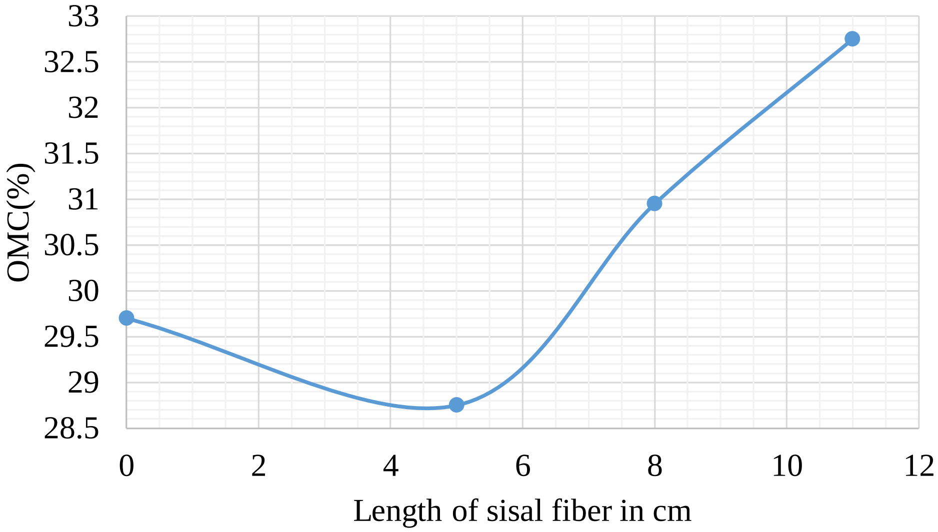

Figure 4. 19: Length of SF Vs OMC curve at constant content of lime and SF

Optimum moisture content of the soil sample S1 increased at 3.5% of lime and 0.8% of sisal fiber content due to the relatively high moisture absorption rate of sisal fiber.

4.6.2. CBR test

CBR test is mainly applicable during pavement construction to determine the bearing capacity of subgrade material. For the pavement design of new roads, the subgrade strength and bearing capacity need to be evaluated so that it can withstand the repetitive traffic load. In transportation geotechnics, the CBR is considered as the most common indentation test to check the quality of subgrade and base material [12]. CBR was conducted by mixing soil sample with 5cm of 0.5% SF+3.5% LC, 8cm of 0.8% SF+3.5% LC and 11cm of 1.1% SF+3.5% LC. The CBR values with varying SF length was determined and graphically presented as follow.

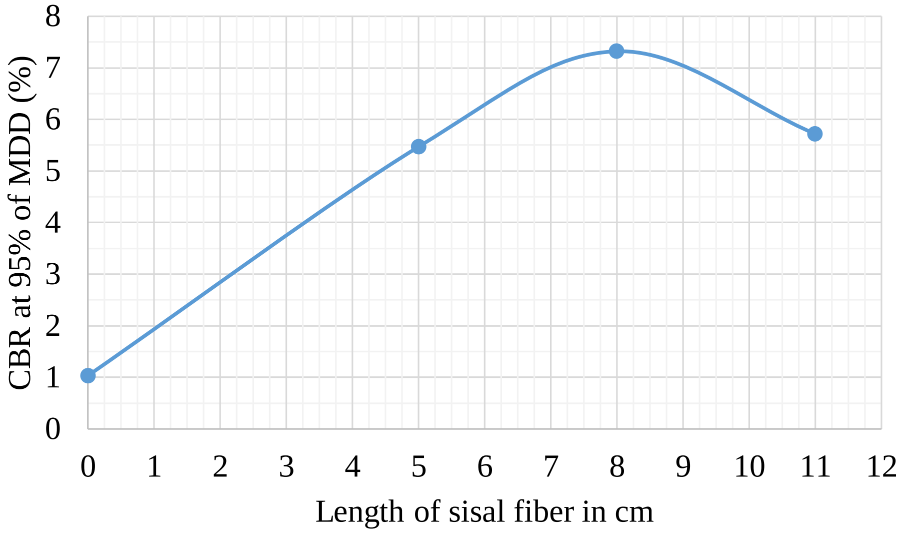

Figure 4. 20: Length of SF Vs CBR curve at constant content of lime and SF

The CBR value of the soil sample S1 showed continuous increment at 3.5% of lime and 0.8% of sisal fiber content with varying SF length and failed after 8cm length of SF. Therefore it was concluded that the optimum amount of SF and lime combination was 3.5% of lime and 0.8% of 8cm long sisal fiber.

4.6.3. CBR swell test

Fiber is effective in controlling the heave of the expansive soil. Heave reduces when the fiber content was increased. The reduction in heave is mainly due to two reasons, one is due to the increase in the fiber content which replaces the expansive soil and the other is due to the reinforcing affect which binds the soil together and does not allow to swell [40]. CBR swell was conducted by mixing soil sample with 5cm of 0.5% SF+3.5% LC, 8cm of 0.8% SF+3.5% LC and 11cm of 1.1% SF+3.5% LC. The CBR swell values with varying SF length was determined and graphically presented as follow.

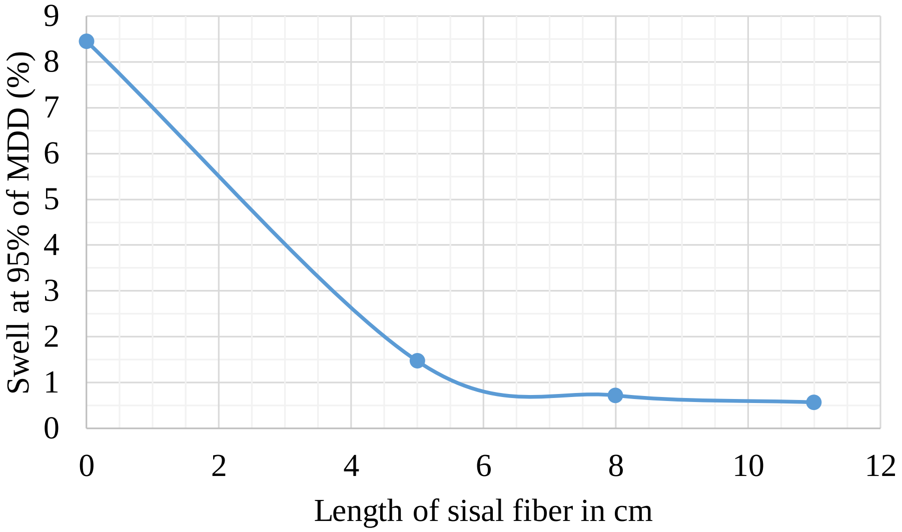

Figure 4. 21: Length of SF Vs CBR swell curve at constant content of lime and SF

Treated samples showed a reduction in swell percent with the increase in stabilizer content [29]. The CBR swell showed a valuable decrement at combined effect of lime and SF. CBR swell of untreated soil was recorded 8.45%; it dropped to 1.47% at 0.8% of 5cm SF+3.5% LC, 0.72% at 0.8% of 8cm SF+3.5% LC and 0.57% at 0.8% of 11cm SF+3.5% LC.

4.6.4. UCS test

UCS test was conducted at optimum amount of sisal fiber and lime combination. The UCS value was increased with the increasing curing time.

4.7. The effect of stabilization on UCS of soil sample S1

The subgrade strength analyzed by its CBR value according to ERA 2013. Therefore UCS was tested at a point where maximum CBR values were recorded (3.5% of lime, 0.8% of 8cm long SF and 0.8% of 8cm long SF mixed with 3.5% of lime) and compared to the UCS of untreated soil sample. The combined effect of lime and SF improved the UCS values by 31.62%, 83.72% and 151.62% with zero days, 7 days and 21 days curing time respectively.

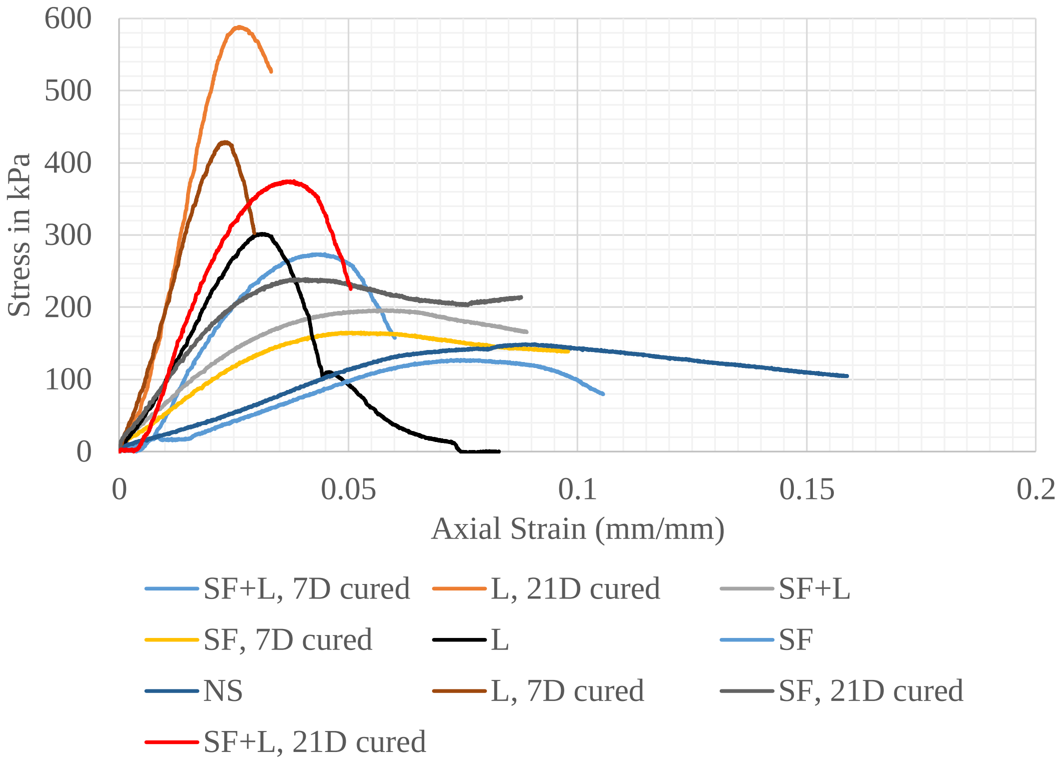

Figure 4. 22: The effect of treatment and curing time on UCS of S1

Table 4. 10: The maximum UCS value of treated and cured soil sample S1

Sample	Max. UCS (kPa)		
	0 Days cured	7 Days cured	21 Days cured
S1	149.0		
Lime treated S1	301.7	428.9	588.3
SF treated S1	127.3	165.1	239.2
Lime & SF treated S1	196.1	273.7	374.9

The maximum UCS values are tabulated on table 4.10. Due to the cementitious behavior of lime; the soil particles stick together to form flocs and capable of resisting compressive stresses. These made the UCS values of lime treated soil sample greater than that of sisal fiber treated. SF reinforces the soil sample and more effective in receiving tensile stress than compressive stress.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The preliminary investigation was conducted on expansive soil and sisal fiber. The natural soil sample was collected from three test pits and laboratory tests were conducted on each of the samples. The natural soil has moisture content of 41.77%, 36.75% and 34.15% for samples S1, S2 and S3 respectively; free swell of 94%, 83% and 71% for samples S1, S2 and S3 respectively; specific gravity of 2.73, 2.71 and 2.70 for samples S1, S2 and S3 respectively; LL and PI of 94.3%, 88%, 84.8% and 61.88%, 57.89% and 55.45% respectively for samples S1, S2 and S3; MDD and OMC of 1.395g/cc, 1.46g/cc, 1.496g/cc and 29.7%, 27.71% and 24% respectively for sample S1, S2 and S3; CBR and CBR swell of 1.035%, 1.49%, 1.66% and 8.45%, 6.60% and 5.83% respectively for sample S1, S2 and S3. The MAR of SF increased to 20.40% for the first 120 minutes and then remain constant, SF fully released the moisture within 100 minutes. 4.87% of SF was decomposed within 90 days testing.

According to ERA 2013, the strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR). The stabilization is held on the sample which has relatively poor engineering properties based on the laboratory test result which is sample S1, this is because the stabilization that meets the specifications of ERA and AASHTO standard specification for sample with poor engineering properties obviously stabilizes relatively good material.

The MDD increased from 1.395 g/cc to 1.489 g/cc at optimum (3.5%) LC and decreased to 1.334g/cc at optimum (0.8%, L=8cm) SF content; according to [12] lime is used up to form cementitious gel products i.e. CSH and CAH. Lime changes the chemical properties of the soil and stick the fine particles of the soil together to form flocs and this densified the sample; and according to [24] The reduction in the MDD is attributed to the SF having low density when compared to the density of the soil and thus reducing the average unit weight of the compacted soil solids in the mixture. Therefore addition of light weighted sisal fiber relative to the soil decreased the density of the sample. The OMC increased from 29.7% to 31.58%

at optimum SF content due to the high moisture absorption behavior of the SF. The CBR increased from 1.035% to 4.4% at optimum lime content which is 325.12% improvement and to 5.73% at optimum sisal fiber content which is 453.62% improvement. The CBR swell decreased at 227.52% improvement from 8.45% to 2.58% at optimum amount of lime content and to 1.69% at optimum amount of sisal fiber content which is 400% improvement. The UCS of S1 was improve from 149 kPa to 301.7 kPa, 428.9 kPa and 588.3 kPa respectively at 0 days, 7 days and 21 days curing time at 3.5% of lime content. At 0.8% of 8cm long SF, UCS was increased to 165.1 kPa and 239.2 kPa at 7 days and 21 days curing time. At 0 days curing time the UCS of SF treated sample S1was decreased from 149 kPa to 127.3 kPa; this is because of the density loss of soil sample by the addition of light weight SF.

The optimum amount of lime and sisal fiber is determined as 3.5% and 0.8% respectively from the laboratory test result. The best combination of lime and sisal fiber that can yield maximum CBR is determined by laboratory test with varying the length of the sisal fiber at 5cm, 8cm and 11cm. 8cm long sisal fiber at 0.8% by dry weight of the soil and 3.5% of lime by the dry weight of the soil was determined as the optimum combination of lime and sisal fiber. The combined effect of lime and sisal fiber at optimum percentage improved the CBR from 1.035% to 7.32% which is 607.25% improvement and CBR swell improved from 8.45% to 0.72%. The combined effect of lime and SF has improved the UCS of soil sample S1 by 31.62%, 83.72% and 151.62% at 0 days, 7 days and 21 days respectively.

Generally the expansive soil stabilized by mixing sisal fiber with lime meets the ERA standard specification of subgrade requirement; with CBR of 7.32% which is greater than 3% and CBR swell of 0.72% which is less than 3. The subgrade strength class was changed from S1 to S3 according to ERA pavement design manual 2013.

5.2. Recommendation

Based on the experimental results; the following recommendations are outlined

- ❖ It is better to perform surface treatment of sisal fiber for its long time validity for further study.
- ❖ The parameters that are not checked in this paper like PH value test, volumetric shrinkage, mineralogical tests and others should be tested for further study.

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Appendix

Appendix A: Laboratory test results on natural soil

Natural Moisture Content			
	Sample Location		
	S_1	S_2	S_3
Container code	A_{10}	A_{13}	B_5
Wt. of container + Wet soil (g)=W_1	215	219	203
Wt. of container + Dry soil (g)=W_2	159.9	167.4	158.2
Wt. of Container (g)= W_3	28	27	27
Weight of Moisture (g)= W_1-W_2=A	55.1	51.6	44.8
Weight of Dry soil (g)=W_2-W_3=B	131.9	140.4	131.2
Moisture Content (%)=(A/B)*100	41.77	36.75	34.15

Free Swell index			
	S1	S2	S3
Volume in Kerosine (V_k)	10	10	10
Volume in water (V_w)	19.4	18.3	17.1
DSI = ((V_w- V_k)/ V_k)*100	94%	83%	71%

Grain size analyis of Sample from Adventist sefer (S1)			
SOIL CLASSIFICATION, (AASHTO M- 145)			
Soil Classification,(Group Index)		45	A-7-5 (45)
Weight Before Washing, (gm)			600
Sieve sizes (mm)	Wt Retained (gm)	%	Cum.%
		Retained	Pass
4.75	0	0.00	100.0
2	0.0	0.00	100.0
0.425	2.2	0.37	99.63
0.075	10.1	1.68	97.95
pan	587.7	97.95	

Grain size analysis of sample from Stadium sefer (S2)		
SOIL CLASSIFICATION, (AASHTO M- 145)		
Soil Classification,(Group Index)	43	A-7-5 (43)

Weight Before Washing, (gm)			600
Sieve sizes (mm)	Wt Retained (gm)	% Retained	Cum.% Pass
4.75	0	0.00	100.0
2	0.0	0.00	100.0
0.425	8.1	1.35	98.65
0.075	19.3	3.22	95.43
pan	572.6	95.43	

Grain Size analysis of sample from Bahil Adarash sefer (S3)			
SOIL CLASSIFICATION, (AASHTO M- 145)			
Soil Classification,(Group Index)		39	A-7-5 (39)
Weight Before Washing, (gm)			600
Sieve sizes (mm)	Wt Retained (gm)	% Retained	Cum.% Pass
4.75	0	0.00	100.0
2	0.0	0.00	100.0
0.425	16.2	2.70	97.3
0.075	35.5	5.92	91.38
pan	548.3	91.38	

liquid limit and plastic limits of sample S1					
Test Method: AASHTO T 89					
	Liquid Limit			Plastic Limit	
Test No.	1	2	3	1	2
No. of Blows	32	27	16		

Container Number	15	22	34	G	41
Wt. of Container + Wet Soil (g) = (W_1)	28.04	28.8	32.44	11.72	11.87
Wt. of Container + Dry Soil (g) = (W_2)	19.32	19.70	21.33	11.27	11.44
Wt. of Container (g) = (W_3)	9.62	9.83	10.09	9.87	10.03
Weight of Moisture (g) = ($W_1 - W_2$) = A	8.72	9.13	11.11	0.45	0.43
Weight of Dry Soil (g) = ($W_2 - W_3$) = B	9.70	9.87	11.24	1.40	1.41
Moisture Content (%) = (A / B)x 100	89.9	92.5	98.8	32.1	30.5
			Av. PL	31.3	

Determination of PI for sample S1	
Plastic limit (%) = PL	31.32
Liquid Limit (%) = LL	93.20
Plasticity index (%)= PI = LL-PL	61.88

liquid limit and plastic limits of sample S2					
Test Method AASHTO T89					
	Liquid Limit			Plastic Limit	
Test No.	1	2	3	1	2
No. of Blows	34	28	18		
Container Number	22	34	15	C	41
Wt. of Container + Wet Soil (g) = (W_1)	29.72	31.5	32.01	11.82	11.84
Wt. of Container + Dry Soil (g) = (W_2)	20.61	21.53	21.33	11.37	11.42
Wt. of Container (g) = (W_3)	9.83	10.09	9.63	9.87	10.03
Weight of Moisture (g) = ($W_1 - W_2$) = A	9.11	10	10.68	0.45	0.42
Weight of Dry Soil (g) = ($W_2 - W_3$) = B	10.78	11.44	11.70	1.50	1.39
Moisture Content (%) = (A / B)x 100	84.5	87.4	91.3	30.00	30.22
			Av. PL	30.11	

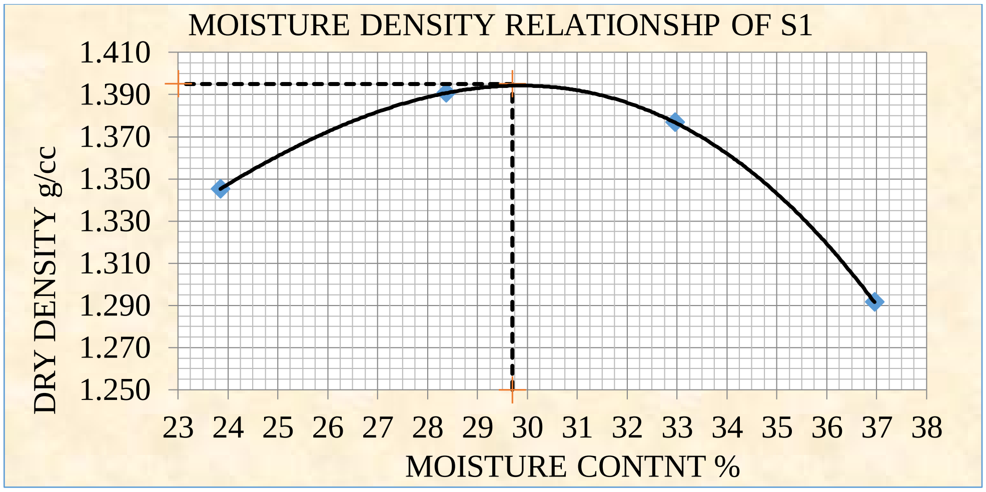
Determination of PI of sample S2	
Liquid limit (%) = LL	88.00
Plastic limit (%) = PL	30.11
Plastic index (%) = PI = LL-PL	57.89

liquid limit and plastic limits of sample S3					
Test Method AASHTO T89					
	Liquid Limit			Plastic Limit	
Test No.	1	2	3	1	2
No. of Blows	34	26	19		
Container Number	22	34	15	C	41
Wt. of Container + Wet Soil (g) = (W_1)	29.52	31	31.08	11.73	11.74
Wt. of Container + Dry Soil (g) = (W_2)	20.65	21.41	21.08	11.31	11.35
Wt. of Container (g) = (W_3)	9.83	10.09	9.63	9.88	10.02
Weight of Moisture (g) = (W_1 - W_2) = A	8.87	9.57	10	0.42	0.39
Weight of Dry Soil (g) = (W_2 - W_3) = B	10.82	11.32	11.45	1.43	1.33
Moisture Content (%) = (A / B)x 100	82.0	84.5	87.3	29.37	29.32
			Av. PL	29.35	

Determination of PI of sample S3	
Liquid limit (%) = LL	84.80
Plastic limit (%) = PL	29.35
Plasticity index (%) = PI = LL-PL	55.45

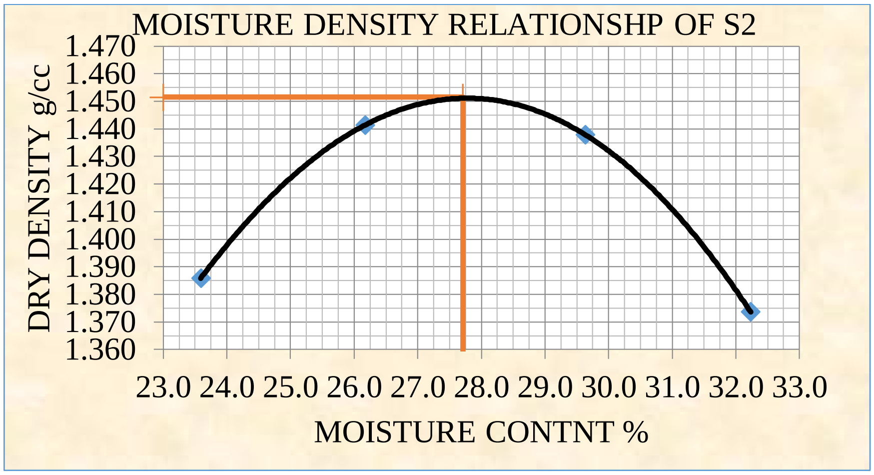
Moisture Density relationship of sample S1
Test Method: AASHTO T-180 Method D

	trial number	1	2	3	4	
DENSITY	Water %	14	18	22	26	
	weight of soil + mold (g) = W_1	9,832	10,085	10,181	10,050	
	weight of mold (g) = W_2	6293	6293	6293	6293	
	volume of mold (Cm^3) = V	2124	2124	2124	2124	
	weight of wet soil (g) = $W_3 = W_1 - W_2$	3,539	3,792	3,888	3,757	
	wet density of soil = (g/Cm^3)=$W_d = W_3/V$	1.666	1.785	1.831	1.769	NMC
MOISTURE	container number	K-1	C-2	A-1	B-3	A-8
	wet soil + container (g) = a	235.2	209.7	203.4	205.1	243.2
	dry soil + container (g) = b	194.8	168.9	159.5	156.8	222.9
	weight of container (g) = c	25.4	25.1	26.3	26.1	26.50
	weight of water (g) = e = a-b	40.4	40.8	43.9	48.3	20.3
	weight of dry soil (g) = d =b-c	169.4	143.8	133.2	130.7	196.4
	moisture content (%) = m= (e/d)*100	23.8	28.4	33.0	37.0	10.34
dry density of soil (g/Cm3) = $D_d = W_d/(100+m)*100$		1.345	1.391	1.377	1.292	



Moisture Density relationship of sample S2

(TEST METHOD: AASHTO T-180 METHOD D)						
TRIAL NUMBER		1	2	3	4	
Density	Water %	14	18	22	26	
	WEIGHT OF SOIL + MOLD (g) W1	9931	10156	10252	10151	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3638	3863	3959	3858	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.713	1.819	1.864	1.816	NMC
Moisture	CONTAINER NUMBER	A-8	K-1	A-1	C-2	B-3
	WET SOIL + CONTAINER (g) a	230	205	200	201	240.00
	DRY SOIL + CONTAINER (g) b	191	168	161	158	220.20
	WEIGHT OF CONTAINER (g) c	26	25	26	25	26.10
	WEIGHT OF WATER (g) e = a-b	39	37	40	43	19.80
	WEIGHT OF DRY SOIL (g) d =b-c	165	143	134	133	194.10
	MOISTURE CONTENT (%) m= (e/d)*100	23.59	26.18	29.64	32.23	10.20
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.386	1.441	1.438	1.374	



Density determination for CBR test of sample S1			
DENSITY DETERMINATION			
Soaking Conditions	Number of blows		
	10	30	65

MOLD NUMBER	F-3	F-2	F-1
WEIGHT OF SOIL + MOLD (g), W1	9617	9883	10118
WEIGHT OF MOLD (g), W2	6433	6297	6331
VOLUME OF MOLD (Cm3), V	2124	2124	2124
WEIGHT OF WET SOIL (g), W3 = W1 - W2	3184	3586	3787
WET DENSITY OF SOIL (g/cm3), Wd = (W3/V)	1.499	1.688	1.783
DRY DENSITY OF SOIL (g/cm3), Dd = Wd/(100+m)*100	1.139	1.272	1.370

Moisture determination for CBR test of sample S1			
MOISTURE DETERMINATION			
	Number of blows		
SOAKING CONDITION	10	30	65
CONTAINER NUMBER	C-4	A-3	K-1
WET SOIL + CONTAINER (g), a	210.8	200.1	193.7
DRY SOIL + CONTAINER (g), b	166	157.2	154.8
WEIGHT OF CONTAINER (g), c	24.5	26.1	25.6
WEIGHT OF WATER (g), d = a - b	44.8	42.9	38.9
WEIGHT OF DRY SOIL (g), e = b - c	141.5	131.1	129.2
MOISTURE CONTENT (%), m =(d/e)*100	31.66	32.72	30.11

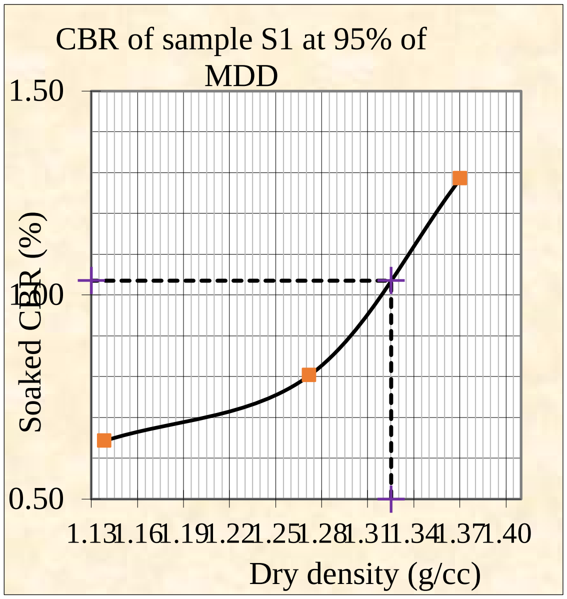
Penetration test data of sample S1						
PENETRATION TEST DATA						
	number of blows					
	10		30		65	
PENETRATION (mm)	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.0424		0.053		0.106	
1.27	0.053		0.0848		0.1272	

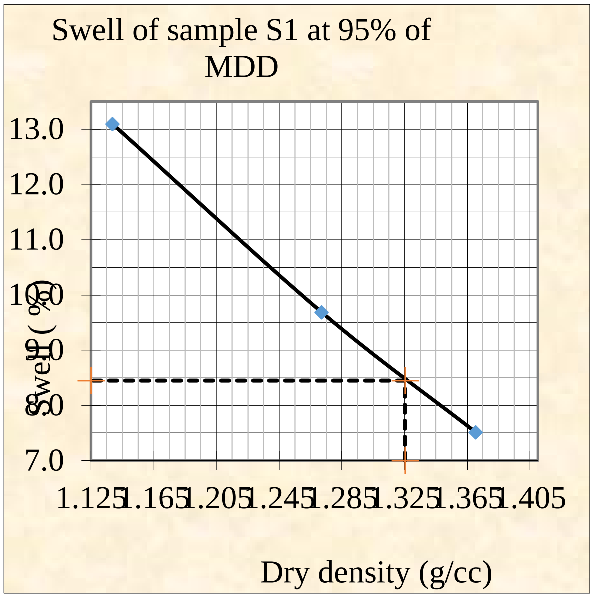
1.91	0.0636		0.0954		0.159	
2.54	0.0848	0.642	0.106	0.803	0.1696	1.285
3.18	0.0954		0.1272		0.1908	
3.81	0.0954		0.1272		0.212	
4.45	0.106		0.159		0.2332	
5.08	0.106	0.530	0.159	0.795	0.2544	1.272
7.62	0.1272		0.212		0.318	
10.16						
12.7						

Swell data of sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING), (mm)	1.75	1.07	0.18
RDG (AFTER) SOAKING), (mm)	17.00	12.35	8.93
PERCENT SWELL	13.10	9.69	7.52

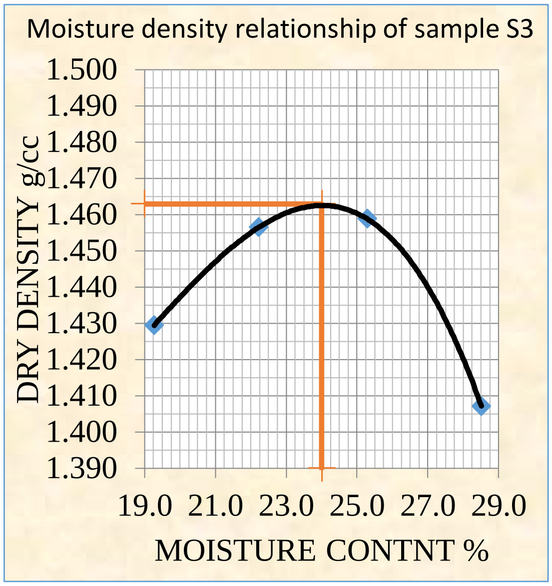
Load Vs soaked CBR of Sample S1					
BLOWS	LOAD (KN)		CBR (%)		SWELL %
	2.54mm	5.08mm	2.54mm	5.08mm	
10	0.0064	0.0053	0.6424	0.5300	13.098
30	0.0080	0.0080	0.8030	0.7950	9.688
65	0.0128	0.0127	1.2848	1.2720	7.515

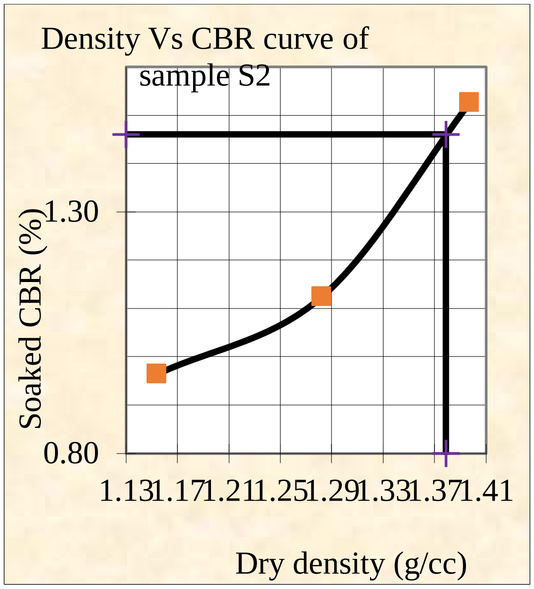
Dry density Vs soaked CBR of sample S1			
No # OF BLOWS	10	30	65
Swell, (%)	13.098	9.688	7.515
DRY DENSITY, (g/cm3)	1.139	1.272	1.370
SOCKED CBR, (%)	0.642	0.803	1.285



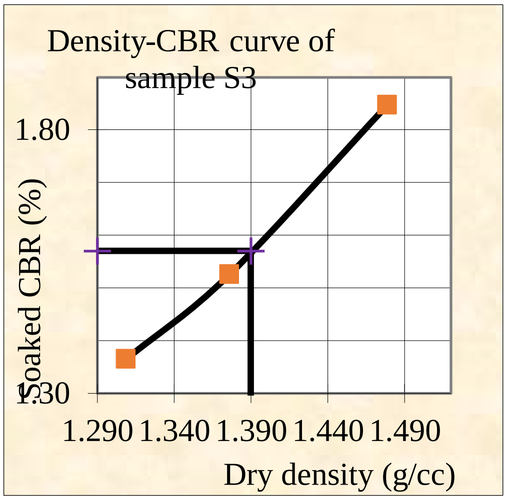


CBR and swell at 95% of MDD of sample S1	
MODIFIED PROCTOR : T 180 - D	
MDD (g/cc) :	1.395
OMC (%) :	29.7
95% of MDD(g/cc)	1.325
CBR % at 95% of MDD	1.035
Swell % at 95% of MDD	8.45





CBR and Swell at 95% of MDD of sample S2	
MODIFIED PROCTOR : T 180 - D	
MDD (g/cc) :	1.452
OMC (%) :	27.71
95% of MDD(g/cc)	1.379
CBR % at 95% of MDD	1.460
Swell % at 95% of MDD	6.70



CBR and Swell of sample S3 at 95% of MDD	
MODIFIED PROCTOR : T 180 - D	
MDD (g/cc) :	1.463
OMC (%) :	24
95% of MDD(g/cc)	1.390
CBR % at 95% of MDD	1.570
Swell % at 95% of MDD	6.22

Specific Gravity				
Specific gravity, AASHTO: T100-95				
Test pits	Trials			average Specific gravity
	1	2	3	
S1	2.78	2.75	2.67	2.73
S2	2.71	2.72	2.68	2.71
S3	2.71	2.68	2.71	2.70

Moisture density relationship of untreated sample S3						
TRIAL NUMBER		1	2	3	4	
Density	Water %	13	17	21	25	
	WEIGHT OF SOIL + MOLD (g) W1	9944	10154	10255	10164	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3651	3861	3962	3871	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.719	1.818	1.865	1.823	NMC
Moisture	CONTAINER NUMBER	C-4	A-3	B-3	K-1	C-5
	WET SOIL + CONTAINER (g) a	229	203	203	216	238.00
	DRY SOIL + CONTAINER (g) b	196	171	167	173	219.10
	WEIGHT OF CONTAINER (g) c	25	26	26	25	26.40
	WEIGHT OF WATER (g) e = a-b	33	32	36	42	18.90
	WEIGHT OF DRY SOIL (g) d =b-c	172	145	141	148	192.70
	MOISTURE CONTENT (%) m= (e/d)*100	19.27	22.22	25.28	28.51	9.81
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.441	1.487	1.489	1.418	

Penetration test analyis data of untreated sample S1			
PENETRATION (mm)	number of blows		
	10	30	65

	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.0424		0.053		0.106	
1.27	0.053		0.0848		0.1272	
1.91	0.0636		0.0954		0.159	
2.54	0.0848	0.642	0.106	0.803	0.1696	1.285
3.18	0.0954		0.1272		0.1908	
3.81	0.0954		0.1272		0.212	
4.45	0.106		0.159		0.2332	
5.08	0.106	0.530	0.159	0.795	0.2544	1.272
7.62	0.1272		0.212		0.318	
10.16						
12.7						

CBR density determination of untreated sample S2			
Soaking Conditions	Number of blows		
	10	30	65
MOLD NUMBER	D-1	F-1	F-2
WEIGHT OF SOIL + MOLD (g), W1	9637	9903	10358
WEIGHT OF MOLD (g), W2	6413	6331	6297
VOLUME OF MOLD (Cm3), V	2124	2124	2124
WEIGHT OF WET SOIL (g), W3 = W1 - W2	3224	3572	4061
WET DENSITY OF SOIL (g/cm3), Wd = (W3/V)	1.518	1.682	1.912
DRY DENSITY OF SOIL (g/cm3), Dd = Wd/(100+m)*100	1.154	1.282	1.397

CBR moisture determination of untreated sample S2

	Number of blows		
SOAKING CONDITION	10	30	65
CONTAINER NUMBER	C-2	A-1	K-1
WET SOIL + CONTAINER (g), a	210.3	202.8	211.4
DRY SOIL + CONTAINER (g), b	165.9	160.9	161.4
WEIGHT OF CONTAINER (g), c	25.1	26.3	25.6
WEIGHT OF WATER (g), d = a - b	44.4	41.9	50
WEIGHT OF DRY SOIL (g), e = b - c	140.8	134.6	135.8
MOISTURE CONTENT (%), m =(d/e)*100	31.53	31.13	36.82

penetration test data of untreated sample S2						
	number of blows					
	10		30		65	
PENETRATION (mm)	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.0636		0.0742		0.106	
1.27	0.0848		0.106		0.1484	
1.91	0.106		0.1272		0.1802	
2.54	0.1272	0.964	0.1484	1.124	0.2014	1.526
3.18	0.1378		0.159		0.212	
3.81	0.1484		0.1696		0.2332	
4.45	0.1696		0.1908		0.2438	
5.08	0.1908	0.954	0.212	1.06	0.2862	1.431
7.62	0.2332		0.265		0.3604	
10.16						
12.7						

dry density Vs socked CBR and swell of untreated sample S2			
No # OF BLOWS	10	30	65
Swell,(%)	11.294	7.850	6.485
DRY DENSITY, (g/cm3)	1.154	1.282	1.397
SOCKED CBR, (%)	0.96	1.12	1.53

CBR density determination of untreated sample S3			
Soaking Conditions	Number of blows		
	10	30	65
MOLD NUMBER	H-1	H-2	F-1
WEIGHT OF SOIL + MOLD (g), W1	9778	10044	10279
WEIGHT OF MOLD (g), W2	6268	6345	6331
VOLUME OF MOLD (Cm3), V	2124	2124	2124
WEIGHT OF WET SOIL (g), W3 = W1 - W2	3510	3699	3948
WET DENSITY OF SOIL (g/cm3), Wd = (W3/V)	1.653	1.742	1.859
DRY DENSITY OF SOIL (g/cm3), Dd = Wd/(100+m)*100	1.309	1.376	1.479

CBR moisture determination of untreated sample S3			
SOAKING CONDITION	Number of blows		
	10	30	65
CONTAINER NUMBER	B-3	A-3	C-5
WET SOIL + CONTAINER (g), a	209.4	200.9	195.7
DRY SOIL + CONTAINER (g), b	171.3	164.2	161.1
WEIGHT OF CONTAINER (g), c	26.2	26	26.5
WEIGHT OF WATER (g), d = a - b	38.1	36.7	34.6
WEIGHT OF DRY SOIL (g), e = b - c	145.1	138.2	134.6

MOISTURE CONTENT (%), m =(d/e)*100	26.26	26.56	25.71

penetration test data of untreated sample S3						
	number of blows					
	10		30		65	
PENETRATION (mm)	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.1166		0.1378		0.159	
1.27	0.1378		0.159		0.1802	
1.91	0.1484		0.1802		0.212	
2.54	0.1802	1.365	0.2014	1.526	0.2438	1.847
3.18	0.2014		0.2226		0.265	
3.81	0.212		0.2332		0.2862	
4.45	0.2332		0.2544		0.3074	
5.08	0.2544	1.272	0.2756	1.378	0.3498	1.749
7.62	0.3074		0.3392		0.4452	
10.16						
12.7						

Dry density Vs socked CBR and swell of untreated sample S3			
No # OF BLOWS	10	30	65
Swell,(%)	7.902	6.416	5.188
DRY DENSITY, (g/cm3)	1.309	1.376	1.479
SOCKED CBR, (%)	1.37	1.53	1.85

Swell data of untreated sample S1

No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.75	1.07	0.18
RDG (AFTER) SOAKING),(mm)	17.00	12.35	8.93
PERCENT SWELL	13.10	9.69	7.52

Swell data of untreated sample S2			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.85	1.17	0.38
RDG (AFTER) SOAKING),(mm)	15.00	10.31	7.93
PERCENT SWELL	11.29	7.85	6.48

Swell data of untreated sample S3			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.62	1.31	0.51
RDG (AFTER) SOAKING),(mm)	10.82	8.78	6.55
PERCENT SWELL	7.90	6.42	5.19

Specific Gravity				
Specific gravity, AASHTO: T100-95				
Test pits	Trials			average Specific gravity
	1	2	3	
S1	2.78	2.75	2.67	2.73
S2	2.71	2.72	2.68	2.71
S3	2.71	2.68	2.71	2.70

Appendix B: Laboratory test results on Lime treated soil

Moisture density relationship of 1.5% lime treated sample S1					
TRIAL NUMBER		1	2	3	4
Den	Water %	12	16	20	24

	WEIGHT OF SOIL + MOLD (g) W1	9763	10081	10136	10112	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3470	3788	3843	3819	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.634	1.783	1.809	1.798	NMC
Moisture	CONTAINER NUMBER	A-2	F-3	C-3	B-1	K-1
	WET SOIL + CONTAINER (g) a	222	204	198	201	239.00
	DRY SOIL + CONTAINER (g) b	186	167	158	157	220.30
	WEIGHT OF CONTAINER (g) c	24	26	27	25	26.50
	WEIGHT OF WATER (g) e = a-b	36	37	40	44	18.70
	WEIGHT OF DRY SOIL (g) d =b-c	162	141	132	132	193.80
	MOISTURE CONTENT (%) m= (e/d)*100	22.07	26.19	30.05	33.38	9.65
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.338	1.413	1.391	1.348	

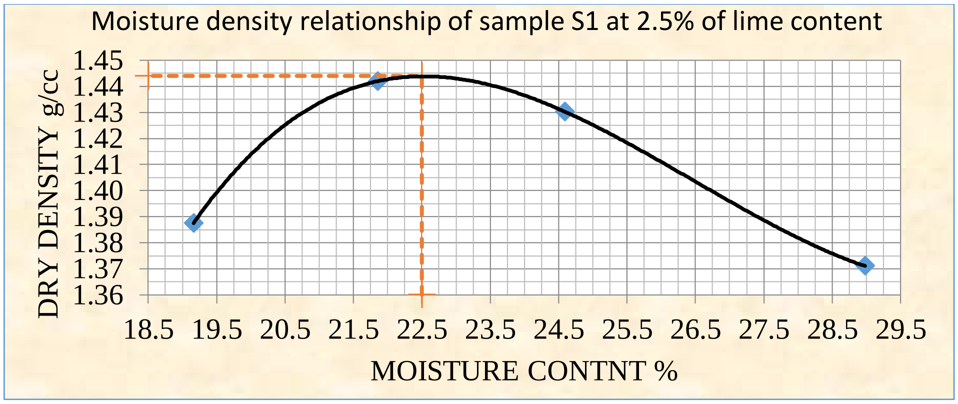
penetration test data of 1.5% lime treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	

0.64	0.1166		0.1696		0.212	
1.27	0.1696		0.2226		0.2756	
1.91	0.2226		0.2862		0.3286	
2.54	0.2968	2.248	0.3498	2.650	0.4028	3.052
3.18	0.318		0.3922		0.4558	
3.81	0.3498		0.424		0.4982	
4.45	0.3922		0.4664		0.5406	
5.08	0.4346	2.173	0.5194	2.597	0.6042	3.021
7.62	0.5618		0.689		0.795	

Swell data of 1.5% lime treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	0.90	1.01	0.59
RDG (AFTER) SOAKING),(mm)	7.42	6.57	5.58
PERCENT SWELL	5.60	4.78	4.29

moisture density relationship of 2.5% lime treated sample S1						
TRIAL NUMBER		1	2	3	4	
Moi Density	Water %	6	10	14	18	
	WEIGHT OF SOIL + MOLD (g) W1	9805	10025	10078	10049	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3512	3732	3785	3756	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.653	1.757	1.782	1.768	NMC
	CONTAINER NUMBER	C-1	B-8	F-1	B-7	A-7

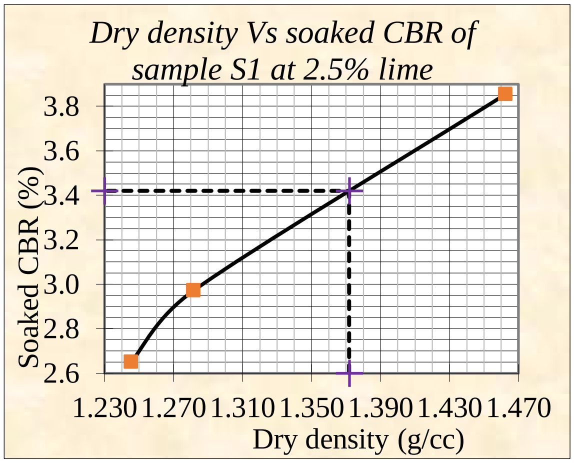
	WET SOIL + CONTAINER (g) a	220	227	216	215	258.80
	DRY SOIL + CONTAINER (g) b	188	191	178	172	235.90
	WEIGHT OF CONTAINER (g) c	23	26	25	26	24.80
	WEIGHT OF WATER (g) e = a-b	32	36	38	42	22.90
	WEIGHT OF DRY SOIL (g) d =b-c	165	165	153	146	211.10
	MOISTURE CONTENT (%) m= (e/d)*100	19.16	21.85	24.59	28.98	10.85
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.388	1.442	1.430	1.371	

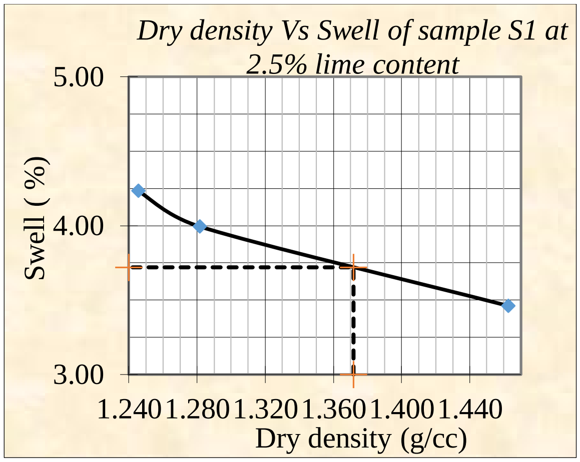


penetration test data of 2.5% lime treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.1908		0.2332		0.2968	
1.27	0.2544		0.2862		0.3604	
1.91	0.2968		0.3286		0.424	
2.54	0.3498	2.650	0.3922	2.971	0.5088	3.855

3.18	0.3922		0.4346		0.5618	
3.81	0.424		0.4876		0.6042	
4.45	0.4558		0.5300		0.6572	
5.08	0.4876	2.438	0.5830	2.915	0.7420	3.710
7.62	0.6784		0.7526		0.954	

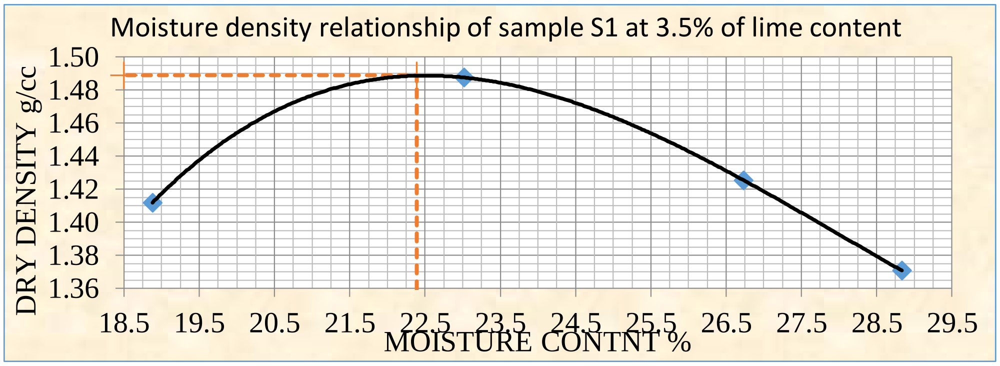
Dry density Vs soaked CBR and Swell of sample S1 at 2.5% of lime content			
No # OF BLOWS	10	30	65
Swell, (%)	4.234	3.994	3.461
DRY DENSITY, (g/cm3)	1.245	1.282	1.463
SOCKED CBR, (%)	2.65	2.97	3.85





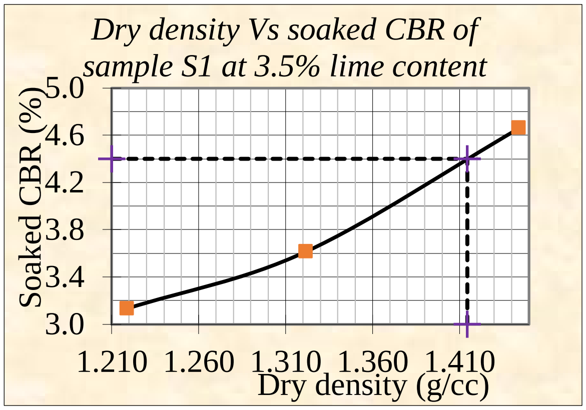
moisture density relationship of 3.5% lime treated sample S1					
TRIAL NUMBER		1	2	3	4
Density	Water %	8	11	14	17
	WEIGHT OF SOIL + MOLD (g) W1	9858	10180	10130	10044
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293

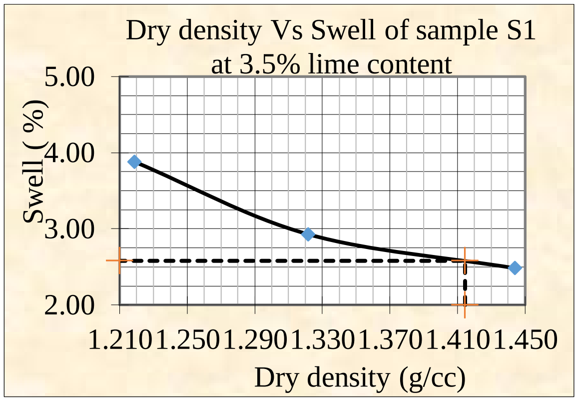
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3565	3887	3837	3751	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.678	1.830	1.806	1.766	NMC
Moisture	CONTAINER NUMBER	A-8	A-11	A-3	C-5	D-1
	WET SOIL + CONTAINER (g) a	270	221	193	195	256.60
	DRY SOIL + CONTAINER (g) b	232	185	157	157	230.80
	WEIGHT OF CONTAINER (g) c	27	26	26	27	26.30
	WEIGHT OF WATER (g) e = a-b	39	37	35	38	25.80
	WEIGHT OF DRY SOIL (g) d =b-c	205	159	131	130	204.50
	MOISTURE CONTENT (%) m= (e/d)*100	18.88	23.02	26.73	28.83	12.62
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.412	1.488	1.425	1.371	



penetration test data of 3.5% lime treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %

0	0		0		0	
0.64	0.2332		0.2756		0.2968	
1.27	0.2862		0.3604		0.3816	
1.91	0.3392		0.4134		0.4982	
2.54	0.4134	3.132	0.477	3.614	0.6148	4.658
3.18	0.4558		0.53		0.6996	
3.81	0.5088		0.5724		0.7738	
4.45	0.5512		0.636		0.848	
5.08	0.6148	3.074	0.6996	3.498	0.9116	4.558
7.62	0.848		0.954		1.0812	





moisture density relationship of 4.5% lime treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	8	10	12	14	
	WEIGHT OF SOIL + MOLD (g) W1	9712	9953	10104	10057	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3419	3660	3811	3764	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.610	1.723	1.794	1.772	NMC

Moisture	CONTAINER NUMBER	A-4	B-3	A-10	B-7	A-12
	WET SOIL + CONTAINER (g) a	259	259	208	192	259.70
	DRY SOIL + CONTAINER (g) b	222	219	174	160	237.20
	WEIGHT OF CONTAINER (g) c	25	25	25	26	26.30
	WEIGHT OF WATER (g) e = a-b	37	40	34	33	22.50
	WEIGHT OF DRY SOIL (g) d =b-c	197	194	149	134	210.90
	MOISTURE CONTENT (%) m= (e/d)*100	18.61	20.45	22.68	24.25	10.67
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.357	1.431	1.462	1.426	

penetration test data of 4.5% lime treated sample S1						
	number of blows					
	10		30		65	
PENETRATION (mm)	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.1908		0.2544		0.2756	
1.27	0.2438		0.318		0.4028	
1.91	0.2968		0.371		0.5088	
2.54	0.3816	2.891	0.4346	3.292	0.6148	4.658
3.18	0.4134		0.4876		0.6784	
3.81	0.4664		0.53		0.7526	
4.45	0.5088		0.5936		0.8268	
5.08	0.5724	2.862	0.6572	3.286	0.9116	4.558
7.62	0.8268		0.9116		1.1236	

Swell data of 4.5% lime treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.45	1.67	1.03
RDG (AFTER) SOAKING),(mm)	5.55	5.32	4.31
PERCENT SWELL	3.52	3.13	2.82

Appendix C: Laboratory test results on Sisal fiber treated soil

moisture density relationship of 5cm long 0.5% sisal fiber treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	14	16	18	20	
	WEIGHT OF SOIL + MOLD (g) W1	10021	10079	10088	10046	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3728	3786	3795	3753	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.755	1.783	1.787	1.767	NMC
Moisture	CONTAINER NUMBER	F-2	A-4	B-7	A-1	E-1
	WET SOIL + CONTAINER (g) a	203	223	199	210	244.60
	DRY SOIL + CONTAINER (g) b	162	176	157	164	219.60
	WEIGHT OF CONTAINER (g) c	26	25	26	26	26.40
	WEIGHT OF WATER (g) e = a-b	41	47	42	46	25.00
	WEIGHT OF DRY SOIL (g) d =b-c	136	151	131	138	193.20
	MOISTURE CONTENT (%) m= (e/d)*100	30.20	31.30	32.11	33.07	12.94
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.348	1.358	1.352	1.328	

penetration test data of 5cm long 0.5% sisal fiber treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.1908		0.212		0.265	
1.27	0.212		0.2968		0.318	
1.91	0.265		0.3286		0.3498	
2.54	0.3392	2.570	0.371	2.811	0.4028	3.052
3.18	0.371		0.4028		0.4346	
3.81	0.4028		0.4452		0.4558	
4.45	0.4558		0.4982		0.5088	
5.08	0.4982	2.491	0.5406	2.703	0.5618	2.809
7.62	0.6466		0.742		0.7738	

Swell data of 5cm long 0.5% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.30	1.61	1.58
RDG (AFTER) SOAKING),(mm)	7.31	7.24	6.82
PERCENT SWELL	5.16	4.84	4.50

moisture density relationship of 5cm long 0.8% sisal fiber treated sample S1					
TRIAL NUMBER		1	2	3	4
Density	Water %	15	17	19	21
	WEIGHT OF SOIL + MOLD (g) W1	9930	9990	10030	10011
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293

	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3637	3697	3737	3718	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.712	1.741	1.759	1.750	NMC
Moisture	CONTAINER NUMBER	C-3	F-3	A-3	B-2	B-7
	WET SOIL + CONTAINER (g) a	204	199	189	215	223.00
	DRY SOIL + CONTAINER (g) b	164	158	149	168	201.90
	WEIGHT OF CONTAINER (g) c	27	26	26	25	25.80
	WEIGHT OF WATER (g) e = a-b	41	41	39	47	21.10
	WEIGHT OF DRY SOIL (g) d =b-c	137	132	123	143	176.10
	MOISTURE CONTENT (%) m= (e/d)*100	29.58	30.71	31.69	32.84	11.98
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.321	1.332	1.336	1.318	

penetration test data of 5cm long 0.8% sisal fiber treated sample S1						
	number of blows					
	10		30		65	
PENETRATION (mm)	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.212		0.2756		0.2968	
1.27	0.2544		0.318		0.3604	
1.91	0.318		0.4452		0.477	
2.54	0.371	2.811	0.5512	4.176	0.6148	4.658
3.18	0.4028		0.583		0.6572	
3.81	0.4558		0.636		0.7314	

4.45	0.5194		0.742		0.7844	
5.08	0.5512	2.756	0.8268	4.134	0.8798	4.399
7.62	0.689		1.166		1.272	

Swell data of 5cm long 0.8% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.40	1.62	1.40
RDG (AFTER) SOAKING),(mm)	5.92	5.51	4.97
PERCENT SWELL	3.88	3.34	3.07

moisture density relationship of 5cm long 1.1% sisal fiber treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	16	18	20	22	
	WEIGHT OF SOIL + MOLD (g) W1	9837	9961	9970	9858	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3544	3668	3677	3565	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.669	1.727	1.731	1.678	NMC
Moisture	CONTAINER NUMBER	A-12	A-7	B-3	C-5	A-5
	WET SOIL + CONTAINER (g) a	215	180	232	166	277.30
	DRY SOIL + CONTAINER (g) b	172	143	181	131	260.80
	WEIGHT OF CONTAINER (g) c	26	25	26	26	26.40
	WEIGHT OF WATER (g) e = a-b	43	37	51	36	16.50
	WEIGHT OF DRY SOIL (g) d =b-c	146	118	155	104	234.40
	MOISTURE CONTENT (%) m= (e/d)*100	29.35	31.78	32.77	34.45	7.04

DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100	1.290	1.311	1.304	1.248	

penetration test data of 5cm long 1.1% sisal fiber treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.1908		0.212		0.265	
1.27	0.212		0.2968		0.318	
1.91	0.265		0.3286		0.3498	
2.54	0.3392	2.570	0.371	2.811	0.4028	3.052
3.18	0.371		0.4028		0.4346	
3.81	0.4028		0.4452		0.4664	
4.45	0.4558		0.4876		0.5088	
5.08	0.4982	2.491	0.5406	2.703	0.5618	2.809
7.62	0.6466		0.742		0.7738	

Swell data of 5cm long 1.1% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.12	1.35	1.15
RDG (AFTER) SOAKING),(mm)	5.35	5.07	4.66
PERCENT SWELL	3.63	3.20	3.01

moisture density relationship of 8cm long 0.5% sisal fiber treated sample S1				
TRIAL NUMBER	1	2	3	4

	Water %	14	16	18	20	
Density	WEIGHT OF SOIL + MOLD (g) W1	10010	10068	10083	10035	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3717	3775	3790	3742	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.750	1.777	1.784	1.762	NMC
Moisture	CONTAINER NUMBER	F-2	A-4	B-7	A-1	E-1
	WET SOIL + CONTAINER (g) a	203	223	199	210	244.60
	DRY SOIL + CONTAINER (g) b	162	176	157	163	219.60
	WEIGHT OF CONTAINER (g) c	26	25	26	26	26.40
	WEIGHT OF WATER (g) e = a-b	41	47	42	47	25.00
	WEIGHT OF DRY SOIL (g) d =b-c	136	151	131	137	193.20
	MOISTURE CONTENT (%) m= (e/d)*100	30.20	31.30	32.11	34.04	12.94
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.344	1.354	1.351	1.314	

penetration test data of 8cm long 0.5% sisal fiber treated sample S1						
	number of blows					
	10		30		65	
PENETRATION (mm)	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.2544		0.2756		0.3286	
1.27	0.3074		0.3922		0.4346	
1.91	0.3604		0.424		0.4664	

2.54	0.4346	3.292	0.4664	3.533	0.5194	3.935
3.18	0.4664		0.4982		0.5512	
3.81	0.4982		0.5406		0.5724	
4.45	0.5512		0.6042		0.6254	
5.08	0.5936	2.968	0.636	3.18	0.6784	3.392
7.62	0.742		0.8374		0.8904	

Swell data of 8cm long 0.5% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.19	1.45	0.88
RDG (AFTER) SOAKING),(mm)	4.64	4.62	3.92
PERCENT SWELL	2.96	2.72	2.61

moisture density relationship of 8cm long 0.8% sisal fiber treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	15	17	19	21	
	WEIGHT OF SOIL + MOLD (g) W1	9948	9985	10025	10006	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3655	3692	3732	3713	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.721	1.738	1.757	1.748	NMC
Moisture	CONTAINER NUMBER	C-3	F-3	A-3	B-2	B-7
	WET SOIL + CONTAINER (g) a	204	199	189	215	223.00
	DRY SOIL + CONTAINER (g) b	163	158	149	168	201.90
	WEIGHT OF CONTAINER (g) c	27	26	26	25	25.80

	WEIGHT OF WATER (g) e = a-b	41	41	39	47	21.10
	WEIGHT OF DRY SOIL (g) d =b-c	137	132	123	143	176.10
	MOISTURE CONTENT (%) m= (e/d)*100	29.96	30.71	31.69	32.84	11.98
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.324	1.330	1.334	1.316	

penetration test data of 8cm long 0.8% sisal fiber treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.318		0.3392		0.4028	
1.27	0.3816		0.5088		0.5724	
1.91	0.4558		0.6466		0.6996	
2.54	0.5194	3.935	0.7526	5.702	0.8586	6.505
3.18	0.5512		0.8268		0.9752	
3.81	0.6148		0.8904		1.113	
4.45	0.689		0.9964		1.2084	
5.08	0.7314	3.657	1.1024	5.512	1.2826	6.413
7.62	0.8692		1.431		1.6112	

Swell data of 8cm long 0.8% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.40	1.35	1.40
RDG (AFTER) SOAKING),(mm)	4.02	3.34	3.01

PERCENT SWELL	2.25	1.71	1.38

moisture density relationship of 8cm long 1.1% sisal fiber treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	16	18	20	22	
	WEIGHT OF SOIL + MOLD (g) W1	9837	9956	9968	9858	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3544	3663	3675	3565	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.669	1.725	1.730	1.678	NMC
Moisture	CONTAINER NUMBER	A-12	A-7	B-3	C-5	A-5
	WET SOIL + CONTAINER (g) a	215	180	232	166	277.30
	DRY SOIL + CONTAINER (g) b	172	143	181	131	260.80
	WEIGHT OF CONTAINER (g) c	26	25	26	26	26.40
	WEIGHT OF WATER (g) e = a-b	43	37	51	36	16.50
	WEIGHT OF DRY SOIL (g) d =b-c	146	118	155	104	234.40
	MOISTURE CONTENT (%) m= (e/d)*100	29.35	31.78	32.77	34.45	7.04
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.290	1.309	1.303	1.248	

penetration test data of 8cm long 1.1% sisal fiber treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %

0	0		0		0	
0.64	0.2544		0.2756		0.318	
1.27	0.3498		0.424		0.4346	
1.91	0.4346		0.4982		0.5194	
2.54	0.5406	4.095	0.6042	4.577	0.6572	4.979
3.18	0.6042		0.6572		0.742	
3.81	0.6572		0.742		0.8268	
4.45	0.7526		0.8268		0.901	
5.08	0.8056	4.028	0.901	4.505	0.9752	4.876
7.62	0.9434		1.1024		1.3356	

Swell data of 8cm long 1.1% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	0.83	1.52	1.22
RDG (AFTER) SOAKING),(mm)	3.04	3.31	2.85
PERCENT SWELL	1.90	1.54	1.40

moisture density relationship of 11cm long 0.5% sisal fiber treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	14	16	18	20	
	WEIGHT OF SOIL + MOLD (g) W1	10006	10064	10079	10031	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3713	3771	3786	3738	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.748	1.776	1.782	1.760	NMC
Moi	CONTAINER NUMBER	F-2	A-4	B-7	A-1	E-1

	WET SOIL + CONTAINER (g) a	203	223	199	208	244.60
	DRY SOIL + CONTAINER (g) b	162	176	157	161	219.60
	WEIGHT OF CONTAINER (g) c	26	25	26	26	26.40
	WEIGHT OF WATER (g) e = a-b	41	47	43	46	25.00
	WEIGHT OF DRY SOIL (g) d =b-c	136	151	130	135	193.20
	MOISTURE CONTENT (%) m= (e/d)*100	30.20	31.30	32.62	34.32	12.94
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.343	1.352	1.344	1.310	

penetration test data of 11cm long 0.5% sisal fiber treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.2226		0.2332		0.265	
1.27	0.2756		0.318		0.3498	
1.91	0.3286		0.3816		0.4134	
2.54	0.3922	2.971	0.4452	3.373	0.4876	3.694
3.18	0.4346		0.4982		0.53	
3.81	0.4876		0.5406		0.583	
4.45	0.5406		0.5936		0.636	
5.08	0.583	2.915	0.6466	3.233	0.6996	3.498
7.62	0.7314		0.7738		0.8692	

Swell data of 11cm long 0.5% of sisal fiber treated sample S1

No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	0.50	1.12	0.18
RDG (AFTER) SOAKING),(mm)	3.01	3.47	2.45
PERCENT SWELL	2.16	2.02	1.95

moisture density relationship of 11cm long 0.8% sisal fiber treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	15	17	19	21	
	WEIGHT OF SOIL + MOLD (g) W1	9906	9981	10023	10004	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3613	3688	3730	3711	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.701	1.736	1.756	1.747	NMC
Moisture	CONTAINER NUMBER	C-3	F-3	A-3	B-2	B-7
	WET SOIL + CONTAINER (g) a	203	199	189	215	223.00
	DRY SOIL + CONTAINER (g) b	163	158	149	168	201.90
	WEIGHT OF CONTAINER (g) c	27	26	26	25	25.80
	WEIGHT OF WATER (g) e = a-b	40	41	39	47	21.10
	WEIGHT OF DRY SOIL (g) d =b-c	137	132	123	143	176.10
	MOISTURE CONTENT (%) m= (e/d)*100	29.23	30.71	31.79	32.84	11.98
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.316	1.328	1.332	1.315	

penetration test data of 11cm long 0.8% sisal fiber treated sample S1	
	number of blows

PENETRATION (mm)	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.212		0.2968		0.318	
1.27	0.2968		0.3498		0.371	
1.91	0.3604		0.4558		0.4876	
2.54	0.424	3.212	0.5724	4.336	0.6042	4.577
3.18	0.477		0.6254		0.636	
3.81	0.53		0.6784		0.689	
4.45	0.5724		0.7526		0.7738	
5.08	0.636	3.180	0.848	4.240	0.901	4.505
7.62	0.848		1.166		1.272	

Swell data of 11cm long 0.8% of sisal fiber treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.40	1.35	1.41
RDG (AFTER) SOAKING),(mm)	3.03	2.71	2.41
PERCENT SWELL	1.40	1.17	0.86

moisture density relationship of 11cm long 1.1% sisal fiber treated sample S1					
TRIAL NUMBER		1	2	3	4
Density	Water %	16	18	20	22
	WEIGHT OF SOIL + MOLD (g) W1	9831	9954	9963	9851
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124

	WEIGHT OF WET SOIL (g) W3 = W1-W2	3538	3661	3670	3558	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.666	1.724	1.728	1.675	NMC
Moisture	CONTAINER NUMBER	A-12	A-7	B-3	C-5	A-5
	WET SOIL + CONTAINER (g) a	215	180	232	166	277.30
	DRY SOIL + CONTAINER (g) b	172	143	181	131	260.80
	WEIGHT OF CONTAINER (g) c	26	25	26	26	26.40
	WEIGHT OF WATER (g) e = a-b	43	37	51	36	16.50
	WEIGHT OF DRY SOIL (g) d =b-c	146	118	155	104	234.40
	MOISTURE CONTENT (%) m= (e/d)*100	29.35	31.78	32.77	34.45	7.04
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.288	1.308	1.301	1.246	

penetration test data of 11cm long 1.1% sisal fiber treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.1908		0.212		0.265	
1.27	0.2968		0.3816		0.424	
1.91	0.3498		0.4346		0.4664	
2.54	0.424	3.212	0.477	3.614	0.5194	3.935
3.18	0.4558		0.5088		0.5724	
3.81	0.4876		0.5512		0.636	

4.45	0.5406		0.6042		0.6996	
5.08	0.6148	3.074	0.6784	3.392	0.7632	3.816
7.62	0.8268		0.954		1.06	

Appendix D: Laboratory test results on Sisal fiber with lime treated soil

moisture density relationship of 5cm long 0.8% sisal fiber mixed with 3.5% of lime treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	6	10	14	18	
	WEIGHT OF SOIL + MOLD (g) W1	9762	9965	10139	10115	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3469	3672	3846	3822	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.633	1.729	1.811	1.799	NMC
Moisture	CONTAINER NUMBER	B-1	B-7	F-1	A-3	B-2
	WET SOIL + CONTAINER (g) a	248	231	212	235	243.20
	DRY SOIL + CONTAINER (g) b	209	190	170	184	218.80
	WEIGHT OF CONTAINER (g) c	25	26	25	26	25.50
	WEIGHT OF WATER (g) e = a-b	39	41	43	51	24.40
	WEIGHT OF DRY SOIL (g) d =b-c	183	164	145	158	193.30
	MOISTURE CONTENT (%) m= (e/d)*100	21.32	25.23	29.37	32.30	12.62
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.346	1.381	1.400	1.360	

penetration test data of 5cm long 0.8% sisal fiber mixed with 3.5% of lime treated sample S1

PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.2968		0.318		0.3392	
1.27	0.4558		0.5512		0.5088	
1.91	0.5406		0.636		0.6148	
2.54	0.6572	4.979	0.6996	5.300	0.7314	5.541
3.18	0.689		0.742		0.7844	
3.81	0.742		0.7844		0.8162	
4.45	0.7844		0.8268		0.848	
5.08	0.8586	4.293	0.9116	4.558	0.901	4.505
7.62	1.1024		1.2296		1.3992	

Swell data of 5cm long 0.8% of sisal fiber mixed 3.5% lime treated sample S1

No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	1.01	0.72	0.55
RDG (AFTER) SOAKING),(mm)	2.96	2.50	2.25
PERCENT SWELL	1.67	1.53	1.46

moisture density relationship of 8cm long 0.8% sisal fiber mixed with 3.5% of lime treated sample S1

	TRIAL NUMBER	1	2	3	4	
Density	Water %	11	15	19	23	
	WEIGHT OF SOIL + MOLD (g) W1	9847	10062	10156	10008	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3554	3769	3863	3715	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.673	1.774	1.819	1.749	NMC
Moisture	CONTAINER NUMBER	A-10	A-8	A-5	B-6	F-2
	WET SOIL + CONTAINER (g) a	179	204	222	221	206.20
	DRY SOIL + CONTAINER (g) b	145	163	175	169	186.30
	WEIGHT OF CONTAINER (g) c	26	27	27	25	25.80
	WEIGHT OF WATER (g) e = a-b	34	41	47	51	19.90
	WEIGHT OF DRY SOIL (g) d =b-c	119	137	148	145	160.50
	MOISTURE CONTENT (%) m= (e/d)*100	28.57	29.75	31.40	35.50	12.40
DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100		1.301	1.368	1.384	1.291	

penetration test data of 8cm long 0.8% sisal fiber mixed with 3.5% of lime treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.3604		0.3816		0.424	

1.27	0.53		0.636		0.6784	
1.91	0.6572		0.7844		0.742	
2.54	0.7844	5.942	0.9116	6.906	0.9964	7.548
3.18	0.8586		0.9964		1.06	
3.81	0.9434		1.0812		1.1872	
4.45	1.0176		1.166		1.3144	
5.08	1.1024	5.512	1.2932	6.466	1.4628	7.314

moisture density relationship of 11cm long 0.8% sisal fiber mixed with 3.5% of lime treated sample S1						
TRIAL NUMBER		1	2	3	4	
Density	Water %	12	16	20	24	
	WEIGHT OF SOIL + MOLD (g) W1	9843	10051	10148	10025	
	WEIGHT OF MOLD (g) W2	6293	6293	6293	6293	
	VOLUME OF MOLD (Cm3) V	2124	2124	2124	2124	
	WEIGHT OF WET SOIL (g) W3 = W1-W2	3550	3758	3855	3732	
	WET DENSITY OF SOIL (g/Cm3) Wd = W3/V	1.671	1.769	1.815	1.757	NMC
Moisture	CONTAINER NUMBER	B-6	C-4	F-2	B-2	B-1
	WET SOIL + CONTAINER (g) a	230	229	248	237	253.90
	DRY SOIL + CONTAINER (g) b	186	181	192	180	230.50
	WEIGHT OF CONTAINER (g) c	25	25	26	25	25.10
	WEIGHT OF WATER (g) e = a-b	44	48	57	58	23.40
	WEIGHT OF DRY SOIL (g) d =b-c	161	156	166	154	205.40
	MOISTURE CONTENT (%) m= (e/d)*100	27.40	30.88	34.12	37.44	11.39

DRY DENSITY OF SOIL (g/Cm3) Dd = Wd/(100+m)*100	1.312	1.352	1.353	1.278	

penetration test data of 11cm long 0.8% sisal fiber mixed with 3.5% of lime treated sample S1						
PENETRATION (mm)	number of blows					
	10		30		65	
	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %	LOAD (Kn)	CBR %
0	0		0		0	
0.64	0.2544		0.2756		0.318	
1.27	0.4028		0.4664		0.5724	
1.91	0.5512		0.6148		0.6996	
2.54	0.6572	4.979	0.7208	5.461	0.8268	6.264
3.18	0.7632		0.8056		0.8904	
3.81	0.8268		0.9116		0.9964	
4.45	0.8904		0.9752		1.0812	
5.08	0.954	4.77	1.06	5.3	1.1872	5.936
7.62	1.2296		1.378		1.5688	

Swell data of 11cm long 0.8% of sisal fiber mixed 3.5% lime treated sample S1			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING),(mm)	0.71	0.52	0.99
RDG (AFTER) SOAKING),(mm)	2.03	1.33	1.41
PERCENT SWELL	1.13	0.70	0.36

Appendix E: Standard specifications

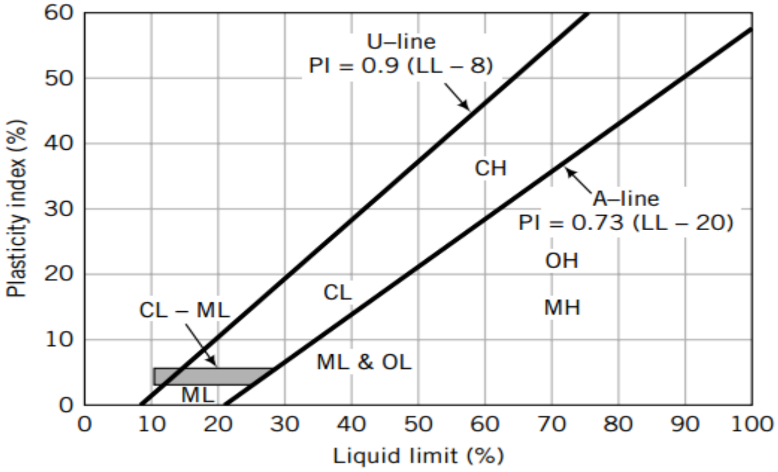


FIGURE 4.11
Plasticity chart.

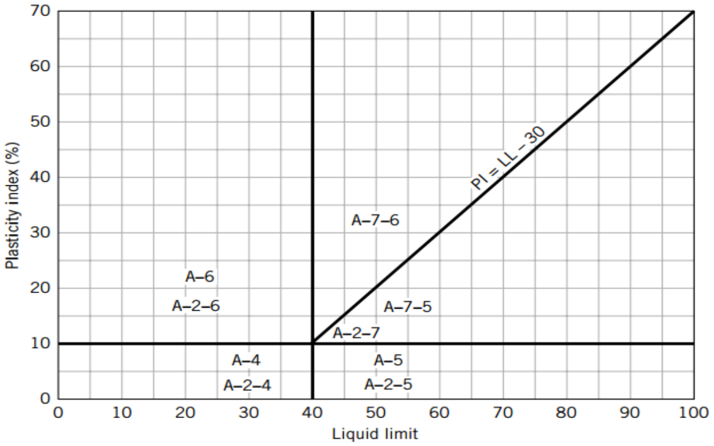


FIGURE 4.12
AASHTO classification of silt and clay within the plasticity chart.

Table 3-1 Subgrade Strength Classes

Class	CBR Range (%)
S1	<3
S2	3,4
S3	5,6,7
S4	8 - 14
S5	15 - 30
S6	>30