# INVESTIGATION ON THE APPLICATION OF NATURAL FIBER (KATCHA) AS A WEAK SUBGRADE SOIL REINFORCEMENT BLENDED WITH SAND: IN CASE OF KOYEFECHE PROJECT 18 ROAD PROJECT


By
Bethel Getamesay Girma


A Thesis Submitted to the department of Civil Engineering,
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering (Specialization in Geotechnical Engineering)


Office of Graduate Studies
Adama Science and Technology University


July, 2021
Adama Ethiopia

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## DECLARATION

I, hereby declare that this Master Thesis entitled "Investigation on the Application of Natural fiber (Katcha) as a Weak Subgrade Soil Reinforcement Blended with Sand: In Case of Koyefeche Project 18 Road Project" is my original work and has not been submitted for the award of any academic degree in any other university. All sources of materials that are used for this thesis have also been duly acknowledged.

| Bethel Getamesay Girma | ____________________ | ______________ |
|---|---|---|
| Name of the student | Signature | Date |

## Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Investigation on the Application of Natural fiber (Katcha) as a Weak Subgrade Soil Reinforcement Blended with Sand: In Case of Koyefeche Project 18 Road Project" prepared under my guidance by Bethel Getamesay Girma submitted in partial fulfillment of the requirements for the degree of Masters of Science in Civil Engineering (Specialization in Geotechnical Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

| | | |
|---|---|---|
| Argaw Asha (Ph.D.) | ______________________ | _______________ |
| Advisor | Signature | Date |

## Approval Sheet

I, the advisors of the thesis entitled "Investigation on the Application of Natural fiber (Katcha) as a Weak Subgrade Soil Reinforcement Blended with Sand: In Case of Koyefeche Project 18 Road Project" and developed by Bethel Getamesay Girma, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

| Argaw Asha (Ph.D.) | ____________________ | ______________ |
|---|---|---|
| Advisor | Signature | Date |

We, the undersigned, members of the Board of Examiners of the thesis by Bethel Getamesay Girma have read and evaluated the thesis entitled "Investigation on the Application of Natural fiber (Katcha) as a Weak Subgrade Soil Reinforcement Blended with Sand: In Case of Koyefeche Project 18 Road Project" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geotechnical Engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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# LIST OF ACRONYMS AND ABBREVIATION

| | |
|---|---|
| AASHTO | American Association of States Highways and Transport Official; |
| ASTM | American Society for Testing Material; |
| CBR | California Bearing Ratio; |
| ERA | Ethiopian Road Authority; |
| g | gram; |
| GI | Group Index; |
| gm/cm$^3$ | Gram per Centimeter Cube; |
| Gs | Specific Gravity; |
| Kpa | Kilopascal; |
| LL | Liquid Limit; |
| MDD | Maximum Dry Density; |
| mm | Millimeter; |
| NMC | Natural Moisture Content; |
| OMC | Optimum Moisture Content; |
| PI | Plasticity Index; |
| PL | Plastic Limit; |
| UCS | Unconfined Compressive Strength; |
| USCS | Unified Soil Classification System; |
| WAC | Water Absorption Capacity, and |
| Wt | Weight. |

# ABSTRACT

*The performance and quality of pavement are highly affected by the subgrade property. Sometimes subgrades might be very weak to support the traffic loading, facing of such a soil is probable in many parts of Ethiopia. The road project in Koyefeche project 18 faces weak subgrade soil, which required external backfill material resulted the delay of project, additional cost and reduction of natural resource. Soil reinforcement is one way of improving the strength of a soil by using different type of natural fibers. Ethiopia is reach in both natural fiber and sand. However, few works have been conducted to investigate the effect of using natural fibers and sand on the properties of subgrade soil. Therefore the main aim of this thesis is to investigate the effect of randomly oriented Katcha fiber and sand on weak subgrade soil properties. Katcha fiber was first treated with kerosene and water absorption test were conducted on kerosene coated and uncoated fiber to determine the fiber with lower water absorption capacity; Kerosene-coated Katcha fiber gave lower water absorption than that of uncoated one. Therefore Kerosene-coated Katcha fiber and Sand were two materials utilized in this thesis. The Katcha fiber was mixed to the clay soil in 0.5%, 1% and 1.5% by dry weight of the soil for 20mm, 35mm and 50mm length of each percent, and 10%, 15%, and 20% sand was mixed by dry weight of the soil. Gradation, Consistency, Volumetric Shrinkage, Compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) properties are particularly investigated. The analysis results showed that mixing of sand reduce the percent of fine, plasticity index and shrinkage limit of the soil and mixing of Katcha fiber showed significant change in Compaction, CBR and UCS of the clay soil. Test results indicate that the MDD decrease, OMC and CBR increases with the increase in fiber length and percent. The increase in CBR value is substantial at 1%, 35 mm length Katcha fiber. It was also observed that mixing sand further decreases the OMC and increases the MDD and CBR value of soil, this increment is considerable at 20% sand content. The application of 1% and 35mm Katcha fiber increased the CBR by 189%, UCS by 59.76%, and a further increase in CBR by 240.91% and UCS by 25.41% was obtained at 20% sand content and introducing sand as layer increased the CBR value by 295.45%. Thus using of Katcha fiber and sand mixing and sand layer is found to be an effective materials to improve the subgrade soil properties.*

**Keywords:** Soil reinforcement, Katcha fiber, Sand, Kerosene, Weak Subgrade

# CHAPTER ONE

# INTRODUCTION

## 1.1. Background

The stability of any structure including road depends on the strength properties of underground soil on which it is constructed. The performance and pavement thickness of a road depends on the properties of subgrade material including strength, drainage, ease of compaction and low compressibility. Usually subgrades are consisted of locally available soil deposits that sometimes might be very weak to support the traffic loading, in this causes where the in-situ conditions are unsuitable, cost effective methods of improving the existing situations must be identified and implemented (Aggarwal & Sharma, 2010; ERA Site Investigation Manual, 2013).

Ground modification refers to a different techniques used to improve the engineering characteristics of the soil. It can be applied in various soil conditions such as expansive soils and soils with inadequate mechanical properties. One way of modifying the ground is the use of reinforcing elements in the form of strips, bars, sheets and fibers. The fiber reinforcement involves mixing of natural or synthetic fibers with soil, where the fibers act as tensile resisting elements that improve soil strength (Torio-kaimo et al., 2020).

A soil stabilized with fiber termed as fiber-reinforced soil and it can be defined as a soil mass that contains randomly distributed, discrete fibers, which provide an improvement in the mechanical behavior of the soil composite. The primary purpose of reinforcing soil mass is to improve stability, increase bearing capacity, and to reduce settlements and occurrence of crack in a soil mass. Reinforcement is not a new experience, it was practiced in ancient times like Great Wall of China and ziggurats of Babylon (Hejazi et al., 2012). Currently increasing attention is being paid to natural fibers, due to the simultaneous awareness is increasing on environment protection from pollution and conserving energy. The renewed interest in the natural fibers has resulted in large number of modifications to bring it equivalence and even superior to synthetic fibers by using different treatment methods including physical and chemical treatment to protect it from moisture induced degradation (Sumi & Unnikrishnan, 2015; Torio-kaimo et al., 2020).

Using of natural fiber like Coir, Palm, Sisal, and Jute fibers is common in different countries like China, India and Philippines, in Ethiopia natural fibers like Tef straw, Sisal, Katcha etc. has been used for mud house construction in rural areas; but the application of natural fibers in road construction is not yet practiced. This indicate more study is needed in locally available natural fibers as a reinforcement material.

A naturally occurring sand can be used as stabilizer to improve the performance of soil. It can be mixed as admixture to cohesive soils to alter the plasticity, compaction and strength of the soil (Kollaros & Athanasopoulou, 2017). Furthermore sand can be introduced as a layer to solve the problem of expansive soils by draining it in addition to reinforcing it (Nini, 2016). Therefore sand can be applied at various form; mixing and intercalation layer to improve the soil property. In this research sand also used as an admixture and as a layer for stabilization of the weak subgrade soil in addition to the natural fiber for further improvement of the soil property.

This thesis presents the results of an experimental investigation on the effect of kerosene coated Katcha fiber and sand on subgrade soil collected from Koyefeche project 18 road project. The coated katcha fiber was introduced as a discrete element with 20 mm, 35 mm and 50 mm length and content of 0.5%, 1% and 1.5%.Sand was mixed in varying ratio 10%, 15% and 20% and it was also introduced as a layer in different position. Laboratory tests which include grain size analysis, Atterberg limit, specific gravity, volumetric shrinkage, compaction, UCS, and soaked CBR tests were conducted for natural and stabilized soils. In addition to this tensile strength, Specific gravity and WAC of uncoated and kerosene coated Katcha fiber was determined.

## 1.2. Statement of the Problem

The road which is constructed in Addis Ababa Koyefeche Project 18 faces unsuitable subgrade soil material which required removal and replacement of the subgrade soil which leads to the increase in construction cost, duration and create inconvenience for the population movement. Furthermore, additional borrow areas are needed to be excavated to get quality materials that contribute to the reduction of nonrenewable natural resource for the next generation and finding the disposal area of material was a problem. Thus, remedial action should be taken aimed at mitigating the ongoing problem in the road construction considering the quality, cost and duration of the project by using mechanical stabilization technique.

## 1.3. Objectives

### 1.3.1. General Objective

The general objective of this thesis is to improve the weak subgrade soil by adding sand and kerosene coated Katcha fiber.

### 1.3.2. Specific Objectives

- ✓ To study the property of subgrade soil.
- ✓ To investigate the effect of sand on gradation and consistency property of subgrade soil.
- ✓ To investigate the effects of Katcha fiber (lengths and percent) and sand on Compaction, CBR and UCS value of subgrade soil.
- ✓ To determine the optimum amount of Katcha fiber, Sand and suitable position of sand layer in reinforced soil.

## 1.4. Research Questions

1) What is the property of good subgrade soil?
2) What is the effect of sand on consistency and gradation property of weak subgrade soil?
3) What is the effect of Katcha fiber and sand on compaction, CBR and UCS characteristic of clay soil?
4) What is the optimum amount of Katcha fiber, sand and suitable position of sand layer to improve the clay soil property?

## 1.5. Significance of the Study

In Ethiopia, many research were done on improving the performance of problematic subgrade soil by using chemical stabilization like cement, lime, marble dust, fly ash, etc. However, this study provides a new ecofriendly method that can be implemented in any weather condition unlike that of the chemical stabilization method.

Since, Ethiopia is rich in both Katcha fiber and Sand this thesis provided a new alternative method of stabilization to improve the bearing capacity and workability of weak subgrade soil by using Katcha fiber and sand. Improving the performance of existing soil can reduce the construction cost of road project by avoiding the cut, disposal and fill material price and moreover it contribute to conservation of natural resources for the upcoming generation

Therefore this study introduces a new economical method to improve the performance of subgrade soil by the combined effect of sand and Katcha fiber. The particular importance of the study is not only for the koyefeche project 18 road project but also for other areas of similar soil type and it can be used as reference material for future studies.

## 1.6. Scope and Limitation of the study

The study considered a quantitative experimental study; to measure the engineering properties of subgrade soil samples collected from two test pits of koyefech project 18 road project at a depth of 1.2 m and to determine the strength of stabilized subgrade soil.

Generally, the experiment includes tests performed in soil laboratory as grain size analysis, consistency test, specific gravity, and volumetric shrinkage for identification of weak subgrade soil and to study the effect of adding sand on the classification of the subgrade soil by AASHTO and USCS classification system and compaction, CBR and UCS tests were conducted for natural and stabilized soil by varying the length and content of Katcha fiber and sand content. A laboratory test was also conducted to determine the physical and tensile properties of individual fibers including individual fiber diameter, tensile strength, specific gravity and moisture content and moisture regain of the fiber. However, this work is limited to determine biochemical composition of the Katcha fiber due to the lack of chemical reagents which are needed to determine the composition of natural fiber so this property of Katcha fiber was adopted from previous researches conducted on Katcha fiber properties.

## 1.7. Structure of the study

The thesis includes five chapters. In the first chapter the background, statement of the problem, objectives, research questions, significance of the study, scope and limitations of the work is presented. The second chapter deals with a brief literature review comprising study on previous similar works relevant to the present study about soil, natural fiber and method of soil reinforcement. In the third chapter the method, description of the study area, the material used, procedures to be followed and tools and techniques engaged in the laboratory to achieve the specified objectives are presented. The fourth chapter presents the analysis and results obtained from the experimental work. Finally, the conclusions drawn and recommendations made from the findings are presented in the fifth chapter.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Origin and Formation of Residual Soils

Soil can be defined as a complex heterogeneous material which contains different types of minerals resulted from disintegration or weathering of parent rock due to various physical phenomena. Soil property is not the same in all areas. The variation in the property, may occur within a few kilometers (Mathur et al., 2017). The geotechnical property of a soil is affected by parent rock, the degree of weathering, and climatic regime of the area (Saffari et al., 2019).

Residual soils are soils derived from the in situ weathering and decomposition of rock which has not been transported from its original location. Residual soils are formed from parent rocks by the in situ weathering of rocks, through Physical, Chemical and Biological processes. Physical process involves on crushing of the rock to produces end products consisting of angular blocks, cobbles, gravel, sand, silt and even clay sized rock flour without altering the mineral constituents of the parent rock, and expose fresh surfaces to chemical. Chemical process, chiefly hydrolysis, cation exchange and oxidation alter the original rock minerals to form more stable clay minerals(Mitchell & Soga, 1994). Biological weathering includes both physical action like splitting by root wedging and chemical action which includes bacteriological oxidation, chelation and reduction of iron and sulphur compounds

Climate has a considerable influence on the rate of weathering. The extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature. Topography controls the rate of weathering by partly determining the amount of available water for each zone of weathering, the slope angle controls the amount of water available to move downward through the weathering zone. On steep slopes precipitation of run-off is greater than infiltration which is not favorable for deep weathering. On the other hand, on flatter slopes, run- off is not so marked and long uninterrupted periods of weathering can take place; producing deep weathered soil profile (Huat et al., 2009). As it is discussed above the property of residual soil such as specific gravity, consistency limits, particle distribution, compaction, bearing capacity, permeability and shear strength is affected by parent rock, the degree of weathering, climate, and topography condition of the area.

## 2.2. Soil Classification

Classification of soil plays important role to check the suitability of soil to be used as a construction materials, identification and classification of soils is mainly done by mineralogical classification and index tests. For mineralogical identification, X-ray diffraction, Differential Thermal Analysis and Electron Microscope resolution are used, on the other hand, index tests consists of grain size analysis, consistency test, and free swell are used for classifying the soil. AASHTO and USCS systems are widely known classification systems which use index property of soils determined by simple laboratory tests for soil classification.

### 2.2.1. AASHTO Classification System

AASHTO classification system is used to classify both soil and soil-aggregates based on laboratory determination of particle-size distribution, liquid limit, and plasticity index. This method is used when a precise engineering classification is needed, especially for highway construction purposes. The system groups soil into seven major groups from A-1 to A-7 with a total of 12 groups, including subgroups. The strength or quality of a soil decrease from left to write across a table except A3 group which is found between A1 and A2 groups. Soil which lays under groups A1- A4 are regarded as an excellent to good while soils lays under group A5-A7 are ranges from fair to poor for subgrade material. Another important number in this classification system is group index; the group index is a function of the liquid limit, the plasticity index and the amount of material passing 0.075 mm sieve (ASTM-D3282, 1997).

The Group index (GI) of the soil is calculated by using equation 2.1

$$GI = (F - 35)\big(0.2 + 0.005(LL - 40)\big) + 0.01(F - 15)(PI - 10) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.1$$

Where: F is percentage passing No. 200 (75-μm) sieve,

LL is liquid limit, and

PI plasticity index

Table 2.1. AASHTO Classification of Soils and Soil-Aggregate (ASTM-D3282, 1997)

| General classification | Granular Materials (35% or less passing No.200) | | | | | | | Silt-Clay Materials (More than 35% passing No.200) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group Classification | A-1 | | A-3 | A-2 | | | | A-4 | A-5 | A-6 | A-7 |
| | A-1-a | A-1-b | | A-2-4 | A-2-5 | A-2-6 | A-2-7 | | | | A-7-5, A7-6 |
| Sieve Analysis, % Passing | | | | | | | | | | | |
| No. 10 (200 mm) | 50 max | … | … | … | … | … | … | … | … | … | … |
| No. 40 (425µm) | 30 max | 50 max | 51 min | … | … | … | … | … | … | … | … |
| No. 200 (75 µm) | 15 max | 25 max | 10 max | 10 max | 35 max | 35max | 35 max | 36 min | 36min | 36 min | 36 min |
| Characteristic of fraction passing No. 40 (425 µm) | | | | | | | | | | | |
| Liquid limit | … | | … | 40 max | 41 min | 40 max | 41 min | 40 max | 41 min | | 41min |
| Plasticity index | 6 max | | N.P | 10 max | 10 max | 11 min | 11 min | 40max | | | 11min |
| | | | | | | | | 10 max | 10 max | | |
| Usual type of Significant constituent materials | Stone Fragment , Gravel and Sand | | Fine Sand | Silty or Clayey Gravel and Sand | | | | 11min | Silty Soils | | Clayey Soils |
| General rating as subgrade | | | | Excellent to Good | | | | | | Fair to poor | |

## 2.2.2. Unified Soil Classification System (USCS)

The USCS use both particle size analysis and plasticity characteristic just like AASHTO classification system. The system is used to determine the suitability of soils for all geotechnical works. In this system the soils are classified in to fifteen groups, first the soils are classified in to two categories as coarse grained soils, if more than 50% of the soil retained on No. 200 (0.075 mm) sieve and fine grained soils, if more than 50% of the soil passes No. 200 sieve. Coarse grained soils are further divided in to eight groups and fine grained soils are divided in to seven group(Arora, 2003).

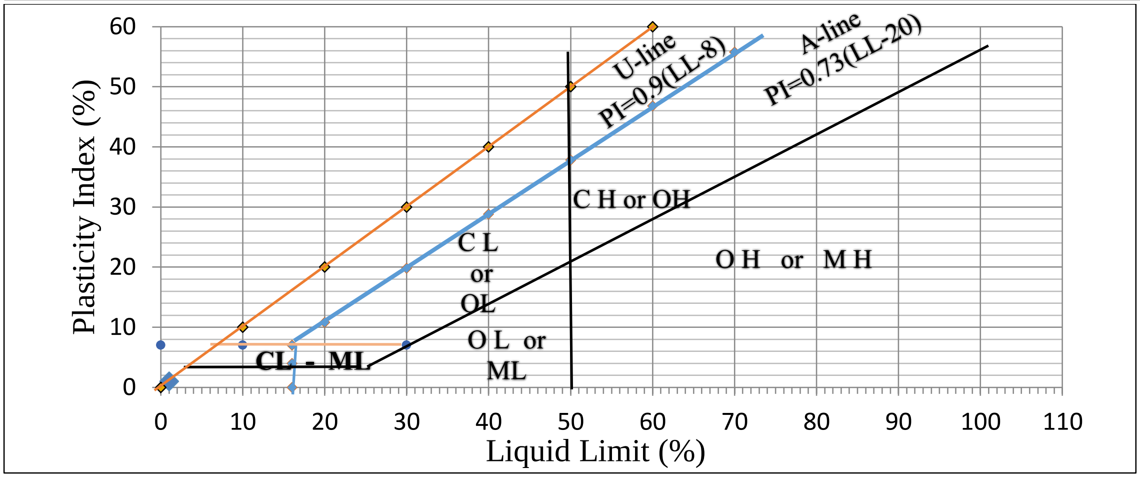



Figure 2.1. USCS plasticity chart (ASTM-D2487, 1985)

## 2.3. Soil Stabilization

The quality of subgrade is the input parameter in pavement design and construction. Practically finding a good subgrade soil is not always possible, thus implementing different mechanism is significant to solve this difficulty; like avoiding the particular site, design the planed structure accordingly, and remove and replacement of soil but all this methods are not always suitable for a certain project. Therefore a ground modification method should be identified and implemented to improve the performance of exciting soil (Aggarwal & Sharma, 2010; Hausman, 1990).

Soil stabilization is the process of alteration of one or more soil properties to create an improved soil material possessing the desired properties for intended construction purpose. Stabilization can be classified in to two major categories as chemical and mechanical processes. Chemical stabilization includes the use of chemicals to modify the behavior of soil and Mechanical stabilization includes methods which improve the soil property without altering the chemical composition of the soil by compaction, and fibrous and other reinforcement of geomaterials to improve strength of a soil (Das, 2003).

### 2.3.1 Soil Reinforcement

Soil reinforcement is included in the mechanical soil stabilization method. In this method either natural or synthesized fibers are used to improve the soil parameters such as bearing capacity, shear strength, compressibility, density and hydraulic conductivity. Both natural and synthetic fibers can be used as a soil reinforcing material but due to simultaneous awareness increase on environment and energy, increasing attention is being paid to natural fibers with a view to conserving energy and protecting the environment rather than using of synthetic fiber, and waste byproducts of different industries (Sumi & Unnikrishnan, 2015).

The standard fiber-reinforced soil is defined as a soil mass that contains randomly distributed, discrete element which provide an improvement in the mechanical behavior of the soil composite. The concept of fiber reinforcement was recognized more than 5000 years ago; ancient civilizations used straw and hay to reinforce mud blocks in order to create reinforced building blocks. There are several examples of reinforcing the soil like Great Wall of China earliest example of reinforced earth using branches of trees as tensile elements, and ziggurats of Babylon woven mats of read were used. The first modern form of soil reinforcement was developed by Henry Vidal in 1966 since then the idea of reinforcement is getting a big concern (Kulhar & Raisinghani, 2018).

### 2.3.2. Synthetic Fibers

Synthetic fibers are manufactured fibers for a certain purpose. Usually synthetic fibers includes steel, glass, plastic, both macro plastic fibers and micro plastic fibers, and carbon fibers. This fibers are widely applicable in different area including production of concrete, blocks, soil reinforcement etc. All synthetic fibers can be used as a soil reinforcing material specifically polypropylene fibers, have demonstrated positive benefits when used as reinforcement for soil (Mohajerani et al., 2019).

A disadvantage of synthetic fibers is that they take a lot more energy to produce due to the production method, hence these fibers are more cost. Some limitations of synthetic fibers include their low biodegradability. For polypropylene fibers, when recycling plastic, there is a risk if the prior history of the plastic is not known. If it was procured from an uncontrolled environment, the resulting properties of the recycled fiber may be unstable and inconsistent and also some of the synthetic fibers including such as glass fiber has smooth surface which results lower friction with in a soil mass and reduce the strength of reinforced soil (Hejazi et al., 2012; Mohajerani et al., 2019).

### 2.3.3. Natural Fibers

Natural fibers include those originated from plant, animal and mineral sources. In soil reinforcement the natural fiber refers to the plant based natural fibers due to bulk availability and higher strength, this fibers are lignocellulosic in nature and are comprised of cellulose, hemicelluloses, lignin, pectin and waxy substances (Sumi & Unnikrishnan, 2015).

These days, natural fibers are widely incorporated in many engineering applications due to their abundance, cost, low density, strength, stiffness, enviromental freindly and so forth. Natural fibers includes those originate from plant parts (banana, jute, coir, sisal, etc.), animal parts (silk, hair, wool, etc.) and minerals sources. Geaotechnical intentions have been projected towards plant fibers in terms of natural fiber based on the availability and applicability for large scale application (Gowthaman et al., 2018; Hejazi et al., 2012; Sumi & Unnikrishnan, 2015).

#### 2.3.3.1. Katcha Fiber

Katcha (ቃጫ) is a fiber which is extracted as a byproduct from Enset (እንሰት) plant. Ensete ventricosum plant commonly known as Enset or false banana plant. It is thicker and larger than banana often reaching up to 12 m in height and more than 1 m in diameter and it usually harvested starting from 3 years (Teli & Terega, 2017).

(a)

(b)

Figure 2.2. Photographic view of; (a) Enset Plant and (b) Katcha Fiber

The Katcha fiber is extracted traditionally from the stalk part of plant by hand decortication method by using a traditional sharp- edged blade against flat wood base plate along the stalk length. The main aim of extraction of the pseudostem and leaf sheaths of Ensete is to produce starchy pulp along with the corm which further processed and used as a food product, and a fiber as a byproduct the extracted fibers are very long, often cut to 1-1.5m during extraction.

#### 2.3.3.1.1. Availability of Katcha Fiber in Ethiopia

Ethiopia is one of the countries where Eniset plant occurs in domestic as well as wild form. The wild Enset occurs in the highlands in the southwestern part whereas the cultivated one grows in a wider area comprising the central, southern and southwestern parts mainly at higher altitudes ranging from 1500 to 3100 m. Enset is well known for its drought resistance presently it is the main crop of a sustainable indigenous African system, which ensures food security. In Ethiopia, more than 20% of the total population, concentrated in the highlands of southern Ethiopia, depend upon Enset. In addition to its use as a source of food, it is also utilized for Katcha fiber production (Teli & Terega, 2017). Since the Enset plant is source of food it is widely available in the country and getting katcha fiber would not be a problem.

## 2.4. Properties of Natural Fiber

### 2.4.1. Biochemical Properties of Natural Fiber

All plant based natural fibers are lignocellulosic in nature and are comprised of cellulose, hemicelluloses, lignin, pectin and waxy substances. The cellulose fibrils made of chained-cellulose molecules, are aligned along the length of the fiber, which provide higher mechanical (tensile and flexural) strength, in addition of providing rigidity it determine the reinforcing ability of fiber. Hemicellulose forms the cementing matrix and it influences the moisture absorbent ability of the fiber structure (Gowthaman et al., 2018; Sumi & Unnikrishnan, 2015). Lignin is a complex hydrocarbon polymer which gives rigidity to the stem. It plays important role as a protection layer which prevent the internal structure of fiber form degradation, Pectin provide flexibility and the waxes make up the last part of the fiber (John & Thomas, 2008).

Generally in natural fiber, Cellulose is responsible for fiber strength, hemicelluloses for thermal, biological and moisture degradation, while lignin for UV degradation and char formation (Sumi & Unnikrishnan, 2015). Thus the overall property of natural fiber is determined by its structure, cell dimension, defects and chemical composition. A typical schematic diagram of fibril matrix structure (strands of cellulose molecules embedded in a matrix of hemicellulose and lignin) from (Gowthaman et al., 2018) is shown in Figure 2.4.

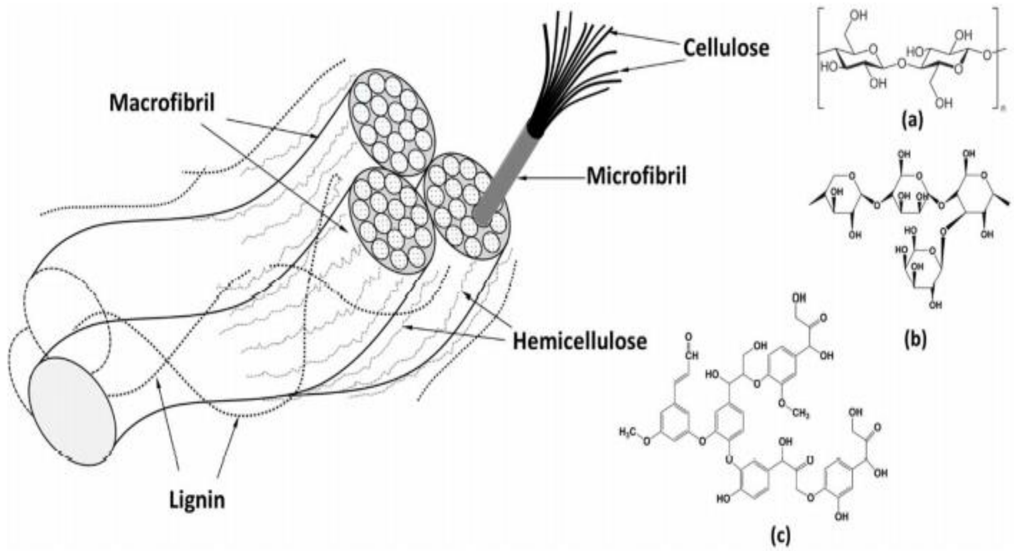



Figure 2.3. Fibril matrix structure of plant fiber and the chemical composition of (a) Cellulose; (b) Hemicellulose; and (c) Lignin (Gowthaman et al., 2018)

Commonly fibers like kenaf, hemp, flax, sisal, jute and bamboo with higher cellulose content more than 50% reflect higher strength property and they are used as a soil reinforcement material. Katcha fiber also exhibit cellulose content of more than 50% this shows the potential applicability of katcha fiber as a reinforcement material. The biochemical compositions and Tensile strength of plant fibers is illustrated in Table 2.2 with respect to their origins.

Table 2.2. Biochemical compositions and Tensile strength of plant fibers

| Source of Fiber | Fiber Origin | Cellulose (%) | Hemicellulose (%) | Lignin (%) | Tensile strength (MPa) | Elongation at Break (%) | References |
|---|---|---|---|---|---|---|---|
| Banana | Leaf | 57.6- 65 | 19-29.1 | 5-13.3 | 392-677 | 2.7-5.9 | (Bhatnagar et al., 2015; Gowthaman et al., 2018; Teli & Terega, 2017) |
| Coir | Fruit | 32–46 | 15-30 | 40–45 | 100–225 | 12-52.45 | (Gowthaman et al., 2018; Sumi & Unnikrishnan, 2015; Teli & Terega, 2017) |
| Jute | Stem | 61-71 | 14-20 | 12-13 | 393-773 | 1.5–1.8 | (Gowthaman et al., 2018; Sumi & Unnikrishnan, 2015; Teli & Terega, 2017) |
| Sisal | Leaf | 57–71 | 10-16 | 11–12 | 317.5 | 3-7 | (Gowthaman et al., 2018; Sumi & Unnikrishnan, 2015; Teli & Terega, 2017) |
| Enset | Stem | 62-67.63 | 19-22.47 | 5-6.88 | 351.7 | 3.2 | (Esayas et al., 2018; Teli & Terega, 2017; Temesgen & Sahu, 2014) |

The biochemical composition of Katcha fiber with respect to their implication are presented in the following table 2.3.

Table 2.3. Biochemical composition of Katcha fiber and their implication

| Fiber Properties | Component (%) | Implication | Reference |
|---|---|---|---|
| Cellulose | 62-67.63 | Complex carbohydrate responsible for fiber strength, provide higher mechanical (tensile and flexural) strength. | (Esayas et al., 2018; Teli & Terega, 2017; Temesgen & Sahu, 2014) |
| Hemicellulose | 19-22.47 | Influences the moisture absorbent ability of the fiber structure and provide protection against thermal, biological and moisture degradation. | (Esayas et al., 2018; Teli & Terega, 2017; Temesgen & Sahu, 2014) |
| Lignin | 5-6.88 | Prevent the internal structure of fiber form degradation and protect from UV degradation and char formation | (Esayas et al., 2018; Teli & Terega, 2017; Temesgen & Sahu, 2014) |

### 2.4.2. Fiber Degradation and Treatment

Despite natural fiber's many advantages, their property still need to be improved to be used in soil reinforcement to avoid or reduce the degradability of fiber in the soil composite. Degradation due to water absorption and microorganisms remains as a major challenge in fiber soil reinforcement technique. Plant based natural fibers contain groups which exhibit a tendency to attract water molecules through hydrogen-bond formation causing the fibers to swell which provides favorable conditions for microorganisms to live. The decrease in strength of lignin, and hemicellulose leads to the increase the rate of degradation in fiber (Gowthaman et al., 2018; Sumi & Unnikrishnan, 2015). In order to reduce degradability of fiber, treatment techniques is needed to increase the hydrophobic property of fiber to ultimately minimize microbial degradation and increases long term mechanical strength.

Different treatment techniques are available for fiber treatment which can be used to improve the fiber performance in soil. The treatment techniques can be either physical or chemical. Alkali treatment is one chemical treatment method which involves on subjecting of fiber to alkali (commonly, aqueous Sodium Hydroxide (NaOH)) in order to modify the surface of fibers leading to increased wettability and interfacial strength of fibers with polymer resin. Treatment of coir fibers with 5% aqueous NaOH at curing periods of 72 h to 96 h resulted in increased wettability and dispersability of fibers in polymer matrix. An increase of 15% in tensile strength was observed. Higher curing periods showed gradual decrease in strength this is due to the alkali can dissolve and remove waxy coating from fiber surface and make it rough, excessive concentration of alkali can possibly damage the fiber (Sumi & Unnikrishnan, 2015).

Other widely used method is physical coating or treatment in which the fiber surface is modified by physical means, mostly using synthetic polymers. Kerosene and Bitumen are widely used for this treatment mechanism which physically prevent the entry of moisture into fiber. A study was conducted by (Ramasubbarao, 2014) on the water absorption capacity of uncoated and kerosene coated coir fibers from the test water absorption capacity of fiber is reduced by 58% for two days mellowing period of coir fiber. 100 % reduction in water absorption capacity was recorded for a Coir fiber soaked in Kerosene for nine days (Torio-kaimo et al., 2020).

## 2.5. Soil Reinforcement Method

Different type of fiber can be used for soil reinforcement in varied forms, texture, stiffness, content, length or aspect ratio, orientation and so forth among which content, length and orientation of fibers are the most practical concerns in geotechnical applications. Basically, fiber reinforced soil can be classified into two types based on their method of application as random distributed fiber inclusion and systematic/planar fiber inclusion (using planar reinforcement) (Gowthaman et al., 2018; Hejazi et al., 2012).

### 2.5.1. Random Inclusion

Random inclusion of fiber is a well-known soil improvement technique in which fibers comprised of desired property and quantity are assorted as randomly distributed, discrete elements and mixed and compacted in situ to provide an improvement in the mechanical behavior of the soil composite (Gowthaman et al., 2018; Hejazi et al., 2012).

Random inclusion provide an isotropic increase in the strength of the soil composite without introducing continuous planes of weakness. The distributed fibers subjected to tension contribute to the increase in strength of specimens. Initially, soil particles subjected to stresses attempt to dansify, which persuades deformation of fiber material, subsequently direct forces are generated on fiber at fiber-soil interlocking stage due to rotation and direct impact of soil particles. Simultaneously, soil particles which are in contact with fiber, induce to develop frictional forces on fibers in addition to interlocking forces. Eventually, the interlocking forces coupled with frictional forces tend to mobilize the tensile stress on fiber material. Moreover, random distribution of fibers mobilizes fiber-soil adhesive bonding, which utilizes additional composite strength and the interaction of the flexible fibers behaves as a structural mesh that holds the soil together which increase the soil structural integrity (Gowthaman et al., 2018).

### 2.5.2. Systematic/Planar Inclusion

In Systematic or planar inclusion fibers introduced by planner or layer systems in vertical, horizontal or both direction. The application of natural fibers systematically requires modification such as weaving, binding, combining or punching based on the requirements of applications. In this system the soil is first compacted to the desired density and then the reinforcement material is placed and the sequence repeated until the required lift is achieved. The Planer inclusion technique mobilizes supplementary frictional strength along the fiber-reinforced planes but compared to random inclusion systematic inclusion has its weakness because the material in planar creates planes of weakness with un-reinforced zones, un-reinforced zones necessitate the survival by its own strength but possibilities still exist to generate failure planes through weaker un-reinforced zone (Gowthaman et al., 2018).

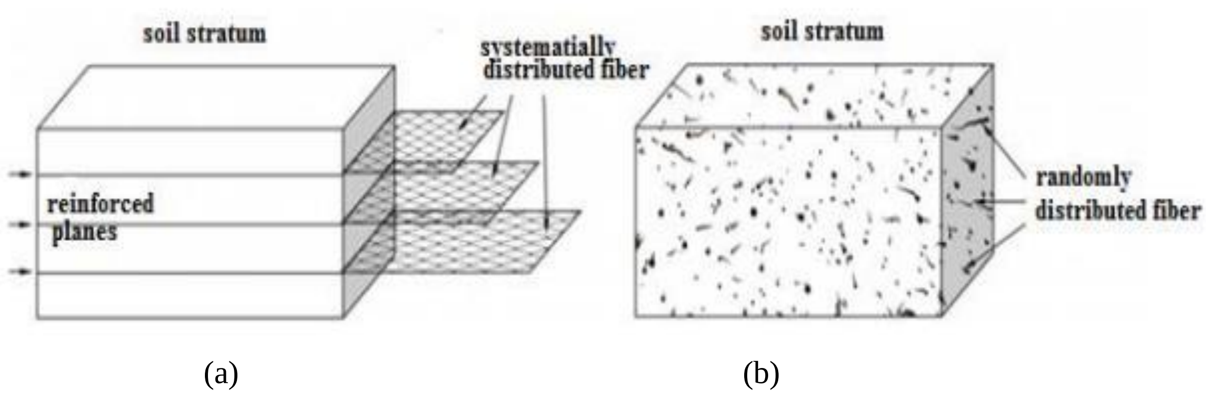



Figure 2.4. Fiber reinforcement mechanism of soil; (a) Systematic/Planer inclusion; (b) Random inclusion (Gowthaman et al., 2018)

## 2.6. Potential Applications of Fiber-Reinforcement

Fiber-reinforcement has been considered in projects including slope stabilization, embankment construction, subgrade stabilization, and as landfill covers. The general advantages of fiber reinforcement are:

1. Conventional construction equipment can be used for field placement of fibers. A rotary mixer of the type typically used in lime-soil mixing can be used to mix the fibers within the soil lift. The lift can then be compacted using standard soil compaction methods, without the concern of damaging the reinforcement (Li, 2005).
2. Unlike chemical stabilization methods lime, cement and other chemicals, fiber-reinforcement is not significantly affected by weather condition it is possible to use fiber reinforcement in any weather condition (Li, 2005; Sumi & Unnikrishnan, 2015).
3. The natural fibers used for reinforcement are relatively cheap, locally and widely available, ecofriendly, easy to process and renewable (Sumi & Unnikrishnan, 2015).

## 2.7. Previous works

Worldwide a number of researches have been carried out so far to improve the properties of weak soil by using different types of natural fibers. Some of them are pointed out here.

### 2.7.1. Banana Fiber

Banana fiber is one of a natural fiber, obtained from the pseudo-stem which is a cylindrical, clustered aggregation of leaf stalk bases of banana plant. It has high strength, light weight, smaller elongation, fire resistance quality, great potentialities and biodegradability and its diameter ranges 0.08-0.25mm and length ranges 1-5 m (Bhatnagar et al., 2015).

A study in India by (Babu, 2019) had been performed to understand the physical mechanism of stabilization of an expansive soil by adding banana fiber. The study aimed at stabilization of black cotton soil with banana fiber in a random inclusion. The materials used in this test were black cotton soil and banana fiber with a cut length of 1.5 cm and 0.3%-1.2% content with an increment of 0.3% by dry weight of soil and compaction, UCS and CBR tests were conducted.

The final result from the experiment showed that, as the percentage of fiber increases the values of OMC increase and MDD reduced. This is due to the water absorption and light weight characteristic of fiber. The study also revealed that regardless of reducing MDD, addition of banana fiber increases the CBR as well as UCS value of a soil. Maximum CBR and UCS value was obtained at 1.2% of fiber the increase is due to the banana fiber acting as reinforcement.

Another study was carried out in Malaysia by random inclusion of banana fiber to improve clay soil property (Bawadi et al., 2020). Banana fibers of 0.3 %, 0.5 % and 1% by weight of soil had been used as a soil reinforcement in influencing the strength of clay soil. In order to investigate the influence of fiber Unconsolidated Undrained Triaxial and CBR tests were conducted. 1% fiber gave the highest CBR and highest shear strength under different cell pressure.

### 2.7.2. Coir Fiber

Coir fiber is obtained from a matured coconut and it has been widely used to reinforce different problematic soils. Generally its diameter ranges 0.1–0.6 mm and length ranges 50-350 mm and coir degradation takes place much more slowly than other natural fibers and it retains much of its tensile strength when it is wet (Rowell et al., 2000).

(Mohan & Manjesh, 2017) conducted a study to investigate the influence of randomly oriented coir and jute fiber on medium compressible clayey soil strength parameter. Fibers with different aspect ratios and percent of 0.25%, 0.5%, 0.75% and 1.0% by dry weight of soil was used.

The compaction test result showed the decreases in MDD and increases OMC with increase in coir fiber dosage. The test result indicates that both un-soaked and soaked CBR value of soil increases with the increase in fiber content. It was also observed that increase in CBR and UCS value of reinforced soil is substantial at fiber content of 0.5 % and cut length of 30mm. It can be concluded that CBR value of soil increases with the inclusion of coir fiber for both soaked and un-soaked conditions substantially reduce the thickness of pavement.

(Lakshmi et al., 2018) conducted an experimental study on clayey sand using coir fiber with varying percentage 0.3%, 0.6%, 0.9%, 1.2% and 1.5% by dry weight of a soil and with a cut length of 10 mm, 20 mm, 30 mm, 40 mm and 50 mm. Standard compaction, CBR and UCS tests were conducted to determine optimum fiber content and fiber length. Just like all researches, the OMC of mix increased and MDD decreased gradually as the percent and length of coir fiber increase, and CBR and UCS value increased up to a 1.2%. Soil with 1.2 % coir fiber of length varying from 2cm to 3cm showed maximum increase in UCS of 43.2 % and 47.4

% respectively and soaked CBR value was found to increase by approximately four times that of unreinforced soil.

### 2.7.3. Jute Fiber

Jute is widely available in Asian Countries as well as Brazil and generally grows to 2.5–4.5 m height with the base stem diameter of around 25 mm. Jute fibers have been found to be effective in improving characteristics of soil and are being used extensively in rural road construction, protection of river banks, stabilization of embankments, and so forth (Gowthaman et al., 2018).

(Aggarwal & Sharma, 2010) used bitumen coated Jute fiber of lengths 5 mm–20 mm by 5 mm interval in different percentages 0.2% to 1.0% with 0.2% interval to reinforce weak subgrade soil. Series of Compaction and CBR tests had been carried out on plane soil and soil with jute fiber. To study the effect of diameter and length of jute fiber, diameter was varied from 2 to 8 mm. The result of proctor test showed that varying diameter of fiber 2-3 mm or 6-8 mm does not make any appreciable trend on the result of OMC and MDD, this shows that the effect of fiber diameter is negligible. The maximum CBR value is observed as 4.62% with 10mm long and 0.8% jute fiber, an increase of more than 2.5 times than the plain soil CBR value of 1.82%.

An experimental study was conducted by (Kumar et al., 2015) to improve CBR value of a subgrade soil by random inclusion of jute fiber of 20 mm to 100 mm length by 20 mm interval and 1% to 5% fiber content by dry weight of the soil with 1% interval. The result showed that as the fiber content increased, the CBR value of soil also increased and the increase is substantial up to 5 % and the optimum length of fiber is between 60 to 80 mm. This shows that length and present of fibers have a significant effects on the CBR value of soil.

### 2.7.4. Katcha Fiber

Katcha fiber is obtained from Enset plant by manual decortication method. Katcha fiber has comparable strength and elongation at break with most commercially available fibers as illustrated in Table 2.2. Its good tensile properties are attributed from its high cellulose content and good crystallite orientation (Teli & Terega, 2017).

A study by (Tirfu, 2018) was conducted to improve the performance of weak subgrade soil by random mixing of Katcha and Tef straw fiber separately on selected road section of Wolaita, South Western Ethiopia. Both fibers were prepared from 0.25% -1.25% by dry weight of soil with an increment of 0.25% and 60 mm length. The result from laboratory test showed that, as amount of both fiber increases, the OMC increased and the MDD decreased. This was explained by the fact that natural fiber water absorption capacity is greater than that of soil replaced by fiber. The value of soaked CBR increase from 2.1% to 5.4 % for Katcha fiber stabilized soil at 1% of fiber content and 4.4% for Teff straw fiber mix at 0.75%.

### 2.7.5. Sisal Fiber

Sisal fibers extracted from the leaves of the plants, which vary in size, between 6-10 cm in width and 50-250 cm in length and diameter about 0.06 - 0.4mm (Kulhar & Raisinghani, 2018). Recently, sisal plant has been recognized as a potential engineering material due to its strength, durability, ability to stretch, and resistance to deterioration.

(Sandyarani et al., 2018) used sisal fiber with varying percentages 0.2%, 0.5%, 0.9% and 1.2% and varying lengths 3 cm, 3.2 cm and 3.4 cm to increase the strength of black cotton soil. As the amount of sisal fiber increase in the soil mix, the OMC increased and MDD of soil decreased. The highest value of UCS and unsoaked CBR recorded at 0.5% and 3.4cm sisal fiber.

## 2.8. Soil Stabilization by Using Natural Sand

### 2.8.1. Properties of Natural Sand

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand, varies depend on parent rock property, but the most common constituent of sand is silica usually in the form of quartz. Because of its chemical inertness and considerable hardness, it is the most common mineral resistant to weathering (Hiwot, 2016). According to USCS sand size is defined as a particle with a diameter of between 0.075mm and 4.75mm, more than 50% of coarse fraction passes number 4 (4.75mm) sieve and more than 50% retained on or above number 200 (75 µm) sieve.A coarse sand from 4.75-mm to 2.00-mm, medium from 2.00-mm to 425-µm, and fine from 425-µm75-µm (ASTM-D2487, 1985).

### 2.8.2. Sand as a Soil Stabilizer

Extensive studies have been carried out on the stabilization of soils by using natural sand either by mixing or by intercalation of sand layer. Some of the researches are pointed out here.

A research in Pakistan had been conducted to improve engineering characteristics of expansive clays by mixing sand in varying percentage from 5%-35% with 5% interval (Farooq & Virk, 2009). The main concern of the research was, to investigate the effects of sand mixing on deformation and strength characteristics of swelling clay. Compaction, CBR and Consolidation tests were performed in addition to basic property tests for pure clay soil and clay-sand samples.

From the tests the pure clay soil showed a swell potential and swell pressure of 3.5% and 90 Kpa respectively this value was reduced to 0.5% and 10Kpa when the clay mixed with 35% of sand. The CBR values increased from a value of 4% in case of pure clay sample to a value of 8% and the MDD increased from 18.2 kN/m3 to 19.4 kN/m3 for clay mixed with 30-35% sand.

Another experimental study had been carried out in Algeria by (Louafi & Bahar, 2012) to understand the physical mechanisms sand as a stabilizer of clay soil by at various forms: mixing and intercalation layer with varying sand content 10%-70% by dry weight of soil by 10%. The aim of this study was to analyze the effect of sand on the consistency and reduction of swelling pressure of the expansive soil. The materials used in this test had been artificial soil clay known as bentonite and beach sand having particle size of 0.1mm up to 2.0 mm. The Consistency, Swelling and Ultrasonic tests were performed for soil, soil-sand mix and soil- sand layer.

The results of bentonite-sand mix showed a marked improvement in soil consistency and swelling action for all percent of sand mix. Sand was introduced to the clay soil under non-conventional forms as a layers of sand for 10%, 20% and 50%, and tested for two possible distributions; a sample of bentonite where sand layer is above, and sand layer is in the middle. The introduction of sand as layer showed reduction in swelling. It was found that the most efficient distribution in reducing swelling is that of layers of sand placed between two layers of clay compared to the sand layer placed on top. The ultrasonic pulse propagation showed an increase in the volume of voids with increasing sand content. This modification in the structure of treated soil by sand, made it possible the reduction in the swelling of clay by sand addition.

The research conducted by (Nini, 2016) to increase the CBR of clay soil by introdicng a layer of sand between clay layers. In the research six type of soils and sand were used. For identification test, sieve analysis, specific gravity, Atterberg limits, Proctor and CBR test were conducted. Primarily, the Proctor test was done separately for all soils to find the OMC and MDD. After it, the CBR test was performed on all soil, then, the CBR test was repeated on these soils but this time after placing the sandy layer. Each time, the position of the sandy layer was changed and termed as bottom, second, third and upper sandy layer.

All the test results showed that the existence of sandy layer improved CBR value. The Deeper is the sandy layer, higher is the drainage of excess pore water. The highest CBR value is obtained for the bottom sand layer. When the position of the sandy layer is moving up it affect the CBR negatively. The results in this research agree with (Louafi & Bahar, 2012) for sand placed between two layers of clay gave lower swelling compared to sand layer at the top.

In a study by (Hiwot, 2016), the effect of crushed and natural sand was studied on different parameters of expansive soil. The sand contents varied 20%-50% by increment of 10% for both sand by dry weight of soil. Gradation, Atterberg Limit, Compaction, Free Swell, Swell consolidation, UCS and CBR test were conducted for pure soil, soil-crushed sand mix and soil-natural sand mix. The classification of the soil is changed from clay of high plasticity CH to medium plasticity MH group for both types of sand. For the compaction test MDD increase and OMC decrease with increasing of sand content, the UCS and CBR value of soil also improved. 40% of both natural and crushed sand found to be the optimum amount for stabilization.

(Rathod & Sathe, 2017) made an experimental study on four type of soil: Black cotton, Sandy gravel, sandy silty and Loamy soil mixed with varying concentrations of coarse sand 10%, 20% and 30%. Wet sieve, Atterberg limits, Compaction and soaked CBR tests were carried out on native soils and soil-sand mix. Results of compaction tests showed that OMC decreased and MDD increased with addition of sand for all type of soil. The CBR results exhibited a linearly increasing trend for all soil-sand mix, 30% sand was found to be the maximum value which give the highest CBR and MDD value. From the experiment it can be concluded that coarse sand is an effective stabilizer for Black cotton and Loamy soil but it doesn’t have much influence on Sandy gravel and Sandy silt soil. A similar study by (Tare et al., 2018), investigated the behavior of black cotton soil used in subgrade stabilized with varying concentrations of coir fiber from 0.15%-0.75% by 0.15% variation and sand of (3%-15%) by conducting Index properties for native soil and Compaction and CBR for native soil, soil-coir mix and soil- coir- sand mix with different percentages of sand. 0.45% Coir fiber and 15% sand found to be the optimum stabilization scheme, which exhibited the greatest improvements in CBR value of a soil.

## 2.9. Summary of Literature Review

The literatures reviewed in this thesis have generally show that strength of the soil is improved by reinforcement and sand mixing. The increase in strength of reinforced soil was reported to be a function of: Fiber characteristics; such as; aspect ratio, percentage, strength, and fiber soil interaction and method of mixing. Fiber length and content plays great roll than its diameter in determining the strength, MDD and OMC of the soil fiber mix, this is due to the small diameter size of natural fiber.

In comparison with systematically reinforced soils, randomly distributed reinforced soils exhibit some advantages. Discrete fibers are easily applicable in the field by simply adding and mixing with the soil, much like lime, cement or other additives. In addition it offers strength isotropy and limit the development of potential planes of weakness parallel to oriented reinforcement.

Introduction of fiber to a soil generally increase the strength, reduce the MDD and increase the OMC of a soil. The strength of reinforced soil increased due to interlocking and friction force between soil and fiber which tend to mobilize the tensile stress on fiber and additionally fibers behaves as a structural mesh that holds the soil together which increase the soil structural integrity. The optimum amount of fiber content and length is varied based on fiber and soil type. From different researches it can be concluded that as the length and percentage of fiber increased beyond optimum content the strength of the soil composite reduced or does not show any improvement. Comprehensive literature review shows that using of natural fibers in geotechnical engineering is feasible in different fields including pavement layers, retaining walls, earth block production etc.

As it is described in the previous researches it can be concluded that the strength and deformation characteristics of expansive soil have been observed to be improved by sand mixing and by intercalation of sand layer. By applying such method in practice, the unfavorable effects of swelling clays to civil engineering structures, can be effectively mitigated and the workability of soil also improved. Generally application of sand and fiber together can enhance weak performance of soil. Related woks about stabilization of soil by using natural fiber and sand are summarized in Table 2.4 and 2.5 respectively.

Table 2.4. Summary of related works on natural fiber

| Authors | Title of the study | Fiber | | | Major finding |
|---|---|---|---|---|---|
| | | Type | Length (mm) | Percent (%) | |
| (Babu, 2019) | Soil Stabilization by using Banana Fiber | Banana | 15 | 0.3.0.6, 0.9 and 1.2 | The highest CBR and UCS value obtained at 1.2 % |
| (Bawadi et al., 2020) | Influence of Banana Fiber on Shear Strength of Clay Soil | Banana | 20-50 | 0.3, 0.5 and 1 | The highest CBR and shear strength value recorded at 1% banana fiber |
| (Mohan & Manjesh, 2017) | A Study on Stabilization of Subgrade Soil Using Natural Fibers | Coir and Jute | 10, 20, 30, 40 and 50 | 0.25, 0.5, 0.75 and 1.0 | The CBR and UCS value substantial at 0.5 % and 30mm. |
| (Lakshmi et al., 2018) | Utilization of Coconut Coir Fiber For Improving Subgrade Strength Characteristics Of Clayey Sand | Coir | 5, 10, 15, and 20 | 0.3, 0.6, 0.9, 1.2 and 1.5 | 1.2 % of length 20mm to 30 mm showed maximum increase in UCS of 43.2 % and 47.4 % respectively and soaked CBR value was increased four times than that of unreinforced soil. |
| (Aggarwal & Sharma, 2010) | Application of Jute Fiber in the Improvement of subgrade Characteristics | Jute | 20, 40, 60, 80 and 100 | 0.2, 0.4, 0.6, 0.8 and 1 | The maximum CBR value was recorded as 4.625 with 10 mm long and 0.8 % jute fiber. |
| (Sandyarani et al., 2018) | Stabilization of black cotton soil by using Sisal fiber | Sisal | 30, 32 and 34 | 0.2, 0.5, 0.9 and 1.2 | 0.5% and 3.4cm sisal fiber gave the highest value of UCS and unsoaked CBR. |
| (Tirfu, 2018) | Problematic Sub-Grade Soil Reinforcement Using Local Natural Fibers | Katcha and Tef straw | 40 and 60 | 0.25, 0.5, 0.75, 1 and 1.25 | The value of soaked CBR increase from 2.1% to 5.4 % for 1% katcha fiber and to 4.4% for Teff straw fiber of 0.75 %. |

Table 2.5. Summary of related works on sand as stabilizer

| Authors | Title of the study | Sand (%) | Major finding |
|---|---|---|---|
| (Farooq & Virk, 2009) | Improvement of engineering characteristics of expansive clays by sand mixing | 5, 10, 15, 20, 25, 30 and 35 | Swell potential and swell persure of the soil decrease from 3.5 % to 0.5 % and 90 Kpa to 10 Kpa respectively, MDD increase from 18.2 kN/m3 to 19.4 kN/m3 and CBR value increases from 4 % to 8 % for 30- 35 % sand mixing |
| (Louafi & Bahar, 2012) | Sand: an additive for stabilization of swelling clay soils. | 10- 70 by 10 % interval | The consistency limit and swelling of clay soil reduced, and sand layer between two soil layers showed a substantial effect on the soil swell reduction |
| (Nini, 2016) | CBR of Soaked Clay Drained by Sandy Layer | | Sand was introduced as a bottom, 2nd layer, 3rd layer and upper sand layer. The 2nd sand layer give the highest CBR value under 5 mm penetration. |
| (Hiwot, 2016) | An alternative for Stabilization of Addis Ababa Expansive Soil by Crushed and Natural Sand | 10, 20 30, 40 and 50 | The LL,PL, and PI, OMC reduced and MDD, CBR and UCS value increased as sand percent increased 40 % of each sand fond to be the optimum sand content of the mix |
| (Rathod & Sathe, 2017) | Soil Stabilization by Coarse Sand for Different Soils and Pavement Cost Evaluation | 10 , 20 and 30 | The percentage of fines decreases and percent gravel increases the sand content increases from 0 to 10 30%. The MDD increases and OMC decreases, the CBR showed substantial increase for black cotton soil by 59 % at 30 % sand. |

# CHAPTER THREE

# MATERIALS AND METHODS

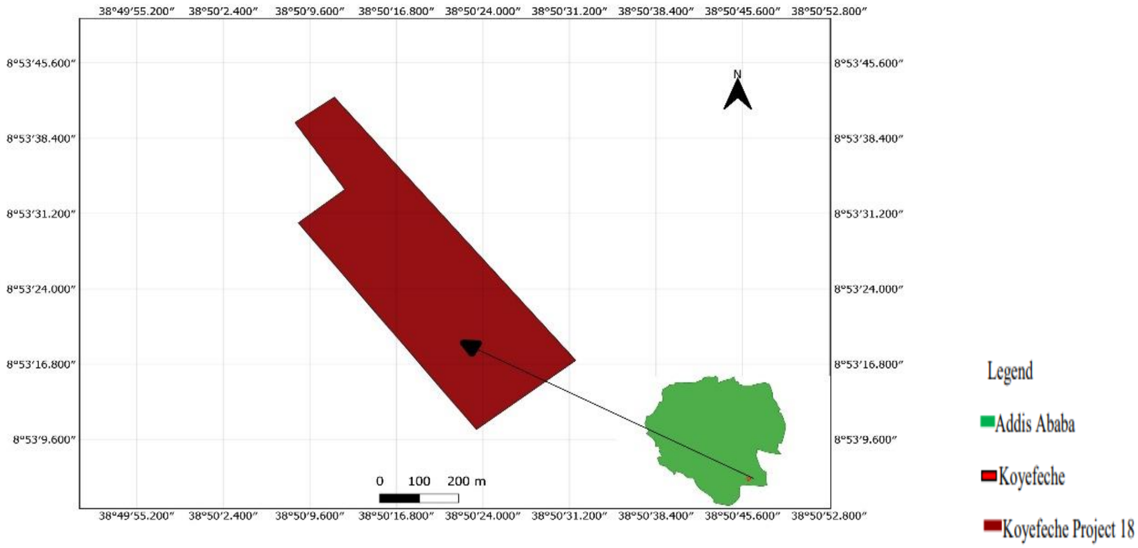
## 3.1. Introduction

The study area, soil sampling techniques, materials used, laboratory testing methods and tools are briefly discussed in this section. The laboratory tests for soils were conducted in the civil engineering laboratories at Adama Science and Technology University civil engineering department soil laboratory and Ethiopian Construction Design and Supervision Works Corporation (ECDSWC) geotechnical laboratory and tensile strength test of Katcha fiber at Ethiopian Conformity Assessment Enterprise (ECAE). As outlined in (ERA Site Investigation Manual, 2013) moisture content, sieve analysis, plasticity index, compaction, CBR, and swell tests are the fundamental parameters that have to be checked for subgrade material and also UCS have to be checked for stabilized soil. Thus an experimental program was carried out to determine moisture content, specific gravity, particle size distribution, Atterberg limit, volumetric shrinkage, Compaction, CBR and UCS of native and stabilized soils.

## 3.2. Description of the Study Area

Addis Ababa, the capital city is found at the central part of the country. It is located at the geographical coordinate of 9$^{o}$ North and 38$^{o}$ 45'East, with the general elevation of 2400 m above sea level.

The Koyefeche condominium construction site is located in the South-Eastern Part of Addis Ababa city in former Akaki kality sub city of district 09 current Lemi Kura sub city commonly called 'Koye-Feche' situated at about 7 km in the eastern direction of Akaki town. In terms of geographical coordinates, the site extends from 8$^{o}$53'00" North to 8$^{o}$54'30" North latitude, and 38$^{o}$ 48'45" East to 38$^{o}$50'15" East longitude (Degife et al., 2018). From the total houses and road projects Koyefeche Project 18 is still the ongoing project in which the construction of houses and road infrastructures are on progress. The project consists 4 road projects that cover a total length of 14 Kms.




(a)


(b)

Figure 3.1. Study area (a) map of the study area and (b) Satellite view of the study area

The general elevation of Addis Ababa decreases towards the south and south east direction. As such, in the Akaki-Kaliti sub-city, where the Koyefeche project 18 situated, the altitudinal ranges of 1500 and 2300 m above sea level. The topography of study area is characterized by gentle and relatively flat topography. The entire site has a slope between 0 to 8 percent. This indicates that large part of the area is predominantly flat (Degife et al., 2018).

The climate of Addis Ababa City and its suburbs is characterized by two distinct seasonal weather patterns Kiremt which represent the main wet season, extends from June to September, contributing about 70% of the total annual rainfall. A minor rainy season, locally known as

Belg, contributes moisture to the region from mid-February to mid-April. The remaining months are dry season. The mean annual temperature of the study area over the record periods (1997-2007) lays between 20.33 $^{O}$C and 21$^{O}$C. The highest and lowest mean annual temperature was registered in the year 2007 and 1999 as 21.19$^{O}$C and 19.29 $^{O}$C respectively. The mean annual rainfall over 33 years was found to be 1038.66 mm and the highest and lowest rainfall was recorded in the year 1977 and 2001 as 1487.3 mm and 771.3 mm respectively (Degife et al., 2018; Industrial Parks Development Corporation, 2017).

## 3.3. Study Design

This research considered quantitative experimental study since it was to measure the index and engineering properties of soil and the improvement on the soil properties by random inclusion of natural katcha fiber and Sand. Two representative disturbed soil samples at of depth of 1.2 m were collected from different locations of a road section by systematic random sampling technique by using field observation and previous laboratory test results. A laboratory experiment program was designed to conduct all of the fundamental laboratory tests to investigate the subgrade soil property, the effect of Katcha fiber and sand on properties of subgrade soil. The disturbed soil samples were first air-dried and different laboratory tests were conducted according to the American Society for Testing and Materials (ASTM) soil testing procedures.

## 3.4. Materials

### 3.4.1. Soil

The soil was collected from a site called Koyefeche project 18 road project. Two study test pits site 6 and site 9 were selected where the problematic soils were encountered. The sample soil was extracted at a depth of 1.2 m from site 6, designated as test pit 1 and site 9, designated as test pit 2 and different identification tests were performed in order to select the weaker soil for stabilization work.

(a) (b)

Figure 3.2. Photographic view of (a) Pit excavation and (b) Disturbed soil sample

### 3.4.2. Natural Sand

The sand was collected from local market of Addis Ababa it is originated from Wonji, one of the sand provider area for Addis Ababa city. Gradation and specific gravity of sand were determined in the laboratory. Three percentages of sand were employed for stabilization (10%, 15% and 20%) by dry weight of the soil in order to improve the property of the soil.

### 3.4.3. Katcha Fiber

Katcha is one of a well-known and easily available natural fiber in Ethiopia. The fiber was almost white in color, it is purchased from local market of Gurage zone Aklil and Moher wereda specifically from Dengez Kebele. The katcha fiber is selected from other locally available natural fibers because it is abundant and viable natural resource than other natural fibers and has good tensile strength which is comparable with other natural fibers. Its length ranges from 1m to 1.5 m.

#### 3.4.3.1. Katcha Fiber Preparation

The primary task before starting mixing Katcha fiber with a clay soil is fiber treatment with Kerosene gas to reduce the water absorption capacity and to reduce the rate of degradation and microbial attack due to WAC of the Katcha fiber. As it is shown in Figure 3.3 the dried Katcha fiber was soaked in Kerosene for 1, 2 and 3 days to determine the effect of kerosene on water absorption capacity of Katcha fiber. After soaking the Katcha fiber were removed from the soaking dish after 24, 48 and 72 hours and allowed to dry by using sunlight. Then the fiber was cut in to different three lengths of 20, 35 and 50 mm and it is prepared into three percent as 0.5,1 and 1.5% by weight of the dry soil. During mixing of fiber with dry soil was difficult as the length and percent increased with in a soil mass.


(a) (b) (c)

Figure 3.3. Photographic view of (a) Katcha fiber soaking; (b) Air dried Kerosene soaked Katcha fiber and (c) 35 mm length Katcha fiber and Sand.

### 3.4.4. Kerosene

Kerosene gas was used as a physical coating liquid to treat the Katcha fiber. 5 Liters of Kerosene was purchased from TOTAL gas station located in Addis Ababa around Kebena near to British embassy, and used for fiber treatment. It is was selected from other type of treatment chemicals and physical treatment material because it is easily and widely available in Ethiopia, easy for the application and also few litters of kerosene can be used to coat large amount of katcha fiber.

## 3.5. Test Programs

Generally the experimental program was divided in to four parts:

i. In the first part, the properties of the Clay Soil, Sand and Katcha were identified.

Sieve analysis, consistency test, modified compaction and CBR tests were conducted to determine the property of the clay soil and gradation and consistency tests were also conducted for sand; tensile strength and specific gravity of Katcha fiber were determined for both Kerosene coated and uncoated Katcha fiber.

ii. In the second part, the clay soil mixed with 0.5%, 1% and 1.5% Katcha fiber of each 20 mm, 35 mm and 50 mm length the mixing process was conducted by hand as shown in figure 3.4 and modified compaction and CBR tests were conducted on soil fiber mix. The optimum fiber content and length was determined from CBR test. The fiber content and length used for reinforcement are presented in Table 3.1

Table 3.1. Katcha fiber used for soil reinforcement.

| Soil Mixture | Fiber | | | |
|---|---|---|---|---|
| | Length (mm) | 20 | 35 | 50 |
| | Percent (%) | | | |
| 100 % Soil | | 0 | 0 | 0 |
| 99.5 % soil | | 0.5 | 0.5 | 0.5 |
| 99 % soil | | 1 | 1 | 1 |
| 98.5 % soil | | 1.5 | 1.5 | 1.5 |

iii. Based on the test results after determining the optimum fiber content and length, three percentages of sand were employed (10%, 15% and 20%) to the soil to study effect of sand on gradation and index property of the soil and to soil fiber mix to study the effect of sand on Compaction, CBR and UCS of the reinforced soil.

Table 3.2. Katcha fiber and Sand used for soil stabilization.

| Soil Mixture | Percentage (%) | | |
|---|---|---|---|
| | Clay Soil | Fiber | Sand |
| 0% Katcha fiber and 0% sand | 100 | 0 | 0 |
| 10% Sand and 0% Katcha fiber | 90 | 0 | 10 |
| 15% Sand and 0% Katcha fiber | 85 | 0 | 15 |
| 20% Sand and 0% Katcha fiber | 80 | 0 | 20 |
| 10% Sand and 1% Katcha fiber | 89 | 1 | 10 |
| 15% Sand and 1% Katcha fiber | 84 | 1 | 15 |
| 20% Sand and 1% Katcha fiber | 79 | 1 | 20 |

iv. This step involves on the introduction of Sand as a layer in three different position as 1st, 2nd and 3rd sand layer in the CBR test to determine the suitable position of sand layer.

Figure 3.4. Photographic view of one of the position of sandy layer in compaction mould.

## 3.6. Methods

A series of laboratory tests including Natural Moisture Content, Grain size analysis, Specific gravity, Atterberg limits, and volumetric shrinkage tests were conducted on the natural clay soil, and soil-sand mix. The Modified Compaction, CBR, and UCS test were conducted on native soil, soil-fiber mix, and soil-fiber-sand mix in order to determine weaker soil, maximum amount of katcha fiber, and maximum amount of sand for stabilization.

### 3.6.1. Sample Preparation

The Katcha fiber was taken as 0.5%, 1%, and 1.5% by dry weight of the soil and length of 20 mm, 35 mm and 50 mm was taken for each fiber percent. The mixing of fiber with the soil is conducted by hand first the soil was spread on the mixing dish then Katcha fiber with a desired amount and length of Katcha fiber was spread on the soil and the clay soil and fiber were mixed in dry state and finally the specified amount of water was added for both compaction and CBR test, no mixing equipment were used since the amount of soil and Katcha fiber used was small.

After the optimum amount of Katcha fiber determined from the CBR test sand was introduced in to three different percentage (10%, 15%, and 20%) by dry weight of soil and Katcha fiber mix. For this mixing the fiber and sand were added to a soil in dry state and mixed by hand as shown in figure 3.5. After observing uniform distribution of fiber and sand on the clay soil mass, water was added and wet mixing was conducted by hand.

After determining the optimum amount of sand, sand was introduced as a layer in a non-conventional form to study the efficiency of using layers of sand for stabilization and it was introduced in three possible distributions; first sand layer; a sand layer between one bottom soil-fiber mix and three top soil-fiber mix layers, second sand layer a sand layer sandwiched between two soil-fiber mix layers, and third sand layer a sand layer with three soil-fiber mix at the bottom and followed by one soil-fiber mix layer at the top and CBR test was conducted for all positions of the sand layer all replacement levels were made by mass.

While conducting mixing of clay soil and fiber difficulty was observed on the workability property of the mix as the amount and length of fiber increased but this difficulty was solved as sand was mixed to a soil.

### 3.6.2. Moisture Content

The moisture content is an indicator of the amount of water present in soil. The moisture content of the soil samples were determined according to (ASTM-D2216, 1998) procedures, while the moisture content ($MC_f$) and moisture regain (Mr) of katcha fiber was conducted in accordance with (ASTM-D2495, 2007) procedures and the corresponding results were calculated according to equation 3.1 and 3.2.

$$MCs\ and\ Mr\ = \frac{(Mos - Mod) * 100}{Mod} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.1$$

$$\mathrm{MCf} = \frac{(\mathrm{Mos}-\mathrm{Mod})*100}{Mos} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.2$$

Where Mos: mass of original sample, and Mod: mass of oven dry sample.

Drying oven, Balance, Moisture can, and Container Handling Apparatus (gloves, tongs) were used to conduct this test.

### 3.6.3. Specific Gravity

The specific gravity (Gs) can be defend as the ratio of the mass of a given volume of a material to the mass of an equal volume of water. In general it tells how much the material is lighter or heavier than water. The test was conducted for native soil, sand, soil-sand mix, and katcha fiber. Gs of soil was determined to be used in the particle size analysis for hydrometer test. The test was conducted by following (ASTM-D854, 2002) procedure. To complete this test Pycnometer, Balance, Drying Oven, and Hot plate capable of maintaining a temperature adequate to boil water to remove entrapped air were used.

### 3.6.4. Particle Size Distribution

Grain size analysis is widely used in engineering classification of soils. It's the quantitative determination of the distribution of particle sizes in soils. The test can be performed in two ways: Mechanical sieving for soils having relatively larger particle generally it used to identify particles with a size greater than 75 μm and Hydrometer analysis performed for soil particle less than 75 μm. The hydrometer test works based on Stokes' low, which stats that the larger the grain size, the greater it's settling velocity in a fluid (Liu & Evett, 2000). Grain size analysis was conducted for native soils and soil-sand mix in order to determine the effect of sand on the gradation of the soil according to (ASTM-D422, 1998).

A hydrometer test was conducted by using solution of 40 g of sodium hexametaphosphate/liter of solution. For hydrometer analysis 50 gram of soil and soil-sand mix passing sieve number 10 (2 mm) with three different percentage of sand was placed in the 150 milliliter beaker, for samples tested with solution 125 milliliter of sodium hexametaphosphate solution (40 g/L) was added and stirred until the soil is thoroughly wetted and allowed to soak for at least 16h and immediately after dispersion, the soil-water slurry transferred to the glass sedimentation cylinder, and distilled water was added until the total volume is 1000 milliliter, a hydrometer reading was conducted by using hydrometer 152H. Finally, the result from the two methods were combined to produce the overall particle size distribution curve.

To accomplish both mechanical and hydrometer, Balances, Stirring Apparatus, Hydrometer 152H, Sedimentation Cylinder, Thermometer, Sieves, and Water Bath for maintaining the soil suspension at a constant temperature during the hydrometer analysis were used.

### 3.6.5. Atterberg Limits Test

This test was conducted to determine the plastic limit (PL), Liquid Limit (LL), and the plasticity index (PI) of the soils, and soil-sand mix by following the method given in (ASTM-D4318, 2000). Both the soil sample and sand used for the tests passed through number 40 (425 μm) sieve and sand was mixed with a soil according to a specified proportion (10%, 15%, and 20%).

As stated in ASTM-D4318, LL is the water content, in percent, of a soil at the arbitrarily defined boundary between the semi liquid and plastic states and it was determined by using the Casagrande cup in which a groove is cut in the soil sample and the sample cup is raised and dropped a specified number of times for the groove to barely close. The soil moisture content at which this happens is termed as the liquid limit. The relationship between the water content and number of blow is plotted on the graph and the water content corresponding to the intersection of the line with the 25 blow abscissa is termed as the liquid limit of the soil.

The plastic limit is defined as the water content, in percent, of a soil at the boundary between the plastic and semi-solid states, and it was determined by alternately pressing together and rolling a soil into a 3 mm diameter thread until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The plasticity index (PI) is calculated as the difference between the liquid limit and the plastic limit. Variations in the LL, PL, and PI of native and sand mixed soils were then studied.

To conduct this tests in the laboratory, Liquid Limit Device (Casagrande cup), Flat Grooving Tool, Spatula, Ground Glass Plate, Drying Oven, and Moisture Content Can were used.

### 3.6.6. Soil Classification

The most widely used soil classification systems are AASHTO and USCS systems. For this study both classification systems were used to classify the soils and soil sand mix by using (ASTM-D2487, 1985; ASTM-D3282, 1997) respectively.

### 3.6.7. Determination of Volumetric Shrinkages

The volumetric shrinkage test is one of the Atterberg Limit tests used for determining the shrinkage limit. This test was carried out in accordance with (ASTM-D427, 1998). The shrinkage limit value obtained from the laboratory test can be used to evaluate the shrinkage potential or possibility of development, of cracks in earthworks involving cohesive soils.

About 30 g of the soil samples and sand mixed soil passing number 40 (425 μm) sieve was mixed with distilled water; the thoroughly mixed soil and soil sand paste was placed in the shrinkage dish, and then allowed to dry in air for 24 h until the color of the soil turns from dark to light and the sample was oven-dried to constant mass at 110$^{o}$C. The volume of the dry soil pat was determined by removing the pat from the shrinkage dish and immersing it in the glass cup full of mercury.

The test was conducted for native soils and soil-sand mix. In order to accomplish the test Evaporating Dish, Spatula, Shrinkage Dish, Glass Cup, Glass Plate, Balance, Mercury and Shallow Pan were used.

### 3.6.8. Compaction Test

The compaction test is performed to understand the relationship between the dry density and the moisture content of soil for some stated compaction energy. The compaction test can be performed either by standard or modified procedure. For this study the Modified Compaction tests were conducted by following (ASTM-D1557, 2000) procedures, to determine the MDD and OMC of the investigated soils, soil-fiber mix, and soil-fiber-sand mix. The modified compaction method was selected so that the density achieved in the laboratory would be closer to those obtained by very heavy compaction equipment as employed in a road project.

ASTM D 1557-00 provide three alternative methods to determine the MDD and OMC of the soil. Method A was followed since 20 % or less by mass of the soil was retained on the No. 4 (4.75-mm) sieve. According to this method the soil is compacted in five layers with 25 blows per layer by dropping 4.5Kg rammer from height of 457 mm in mold with 101.6 mm diameter. The soil mixtures, with and without additives, were thoroughly mixed for one day prior to compaction. The first series of compaction tests was aimed at determining the compaction properties of native soils. The second series was carried out to determine the compaction properties of the stabilized soils with varying amounts and length of Katcha fiber and natural sand. All the soil samples and soil mix samples were not reused in the compaction test.

(a) (b) (c) (d)

Figure 3.5. Photographic view of (a) dry mix of clay soil and Katcha fiber; (b) preparation of soil-fiber– sand mix, (c) mix preparation for compaction test (d) remold soil sample of reinforced soil.

Different equipment including Mold with 101.6 mm average inside diameter, a height of 116.4 mm, and a volume of 944.cm3, manually operated Rammer with 4.54 Kg free falling from 457 mm height, Sample Extruder, Balance, 4.75mm opening Sieves, Mixing Tools, and plastic bags were the main equipment which were used in the laboratory.

### 3.6.9. California Bearing Ratio Test

The CBR test is a test which used to indicate the strength of subgrade, sub base, and base course materials for road pavement. In this study CBR test of soils with and without reinforcement and sand mixing was conducted in accordance to (ASTM-D1883, 1999) procedures to study the influence of length and content of kerosene coated Katcha fiber and effect of sand on CBR values. For the preparation of reinforced soil samples, the desired amount of kerosene coated Katcha fiber was randomly mixed in dry state before the addition of water. Then the water corresponding to OMC was added, mixed thoroughly and the samples were compacted to MDD with five approximately equal layers in the CBR mould, each layer subjected to 56 uniformly distributed blows by using rammer of 4.5 Kg. The same procedure was implemented when the sand was added to the soil Katcha fiber composite. Samples from native soil and each soil mixture have been tested after being soaked in water for 96 hours. The soaked condition simulates the behavior of subgrade under heavy rainfall or flooded situations.

a

b

Figure 3.6. photographic view of (a) Soaked CBR and (b) CBR Reading

The CBR value is calculated at 2.54 mm penetration since the CBR value decreases as the penetration increases. Occasionally, the ratio at 5.08 mm depth is higher than 2.54 mm depth and test must be repeated. If the check test shows similar results, the stress from 5.08 mm penetration depth is taken as CBR value. The CBR value in %, was calculated according to equation 3.3.

$$CBR(\%) = \frac{Load\ at\ 2.54mm\ or\ 5\ mm}{Standard\ load\ at\ 2.54mm\ or\ 5mm} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

To complete the full laboratory test, Loading Machine, Mold with diameter of 152.4 mm and a height of 177.8 mm, Spacer Disk with 150.8 mm diameter and 61.37 mm in height, 4.5 kg

Rammer, two Weights (surcharge weight) each of 2.27kg a total of 4.5kg used to simulate the weight of the pavement and other loads specified, Expansion-Measuring Apparatus (tripod supporting dial gage) and Gages for measuring the amount of swell during soaking and other general apparatus such as mixing bowl, soaking tank, draying can and oven were used.

### 3.6.10. Unconfined Compressive Strength Test

The unconfined compressive strength of a soil mostly conducted for cohesive soils to investigate the approximate shear strength in terms of total stress. In this test method, UCS is taken as the maximum load attained per unit area and the shear strength (Cu), was calculated to be half of the compressive stress at failure (ASTM-D2166, 2000).

This test was conducted in the laboratory for native soil, soil-fiber and soil-fiber- sand mixture according to (ASTM-D2166, 2000) procedures. The soil samples and sand which passed through sieve number 4 (4.75mm) used to prepare the remolded sample of 37 mm diameter and 74 mm height using OMC of a soil, soil-fiber-mix and soil-fiber-sand mix from compaction.


(a) (b) (c)

Figure 3.7. The photographic view of (a) pure soil; (b) 1% and 35 mm reinforced soil and (c) reinforced soil with 20% sand

Compression Device, Sample Extruder, Deformation Indicator, Dial Comparator, Timer, and Balance were used. Since the soil samples in the research were not soft Vernier calipers were used as dial comparator for measuring the physical dimension of the specimens. To accomplish the test additional miscellaneous apparatus, including specimen trimming and carving tools, remolding apparatus, cans, and data sheets, were used.

### 3.6.11. Water Absorption Capacity Test of Katcha Fiber

Water Absorption (WA) tests was conducted on katcha fibers of 20 mm, 35 mm and 50 mm length by immersing the fiber in water for 24 hour. Prior to this test the Katcha fiber was soaked in kerosene for 24, 48 and 72 hours and air dried for 2 days and then the Katcha fiber was cut in to the desired length to conduct the test. Thus this test was conducted for 0day, 1day, 2day and 3day kerosene coated Katcha fibers to select the soaking duration which gives the lowest water absorption capacity. 10 gram of fiber was used for both treated and untreated fibers for each length and the water absorption is determined.

(a)

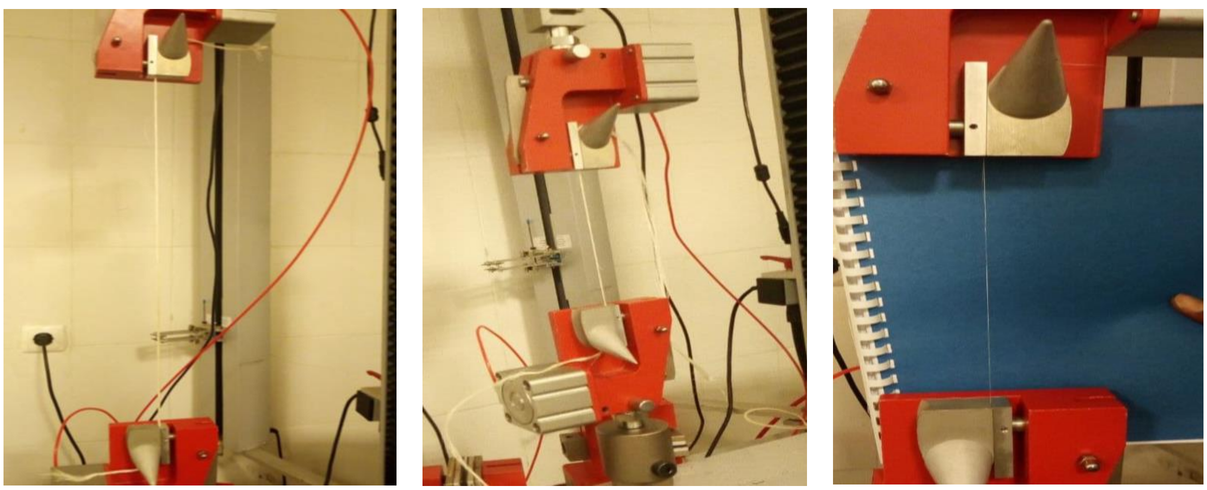
(b)

Figure 3.8. Water Absorption test of Katcha fiber of (a) 20 mm (b) 35 and 50 mm length

To complete the test Soaking Container, Scissor, Ruler to measure the length, Balance and Soaking dish to soak the fiber in the water were used.

### 3.6.12. Tensile Strength Test of Katcha Fiber

Tensile properties were determined according to the specified standard method in Ethiopian Standard (ES 127, 2001) which is adopted from ASTM 3822-07 by using tensile testing machine. Before conducting the test both kerosene coated and uncoated fibers were conditioned for 24 hours by exposing them to freely moving air in an atmosphere having a relatively humidity of 25% and a temperature of $25^{o}$ c . Nearly 20 individual fibers were randomly tested by using a gauge length of 200 mm and 600 mm for both Kerosene coated and uncoated fiber, with a speed of 10mm/min and then average values of the readings were calculated. in the second face additional 5 bundles of fiber each contains 65 single strand fiber were randomly tested by using a gauge length of 200 mm and 600 mm for both coated and uncoated fibers, with a speed of 10 mm/min and then average values of the readings were calculated and the tensile strength of individual fiber is obtained by dividing the tensile strength of bundle of fibers to a number of fibers this test is conducted to compare the result obtained from individual fiber length test.



(a) (b) (c)

Figure 3.9. Photographic view of tensile strength test of Katcha fiber (a) 600 mm length, (b) 200 mm length Katcha fiber and (c) 200 mm length single strand Katcha fiber

The tensile strength, T in Mpa, was calculated according to equation 3.4

$$T = \frac{F}{A} \qquad 3.4$$

Where F: Tensile force exerted in newton (N) and

A: Cross-sectional area of the fiber in square millimeter (mm$^2$). Since the fiber is almost circular through all its length, the cross-section was assumed to be circular.

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1. Introduction

The analysis part was carried out based on the results obtained from the laboratory tests on soil samples, soil sand mix, soil-fiber mix and soil-fiber-sand mix. Results obtained from the experiment program were analyzed and interpreted using the statistical description method.

## 4.2. Properties of Natural soils

The first laboratory tests were conducted on soil samples from test Pit 1 and Pit 2 to analyze the behavior of each soil sample and to identify weaker soil. The results obtained from the identification test are presented in table 4.1.

Table 4.1. Properties of Natural Soils

| Test Type | Soil Test Results | |
|---|---|---|
| | Pit 1 | Pit 2 |
| NMC (%) | 25.51 | 22.9 |
| Specific Gravity | 2.73 | 2.78 |
| Atterberg Limit | | |
| Liquid Limit% | 75.40 | 70.40 |
| Plastic Limit% | 44.60 | 44.60 |
| Plastic Index% | 30.80 | 25.80 |
| Sieve Analysis | | |
| Clay% | 39.71 | 7.39 |
| Silt% | 48.00 | 25.76 |
| Sand % | 7.07 | 48.84 |
| Gravel % | 5.17 | 18.00 |
| Percent Passing No. 200 sieve | 87.77 | 33.15 |
| Soil Classification | | |
| AASHTO Classification | A-7-5 (35) | A-2-7(3) |
| Unified Soil Classification | MH | SM |
| Modified Compaction | | |
| MDD % | 1.4 | 1.47 |
| OMC % | 30.3 | 28.75 |
| CBR % | 1.76 | 2.11 |

The grain size distribution of the soils has been determined by both the wet sieve and hydrometer analysis in according with (ASTM-D422, 1998). Results from the two methods were combined by using accepted standards and the particle size distribution curves that are shown in Figure 4.1 were generated. Particle size distribution curve for soil samples from Pit 1 and Pit 2 shows that about 87.77% and 33.15% of the soil passes through No. 200 sieve respectively. The LL, PL and PI of the soil sample from pit 1 were determined to be 75.4%, 44.6%, and 30.8% while the value of LL, PL, and PI of the soil sample from pit 2 was 70.4%, 44.6%, and 25.8%. The consistency test result of the soil samples showed that the PL of the two soils is similar while the LL of Pit 1 soil is higher than Pit 2. The variation in LL resulted different value of PI. The PI value of the soils indicates that Pit 1 is highly plastic than Pit 2.

According to the AASHTO classification, the soil from Pit 1 lays under group A-7-5 (35), which have fair to poor subgrade material property and soil sample from Pit 2 lays under A-2-7(3) group, which are generally rated as excellent to good subgrade material property, according to USCS the soil from Pit 1 grouped under MH (inorganic silt with high plasticity) and Pit 2 lays under the group SM (Silty sand).

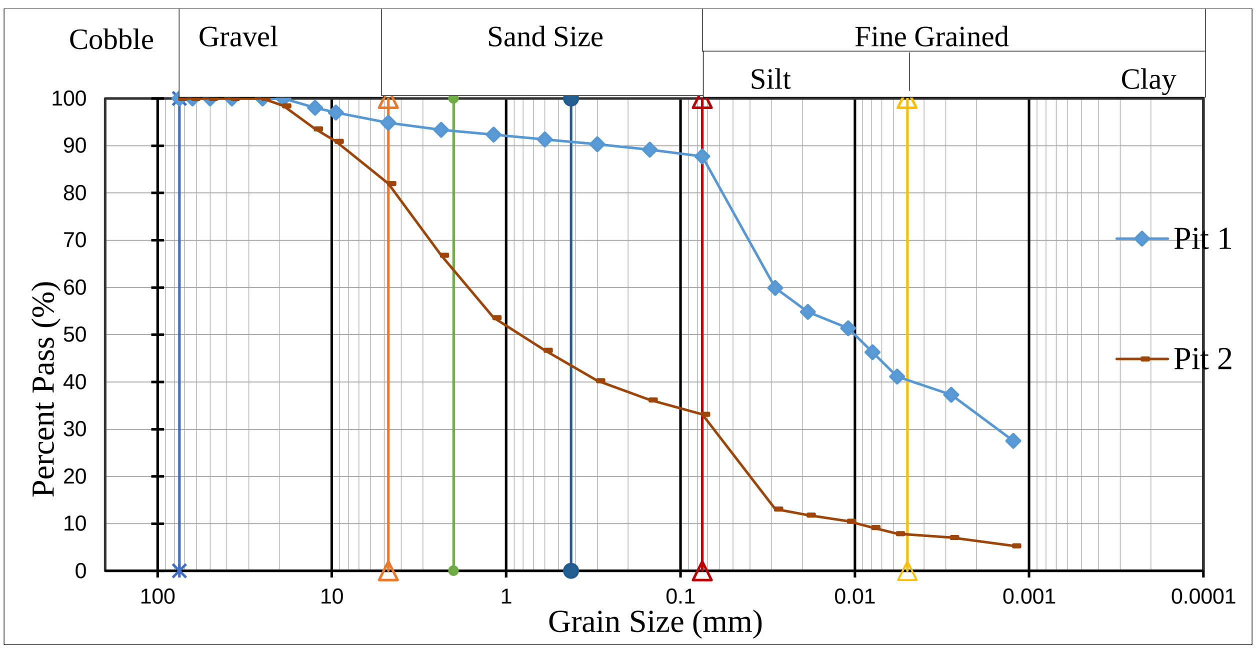



Figure 4.1. Grain size distribution curve of Natural Soils

The specific gravity of the soils was found to be 2.73 and 2.78 for soil samples of Pit 1 and Pit 2 respectively, the results lays within the range of 2.7-2.8 that is for inorganic clayey soils classification according to (Liu & Evett, 2000).

The soil from Pit 1 has MDD of 1.4 g/cm$^3$ and OMC of 30.3% and the soil from Pit 2 has MDD of 1.47g/cm$^3$ and OMC of 28.75%. The soaked CBR value of the soils was found to be 1.76% and 2.11% with percent swell of 7.46% and 7.0% for pit 1 and pit 2 soil samples respectively. ERA Pavement Design manual assigns the subgrade material strength for design to six strength classes reflecting the sensitivity of thickness design to subgrade strength (ERA Pavement Design Manuals, 2013). The CBR value of both soils in this research lays under the S1 class which represents a subgrade material with a CBR value of less than 3% but as it is stated in the manual, subgrades with CBR value less than 2%, required special treatment otherwise a cut and fill is needed. Therefore, from AASHTO classification and from CBR value; soil sample from Pit 1 with a CBR value of 1.76 % was selected for stabilization.

## 4.3. Properties of Sand

The sand used as a stabilizer for this research is characterized by the following properties obtained from the laboratory tests: Gs= 2.66, LL= 28.5 (%), PL= 0 (%), PI= 28.5%, Gravel= 3.52%, Sand= 95.98% and Fine= 0.5%. Figure 4.2 shows the grain size distribution of the sand.

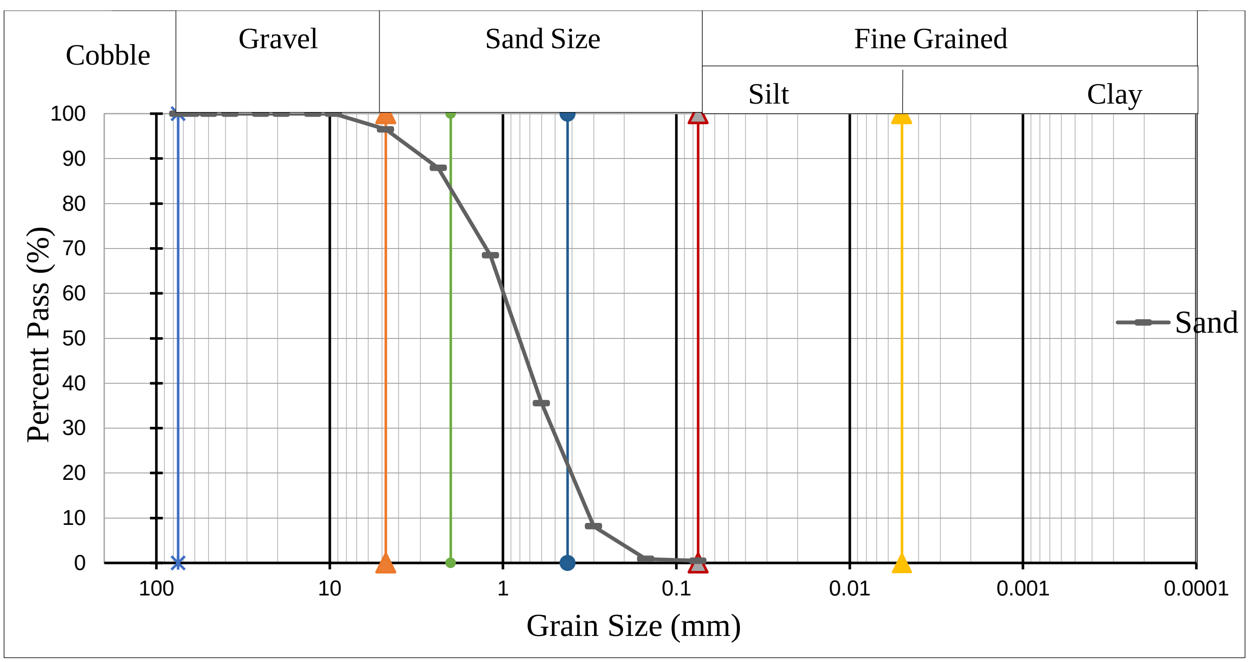



Figure 4.2. Grain size distribution curve of sand

## 4.4. Properties of Katcha Fiber

The physical and tensile properties of Katcha fibers were studied in terms of diameter, specific gravity, moisture content and regain, the water absorption capacity of kerosene treated and untreated fiber and tensile strength of both treated and untreated fiber. The test results revealed that the individual fibers showed average diameter of 128μm, Specific gravity of 1.12, the Gs of katcha fiber is almost the same as the Gs of other natural fibers like jute (Aggarwal & Sharma, 2010). The moisture content and moisture regain were determined as 12.3%, and 13.64% for uncoated and 11.1% and 11.36% for coated katcha fiber respectively as it can be seen from the test result the moisture content and moisture regain of treated fiber is less than that of untreated fiber this might have resulted from air drying process and effect of Kerosene of Kerosene coated katcha fiber.

Moreover, the tensile strength test was conducted on both kerosene coated and uncoated fibers of two different lengths, 200 and 600 mm. From the single tensile strength test, the average tensile strength of kerosene coated fiber was found to be 403.55Mpa and 314.46Mpa for 200 mm and 600 mm respectively and for uncoated fiber it is found to be 340.74Mpa for 200 mm and 302.5Mpa for 600 mm fiber length. And also the strength calculated from bundles of fiber found to be 415.25Mpa and 321.86Mpa for kerosene coated Katcha fiber of 200 and 600 mm length and 343.33Mpa and 313.81Mpa for uncoated fiber of 200 and 600 mm length. As it can be seen from the result the tensile strength obtained from the bundles of fiber is greater than the strength obtained from the individual fiber for both fibers; this increase might be attributed from the effect of group of fiber but the variation is not that much significant.

The tensile strength test result showed that the shorter the fiber length attributed to the higher tensile strength which agreed with a statement stated in (ASTM-D3822, 2007). Similar findings have been reported in other experimental works on the characterization of  Katcha fiber (Teli & Terega, 2017) and also it was observed that kerosene coating increased the tensile strength.

### 4.4.1. Effect of Kerosene on Water Absorption Capacity of Katcha Fiber

This test is conducted to determine the effect of kerosene on the water absorption capacity of Katcha fiber. Table 4.2 shows the effect of Kerosene soaking duration on the water absorption capacity of Katcha fiber. The moisture content of both treated and untreated fiber was determined based on (ASTM-D2495, 2007).

Table 4.2. Water Absorption Capacity of Kerosene coated and uncoated Katcha fiber

| Fiber Condition | Fiber Length (mm) | Moisture Content (%) | Average Moisture Content (%) | Percent Reduced |
|---|---|---|---|---|
| Untreated fiber | 20 | 304 | 303.01 | - |
| | | 302.02 | | |
| | | 313 | | |
| 1day kerosene soaked fiber | 20 | 212.87 | 204.435 | 32.532 |
| | | 196 | | |
| | | 215 | | |
| 2days kerosene soaked fiber | 20 | 137 | 136.815 | 55.435 |
| | | 136.63 | | |
| | | 154 | | |
| 3days kerosene soaked fiber | 20 | 129.29 | 127.145 | 58.039 |
| | | 125 | | |
| | | 146 | | |

It is noticed that the maximum reduction is observed for 2 and 3 days soaked fiber. 2 days soaking reduces the WAC by 55.43% and 3 days soaking reduced by 58.039% figure 4.3 illustrate the WAC reduction of Katcha fiber. Similar behavior was also observed in the literature kerosene coated coir fiber-reinforced expansive soil by (Ramasubbarao, 2014).

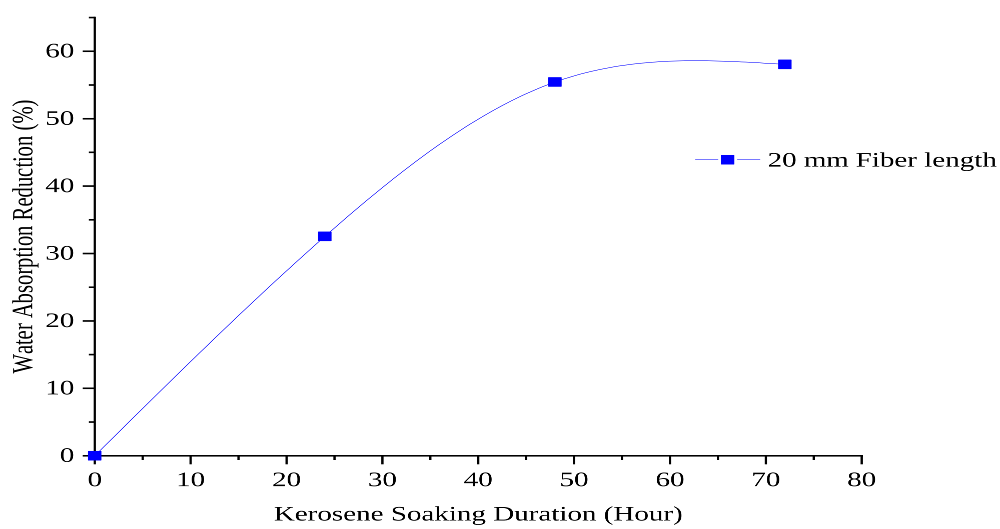



Figure 4.3. Effect of Kerosene Soaking on Water Absorption Capacity of Katcha Fiber

The explanation of reduction in WAC of kerosene coated fiber is probably a consequence of the following reasons: (1) the Kerosene coating causes the surface of fiber hydrophobic and hence alters the moisture absorption of the Katcha fiber without reducing its strength and (2) Kerosene coating physically prevent the entry of moisture into the fiber, and it makes fiber more durable in addition to the natural content of Hemicellulose (19% -22.47%) and Lignin(5%-6.88%) (Esayas et al., 2018; Gowthaman et al., 2018; Teli & Terega, 2017; Temesgen & Sahu, 2014). Thus soaking of Katcha fiber in kerosene reduced the water absorption affinity, it can be said that the durability of kerosene coated Katcha fiber is increased against biological degradation. Based on WAC test 3days kerosene soaking of fiber was selected for reinforcement since the list WAC is found for 3 days kerosene soaking Katcha fiber.

Table 4.4. Physical and Tensile properties of Katcha Fibers

| Fiber property | Fiber condition | | | |
|---|---|---|---|---|
| | Uncoated Fiber | | 3 Days kerosene Coated Fiber | |
| Diameter (mm) | 0.128 | | 0.128 | |
| Specific Gravity Gs | 1.12 | | 1.12 | |
| Tensile strength (MPa) | 200 mm | 600mm | 200mm | 600mm |
| | 340.740 | 302.5 | 403.55 | 314.46 |
| Moisture content (MC) % | 12.30 | | 11.10 | |
| Moisture regain (MR) % | 13.64 | | 11.36 | |

## 4.5. Effect of sand on Index property of soil

### 4.5.1. Effect of Sand on Particle Size Distribution of Soil

Grain size analysis was conducted on four samples soil, i.e. unmixed soil, 10%, 15%, and 20% sand mixed soil samples by following (ASTM-D422, 1998) procedures. The grain size distribution of the soil and mixed soils with different percent of sand is shown in Figure 4.4.

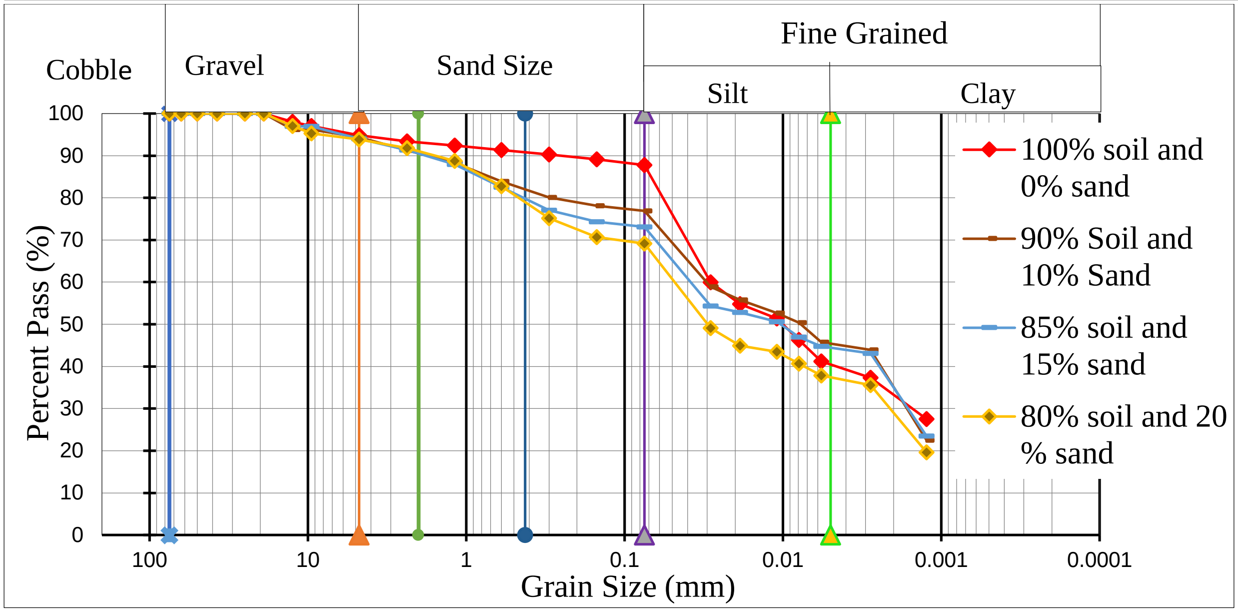



Figure 4.4. Grain size distribution curve of the natural soils and soil-sand mix

It is clearly seen from Figure 4.4 that percentage passing No. 200 sieve (0.075 mm) reduced from 87.77% to 76.87%, 73.13% and 69.15% for 10%, 15% and 20% sand mix respectively, as the percentage of sand increased the content of gravel, sand and fines varied significantly.

Table 4.5. Percent Gravel, Sand and Fines of Soil + Sand

| Soil mixture | Gravel (%) | Sand (%) | Fines (%) |
|---|---|---|---|
| 100% Soil and 0 Sand % | 5.16 | 7.07 | 87.77 |
| 90% soil and 10% Sand | 5.60 | 17.53 | 76.87 |
| 85 % Soil and 15% Sand | 6.00 | 20.87 | 73.13 |
| 80 % Soil and 20% Sand | 6.16 | 24.69 | 69.15 |

For 20% sand mixed in a soil, the percentage of fines has reduced by 21.21%, and percent of gravel and sand content increased by 19.38%% and 249.22% respectively. It can be concluded that sand is an effective stabilizer to reduce the percent fines and increase percent of gravel and sand of a soil.

### 4.5.2. Effect of Sand on Atterberg Limits

The sand used for this research has lower LL and zero PL. Thus the introduction of sand into the soil resulted in a general decrease in LL and PI of a soil. Table 4.6 presents the results of Atterberg limits value determined under different sand contents.

Table 4.6. Atterberg Limits of the studied mixtures.

| Soil mixture | LL | PL | PI |
|---|---|---|---|
| 100% Soil and 0 Sand % | 75.4 | 44.60 | 30.80 |
| 90% soil and 10% Sand | 67.5 | 42.47 | 25.03 |
| 85 % Soil and 15% Sand | 62.5 | 40.28 | 22.22 |
| 80 % Soil and 20% Sand | 60.0 | 38.89 | 21.11 |

The LL, PL, and PI variations for both native and mixed soils are also shown in figure 4.5. As the percent of sand increased from 0% to 20%, LL, PL, and PI of a soils reduced, this is due to the fact that the percent fines, which is responsible for the plasticity of the soil, is reduced by mixing of sand. It is observed that the addition of 20% sand was sufficient to enhance workability of the soil by reducing the PI from 30.80% to 21.11%. Similar behavior was found by other experimental work on stabilization of soil by sand (Kollaros & Athanasopoulou, 2017).

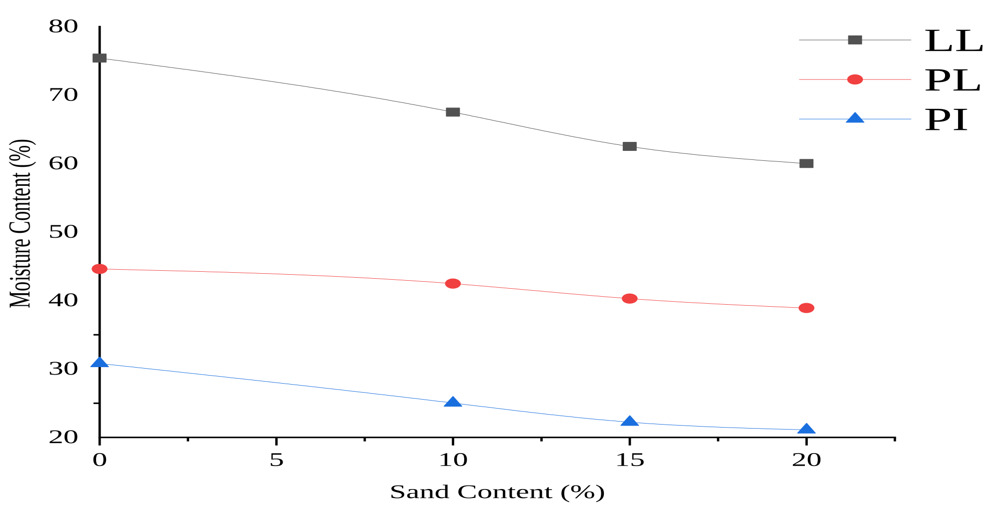



Figure 4.5. Atterberg Limits of Soil mixtures with varying sand content.

The Casagrande plasticity chart was drawn as shown in figure 4.6 to classify the soil and soil sand mix. It is clearly seen from the figure 4.6 that the soil is categorized as MH (inorganic silt of high plasticity) class. After the addition of sand, the mixed soil also falls in the same class of MH soil, however, the LL and PI of soil decreased which showed a decrease in plasticity.

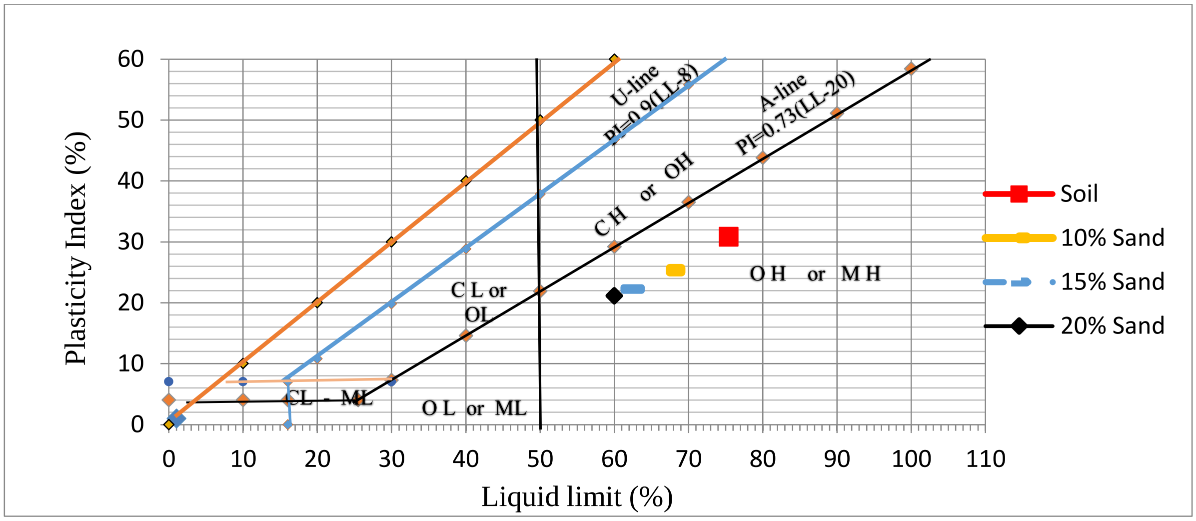



Figure 4.6. The Casagrande Plasticity chart of soil and Sand mixed soils

According to AASHTO classification system the native soil classified as A-7-5 (35) however sand mixing changed the soil class from A-7-5 (35) to A-7-5 (23), A-7-5 (19) and A-7-5 (16) for 10%, 15% and 20% sand respectively. According (ERA Pavement Design Manuals, 2013), soil having GI of 20 or more indicates a poor subgrade material. Mixing of 15% and 20% sand reduces the GI from 35 to 19 and 16 respectively.

### 4.5.3. Effect of Sand on Specific Gravity of Soil

The Specific Gravity Gs of the soil samples and soil-sand mix was determined using (ASTM-D854, 2002). Table 4 .7 show Gs of soil and soil sand mix of different proportions.

Table 4.7. The specific gravity of the studied soils and soil sand mix

| Soil mixture | Specific Gravity (Gs) |
|---|---|
| 100%Soil and 0 Sand % | 2.73 |
| 90% soil and 10% Sand | 2.62 |
| 85 % Soil and 15% Sand | 2.64 |
| 80 % Soil and 20% Sand | 2.59 |

As it is seen the Gs of the soil changed from 2.73 to 2.59 with increasing of sand. (Liu & Evett, 2000) suggested that Gs of inorganic clay soil is in the range of 2.7–2.80 and Gs of silty sand is in the range of 2.67 to 2.7. The result indicates that the Gs changed from clay to silty sand.

### 4.5.4. Effect of Sand on Volumetric Shrinkage

The volumetric shrinkage is used for determining the shrinkage limit of a soil. It is defined as the moisture content at which the soil does not undergo any further change in volume with loss of moisture. This test was carried out in accordance with (ASTM-D427, 1998).

Table 4.8. Volumetric shrinkage test results for soil and soil-sand mix

| Soil mixture | Shrinkage Limit % |
|---|---|
| 100%Soil and 0 Sand % | 18.15 |
| 90% soil and 10% Sand | 14.36 |
| 85 % Soil and 15% Sand | 11.39 |
| 80 % Soil and 20% Sand | 7.05 |

As it is illustrated in Table 4.8. The volumetric shrinkage of a soil reduced by 20.88%, 37.25% and 61.16% as sand content increased from 10% to 20%. The reduction obtained by mixing of 20% sand is more than 50%, thus the result obtained by sand mixing can be taken as a promising result to reduce the occurrence of desiccation crack in a clay soil mass.

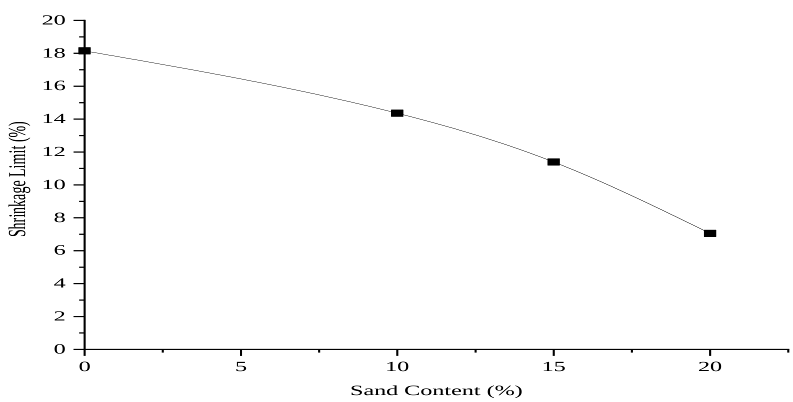



Figure 4.7. Variation in shrinkage limit of soil with varying amounts of sand

## 4.6. Effect of Katcha fiber on Soil Property

The kerosene coated Katcha fiber of 20, 35, and 50 mm was mixed to the soil as 0.5%, 1% and 1.5% by dry weight of the soil for each length. A total of nine combinations thus were studied.

### 4.6.1. Effect of Katcha fiber on Compaction Characteristics of Soil

The compaction test was performed to determine the effect of Katcha fiber (length and percent) on OMC and MDD of the studied soil. The test is conducted by using modified compaction effort by following (ASTM-D1557, 2000) procedures.

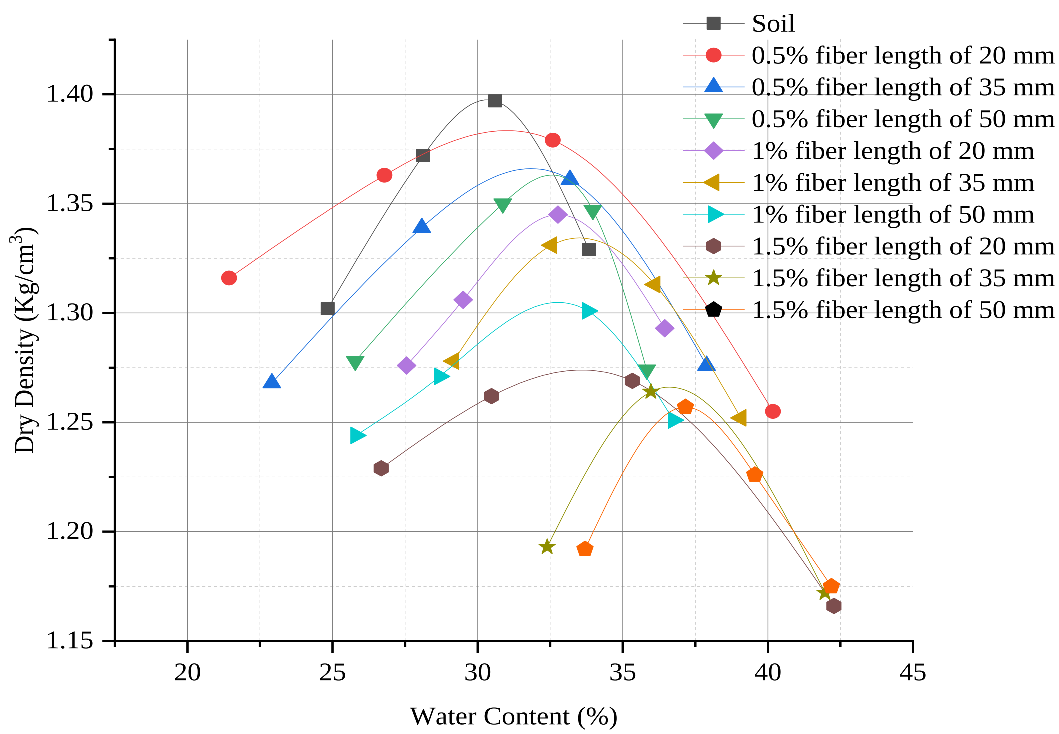



Figure 4.8. Combined compaction curve of soil and reinforced soil

It is clearly seen from Figure 4.8 that the MDD decreases from 1.4gm/cm$^3$ to 1.25gm/cm$^3$ and OMC increase from 30.3% to 37.5% when the Katcha fiber content increases from 0% to 1.5% for each fiber length.

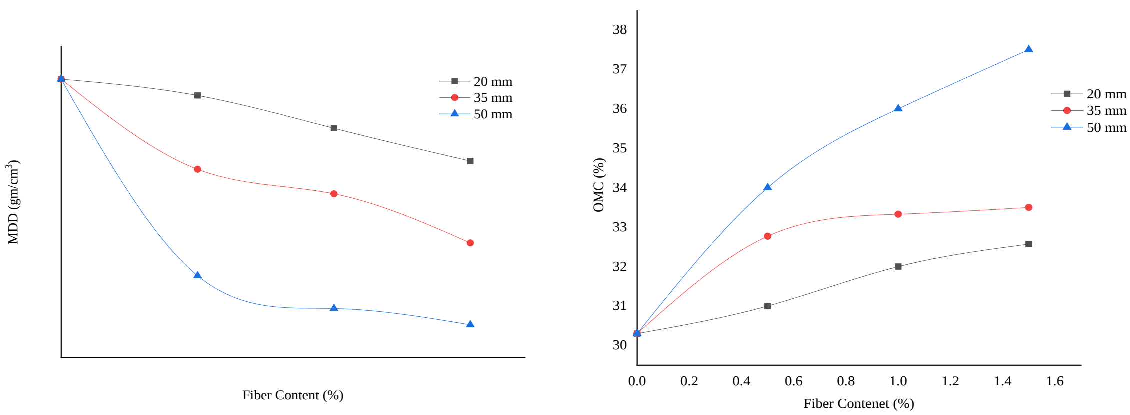
Table4.9 illustrated the effect of adding fiber on the compaction properties of the soil sample and reinforced soil. It can be clearly seen that adding kerosene coated fiber increased the OMC and decreased the MDD with increasing fiber length and content.

Table 4.9. Compaction property of Soil and Reinforced soil sample.

| Test type | Soil | Mixed soil with Fiber | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.5% Fiber | | | 1% Fiber | | | 1.5% Fiber | | |
| | | Fiber Length (mm) | | | | | | | | |
| Modified Procter density | | 20 | 35 | 50 | 20 | 35 | 50 | 20 | 35 | 50 |
| MDD (g/cm3) | 1.40 | 1.39 | 1.37 | 1.35 | 1.345 | 1.33 | 1.3 | 1.28 | 1.26 | 1.25 |
| OMC (%) | 30.3 | 31.0 | 32.0 | 32.57 | 32.77 | 33.33 | 33.5 | 34.00 | 36.0 | 37.5 |

As it can be seen in the table the increase in OMC and decrease in MDD occur gradually with the increase in fiber content and fiber length. Similar behavior was also observed in different literatures which study about the natural fiber reinforced soils (Babu, 2019; Bawadi et al., 2020; Lakshmi et al., 2018; Mohan et al., 2018; Sandyarani et al., 2018; Tirfu, 2018).

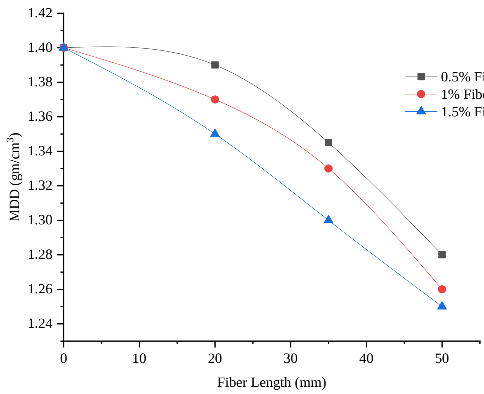
The relationship between the OMC and MDD with respect to fiber content and length are shown in Figure. 4.9 (a) and (b) and Figure 4.10 (a) and (b), it is apparently seen that the results obtained from the compaction test of the studied soil and reinforced soil samples that the OMC increased and MDD decreased with increasing of fiber content and length.



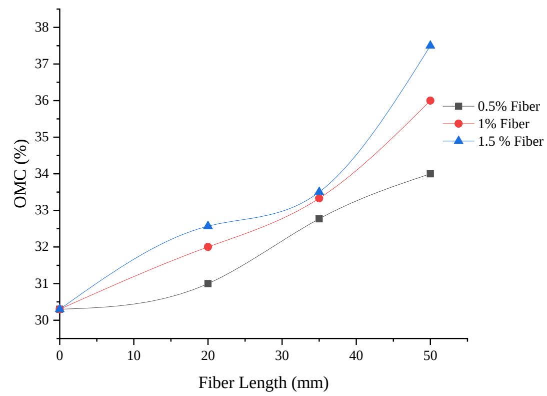

(a) (b)

Figure 4.9. Effect of fiber content on (a) MDD; and (b) OMC of reinforced soil

From figure 4.9 (a) and (b) it can be seen that for the same fiber length, as the percentage of fiber increases, MDD decreases and the OMC increase gradually. Higher value of MDD and lower value of OMC of a reinforced soil is recorded at 0.5% fiber content and lower value of MDD and higher value of OMC is obtained at 1.5% fiber content of 50 mm fiber lengths.




(a)




(b)

Figure 4.10. Effect of Katcha fiber length on (a) MDD; and (b) OMC of reinforced soil

Figure 4.10 (a) and (b) shows that the length of Katcha fiber and MDD are inversely related, as the fiber length increases the MDD decreases while the OMC is directly related with fiber length. From the results it can observed that as the length of fiber increased from 20 mm to 50 mm, MDD decreased meanwhile OMC increased.

Table 4.10. Summary of MDD and OMC Property of reinforced soil

| Fiber content (%) | Length (mm) | MDD (gm/cm$^3$) | OMC (%) | Decrease in MDD (%) | Increase in OMC (%) |
|---|---|---|---|---|---|
| 0.5 | 0.00 | 1.40 | 30.30 | - | - |
| | 20 | 1.39 | 31.00 | 0.71 | 2.31 |
| | 35 | 1.37 | 32.00 | 2.14 | 5.61 |
| | 50 | 1.36 | 32.57 | 2.86 | 7.49 |
| 1 | 0.00 | 1.40 | 30.30 | - | - |
| | 20 | 1.35 | 32.77 | 3.57 | 8.15 |
| | 35 | 1.33 | 33.33 | 5.00 | 10 |
| | 50 | 1.30 | 33.50 | 7.14 | 10.56 |
| 1.5 | 0.00 | 1.40 | 30.30 | - | - |
| | 20 | 1.28 | 34.00 | 8.57 | 12.21 |
| | 35 | 1.26 | 35.70 | 10.00 | 17.82 |
| | 50 | 1.25 | 37.50 | 10.71 | 23.76 |

Generally adding of fiber increased OMC and decreased the MDD when compared to 100%

soil sample. The explanation of this behavior is probably a consequence of the following reasons: (1) the light weightiness of fiber, hence alters the MDD of the soils; the specific gravity of fiber is generally lower than that of soil tested; (2) water absorbent characteristic of Katcha fiber, as the content of fiber increased in the soil mass the soil fiber matrix become more water absorbent than the soil alone and (3) the fiber length also attribute to the increase in OMC and decrease in MDD because as the length of fiber increases the WAC also increased.

### 4.6.2. Effect of Katcha fiber on CBR and Percent Swell of Soil

CBR test is the most suitable test to quantify the quality of compacted subgrade material. The load versus penetration graph of unreinforced and reinforced soil are shown in Figure 4.11.

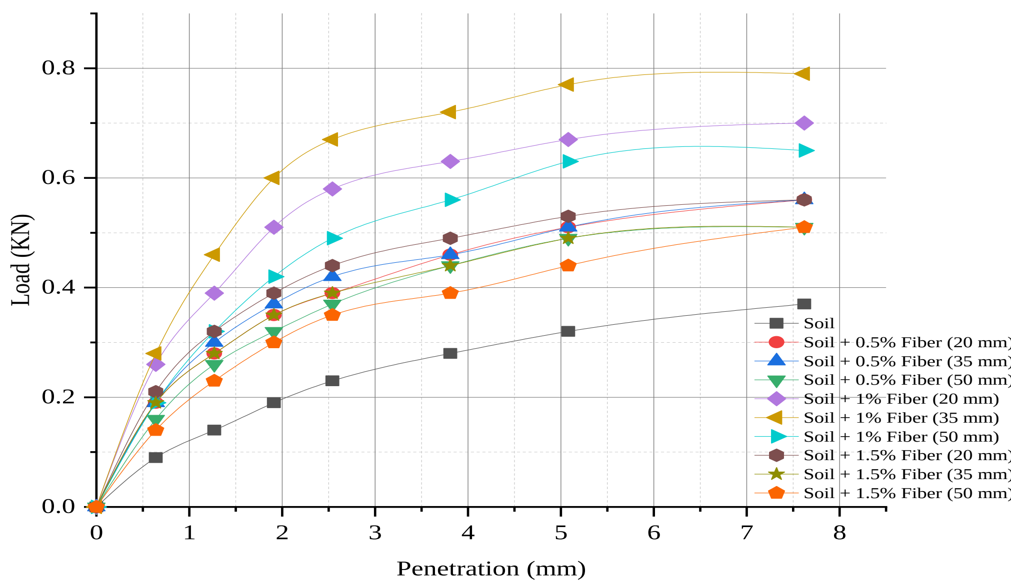
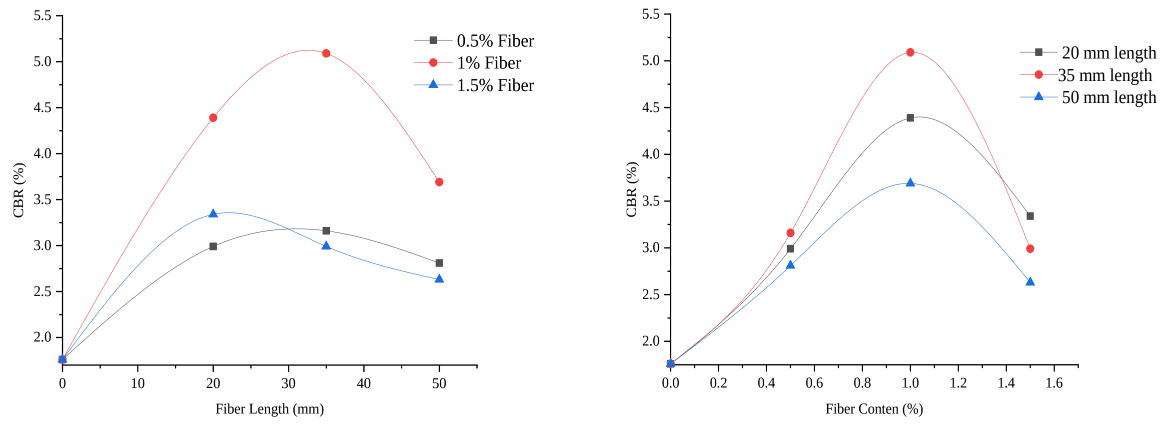



Figure 4.11. Load Versus Penetration Curve of Unreinforced and Reinforced soil samples

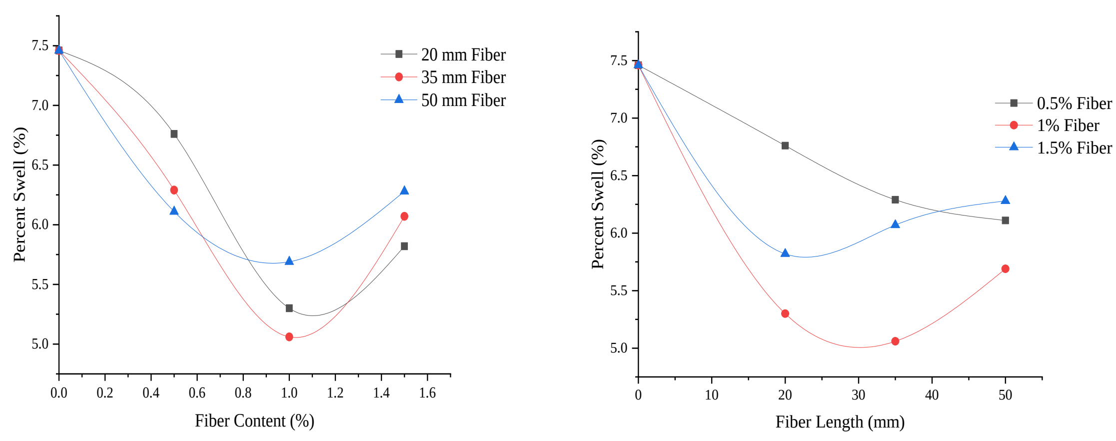
The CBR value is calculated from the load versus penetration curve and the results showed that the CBR increased for all fiber content and length regardless of decreasing MDD. This increment may be attributed from the reinforcement effect of Katcha fiber.




(a) (b)

Figure 4.12. CBR of reinforced soil with respect to (a) fiber length and (b) fiber content

It should be noted from Figure 4.12 CBR value greater than 2% was attained by reinforcing the soil, which shift subgrade strength class of a soil from S1 with CBR value of < 3% to subgrade strength class of S2 and S3 with CBR value of 3% and 4% and 5%, 6% and 7% respectively (ERA Pavement Design Manuals, 2013) for all reinforced soil samples. It is observed from the figure that as the fiber content and length increased the CBR value of soil also increased.




(a) (b)

Figure 4.13. Percent swell values of reinforced soil (a) fiber content and (b) fiber length

The Katcha fiber has decreased the percent swell value from 7.46 % to 5.00% with an increase in fiber content from 0% to 1%. It should be noted from Figure. 13 that a 5% minimum swell value required for pavement subgrades was thus attained by 1% and 35 mm length reinforced soil samples. At 1.5% katcha fiber the swell percent of reinforced soil increased however the recorded percent swell is lower than that of unreinforced soil.

Table 4.11. CBR and Percent Swell values of the reinforced and unreinforced soil

| Length (mm) | Fiber content (%) | CBR (%) | Percent swell (%) | Increase in CBR (%) | Decrease in Swell (%) |
|---|---|---|---|---|---|
| 20 | 0.00 | 1.76 | 7.46 | - | - |
| | 0.50 | 2.99 | 6.76 | 69.89 | 9.34 |
| | 1.00 | 4.39 | 5.30 | 149.43 | 28.95 |
| | 1.50 | 3.34 | 5.82 | 89.77 | 21.98 |
| 35 | 0.00 | 1.76 | 7.46 | - | - |
| | 0.50 | 3.16 | 6.29 | 79.55 | 15.68 |
| | 1.00 | 5.09 | 5.06 | 189.20 | 32.17 |
| | 1.50 | 2.99 | 6.07 | 69.89 | 18.63 |
| 50 | 0.00 | 1.76 | 7.46 | - | - |
| | 0.50 | 2.99 | 6.11 | 69.89 | 18.1 |
| | 1.00 | 3.69 | 5.69 | 109.66 | 23.73 |
| | 1.50 | 2.63 | 6.28 | 49.43 | 15.82 |

The highest CBR value and lowest swell of a reinforced soil was recorded for 1% of 35 mm fiber length. The explanation of the increase in CBR value and reduction in swell percent is probably due to the following reasons: (1) randomly distributed Katcha fiber in a soil mass improves the load-deformation behavior by interacting with the soil particles mechanically through surface friction and interlocking. (2) the interlock transfers the stress from the soil to the discrete fibers by mobilizing the tensile strength of the discrete fibers. Thus, fiber reinforcement works as frictional and tension resistance elements. However, further increment of Katcha fiber beyond optimum fiber content and length attributed to the reduction in CBR value and increase in percent swell this may be due to the local aggregation and balling of fiber in the soil matrix without creating interlocking with the soil particle and increasing water-absorbing characteristic of Katcha fiber.

## 4.7. Effect of Sand on Reinforced Soil

After determining the optimum fiber content of a reinforced soil from CBR, sand was introduced to the reinforced soil in to two forms by mixing with the soil and as a layer.

### 4.7.1. Effect of Sand on Compaction Characteristic of Reinforced Soil

A modified compaction test was employed to determine the OMC and MDD of reinforced sand mixed soil by following (ASTM-D1557, 2000) standard.

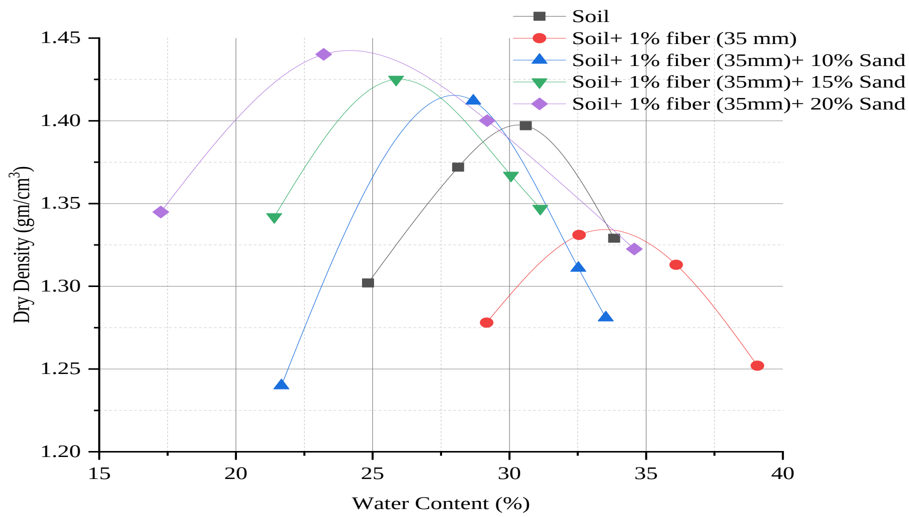



Figure 4.14. Combined compaction curve of Soil and Stabilized Soils

By mixing sand as stabilizer, the OMC decreases and the MDD increases, as shown in Figure. 4.14. It is interesting to note from Figure 4.14 that the significant reduction in MDD by adding 1% and 35mm fiber has been compensated by adding 20% sand. Figure 4.15 shows the increase in MDD and decrease in OMC of sand mixed and unmixed reinforced soil.

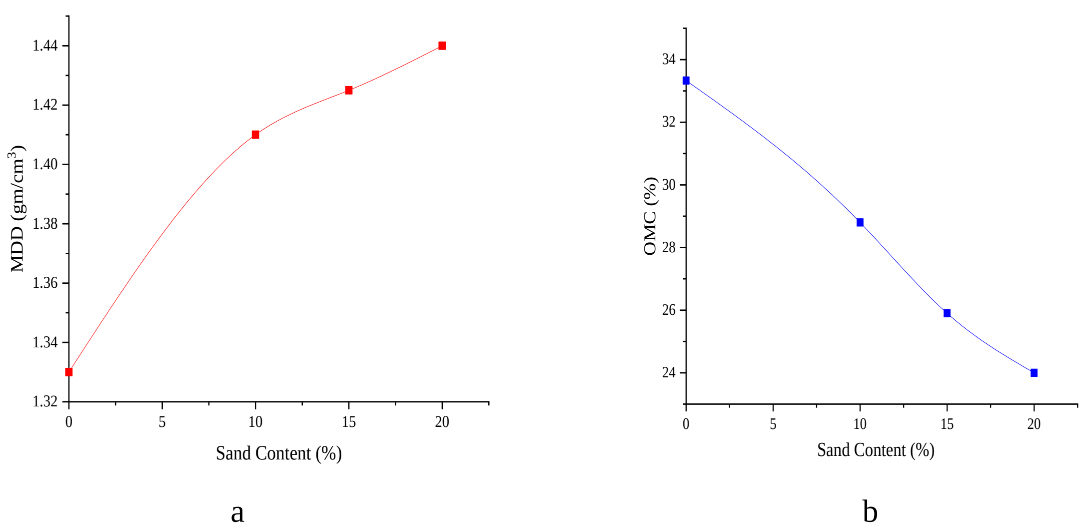



Figure 4.15. Effect of Sand mixing on (a) MDD and (b) OMC of reinforced soil

Mixing of 20% sand to the reinforced soil increased the MDD by 7.64% and reduced the OMC 27.99%. As it can be seen mixing sand into the soil is more effective in increasing MDD and reducing OMC than soil reinforcement. When 20% sand mixed soil compared to the native soil the MDD of soil increased by 2.78% and the OMC reduced by 20.79% for 20% of sand mixing. The increase in MDD is an indicator of soil properties improvement by blending of sand. A similar trend has been observed by (Tare et al., 2018) when sand was used as a stabilizer for coir fiber reinforced soil sample. In addition to increasing the MDD and reducing OMC blending of sand improves the workability of soil fiber mix during the laboratory tests.

## 4.7.2. Effect of Sand on CBR value of Reinforced Soil

### 4.7.2.1. Effect of Sand Mixing on CBR value of Reinforced soil

The CBR test was also conducted for sand mixed reinforced soil in order to study the effect of sand on the bearing capacity and swell percent of the reinforced soil. The results obtained from the CBR tests carried out on both reinforced and sand blended reinforced soil samples are shown in Figure 4.16

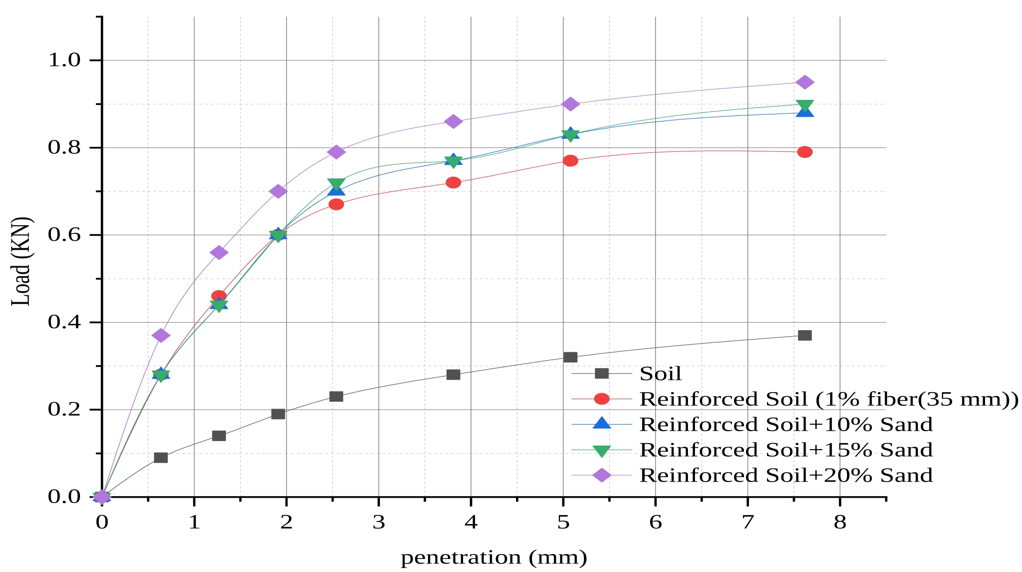



Figure 4.16. Load Versus Penetration graph of soil and stabilized soil

From the load penetration curve, it is clearly seen that load is increased for increasing sand content. The mixing of 20% sand showed the highest load caring capacity, 10% and 15% sand produce almost similar load caring capacity.

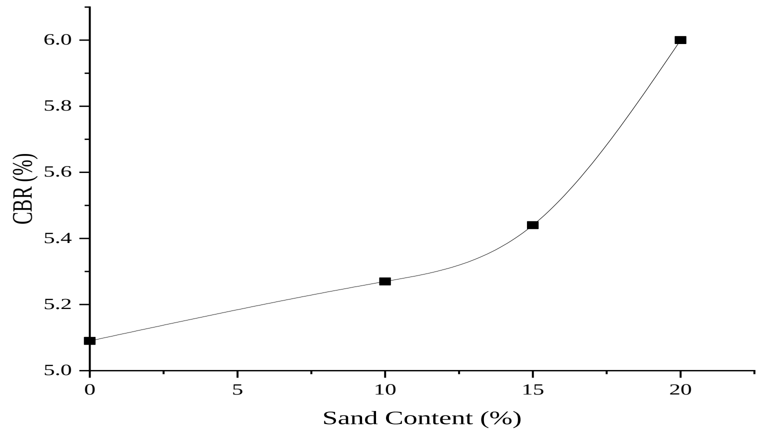



Figure 4.17. Variation in CBR of reinforced soil with varying amounts of sand

The results from the CBR test show that the CBR increased from 5.09% to 5.27%, 5.44% and 6.00% with an increase in sand content from 0% to 10%, 15% and 20% respectively. The increment in CBR may be resulted from the gradual increase in MDD of reinforced soil and reduction of percent swell. The Katcha fiber alone has increased the CBR value from 1.76 to 5.09% with an increase in fiber content from 0% to 1% at 35 mm length.

Table 4.12. CBR value of Soil and Reinforced (1% and 35mm) soil mixed with sand

| Material | | CBR (%) | Percent swell (%) | Percent increase in CBR (%) | Percent decrease in Swell (%) |
|---|---|---|---|---|---|
| Soil (100%) | | 1.76 | 7.46 | - | - |
| Reinforced soil (1% and 35 mm) | | 5.09 | 5.06 | 189.20 | 32.17 |
| Sand (%) | 10.00 | 5.27 | 5.10 | 199.43 | 31.64 |
| | 15.00 | 5.44 | 5 | 209.09 | 33.00 |
| | 20.00 | 6.00 | 4.80 | 240.91 | 35.66 |

As it can be seen in Table 4.12 when sand is mixed in to a reinforced soil, the soil enhanced the CBR more effectively than fiber alone for increasing the CBR value by 240.91%. The percent swell of the soil also reduced by 35.66% for 20% sand, similar reduction in swell was determined by (Louafi & Bahar, 2012) when sand was used as an additive for stabilization of swelling clay soils. As stated previously on the compaction test blending of sand to the reinforced soil improved the workability of the soil.

#### 4.7.2.2. Effect of Introducing Sand Layer to the Reinforced soil

After determining the optimum amount of sand from the CBR test, sand was introduced as a layer at different positions. Three different positions of the sand layer designated as 1st, 2nd and 3rd sand layer were studied for 20% sand. Figure 4.18 show the load versus penetration curve of soil and reinforced soil with different position of sand layer.

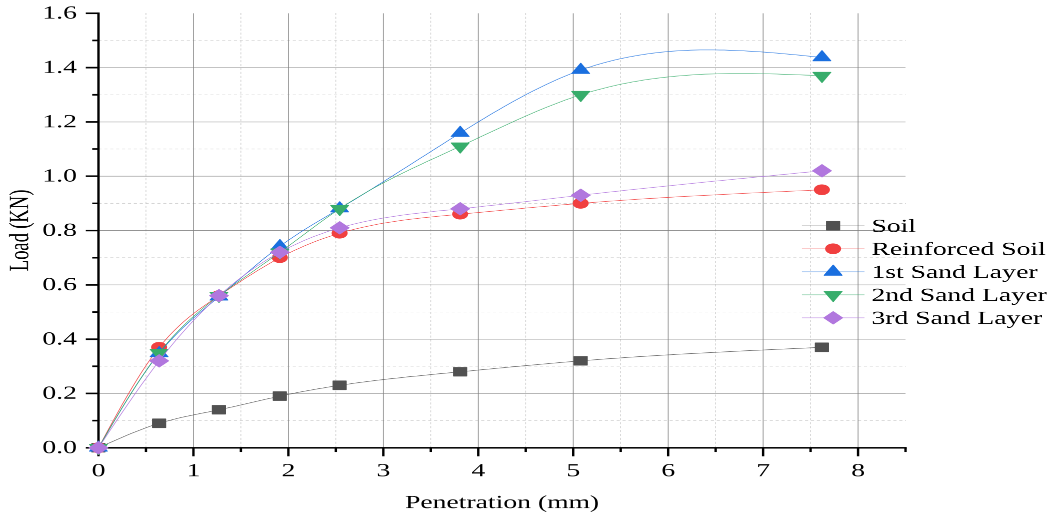



Figure 4.18. Load versus Penetration curve of the sand layer on reinforced soil sample

Introducing of the sand layer to the reinforced soils showed an increase in CBR value for different positions of the sand layer. The increase in CBR might be attributed to the draining effect of the sand layer which resulted from the reduction in swell, high bearing capacity of sand and increase in dry density of the reinforced soil sample.

Table 4.13. Sand layer position and CBR value of a reinforced soil

| Position of sand layer | Penetration (mm) | CBR (%) | Swell (%) |
|---|---|---|---|
| 1st | 2.54 | 6.67 | 4.01 |
| | 5.08 | 6.96 | |
| 2nd | 2.54 | 6.67 | 4.27 |
| | 5.08 | 6.49 | |
| 3rd | 2.54 | 6.15 | 4.71 |
| | 5.08 | 4.64 | |

As it can be seen from table 4.13 the highest CBR value is recorded for the 1st sand layer at 5.08 mm penetration, CBR value also increased for the 2nd and 3rd sand layer but at 2.54 mm. Using sand layer is effective in reducing swelling of the reinforced soil sample. It was found that the most efficient position of the sand layer in reducing swelling is the 1st sand layer compared to the 2nd and 3rd sand layer. The percent swell was reduced by 20.75%, 15.61% and 6.92% for 1st, 2nd, and 3rd sand layers respectively when compared with reinforced soil. A similar finding was observed in the research conducted by (Nini, 2016) to improve the CBR of the clay by introducing sand layer as a draining filter and also the reduction in swell of a clay soil was also observed on a test conducted by (Louafi & Bahar, 2012) by using sand layer as an additive for stabilization of swelling clay soils.

Generally the introduction of sand as a layer gave a promising result in increasing the CBR value and reducing the percent swell for a subgrade material. So this method can be used as an alternative method to improve the performance of a subgrade soil.

## 4.8. Unconfined Compressive Strength Test

Unconfined Compressive Strength (UCS) test was only conducted for optimum percentage of Katcha fiber and Sand which was selected based on CBR value which was 1% and 20% percentage replacement of 35 mm Katcha fiber and Sand respectively and for native soil.

The tests were conducted according to (ASTM-D2166, 2000) procedures. Stress-Stain plots of the native soil, reinforced soil and Sand mixed reinforced soils are shown in Figure. 4.19.

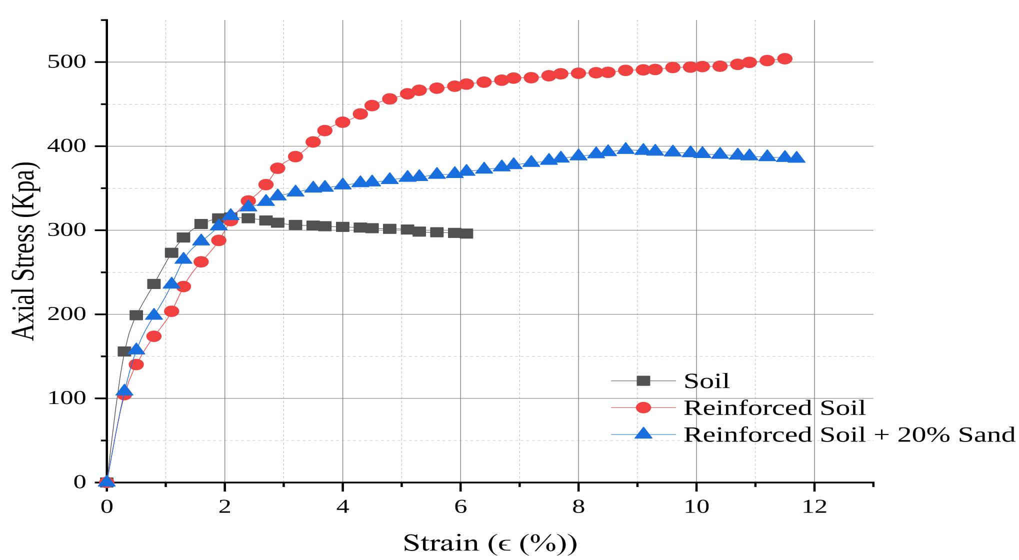



Figure 4.19. Stress-Strain curve of Soil and Stabilized soil

According to (ERA Site Investigation Manual, 2013) the UCS of stabilized soil have to be checked in order to determine the effect of stabilizer on the native soil property.

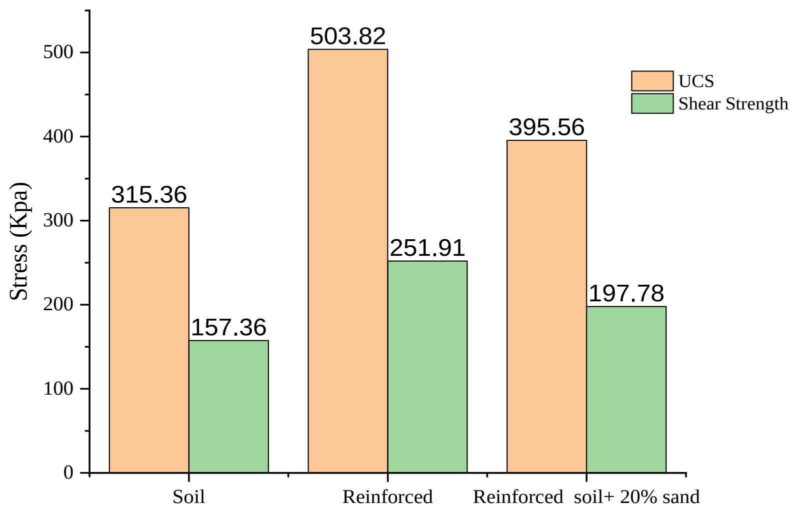



Figure 4.20. UCS and Shear strength of soil, Reinforced soil and Reinforced soil +20% sand

As it can be seen in the figure the UCS of soil is found to be 315.36Kpa and the highest UCS was recorded as 503.82 Kpa for reinforced soil by 1%, 35 mm kerosene coated Katcha fiber. The UCS of reinforced sand blended soil showed a lower value of UCS than that of reinforced soil. The addition of sand to reinforced soil reduces the interlock between the soil particles and the soil fiber interaction, as a result lower value of UCS was recorded but this value of mixed soil is greater than that of the native soil. As it can be seen in table 4.14 reinforcing the soil increased the UCS of a soil by 59.76% while mixing of sand increased the UCS of a soil by 25.41% the decrease in UCS of soil resulted from the non-cohesive property of sand.

Table 4.14. Summary of UCS, shear strength (Cu) and Percent increase in UCS value

| Mix | UCS (Kpa) | CU (Kpa) | Increase in UCS (%) |
|---|---|---|---|
| Soil | 315.36 | 157.36 | 0 |
| Reinforced Soil | 503.82 | 251.91 | 59.76 |
| Reinforced soil +20% Sand | 395.56 | 197.78 | 25.41 |

The shear strength (Cu) of the soil samples was calculated as half of the unconfined compression strength (qu). The shear strength was improved by the addition of Katcha fiber and thereafter it decreases with addition of sand. The increase in shear strength is due to perfect interlocking of Katcha fiber with the soil and thereafter it decreased when sand was mixed due to reduced interlock between soil and fiber mix by non-cohesive property of sand.

## 4.9. Subgrade Construction Cost

The subgrade construction cost is calculated for both removal and replacement and stabilization construction methods. The construction cost by removal and replacement of subgrade material is taken from the current material cost used in the site including labor, equipment, and overhead and profit costs.

The construction cost comparison is done by considering: the road layers above the subgrade are the same, site clearance and removal of top soil to a depth of 0.2 m and placing and compaction cost is the same for both methods, the optimum amount 1% Kerosene coated Katcha fiber of length 35 mm and 20% sand by weight of soil determined from CBR test, the current cost of 16 $m^3$ sand is 3200 Birr and 4 Liter of kerosene was used for soaking 7 Kg Katcha fiber.

Table 4.15. Construction cost of subgrade by removal and replacement method

| No | Description | Unit | Quantity | Unit price (birr) | Total price (birr) |
|---|---|---|---|---|---|
| 1 | SITE CLEARANCE | | | | |
| 1.2 | Clearing and Grubbing | $m^2$ | 7000 | 20 | 140000 |
| 2 | EARTH WORK | | | | |
| | Removal of unsuitable material | | | | |
| 2.1 | In layer thickness of 200mm or less | $m^3$ | 1400 | 120 | 168,000 |
| 2.2 | In layer thickness of exciding 200mm | $m^3$ | 7000 | 320 | 2,240,000 |
| 3 | BACKFILLING | | | | |
| 3.1 | Using imported selected material | $m^3$ | 7000 | 375 | 2,625,000 |
| 4 | ROAD BED PREPARATION AND COMPACTION | | | | |
| 4.1 | Compaction to 95% of modified AASHTO density | $m^3$ | 7000 | 175 | 1,225,000 |
| | Total (birr) | | | | 6,398,000 |

Table 4.16 Construction cost of subgrade by stabilization method

| No | Description | Unit | Quantity | Unit price (birr) | Total price (birr) |
|---|---|---|---|---|---|
| 1 | SITE CLEARANCE | | | | |
| 1.2 | Clearing and Grubbing | $m^2$ | 7000 | 20 | 140000 |
| 2 | EARTH WORK | | | | |
| 2.1 | In layer thickness of 200mm or less | $m^3$ | 1400 | 120 | 168,000 |
| 3 | BACKFILLING | | | | |
| | Using stabilized excavated material | | | | |
| 3.1 | Katcha Fiber | Kg | 70,000 | 16 | 1120,000 |
| 3.2 | Sand | $m^3$ | 1400 | 200 | 280,000 |
| 3.3 | Kerosene | L | 40,000 | 21.50 | 860,000 |
| 4 | ROAD BED PREPARATION AND COMPACTION | | | | |
| 4.1 | Compaction to 95% of modified AASHTO density | $m^3$ | 7000 | 175 | 1,225,000 |
| | Total (birr) | | | | 3,793.000 |

Table 4.17. Total cost comparison of subgrade construction

| No | Description | Total cost in birr |
|---|---|---|
| 1 | Subgrade construction by removal and replacement method | 6,398,000 |
| 2 | Subgrade construction by stabilized Soil | 3,793.000 |
| 3 | Difference | 2,605,000 |

From table 4.17 it is seen that for native soil total cost of construction is around 6,398,000 Birr/km, and for 1% , 35 mm Katcha fiber and 20% sand stabilized soil the cost of construction is 3,793.000 Birr/km, by stabilizing the existing soil it can be saved up to 2,605,000 Birr /km.

# 5. CONCLUSIONS AND RECOMMENDATIONS

## 5.1. Conclusions

The thesis investigate the potential applicability of katcha fiber and Sand to improve the performance of weak subgrade soil to avoid removal and replacement of the residual soil. Thus, the thesis presents the effect of Katcha fiber on strength of the soil and sand on gradation, consistency and volumetric shrinkage of soil and on compaction, CBR and UCS of reinforced soil. On the basis of the test results, the following conclusions can be drawn:

- ✓ From the laboratory test results of natural soil, it is observed that the properties of soil under the study did not full fill the requirement to be used as a subgrade material unless the properties of the soil are improved.
- ✓ The water absorption capacity of Katcha fiber is reduced by Kerosene coating. The WAC of the fiber reduced by 58% for three days kerosene soaked fiber. The tensile strength is found to be 340.74MPa and 302.5MPa for untreated fiber and 403.55MPa and 314.46MPa for kerosene treated fiber of 200 and 600 mm fiber length respectively.
- ✓ The gradation of the soil after mixing of 10%, 15% and 20% sand varied compared to gradation of native soil, as percentage of sand increased the content of gravel and sand increased while percent of fines decreased significantly. Mixing of 20% sand increased percent of gravel and sand from 5.16% to 6.16% and from 7.07 to 24.69% respectively.
- ✓ The PI of soil decreased from 30.8% to 21.11% with increasing sand content. Reduction of PI is an indicator of improvement correlated with an increase in the strength and a reduction in swelling and compressibility. Although volumetric shrinkage of sand mixed soil have been considerably reduced with increasing sand content when compared to native soil, mixing of 20% sand reduce the volumetric shrinkage of the soil by 61.2%.
- ✓ The MDD and OMC of soil was significantly affected by mixing of Katcha fiber. The MDD reduced and OMC increased as the fiber content and length increased with in the soil mass. The considerable drop in MDD 1.33gm/cm$^3$ obtained at 1% fiber of 35mm length has been compensated by mixing 20% sand to 1.44gm/cm$^3$. On the other hand, the OMC was also reduced from 33.33% to 24% when 20% sand mixed to 1%, 35mm length Katcha fiber reinforced soil.

- ✓ The notable improvement in CBR of a soil observed at 1% katcha fiber of 20 and 35 mm length. The CBR of a soil increased from 1.76% to 5.1% for 1%, 35mm Katcha fiber, the CBR increase is 190% over unreinforced soil. Mixing of sand showed further improvement on the CBR value of reinforced soil; the increment is around 240 % over native soil. Also the swell percent of a soil reduced by reinforcement and blending of sand, the swell percent of a soil was reduced from 7.44% to 5.06% and 4.8% for reinforced soil by 1% 35mm fiber and for 20 % sand mixing respectively. Although the CBR test demonstrated that the existence of sandy layer is advantageous for CBR value of a soil. The highest CBR value and the lowest swelling potential obtained at lower sandy layer.
- ✓ The values of UCS of a soil increased from 315.36Kpa to 503.8Kpa at 1% of 35mm katcha fiber. While mixing of sand reduce the reinforced soil strength but the UCS of a soil is greater than that of native soil strength. The decrease in UCS value is resulted from the decrease in bond between the soil and Katcha fiber due to non-cohesive property sand.
- ✓ The road construction cost can be reduced by stabilizing the in situ subgrade soil with 1%, 35mm Katcha fiber and 20% Sand. The stabilization method reduced the total construction cost of subgrade by 40.71%/for 1Km road section construction.

From the foregoing investigation, it would appear that kerosene coated Katcha fiber performs satisfactorily to improve the performance of weak subgrade soil. Further improvement on index property, strength and workability of a soil and reinforced soil can be achieved by sand mixing. And also introducing of sand as a layer improved the bearing capacity of the soil and it can be considered as an alternative stabilization method. Therefore using Katcha fiber and sand can be considered as an economic and ecofriendly stabilization practice, because of the cost, availability and environmental friendly property of katcha fiber and sand.

## 5.2. Recommendations

This thesis has attempted to obtain the optimum stabilization proportion of Katcha fiber with respect to its length and content and sand to improve the performance of weak subgrade soil. However, due to financial constraints, lack of laboratory, and lack of chemical reagents and time limitations the present research work did not cover the biochemical tests on the Katcha fiber. In view of this, it would be desirable to consider the following recommendations on better use of natural fiber and sand in road construction.

- The country is endowed with widely distributed different type of natural fiber including katcha, Tef straw, barley straw etc. Therefor it is recommended to study the biochemical composition of fibers to determine their strength and suitability for soil reinforcement.
- In order to prepare proportioning guide-line on Katcha fiber and sand application as a soil stabilizer, an intensive and deep research is recommended on the applicability of Katcha fiber and Sand on different type of soils.
- Further study is recommended on durability and life span of Katcha fiber with in the soil mass without losing its strength.
- Further study is recommended on the effect of Kerosene on Biochemical composition, and Physical properties of Katcha fiber and its effect on the soil mass and surrounding environment.
- The fibers can either be mixed to the soil matrix manually or mechanically by using different mixing machines. However there are no standard designed machine to cut the fibers in a desired length, thus a machine capable of cutting fiber to a desired length should be designed for bulk application of fiber in the field.

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**Adama, Ethiopia**

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# APPENDICES

# Appendix-A

# Test Results of Natural Soils

Table A-1 Natural Moisture Content of soil sample 1(pit 1) and soil sample 2(pit 2)

| Test Method | ASTM-D4643-00 | | | |
|---|---|---|---|---|
| Specimen reference | Pit 1 | | Pit 2 | |
| Container no | 333 | Z | D | 16 |
| Mass of wet Soil +Container (m2) gm | 97 | 100 | 107.2 | 88 |
| Mass of dry Soil +Container (m3) gm | 81 | 81.2 | 90.2 | 73.5 |
| Mass of container (m1) gm | 16 | 10 | 16 | 10 |
| Mass of moisture(m2-m3) gm | 16 | 18.8 | 17 | 14.5 |
| Mass of dry soil (m3-m1) gm | 65 | 71.2 | 74.2 | 63.5 |
| Moisture content (m3-m1)*100/(m3-m1) % | 24.615 | 26.404 | 22.911 | 22.835 |
| Average moisture content (%) | 25.51 | | 22.87 | |

Table A-2 Specific Gravity of Soil Sample1 (Pit1) and Soil Sample 2(pit 2)

| Test Method | ASTM-D 854 | | | |
|---|---|---|---|---|
| Determination number | Pit 1 | | Pit 2 | |
| Bottle no | 6 | 9 | 12 | 7 |
| Wt. of bottle + Water+ Soil (g) | 167.4 | 167.6 | 166.7 | 167.3 |
| T | | | | |
| Wt. of bottle + Water (g) | 157.8 | 158 | 157.2 | 157.8 |
| Wt. of bottle + Dry soil (g) | 67 | 64.2 | 66.7 | 67 |
| Wt. of bottle (g) | 52.000 | 50.000 | 51.900 | 52.000 |
| Wt. of soil (g) | 15 | 15 | 15 | 15 |
| Specific Gravity | 2.778 | 2.778 | 2.727 | 2.727 |
| Average Specific Gravity | 2.78 | | 2.73 | |

Table A-3 Grain Size Analysis of soil sample 1(pit 1)

| Sieve size | Retained for 1st Sieving | | Percent Passing |
|---|---|---|---|
| (mm) | Weight | % Rtd. | (%) |
| 75 | 0.00 | 0.00 | 100.00 |
| 63 | 0.00 | 0.00 | 100.00 |
| 50 | 0.00 | 0.00 | 100.00 |
| 37.5 | 0.00 | 0.00 | 100.00 |
| 25 | 0.00 | 0.00 | 100.00 |
| 19 | 0.00 | 0.00 | 100.00 |
| 12.5 | 8.80 | 1.95 | 98.05 |
| 9.5 | 4.50 | 1.00 | 97.05 |
| 4.75 | 10.00 | 2.22 | 94.84 |

| | | | |
|---|---|---|---|
| 2 | 6.60 | 1.46 | 93.37 |
| 1.18 | 4.50 | 1.00 | 92.38 |
| 0.6 | 4.60 | 1.02 | 91.36 |
| 0.3 | 4.80 | 1.06 | 90.29 |
| 0.15 | 5.10 | 1.13 | 89.16 |
| 0.075 | 6.30 | 1.40 | 87.77 |
| Pan | 396.10 | 87.77 | |
| Total | 451 | 100 | |

b. Hydrometer

| Elapsed Time, t,min | Actual Hydrometer Reading Ra | Temp (ºC) | Effective Depth, L (cm) | K From Table | Temprature Correction Factor Ct | Modified Hydrometer Reading R= Ra - Cz+Ct | Particle Diameter D (mm) | Percentage Pass (%) | Corrected Percentage Pass (%) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 2 | 41.500 | 19 | 9.28 | 0.01329 | -0.25 | 35.111 | 0.0286 | 68.29 | 59.93 |
| 5 | 38.500 | 19 | 9.78 | 0.01329 | -0.25 | 32.111 | 0.0186 | 62.45 | 54.81 |
| 15 | 36.500 | 19 | 10.11 | 0.01329 | -0.25 | 30.111 | 0.0109 | 58.56 | 51.40 |
| 30 | 33.500 | 19 | 10.60 | 0.01329 | -0.25 | 27.111 | 0.0079 | 52.73 | 46.28 |
| 60 | 30.500 | 19 | 11.10 | 0.01329 | -0.25 | 24.111 | 0.0057 | 46.89 | 41.16 |
| 250 | 27.500 | 21 | 11.59 | 0.01296 | 0.18 | 21.856 | 0.0028 | 42.51 | 37.31 |
| 1440 | 22.500 | 19 | 12.42 | 0.01329 | -0.25 | 16.111 | 0.0012 | 31.33 | 27.50 |

Table A-4 Grain Size Analysis of soil sample 2 (pit 2)

| Sieve Size | Retained for 1st Sieving | | Percent Passing |
|---|---|---|---|
| (mm) | Weight | % Rtd. | (%) |
| 75 | 0.00 | 0.00 | 100.00 |
| 63 | 0.00 | 0.00 | 100.00 |
| 50 | 0.00 | 0.00 | 100.00 |
| 37.5 | 0.00 | 0.00 | 100.00 |
| 25 | 0.00 | 0.00 | 100.00 |

| | | | |
|---|---|---|---|
| 19 | 9.20 | 1.53 | 98.47 |
| 12.5 | 29.40 | 4.89 | 93.58 |
| 9.5 | 15.90 | 2.64 | 90.94 |
| 4.75 | 53.80 | 8.94 | 82.00 |
| 2 | 91.20 | 15.16 | 66.83 |
| 1.18 | 79.40 | 13.20 | 53.63 |
| 0.6 | 41.70 | 6.93 | 46.70 |
| 0.3 | 38.70 | 6.43 | 40.27 |
| 0.15 | 24.30 | 4.04 | 36.23 |
| 0.075 | 18.40 | 3.06 | 33.17 |
| pan | 199.50 | 33.17 | |
| Total | 602 | 100 | |

b. Hydrometer

| Elapsed Time, t,min | Actual Hydrometer Reading Ra | Te ºC | Effective Depth, L (mm) | K From Table | $T^0$ Correction Factor Ct | Modified Hydrometer Reading R= Ra - Cz+Ct | Particle Diameter D (mm) | Percent Pass (%) | Corrected Percentage Pass (%) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 2 | 26.50 | 19 | 11.76 | 0.01348 | -0.25 | 20.111 | 0.0327 | 39.52 | 13.11 |
| 5 | 24.50 | 19 | 12.09 | 0.01348 | -0.25 | 18.111 | 0.0210 | 35.59 | 11.80 |
| 15 | 22.50 | 19 | 12.42 | 0.01348 | -0.25 | 16.111 | 0.0123 | 31.66 | 10.50 |
| 30 | 20.50 | 19 | 12.75 | 0.01348 | -0.25 | 14.111 | 0.0088 | 27.73 | 9.20 |
| 60 | 18.50 | 19 | 13.08 | 0.01348 | -0.25 | 12.111 | 0.0063 | 23.80 | 7.89 |
| 250 | 16.50 | 21 | 13.41 | 0.01315 | 0.18 | 10.856 | 0.0030 | 21.33 | 7.08 |
| 1440 | 14.50 | 19 | 13.74 | 0.01348 | -0.25 | 8.111 | 0.0013 | 15.94 | 5.29 |

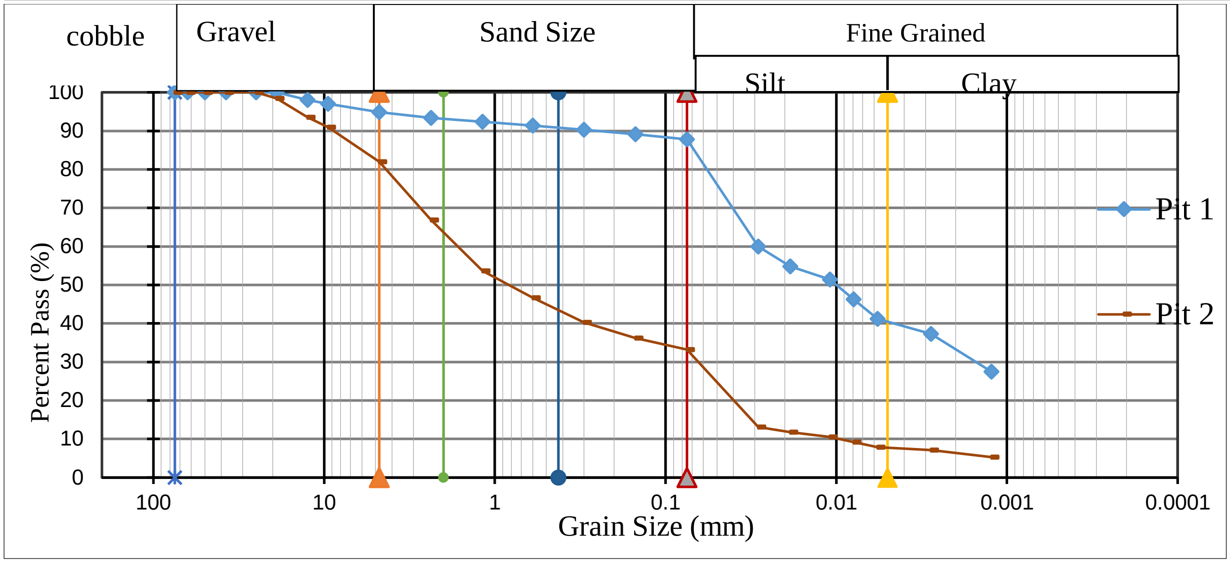


Figure A-1 Particle size distribution curve of pit 1 and Pit 2 soil sample

Table A-5 Liquid Limit and Plastic Limit test of Soil Sample 1(pit1)

| Test Method | | ASTM-D 4318 | | | | | |
|---|---|---|---|---|---|---|---|
| Type of Test | | Liquid Limit Test | | | | Plastic Limit Test | |
| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 1 | Trial 2 |
| No. of Blows | N | 34 | 27 | 23 | 18 | - | - |
| Mass of moist Sample + Can | $M_1$ | 26.35 | 29.49 | 32.46 | 34.72 | 27.54 | 27.54 |
| Mass of Dried Sample + Can | $M_2$ | 21.65 | 23.35 | 24.94 | 25.64 | 23.49 | 23.63 |
| Mass of Can | $M_c$ | 14.85 | 14.91 | 15.11 | 14.77 | 14.35 | 14.92 |
| Mass of Moist | $M_m=M_1-M_2$ | 4.70 | 6.14 | 7.52 | 9.08 | 4.05 | 3.91 |
| Mass of Dried Sample | $M_d=M_2-M_c$ | 6.80 | 8.44 | 9.83 | 10.87 | 9.14 | 8.71 |
| Moisture Content (%) | $= (M_m / M_d) \times 100$ | 69.12 | 72.75 | 76.50 | 83.53 | 44.31 | 44.89 |
| | | Liquid Limit = 75.4% | | | | Plastic Limit= 44.6% | |
| | | Plasticity Index (PI = LL - PL) =30.8 | | | | | |

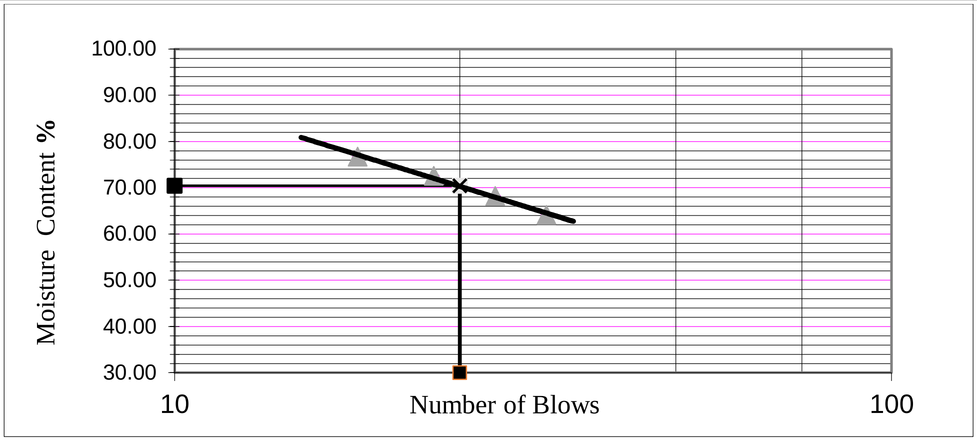


Figure A-2 Liquid Limit determination of soil sample 1(Pit 1)

Table A-6 Liquid limit and Plastic Limit test of Soil Sample 2 (pit 2)

| Test Method | | ASTM-D 4318 | | | | | |
|---|---|---|---|---|---|---|---|
| Type of Test | | Liquid Limit Test | | | | Plastic Limit Test | |
| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 1 | Trial 2 |
| No. of Blows | N | 33 | 28 | 23 | 18 | - | - |
| Mass of moist Sample + Can | $M_1$ | 26.57 | 29.31 | 32.35 | 34.60 | 27.25 | 27.29 |
| Mass of Dried Sample + Can | $M_2$ | 21.80 | 23.65 | 24.64 | 25.91 | 23.35 | 23.38 |
| Mass of Can | $M_c$ | 14.36 | 15.35 | 14.02 | 14.58 | 14.84 | 14.37 |
| Mass of Moist | $M_m=M_1-M_2$ | 4.77 | 5.66 | 7.71 | 8.69 | 3.90 | 3.91 |
| Mass of Dried Sample | $M_d=M_2-M_c$ | 7.44 | 8.30 | 10.62 | 11.33 | 8.51 | 9.01 |
| Moisture Content (%) | $= (M_m / M_d) \times 100$ | 64.11 | 68.19 | 72.60 | 76.70 | 45.83 | 43.40 |
| | | Liquid Limit = 70.4% | | | | Plastic Limit= 44.61% | |
| | | Plasticity Index (PI = LL - PL) = 25.8 | | | | | |

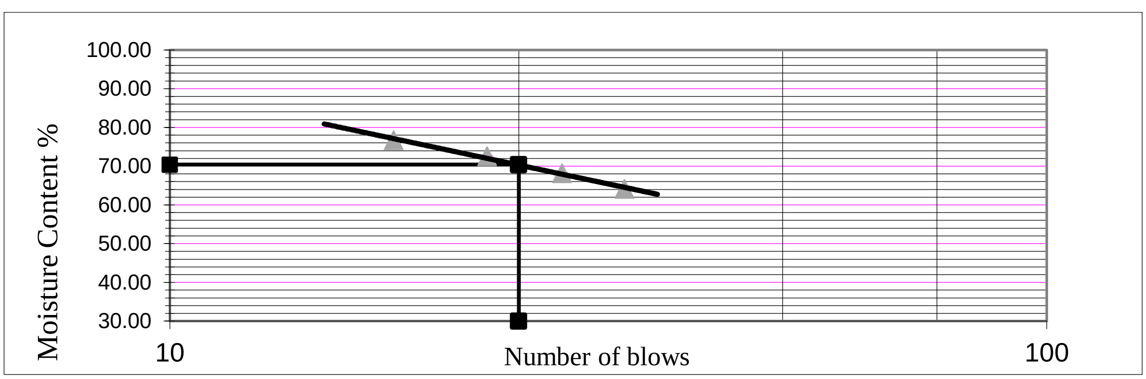


Figure A-3 Liquid Limit determination of soil sample 2 (Pit 2)

Table A-7 Compaction property of Soil Sample 1 (pit1)

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5455.00 | 5580.10 | 5642.80 | 5600.00 |
| Wt.of mould (g) | 3921.00 | 3921.00 | 3921.00 | 3921.00 |
| Wt.of wet soil(g) | 1534.00 | 1659.10 | 1721.80 | 1679.00 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.63 | 1.758 | 1.824 | 1.779 |
| Moisture content | | | | |
| Wet soil + tin (g) | 129.60 | 86.00 | 94.60 | 90.70 |
| Dry soil + tin (g) | 107.00 | 70.70 | 76.30 | 70.30 |
| Wt of tin (g) | 16 | 16.30 | 16.50 | 10.00 |
| Wt of Water (g) | 22.60 | 15.30 | 18.30 | 20.40 |
| Wt of Dry soil (g) | 91.00 | 54.40 | 59.80 | 60.30 |
| Moisture content % | 24.84 | 28.13 | 30.60 | 33.831 |
| Dry Density gm /cm$^3$ | 1.302 | 1.372 | 1.397 | 1.329 |

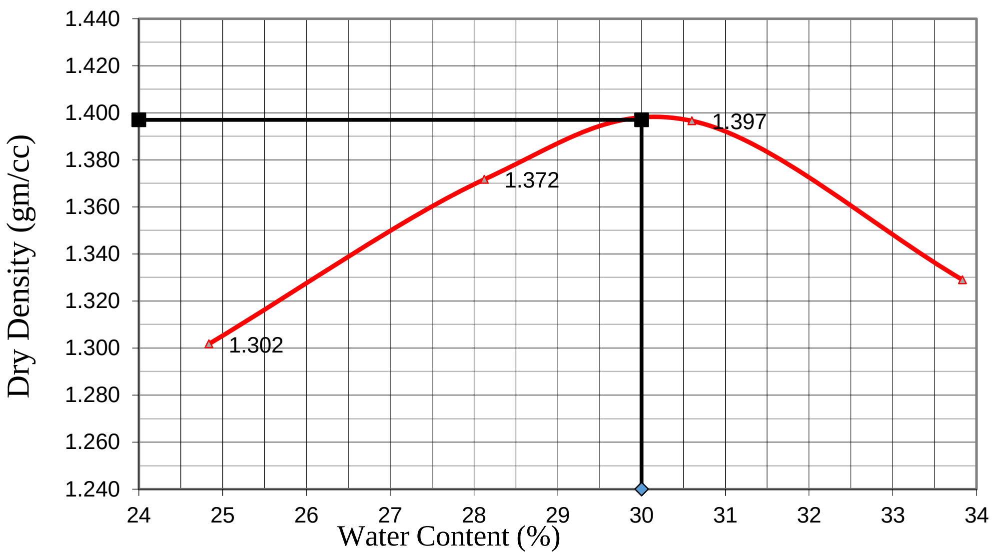


Figure A-4 Compaction Curve of soil sample 1(Pit 1)

Table A-8 Compaction property of Soil Sample 2 (pit 2)

| Test Method | ASTM-D1557 | | | |
|---|---|---|---|---|
| Lab.test No. | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5308.9 | 5485.3 | 5464.2 | 5353.7 |
| Wt.of mould (g) | 3710.3 | 3710.3 | 3710.3 | 3710.3 |
| Wt.of wet soil(g) | 1598.6 | 1775.0 | 1753.9 | 1643.4 |
| Volume of mould cm3 | 944 | 944 | 944 | 944 |
| Wet Density gm /cm3 | 1.69 | 1.88 | 1.858 | 1.74 |
| **Moisture content** | | | | |
| Wet soil + tin (g) | 94.70 | 97.60 | 96.70 | 75.00 |
| Dry soil + tin (g) | 78.80 | 80.00 | 77.60 | 58.30 |
| Wt of tin (g) | 10 | 17.3 | 16.6 | 10 |
| Wt of Water (g) | 15.90 | 17.60 | 19.10 | 16.70 |
| Wt of Dry soil (g) | 68.80 | 62.70 | 61 | 48.3 |
| Moisture content % | 23.11 | 28.07 | 31.31 | 34.58 |
| Dry Density gm /$cm^3$ | 1.376 | 1.468 | 1.415 | 1.294 |

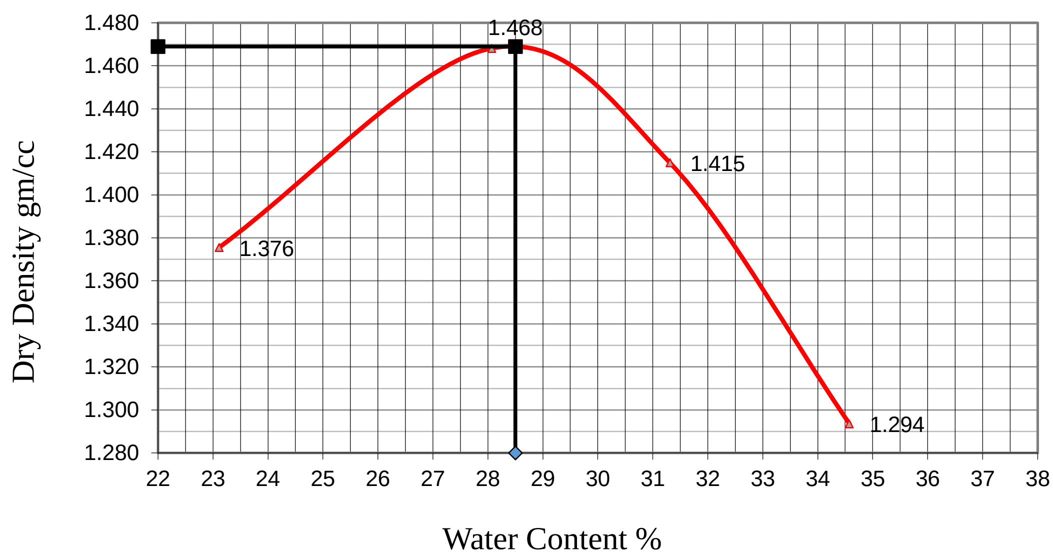


Figure A-5 Compaction Curve of soil sample 2 (Pit 2)

Table A-9 California Bearing Ratio (CBR) of soil sample 1(pit 1)

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration (mm) | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| | | | | Gauge reading | Initial (mm) | Final (mm) |
| 0 | 0 | 46.367 | 0.00 | | 961 | 1909 |
| 0.64 | 2 | " | 0.09 | % swell | 7.465 | |
| 1.27 | 3 | " | | | | |
| 1.91 | 4 | " | 0.19 | | | |
| 2.54 | 5.0 | " | 0.23 | | | |
| 3.81 | 6 | " | 0.28 | | | |
| 5.08 | 7 | " | 0.32 | | | |
| 7.62 | 8 | " | 0.37 | | | |
| | | | 0.00 | | | |

| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR, % | % Swell | Blow/layer= 56/5 |
|---|---|---|---|---|---|
| 2.54 | 0.23 | 13.2 | 1.76 | 7.46 | MDD= 1.4 |
| 5.08 | 0.32 | 20.0 | 1.62 | | OMC 30.3% |

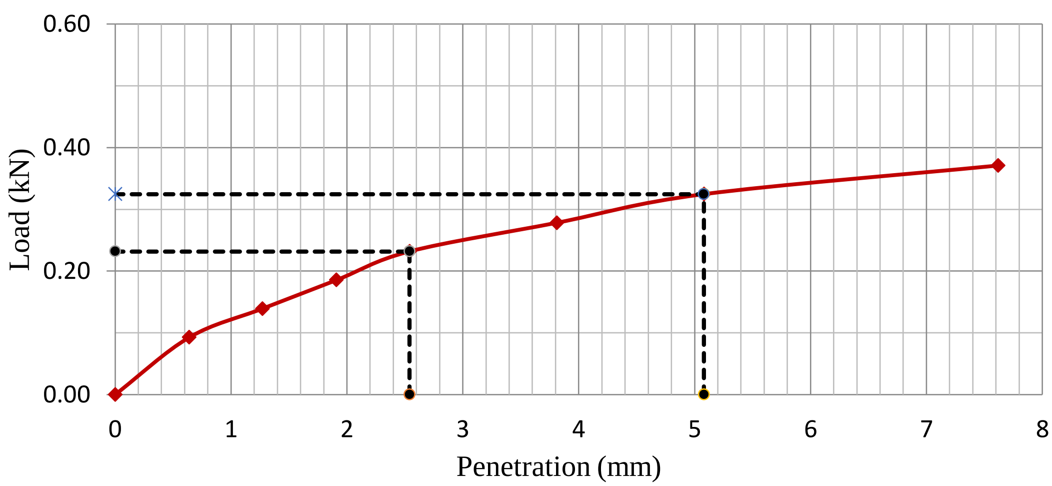


Figure A-6 Load versus Penetration curve of soil sample 1 (pit 1)

Table A-10 California Bearing Ratio (CBR) of soil sample 2 (pit 2)

| Test Method | | | ASTM-D1883 | | | |
|---|---|---|---|---|---|---|
| Penetration (mm) | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| | | | | Gauge reading | Initial (mm) | Final (mm) |
| 0 | 0 | 46.367 | 0.00 | | 890 | 1789 |
| 0.64 | 1.5 | " | 0.07 | % swell | 7.08 | |
| 1.27 | 3.5 | " | 0.16 | | | |
| 1.91 | 5 | " | 0.23 | | | |
| 2.54 | 6 | " | 0.28 | | | |
| 3.81 | 8 | " | 0.37 | | | |
| 5.08 | 9 | " | 0.42 | | | |
| 7.62 | 11 | " | 0.51 | | | |
| | | | 0.00 | | | |

| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR, % | % Swell | Blow/layer= 56/5 |
|---|---|---|---|---|---|
| 2.54 | 0.23 | 13.2 | 2.11 | 7.08 | MDD= 1.32 |
| 5.08 | 0.32 | 20.0 | 2.09 | | OMC 30.89% |

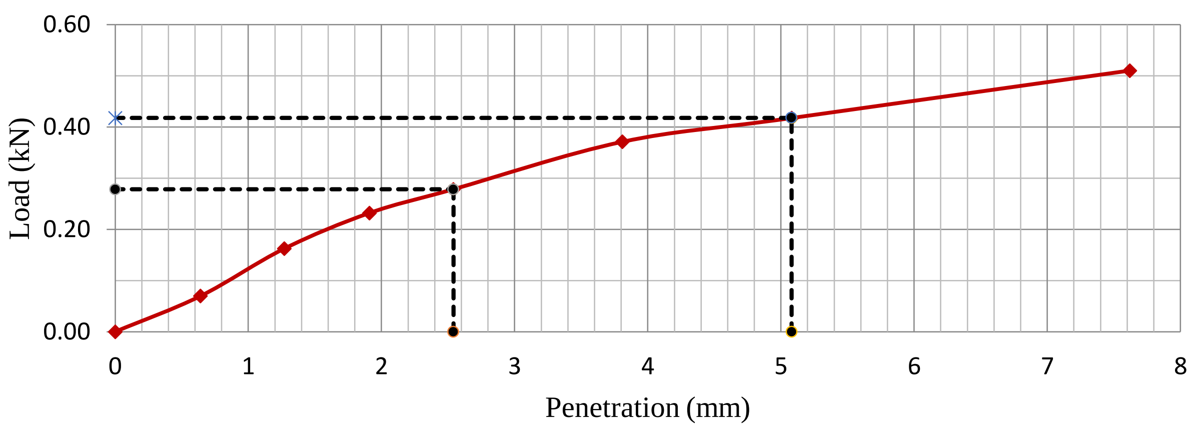


Figure A-7 Load versus Penetration curve of soil sample 2(pit 2).

# Appendix-B

# Test Results of Sand

Table B-1 Specific Gravity of sand

| Test Method | ASTM-D854 | |
|---|---|---|
| Determination number | 1 | 2 |
| Bottle no | 125 | 21 |
| Wt. of bottle + Water+ Soil (g) | 166.55 | 163.1 |
| T | | |
| Wt. of bottle + Water (g) | 157.19 | 153.73 |
| Wt. of bottle + Dry soil (g) | 64.580 | 64.2 |
| Wt. of bottle (g) | 49.580 | 50.000 |
| Wt. of soil (g) | 15 | 15 |
| Specific Gravity | 2.660 | 2.664 |
| Average Specific gravity (Gs) | 2.662 | |

Table B-2 Dry sieve analysis of Sand

| Sieve Size(mm) | Retained for 1st Sieving | | Percent Passing |
|---|---|---|---|
| (mm) | Weight | % Rtd. | (%) |
| 75 | 0.00 | 0.00 | 100.00 |
| 63 | 0.00 | 0.00 | 100.00 |
| 50 | 0.00 | 0.00 | 100.00 |
| 37.5 | 0.00 | 0.00 | 100.00 |
| 25 | 0.00 | 0.00 | 100.00 |
| 19 | 0.00 | 0.00 | 100.00 |
| 12.5 | 0.00 | 0.00 | 100.00 |
| 9.5 | 0.00 | 0.00 | 100.00 |
| 4.75 | 17.70 | 3.52 | 96.48 |
| 2 | 43.10 | 8.58 | 87.90 |
| 1.18 | 97.80 | 19.46 | 68.44 |
| 0.6 | 165.40 | 32.91 | 35.54 |
| 0.3 | 137.70 | 27.40 | 8.14 |
| 0.15 | 36.50 | 7.26 | 0.88 |
| 0.075 | 1.90 | 0.38 | 0.50 |
| | 2.50 | 0.50 | |
| | 503 | 100 | |

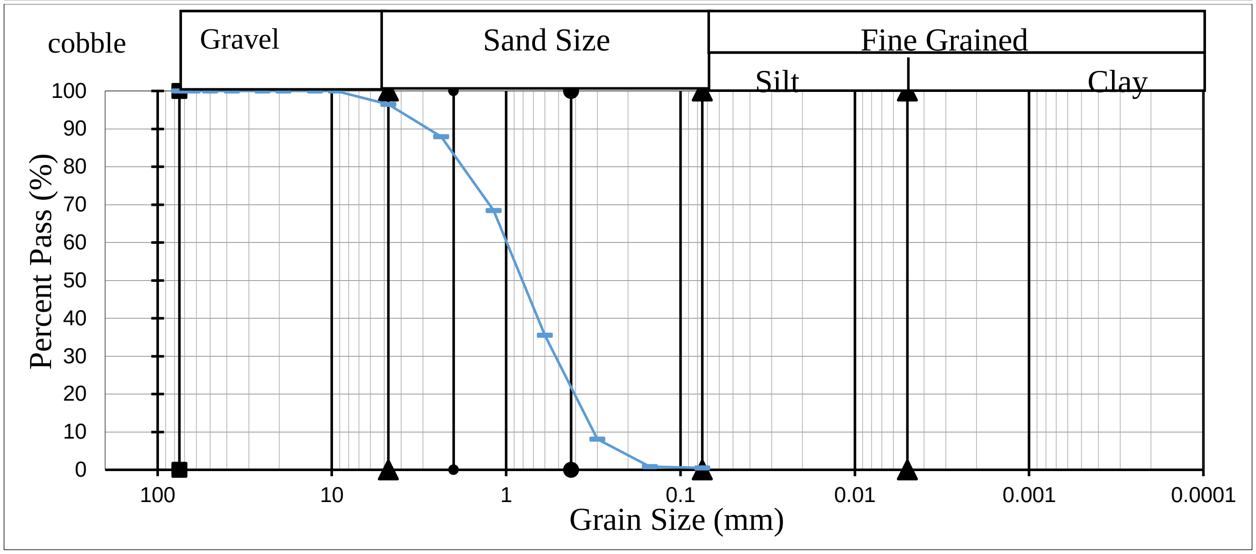


Figure B-1 Particle Size Distribution Curve of Sand

Table B-3 Atterberg Limit of sand

| Test Method | | | | | |
|---|---|---|---|---|---|
| | | ASTM-D 4318 | | | |
| Type of Test | | Liquid Limit Test | | | |
| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| No. of Blows | N | 11 | 16 | 23 | 26 |
| Mass of moist Sample + Can | $M_1$ | 30.15 | 31.70 | 34.53 | 37.64 |
| Mass of Dried Sample + Can | $M_2$ | 28.51 | 29.52 | 30.25 | 32.36 |
| Mass of Can | $M_c$ | 14.95 | 14.36 | 14.92 | 14.54 |
| Mass of Moist | $M_m=M_1-M_2$ | 1.64 | 2.18 | 4.28 | 5.28 |
| Mass of Dried Sample | $M_d=M_2-M_c$ | 13.56 | 15.16 | 15.33 | 17.82 |
| Moisture Content | $= M_m / M_d \times 100$ | 12.09 | 14.38 | 27.92 | 29.63 |
| Liquid Limit (LL) | | 28.5 | | | |
| Plastic Limit (PL) | | 0 | | | |
| Plasticity Index (PI) | | 28.5 | | | |

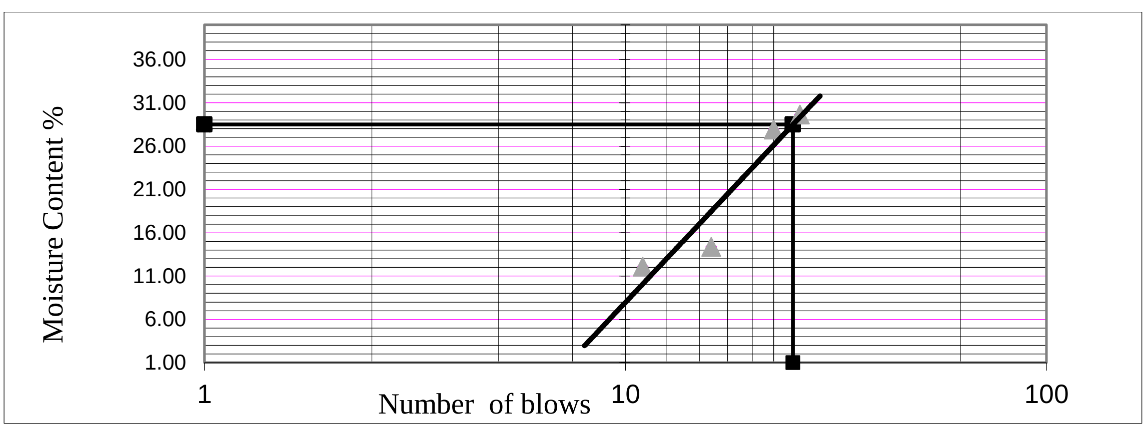


Figure B-2 Liquid Limit determination of sand

# Appendix-C

# Test Results of Katcha fiber

Table C-1 Specific Gravity of Kerosene Coated and uncoated Katcha Fiber

| Test Method | ASTM D854 | | | |
|---|---|---|---|---|
| | Untreated Fiber | | Treated Fiber | |
| botl number | 6 | 9 | 13 | 12 |
| B+W+fiber (g) | 158.2 | 156.4 | 157.2 | 156 |
| B+W (g) | 157.4 | 154 | 156 | 154 |
| B+Dry fiber (g) | 66.6 | 64.2 | 64.8 | 65.4 |
| B (g) | 51.6 | 49.2 | 49.8 | 50.4 |
| Dry fiber (g) | 15 | 15 | 15 | 15 |
| Specific Gravity | 1.06 | 1.19 | 1.09 | 1.15 |
| Average Specific Gravity | 1.12 | | 1.12 | |

Table C-2 Moisture Regain of Katcha fiber

| Test Method | | ASTM D2495 – 07 | | | |
|---|---|---|---|---|---|
| Fiber Condition | | untreated fiber | | 3 days soaked fiber | |
| Wet fiber + can (g) | M1 | 173 | 173 | 173 | 173 |
| dry fiber + can (g) | M2 | 166.8 | 167.2 | 168 | 167.8 |
| can(g) | Mc | 123 | 123 | 123 | 123 |
| moisture mass | Mw= M1-M2 | 6.2 | 5.8 | 5 | 5.2 |
| dry fiber (g) | Md=M2-MC | 43.8 | 44.2 | 45 | 44.8 |
| Moisture Regain (%) =(Md/Mw)*100 | | 14.16 | 13.12 | 11.11 | 11.61 |
| Average Moisture regain (%) | | 13.64 | | 11.36 | |

Table C-3 Moisture content of Katcha fiber

| Test Method | | ASTM D2495 – 07 | | | |
|---|---|---|---|---|---|
| | | untreated fiber | | 2 days soaked fiber | |
| Wet fiber + can (g) | M1 | 173 | 173 | 173 | 173 |
| Dry fiber + can (g) | M2 | 166.7 | 167 | 167.7 | 167.2 |
| Can(g) | Mc | 123 | 123 | 123 | 123 |
| Moisture mass | Mw=M1-M2 | 6.3 | 6 | 5.3 | 5.8 |
| wet fiber (g) | Mn= M1-Mc | 50 | 50 | 50 | 50 |
| Moisture Content ( %)=(Mw/Mn)*100 | | 12.60 | 12.00 | 10.60 | 11.60 |
| Average Moisture Content (%) | | 12.30 | | 11.10 | |

Table C- 4 Water Absorption test of Kerosene Coated and Uncoated 20 mm Katcha fiber

| 20mm fiber length | untreated fiber | | treated for 1 day | | treated for 2 day | | treated for 3 day | |
|---|---|---|---|---|---|---|---|---|
| Wet fiber + can (g) M1 | 218 | 217.3 | 207.6 | 207 | 198.7 | 199.9 | 199.7 | 198.5 |
| Dry fiber + can (g) M2 | 187.6 | 187.4 | 186.1 | 187.4 | 185 | 186.1 | 186.9 | 186 |
| can(g) Mc | 177.6 | 177.5 | 176 | 177.4 | 175 | 176 | 177 | 176 |
| Moisture mass Mw= M1-M2 | 30.4 | 29.9 | 21.5 | 19.6 | 13.7 | 13.8 | 12.8 | 12.5 |
| dry fiber (g)Md=M2-MC | 10 | 9.9 | 10.1 | 10 | 10 | 10.1 | 9.9 | 10 |
| Moisture Content,(Md/Mw)*100 | 304.00 | 302.02 | 212.87 | 196.00 | 137.00 | 136.63 | 129.29 | 125.00 |
| Average moisture content (%) | 303.01 | | 204.44 | | 136.82 | | 127.15 | |

Table C-5 Tensile Strength test data

| | |
|---|---|
| Sample type : Katcha Fiber | Test Type : Tensile |
| Standard : ES 127/ ASTM- D3822 | Test Speed : 10.000 mm/min |
| Diameter=0.128 mm | Area= 0.0129 $mm^2$ |
| Number of strands in one bundle of fiber = 65 | |

Table C-6 Tensile strength test of single strand uncoated Katcha fiber

| Fiber Length | | | | |
|---|---|---|---|---|
| | 200 mm | | 600 mm | |
| TEST No | Force at break (N) | Tensile strength (Mpa) | Force at break (N) | Tensile strength (Mpa) |
| 1 | 4.5 | 348.8372 | 3.72 | 288.3721 |
| 2 | 4.4 | 341.0853 | 3.98 | 308.5271 |
| 3 | 4.5 | 348.8372 | 3.9 | 302.3256 |
| 4 | 4.9 | 379.845 | 4 | 310.0775 |
| 5 | 5.2 | 403.1008 | 3.7 | 286.8217 |
| 6 | 4.55 | 352.7132 | 3.77 | 292.2481 |
| 7 | 4.5 | 348.8372 | 3.88 | 300.7752 |
| 8 | 4.26 | 330.2326 | 3.99 | 309.3023 |
| 9 | 4.3 | 333.3333 | 3.92 | 303.876 |
| 10 | 4.1 | 317.8295 | 3.98 | 308.5271 |
| 11 | 4.5 | 348.8372 | 3.76 | 291.4729 |
| 12 | 4.2 | 325.5814 | 3.98 | 308.5271 |
| 13 | 4.2 | 325.5814 | 3.99 | 309.3023 |
| 14 | 4.5 | 348.8372 | 3.78 | 293.0233 |
| 15 | 4.3 | 333.3333 | 4 | 310.0775 |
| 16 | 4.18 | 324.031 | 3.88 | 300.7752 |
| 17 | 4.2 | 325.5814 | 3.9 | 302.3256 |
| 18 | 4.3 | 333.3333 | 3.92 | 303.876 |
| 19 | 4.2 | 325.5814 | 4 | 310.0775 |
| 20 | 4 | 310.0775 | 4 | 310.0775 |
| Average | 4.3895 | 340.2713 | 3.9 | 302.5 |

Table C-7 Tensile strength test of single strand of kerosene coated Katcha fiber

| Fiber Length | | | | |
|---|---|---|---|---|
| | 200 mm | | 600 mm | |
| TEST No | Force at break (N) | Tensile strength (Mpa) | Force at break (N) | Tensile strength (Mpa) |
| 1 | 5.3 | 412.0845 | 4 | 310.0775 |
| 2 | 5.2 | 403.1008 | 4.1 | 317.8295 |
| 3 | 4.96 | 384.4961 | 4 | 310.0775 |
| 4 | 5.2 | 403.1008 | 4.1 | 317.8295 |
| 5 | 5.2 | 403.1008 | 4 | 310.0775 |
| 6 | 4.95 | 383.7209 | 3.98 | 308.5271 |

| | | | | |
|---|---|---|---|---|
| 7 | 5.2 | 403.1008 | 4 | 310.0775 |
| 8 | 5.28 | 409.3023 | 3.99 | 309.3023 |
| 9 | 5 | 387.5969 | 4.1 | 317.8295 |
| 10 | 4.96 | 384.4961 | 4 | 310.0775 |
| 11 | 5 | 387.5969 | 3.99 | 309.3023 |
| 12 | 4.98 | 386.0465 | 4 | 310.0775 |
| 13 | 5.2 | 403.1008 | 4.2 | 325.5814 |
| 14 | 5.21 | 403.876 | 4.15 | 321.7054 |
| 15 | 5.3 | 410.8527 | 4.1 | 317.8295 |
| 16 | 5.21 | 403.876 | 4.1 | 317.8295 |
| 17 | 5.4 | 418.6047 | 4.2 | 325.5814 |
| 18 | 5.6 | 434.1085 | 4.13 | 320.155 |
| 19 | 5.45 | 422.4806 | 3.99 | 309.3023 |
| 20 | 5.5 | 426.3566 | 4 | 310.077 |
| Average | 5.205 | 403.55 | 4.056 | 314.457 |

Table C-8 Tensile strength test on bundles of Kerosene Uncoated Katcha fiber

| Fiber Length | | | | |
|---|---|---|---|---|
| | 200 mm | | 600 mm | |
| TEST No | Force at break (N) | Tensile strength (Mpa) | Force at break (N) | Tensile strength (Mpa) |
| 1 | 224.44 | 17450.612 | 240 | 18660.43 |
| 2 | 228.2 | 17742.959 | 327.43 | 25458.27 |
| 3 | 233.85 | 18182.256 | 238.06 | 18509.59 |
| 4 | 355.45 | 27636.874 | 205.11 | 15947.67 |
| 5 | 393.21 | 30572.782 | 200.23 | 15568.24 |
| Average | 287.03 | 22317.097 | 242.166 | 18828.84 |
| Single strand | | 343.340 | | 313.814 |

Table C-9 Tensile strength test on bundles of Kerosene Coated Katcha fiber

| Fiber Length | | | | |
|---|---|---|---|---|
| | 200 mm | | 600 mm | |
| TEST No | Force at break (N) | Tensile strength (Mpa) | Force at break (N) | Tensile strength (Mpa) |
| 1 | 237.95 | 18501.039 | 187 | 18271.67 |
| 2 | 419.24 | 32596.661 | 253.04 | 19674.31 |
| 3 | 321.11 | 25036.077 | 296.26 | 23034.75 |
| 4 | 445.27 | 34620.540 | 280.21 | 21786.83 |
| 5 | 311.27 | 24201.800 | 280.85 | 21836.59 |
| Average | 346.968 | 26991.223 | 259.472 | 20920.83 |
| Single strand | | 415.250 | | 321.859 |

# Appendix- D

# Index Property of Sand Mixed soil

Table D-1Specific gravity of Soil Sample1 (Pit1) with 10%, 15% and 20% sand

| Test Method | ASTM D-854 | | | | | |
|---|---|---|---|---|---|---|
| Sand content (%) | 10%sand | | 15% sand | | 20% sand | |
| determination number | | | | | | |
| Bottle no | 3 | 5 | 12 | 17 | 13 | 19 |
| Wt. of bottle + Water+ Soil (g) | 164.59 | 166.91 | 167.53 | 167.37 | 163.51 | 164.75 |
| T | | | | | | |
| Wt. of bottle + Water (g) | 155.36 | 157.59 | 158.26 | 158 | 154.36 | 155.49 |
| Wt. of bottle + Dry soil (g) | 66.31 | 66.3 | 68.21 | 68.38 | 64.32 | 64 |
| **Wt. of bottle (g)** | 31.31 | 51.3 | 53.21 | 53.38 | 49.32 | 49.43 |
| Wt. of soil (g) | 15 | 15 | 15 | 15 | 15 | 15 |
| Specific Gravity | 2.600 | 2.641 | 2.618 | 2.664 | 2.564 | 2.613 |
| Average Specific gravity | | 2.62 | | 2.64 | | 2.59 |

Table D-2 Grain Size Analysis of soil sample 1(pit 1) with 10% sand

Wet Sieve + Hydrometer

| Sieve size (mm) | | Retained for 1st Sieving | | Percent Passing |
|---|---|---|---|---|
| | | Weight | % Rtd. | (%) |
| 3" | 75 | 0.00 | 0.00 | 100.00 |
| 21/2" | 63 | 0.00 | 0.00 | 100.00 |
| 2" | 50 | 0.00 | 0.00 | 100.00 |
| 11/2" | 37.5 | 0.00 | 0.00 | 100.00 |
| 1" | 25 | 0.00 | 0.00 | 100.00 |
| 3/4" | 19 | 0.00 | 0.00 | 100.00 |
| 1/2" | 12.5 | 11.50 | 3.83 | 96.17 |
| 3/8" | 9.5 | 0.00 | 0.00 | 96.17 |
| Nº 4 | 4.75 | 5.30 | 1.77 | 94.40 |
| Nº 10 | 2 | 7.80 | 2.60 | 91.80 |
| Nº 16 | 1.18 | 10.60 | 3.53 | 88.27 |
| Nº 30 | 0.6 | 13.20 | 4.40 | 83.87 |
| Nº 50 | 0.3 | 11.30 | 3.77 | 80.11 |
| Nº 100 | 0.15 | 5.90 | 1.97 | 78.14 |
| Nº 200 | 0.075 | 3.80 | 1.27 | 76.87 |
| Pan | | 230.70 | 76.87 | |
| Total | | 300 | 100 | |

| Elapsed Time, t,min | Actual Hydrometer Reading Ra | Temp (°C) | Effective Depth, L (mm) | K From Table | Temprature Correction Factor Ct | Modified Hydrometer Reading R= Ra - Cz+Ct | Particle DiameterD (mm) | Percentage Pass (%) | Corrected Percentage Pass (%) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 2 | 44.000 | 20 | 8.87 | 0.01375 | 0.0 | 37.959 | 0.0290 | 76.45 | 58.77 |
| 5 | 42.000 | 20 | 9.20 | 0.01375 | 0.0 | 35.959 | 0.0187 | 72.42 | 55.67 |
| 15 | 40.000 | 20 | 9.53 | 0.01375 | 0.0 | 33.959 | 0.0110 | 68.39 | 52.58 |
| 30 | 38.500 | 20 | 9.78 | 0.01375 | 0.0 | 32.459 | 0.0079 | 65.37 | 50.25 |
| 60 | 35.500 | 20 | 10.27 | 0.01375 | 0.0 | 29.459 | 0.0057 | 59.33 | 45.61 |
| 250 | 33.000 | 23 | 10.69 | 0.01326 | 0.7 | 28.324 | 0.0027 | 57.04 | 43.85 |
| 1440 | 20.500 | 20 | 12.75 | 0.01375 | 0.0 | 14.459 | 0.0013 | 29.12 | 22.39 |

Table D-3 Grain Size Analysis of soil sample 1(pit 1) with 15% sand

| Sieve size | | Retained for 1st Sieving | | Percent Passing |
|---|---|---|---|---|
| | (mm) | Weight | % Retained | (%) |
| 3" | 75 | 0.00 | 0.00 | 100.00 |
| 21/2" | 63 | 0.00 | 0.00 | 100.00 |
| 2" | 50 | 0.00 | 0.00 | 100.00 |
| 11/2" | 37.5 | 0.00 | 0.00 | 100.00 |
| 1" | 25 | 0.00 | 0.00 | 100.00 |
| 3/4" | 19 | 0.00 | 0.00 | 100.00 |
| 1/2" | 12.5 | 9.00 | 3.00 | 97.00 |
| 3/8" | 9.5 | 0.00 | 0.00 | 97.00 |
| Nº 4 | 4.75 | 9.00 | 3.00 | 94.00 |
| Nº 10 | 2 | 6.90 | 2.30 | 91.70 |
| Nº 16 | 1.18 | 11.30 | 3.77 | 87.93 |
| Nº 30 | 0.6 | 16.30 | 5.43 | 82.50 |
| Nº 50 | 0.3 | 16.40 | 5.47 | 77.03 |
| Nº 100 | 0.15 | 8.20 | 2.73 | 74.30 |
| Nº 200 | 0.075 | 3.50 | 1.17 | 73.13 |

| | | | | |
|---|---|---|---|---|
| Pan | | 219.40 | 73.13 | |
| Total | | 300 | 100 | |

| Elapsed Time, t,min | Actual Hydrometer Reading Ra | Temp (ºC) | Effective Depth, L (mm) | K From Table | Temprature Correction Factor Ct | Modified Hydrometer Reading R= Ra - Cz+Ct | Particle DiameterD (mm) | Percentage Pass (%) | Corrected Percentage Pass (%) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 2 | 43.000 | 20 | 9.04 | 0.01367 | 0.0 | 36.959 | 0.0291 | 74.09 | 54.18 |
| 5 | 42.000 | 20 | 9.20 | 0.01367 | 0.0 | 35.959 | 0.0185 | 72.08 | 52.72 |
| 15 | 40.500 | 20 | 9.45 | 0.01367 | 0.0 | 34.459 | 0.0108 | 69.08 | 50.52 |
| 30 | 38.000 | 20 | 9.86 | 0.01367 | 0.0 | 31.959 | 0.0078 | 64.07 | 46.85 |
| 60 | 36.500 | 20 | 10.11 | 0.01367 | 0.0 | 30.459 | 0.0056 | 61.06 | 44.65 |
| 250 | 34.000 | 23 | 10.52 | 0.01318 | 0.7 | 29.324 | 0.0027 | 58.78 | 42.99 |
| 1440 | 22.000 | 20 | 12.50 | 0.01367 | 0.0 | 15.959 | 0.0013 | 31.99 | 23.40 |

Table D-4 Grain Size Analysis of soil sample 1(pit 1) with 20% sand

| Sieve size | | Retained for 1st Sieving | | Percent Passing |
|---|---|---|---|---|
| | (mm) | Weight | % Rtd. | (%) |
| 3" | 75 | 0.00 | 0.00 | 100.00 |
| 21/2" | 63 | 0.00 | 0.00 | 100.00 |
| 2" | 50 | 0.00 | 0.00 | 100.00 |
| 11/2" | 37.5 | 0.00 | 0.00 | 100.00 |
| 1" | 25 | 0.00 | 0.00 | 100.00 |
| 3/4" | 19 | 0.00 | 0.00 | 100.00 |
| 1/2" | 12.5 | 8.80 | 2.93 | 97.07 |
| 3/8" | 9.5 | 5.20 | 1.73 | 95.33 |
| Nº 4 | 4.75 | 4.50 | 1.50 | 93.84 |
| Nº 10 | 2 | 6.20 | 2.07 | 91.77 |
| Nº 16 | 1.18 | 9.00 | 3.00 | 88.77 |
| Nº 30 | 0.6 | 18.00 | 6.00 | 82.77 |
| Nº 50 | 0.3 | 22.80 | 7.60 | 75.17 |
| Nº 100 | 0.15 | 13.40 | 4.47 | 70.71 |
| Nº 200 | 0.075 | 4.70 | 1.57 | 69.14 |
| Pan | | 207.50 | 69.14 | |
| Total | | 300 | 100 | |

| Elapsed Time, t,min | Actual Hydrometer Reading Ra | Temp (ºC) | Effective Depth, L (mm) | K From Table | Temprature Correction Factor Ct | Modified Hydrometer Reading R= Ra - Cz+Ct | Particle DiameterD (mm) | Percentage Pass (%) | Corrected Percentage Pass (%) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 2 | 41.000 | 20 | 9.37 | 0.01388 | 0.0 | 34.959 | 0.0300 | 70.91 | 49.03 |
| 5 | 38.000 | 20 | 9.86 | 0.01388 | 0.0 | 31.959 | 0.0195 | 64.83 | 44.82 |
| 15 | 37.000 | 20 | 10.03 | 0.01388 | 0.0 | 30.959 | 0.0113 | 62.80 | 43.42 |
| 30 | 35.000 | 20 | 10.36 | 0.01388 | 0.0 | 28.959 | 0.0082 | 58.74 | 40.62 |
| 60 | 33.000 | 20 | 10.69 | 0.01388 | 0.0 | 26.959 | 0.0059 | 54.69 | 37.81 |
| 250 | 30.000 | 23 | 11.18 | 0.01339 | 0.7 | 25.324 | 0.0028 | 51.37 | 35.52 |
| 1440 | 20.000 | 20 | 12.83 | 0.01388 | 0.0 | 13.959 | 0.0013 | 28.32 | 19.58 |

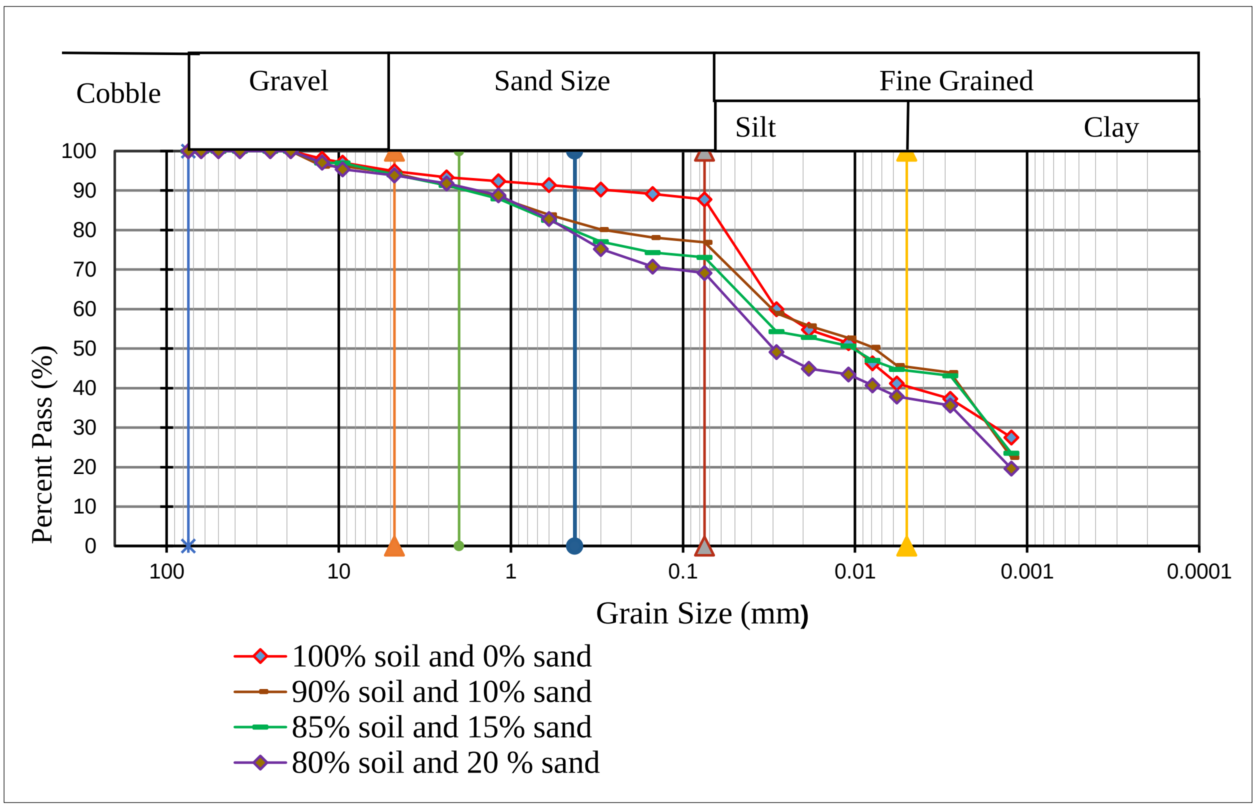


Figure D-1 Particle size distribution curve of Pit 1 soil with 10%, 15% and 20% sand

Table D-5 Liquid Limit and Plastic Limit of Pit 1 Soil with 10% sand

| Test Method | | | | | | | ASTM-D 4318 |
|---|---|---|---|---|---|---|---|
| Type of Test | | Liquid Limit Test | | | | Plastic Limit Test | |
| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 1 | Trial 2 |
| No. of Blows | N | 33 | 25 | 22 | 15 | - | - |
| Mass of moist Sample + Can | $M_1$ | 26.50 | 28.40 | 30.40 | 34.50 | 25.50 | 25.40 |
| Mass of Dried Sample + Can | $M_2$ | 22.00 | 23.00 | 24.00 | 26.00 | 22.30 | 22.20 |
| Mass of Can | $M_c$ | 14.94 | 15.09 | 14.63 | 14.88 | 14.85 | 14.58 |
| Mass of Moist | $M_m=M_1-M_2$ | 4.50 | 5.40 | 6.40 | 8.50 | 3.20 | 3.20 |
| Mass of Dried Sample | $M_d=M_2-M_c$ | 7.06 | 7.91 | 9.37 | 11.12 | 7.45 | 7.62 |
| Moisture Content (%) | $= (M_m / M_d) \times 100$ | 63.74 | 68.27 | 68.30 | 76.44 | 42.95 | 41.99 |
| | | Liquid Limit = 67.5 % | | | | Plastic Limit= 42.47% | |
| | | Plasticity Index (PI = LL - PL) = 24.53 | | | | | |

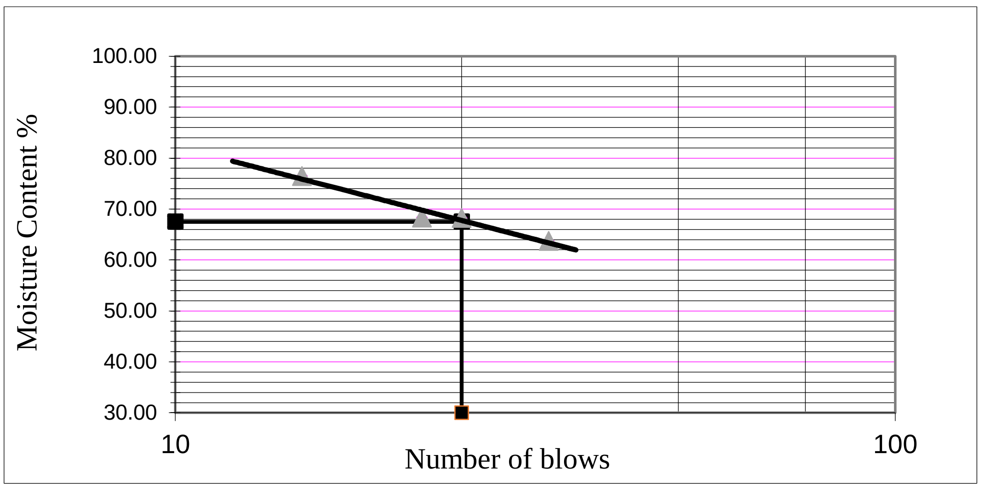


Figure D-2 Liquid limit determination of Pit 1 Soil with 10% Sand

Table D-6 Liquid Limit and Plastic Limit of pit 1Soil with 15% sand

| **Test Method** | | | | | | | **ASTM-D 4318** |
|---|---|---|---|---|---|---|---|
| Type of Test | | Liquid Limit Test | | | | Plastic Limit Test | |
| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 1 | Trial 2 |
| No. of Blows | N | 32 | 28 | 22 | 17 | - | - |
| Mass of moist Sample + Can | $M_1$ | 25.45 | 25.83 | 27.00 | 28.50 | 28.22 | 29.11 |
| Mass of Dried Sample + Can | $M_2$ | 21.50 | 21.56 | 22.30 | 23.00 | 24.28 | 25.05 |
| Mass of Can | $M_c$ | 14.87 | 14.52 | 14.88 | 15.07 | 14.85 | 14.58 |
| Mass of Moist | $M_m=M_1-M_2$ | 3.95 | 4.27 | 4.70 | 5.50 | 3.94 | 4.06 |
| Mass of Dried Sample | $M_d=M_2-M_c$ | 6.63 | 7.04 | 7.42 | 7.93 | 9.43 | 10.47 |
| Moisture Content (%) | $= (M_m / M_d) \times 100$ | 59.58 | 60.65 | 63.34 | 69.36 | 41.78 | 38.78 |
| | | Liquid Limit = 62.5 % | | | | Plastic Limit= 40.28% | |
| | | Plasticity Index (PI = LL - PL) = 22.22 | | | | | |

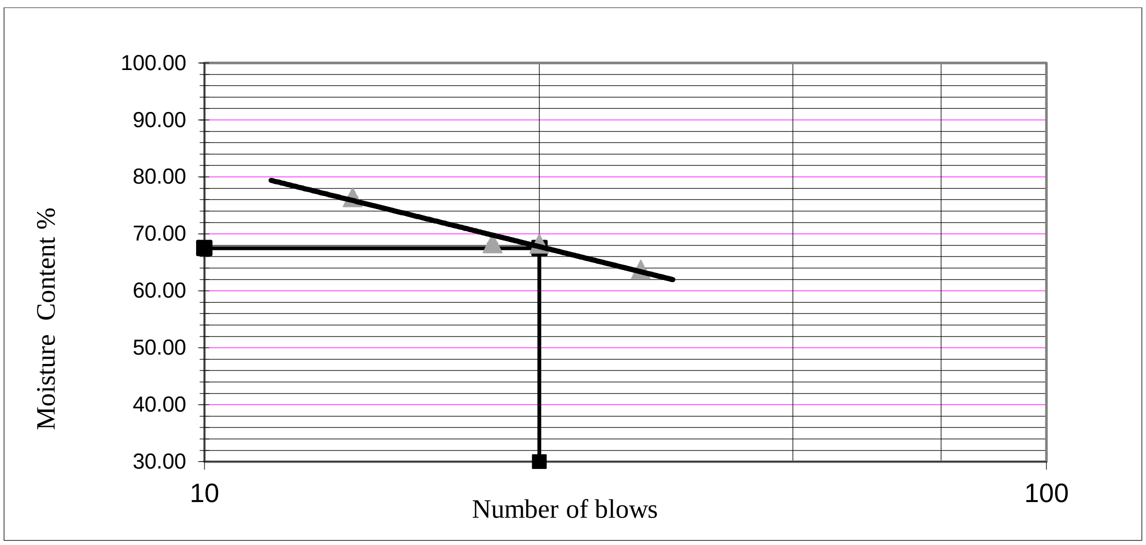


Figure D-3 Liquid Limit determination of Pit 1) Soil with 15% Sand

Table D-7 Liquid Limit and Plastic Limit pit 1 Soil with 20% sand

| **Test Method** | | | | | | **ASTM-D 4318** | |
|---|---|---|---|---|---|---|---|
| Type of Test | | Liquid Limit Test | | | | Plastic Limit Test | |
| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 1 | Trial 2 |
| No. of Blows | N | 35 | 27 | 22 | 17 | - | - |
| Mass of moist Sample + Can | $M_1$ | 26.20 | 28.30 | 27.20 | 25.40 | 29.43 | 30.64 |
| Mass of Dried Sample + Can | $M_2$ | 22.10 | 23.40 | 22.50 | 21.20 | 25.20 | 26.37 |
| Mass of Can | $M_c$ | 14.91 | 15.14 | 14.93 | 14.50 | 14.75 | 14.92 |
| Mass of Moist | $M_m=M_1-M_2$ | 4.10 | 4.90 | 4.70 | 4.20 | 4.23 | 4.27 |
| Mass of Dried Sample | $M_d=M_2-M_c$ | 7.19 | 8.26 | 7.57 | 6.70 | 10.45 | 11.45 |
| Moisture Content (%) | $= (M_m / M_d) \times 100$ | 57.02 | 59.32 | 62.09 | 62.69 | 40.48 | 37.29 |
| | | Liquid Limit = 60.00 % | | | | Plastic Limit= 38.89% | |
| | | Plasticity Index (PI = LL - PL) = 21.11 | | | | | |

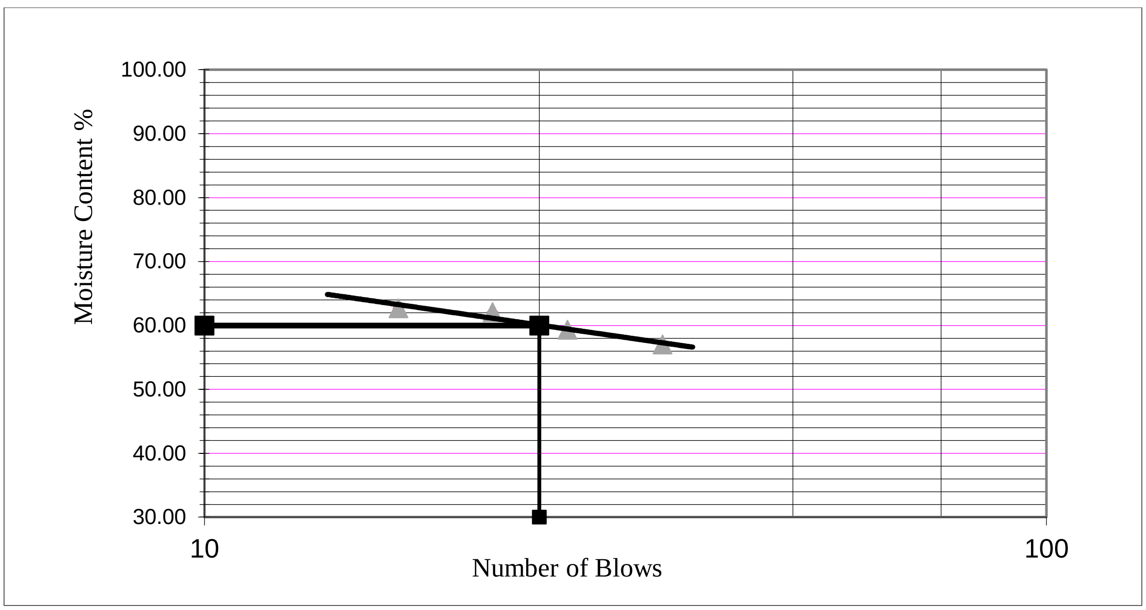


Figure D- 4 Liquid Limit determination of Pit 1 Soil with 20% Sand.

Table D-8 Volumetric Shrinkage of Pit 1 Soil with 0%, 10% 15%, and 20% sand

| Test Method | | | | | | | | | ASTM- D427 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sand Content | | | 0% | | 10% | | 15% | | 20% | |
| Mass of dish + wet soil | W1 | g | 64.33 | 64.17 | 62.24 | 61.9 | 59 | 58 | 57.02 | 55.63 |
| Mass of dish + dry soil | W3 | g | 53.85 | 53.67 | 52.93 | 51.32 | 49.1 | 49 | 47.26 | 46.33 |
| Mass of dish | Wd | g | 37.4 | 37.17 | 37.33 | 35 | 33 | 35.34 | 32.35 | 32.18 |
| Mass of water | $(W_1 - W_3)$ | g | 10.48 | 10.5 | 9.31 | 10.58 | 9.9 | 9 | 9.76 | 9.3 |
| Mass of dry soil | $(W_3\text{-}W) = W_0$ | g | 16.45 | 16.5 | 15.6 | 16.32 | 16.1 | 13.66 | 14.91 | 14.15 |
| Mass of wet soil | $(W_1\text{-}W) = W_2$ | g | 26.93 | 27 | 24.91 | 26.9 | 26 | 22.66 | 24.67 | 23.45 |
| Moisture Content $\frac{W1-W3}{Wo}$x 100 | w | % | 63.71 | 63.64 | 59.68 | 64.83 | 61.49 | 65.89 | 65.46 | 65.72 |
| Volume of dish | V | Cm3 | 19.00 | 19.50 | 13.50 | 15.60 | 15.5 | 14 | 17 | 17 |
| Volume of dry soil | V0 | Cm3 | 11.50 | 12.00 | 6.30 | 7.50 | 7.5 | 6.5 | 8.5 | 8.5 |
| Volume change (V - V0) | ΔV | ml | 7.50 | 7.50 | 7.20 | 8.10 | 8.00 | 7.5 | 8.50 | 8.50 |
| Unit Volume Change $\frac{\Delta V}{Wo} * 100$ | ΔU | % | 45.59 | 45.45 | 46.15 | 49.63 | 49.69 | 54.9 | 57.01 | 60.07 |
| Shrinkage Limit ( W- Δ U) | SL | % | 18.12 | 18.18 | 13.53 | 15.20 | 11.80 | 10.98 | 8.45 | 5.65 |
| Average Shrinkage Limit | % | | 18.15 | | 14.36 | | 11.39 | | 7.05 | |

# Appendix E

# Moisture-Density Relation of Reinforced Soil and Reinforced Sand mixed soil

Table E-1 Moisture-Density relations of Reinforced Soil with 0.5% of 20mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 4512.60 | 4634.50 | 4730.00 | 4665.00 |
| Wt.of mould (g) | 3003.70 | 3003.70 | 3003.70 | 3003.70 |
| Wt.of wet soil(g) | 1508.90 | 1630.80 | 1726.30 | 1661.30 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.598 | 1.728 | 1.829 | 1.760 |
| Moisture content | | | | |
| Wet soil + tin (g) | 82.10 | 99.60 | 86.60 | 89.20 |
| Dry soil + tin (g) | 70.50 | 82.00 | 67.60 | 66.50 |
| Wt of tin (g) | 16.40 | 16.30 | 9.30 | 10.00 |
| Wt of Water (g) | 11.60 | 17.60 | 19.00 | 22.70 |
| Wt of Dry soil (g) | 54.10 | 65.70 | 58.30 | 56.50 |
| Moisture content % | 21.44 | 26.79 | 32.59 | 40.18 |
| Dry Density gm /$cm^3$ | 1.316 | 1.363 | 1.379 | 1.255 |

MDD= 1.386 gm /$cm^3$ and OMC=31%

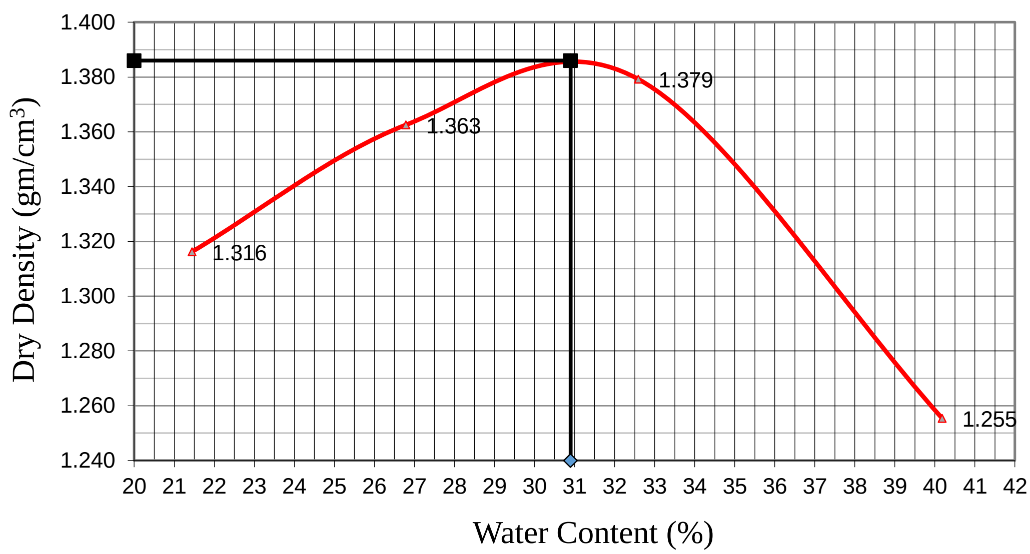


Figure E-1 Compaction Curve of Reinforced Soil with 0.5% of 20mm fiber

Table E-2 Moisture-Density relations of Reinforced Soil with 0.5% of 35mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5395.70 | 5542.70 | 5635.20 | 5584.60 |
| Wt.of mould (g) | 3924.00 | 3924.00 | 3924.00 | 3924.00 |
| Wt.of wet soil(g) | 1471.70 | 1618.70 | 1711.20 | 1660.60 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.559 | 1.715 | 1.813 | 1.759 |
| Moisture content | | | | |
| Wet soil + tin (g) | 83.30 | 84.20 | 69.90 | 104.30 |
| Dry soil + tin (g) | 71.00 | 69.40 | 55.00 | 80.20 |
| Wt of tin (g) | 17.30 | 16.70 | 10.10 | 16.60 |
| Wt of Water (g) | 12.30 | 14.80 | 14.90 | 24.10 |
| Wt of Dry soil (g) | 53.70 | 52.70 | 44.90 | 63.60 |
| Moisture content % | 22.91 | 28.08 | 33.18 | 37.89 |
| Dry Density gm /$cm^3$ | 1.268 | 1.339 | 1.361 | 1.276 |

MDD= 1.365gm /$cm^3$ and OMC=32%

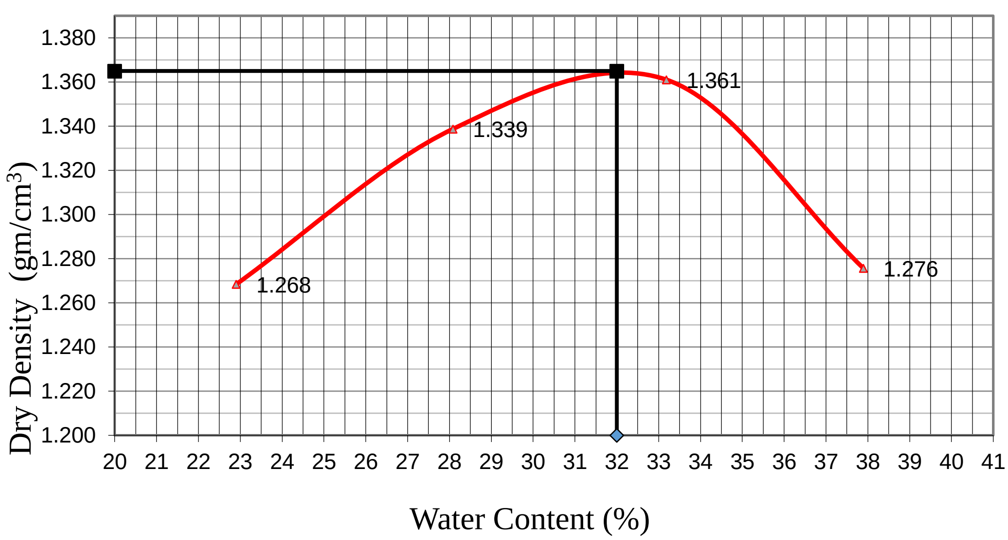


Figure E-2 Compaction Curve of Reinforced Soil with 0.5% of 35mm fiber

Table E-3 Moisture-Density relations of Reinforced Soil with 0.5% of 50mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5052.90 | 5197.80 | 5239.40 | 5168.50 |
| Wt.of mould (g) | 3535.40 | 3535.40 | 3535.40 | 3535.40 |
| Wt.of wet soil(g) | 1517.50 | 1662.40 | 1704.00 | 1633.10 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.608 | 1.761 | 1.805 | 1.730 |
| Moisture content | | | | |
| Wet soil + tin (g) | 77.50 | 110.30 | 114.90 | 101.30 |
| Dry soil + tin (g) | 65.10 | 88.20 | 90.10 | 78.80 |
| Wt of tin (g) | 17.00 | 16.60 | 17.10 | 17.00 |
| Wt of Water (g) | 12.40 | 22.10 | 24.80 | 22.50 |
| Wt of Dry soil (g) | 48.10 | 71.60 | 73.00 | 61.80 |
| Moisture content % | 25.78 | 30.87 | 33.97 | 36.41 |
| Dry Density gm /cm$^3$ | 1.278 | 1.346 | 1.347 | 1.268 |

MDD= 1.356 gm /cm$^3$ and OMC=32.56%

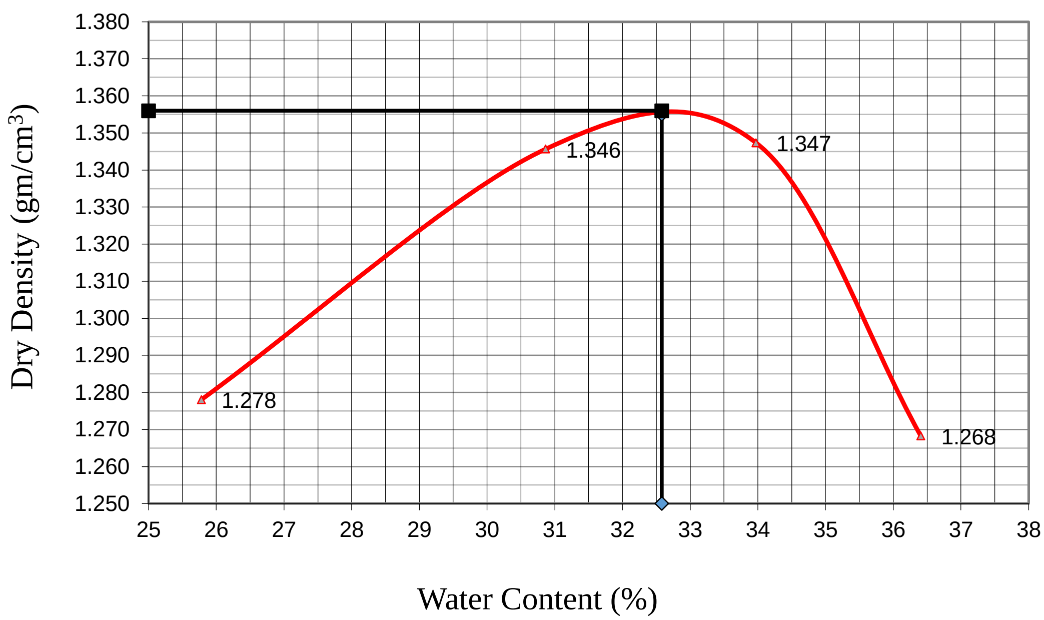


Figure E-3 Compaction Curve of Reinforced Soil with 0.5% of 50mm fiber

Table E-4 Moisture-Density relations of Reinforced Soil with 1% of 20mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5460.70 | 5520.20 | 5609.60 | 5590.00 |
| Wt.of mould (g) | 3924.00 | 3924.00 | 3924.00 | 3924.00 |
| Wt.of wet soil(g) | 1536.70 | 1596.20 | 1685.60 | 1666.00 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.628 | 1.691 | 1.786 | 1.765 |
| Moisture content | | | | |
| Wet soil + tin (g) | 98.70 | 101.30 | 82.90 | 88.80 |
| Dry soil + tin (g) | 79.50 | 80.50 | 65.30 | 69.70 |
| Wt of tin (g) | 9.80 | 10.00 | 11.60 | 17.30 |
| Wt of Water (g) | 19.20 | 20.80 | 17.60 | 19.10 |
| Wt of Dry soil (g) | 69.70 | 70.50 | 53.70 | 52.40 |
| Moisture content % | 27.55 | 29.50 | 32.77 | 36.45 |
| Dry Density gm /$cm^3$ | 1.276 | 1.306 | 1.345 | 1.293 |

MDD= 1.345gm /$cm^3$ and OMC=32.56%

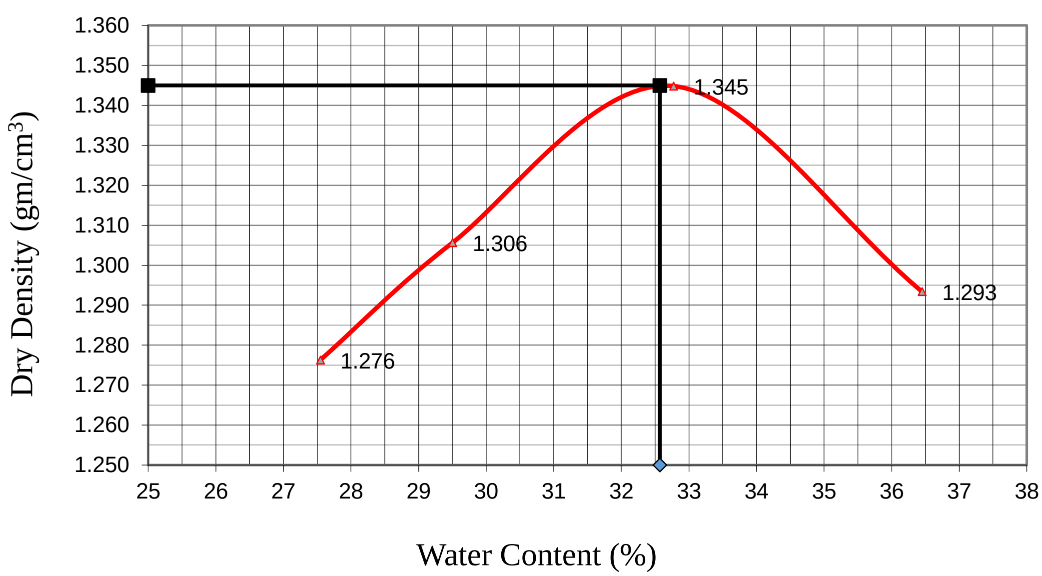


Figure E-4 Compaction Curve of Reinforced Soil with 1% of 20mm fiber

Table E-5 Moisture-Density relations of Reinforced Soil with 1% of 35mm fiber

| Test Method ASTM- D 1557 | | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5268.90 | 5376.30 | 5397.20 | 5353.70 |
| Wt.of mould (g) | 3710.30 | 3710.30 | 3710.30 | 3710.30 |
| Wt.of wet soil(g) | 1558.60 | 1666.00 | 1686.90 | 1643.40 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.651 | 1.765 | 1.787 | 1.741 |
| Moisture content | | | | |
| Wet soil + tin (g) | 93.70 | 95.90 | 96.90 | 73.00 |
| Dry soil + tin (g) | 74.80 | 76.60 | 75.60 | 55.30 |
| Wt of tin (g) | 10.00 | 17.30 | 16.60 | 10.00 |
| Wt of Water (g) | 18.90 | 19.30 | 21.30 | 17.70 |
| Wt of Dry soil (g) | 64.80 | 59.30 | 59.00 | 45.30 |
| Moisture content % | 29.17 | 32.55 | 36.10 | 39.07 |
| Dry Density gm /$cm^3$ | 1.278 | 1.331 | 1.313 | 1.252 |

MDD= 1.33gm /$cm^3$ and OMC=33.33%

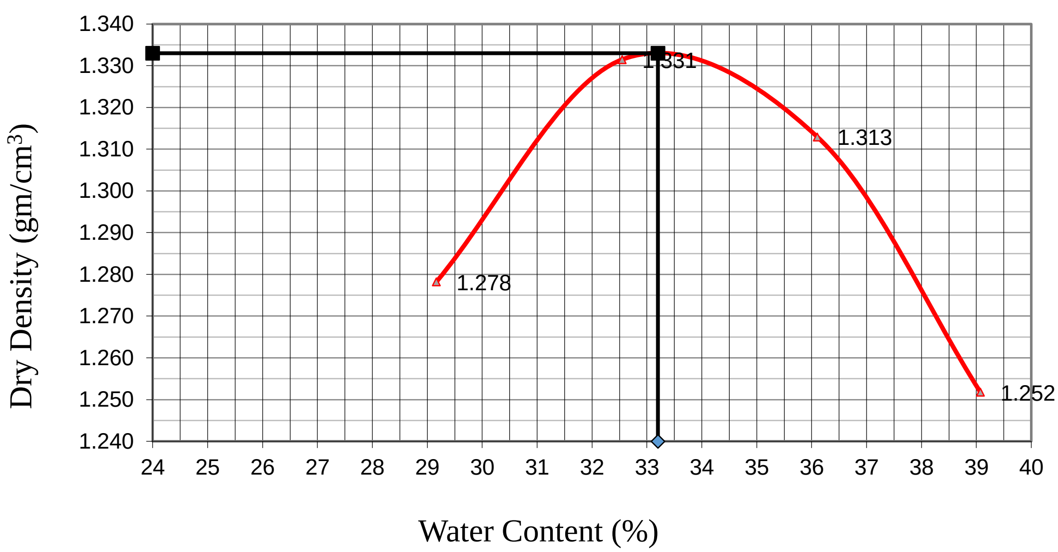


Figure E-5 Compaction Curve of Reinforced Soil with 1% of 35mm fiber

Table E-6 Moisture-Density relations of Reinforced Soil with 1% of 50mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 4481.20 | 4548.00 | 4647.00 | 4618.00 |
| Wt.of mould (g) | 3003.70 | 3003.70 | 3003.70 | 3003.70 |
| Wt.of wet soil(g) | 1477.50 | 1544.30 | 1643.30 | 1614.30 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.565 | 1.636 | 1.741 | 1.710 |
| Moisture content | | | | |
| Wet soil + tin (g) | 99.00 | 106.70 | 94.60 | 100.80 |
| Dry soil + tin (g) | 82.30 | 85.10 | 74.80 | 78.20 |
| Wt of tin (g) | 17.60 | 9.80 | 16.20 | 16.70 |
| Wt of Water (g) | 16.70 | 21.60 | 19.80 | 22.60 |
| Wt of Dry soil (g) | 64.70 | 75.30 | 58.60 | 61.50 |
| Moisture content % | 25.81 | 28.69 | 33.79 | 36.75 |
| Dry Density gm /cm$^3$ | 1.244 | 1.271 | 1.301 | 1.251 |

MDD= 1.302gm /cm$^3$ and OMC=33.35%

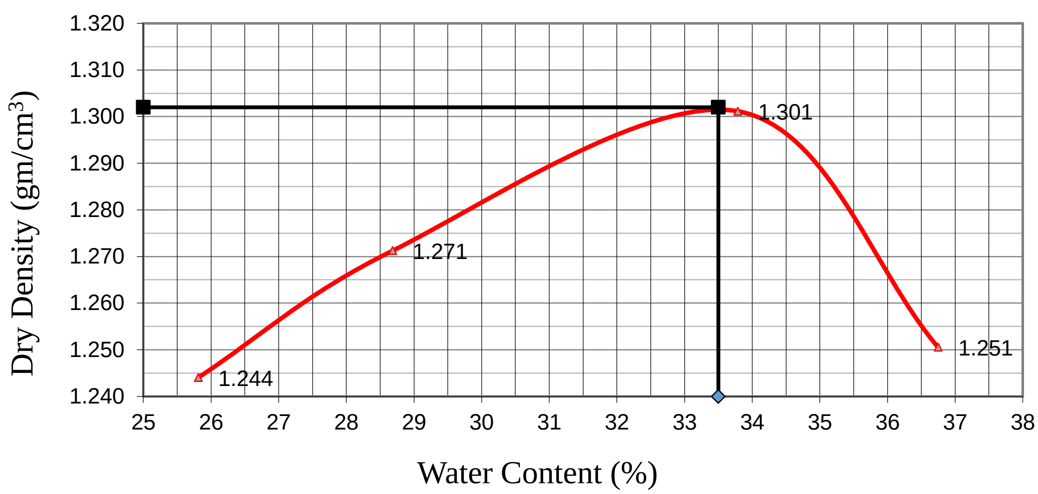


Figure E-6 Compaction Curve of Reinforced Soil with 1% of 50mm fiber

Table E-7 Moisture-Density relations of Reinforced Soil with 1.5% of 20mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5399.00 | 5483.30 | 5560.00 | 5495.00 |
| Wt.of mould (g) | 3928.80 | 3928.80 | 3928.80 | 3928.80 |
| Wt.of wet soil(g) | 1470.20 | 1554.50 | 1631.20 | 1566.20 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.557 | 1.647 | 1.728 | 1.659 |
| Moisture content | | | | |
| Wet soil + tin (g) | 81.30 | 86.50 | 108.80 | 101.10 |
| Dry soil + tin (g) | 67.80 | 70.10 | 84.60 | 75.90 |
| Wt of tin (g) | 17.70 | 16.30 | 16.10 | 16.30 |
| Wt of Water (g) | 13.50 | 16.40 | 24.20 | 25.20 |
| Wt of Dry soil (g) | 50.10 | 53.80 | 68.50 | 59.60 |
| Moisture content % | 26.95 | 30.48 | 35.33 | 42.28 |
| Dry Density gm /$cm^3$ | 1.227 | 1.262 | 1.277 | 1.166 |

MDD= 1.283gm /$cm^3$ and OMC=34%

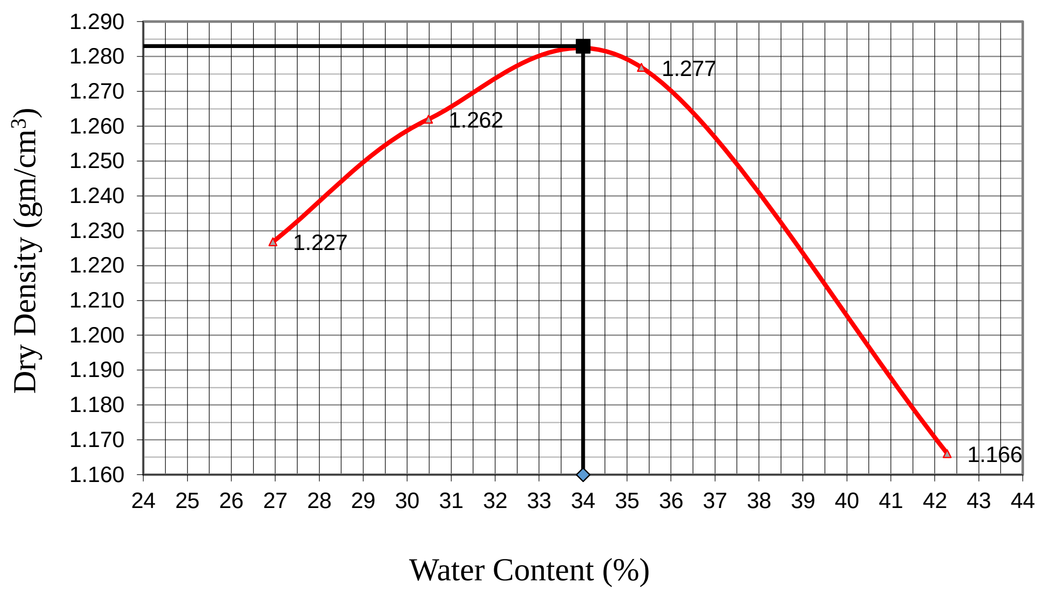


Figure E-7 Compaction Curve of Reinforced Soil with 1.5% of 20mm fiber

Table E-8 Moisture-Density relations of Reinforced Soil with 1.5% of 35mm fiber

| Test Method | ASTM- D 1557 | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 |
| Water in cc | - | - | - |
| Wt.of mould + Wet sample(g) | 5411.70 | 5543.40 | 5492.00 |
| Wt.of mould (g) | 3921.00 | 3921.00 | 3921.00 |
| Wt.of wet soil(g) | 1490.70 | 1622.40 | 1571.00 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.579 | 1.719 | 1.664 |
| Moisture content | | | |
| Wet soil + tin (g) | 101.70 | 96.00 | 115.30 |
| Dry soil + tin (g) | 80.90 | 75.10 | 86.30 |
| Wt of tin (g) | 16.70 | 17.00 | 17.20 |
| Wt of Water (g) | 20.80 | 20.90 | 29.00 |
| Wt of Dry soil (g) | 64.20 | 58.10 | 69.10 |
| Moisture content % | 32.40 | 35.97 | 41.97 |
| Dry Density gm /cm$^3$ | 1.193 | 1.264 | 1.172 |

MDD= 1.264gm /cm$^3$ and OMC=35.7%

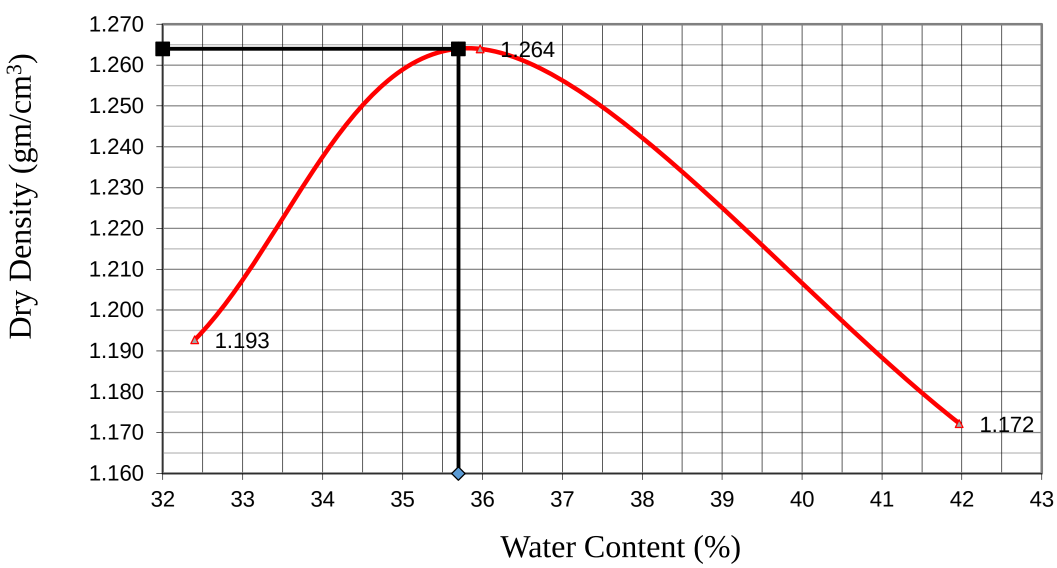


Figure E-8 Compaction Curve of Reinforced Soil with 1.5% of 35mm fiber

Table E-9 Moisture-Density relations of Reinforced Soil with 1.5% of 50mm fiber

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5426.00 | 5548.00 | 5536.00 | 5498.00 |
| Wt.of mould (g) | 3921.00 | 3921.00 | 3921.00 | 3921.00 |
| Wt.of wet soil(g) | 1505.00 | 1627.00 | 1615.00 | 1577.00 |
| Volume of mould cm3 | 944.00 | 944.00 | 944.00 | 944.00 |
| Wet Density gm /cm3 | 1.594 | 1.724 | 1.711 | 1.671 |
| Moisture content | | | | |
| Wet soil + tin (g) | 94.20 | 102.40 | 104.10 | 107.00 |
| Dry soil + tin (g) | 72.90 | 79.10 | 79.30 | 80.00 |
| Wt of tin (g) | 9.70 | 16.40 | 16.60 | 16.00 |
| Wt of Water (g) | 21.30 | 23.30 | 24.80 | 27.00 |
| Wt of Dry soil (g) | 63.20 | 62.70 | 62.70 | 64.00 |
| Moisture content % | 33.70 | 37.16 | 39.55 | 42.19 |
| Dry Density gm /cm$^3$ | 1.192 | 1.257 | 1.226 | 1.175 |

DD= 1.255gm /cm$^3$ and OMC=37.48%

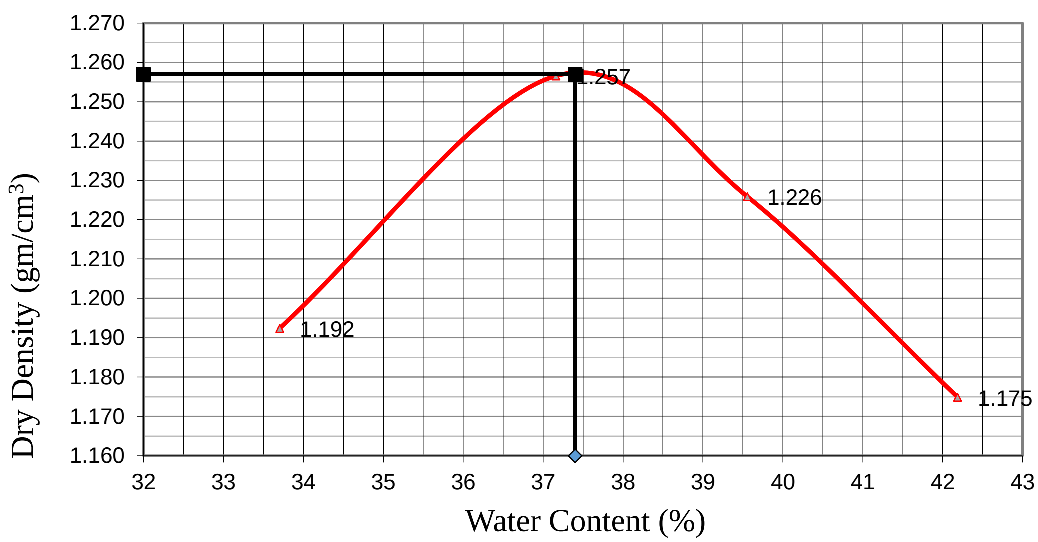


Figure E-9 Compaction Curve of Reinforced Soil with 1.5% of 50mm fiber

Table E-10 Moisture-Density relations of Stabilized Soil with 1% of 35mm +10% Sand

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| Lab.test No. | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 4525.8 | 4717.4 | 4641.6 | 4616.00 |
| Wt.of mould (g) | 3001.8 | 3001.8 | 3001.8 | 3001.8 |
| Wt.of wet soil(g) | 1524.0 | 1715.6 | 1639.8 | 1614.2 |
| Volume of mould cm3 | 944 | 944 | 944 | 944 |
| Wet Density gm /cm3 | 1.61 | 1.82 | 1.74 | 1.71 |
| **Moisture content** | | | | |
| Wet soil + tin (g) | 101.10 | 100.20 | 108.70 | 109.40 |
| Dry soil + tin (g) | 86.00 | 81.50 | 86.10 | 86.10 |
| Wt of tin (g) | 16.3 | 16.3 | 16.6 | 16.6 |
| Wt of Water (g) | 15.10 | 18.70 | 22.60 | 23.30 |
| Wt of Dry soil (g) | 69.7 | 65.2 | 69.5 | 69.5 |
| Moisture content % | 21.66 | 28.68 | 32.52 | 33.53 |
| Dry Density gm /cm$^3$ | 1.240 | 1.412 | 1.311 | 1.281 |

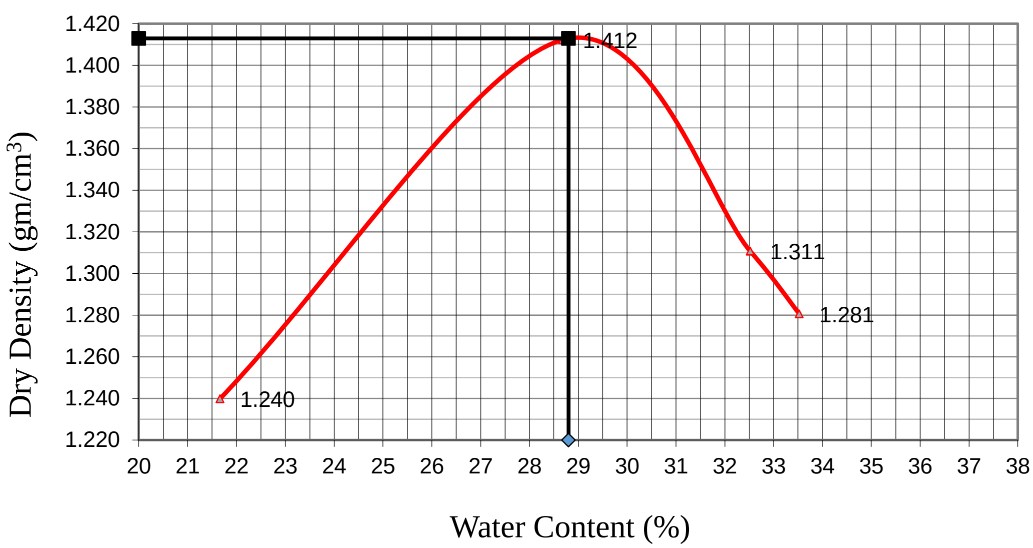


Figure E-10 Compaction Curve of Reinforced Soil with 1% of 35mm+10% Sand

Table E-11 Moisture-Density relations of Stabilized Soil with 1% of 35mm +15% Sand

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| Lab.test No. | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 5467 | 5622 | 5608 | 5596 |
| Wt.of mould (g) | 3929.1 | 3929.1 | 3929.1 | 3929.1 |
| Wt.of wet soil(g) | 1537.9 | 1692.9 | 1678.90 | 1666.9 |
| Volume of mould cm3 | 944 | 944 | 944 | 944 |
| Wet Density gm /cm3 | 1.63 | 1.79 | 1.778 | 1.766 |
| **Moisture content** | | | | |
| Wet soil + tin (g) | 113.60 | 130.30 | 131.1 | 131 |
| Dry soil + tin (g) | 96.50 | 107.00 | 104.5 | 103.7 |
| Wt of tin (g) | 16.6 | 16.9 | 16 | 16 |
| Wt of Water (g) | 17.10 | 23.30 | 26.60 | 27.3 |
| Wt of Dry soil (g) | 79.9 | 90.1 | 88.5 | 87.7 |
| Moisture content % | 21.4 | 25.86 | 30.06 | 31.13 |
| Dry Density gm /cm$^3$ | 1.342 | 1.425 | 1.367 | 1.347 |

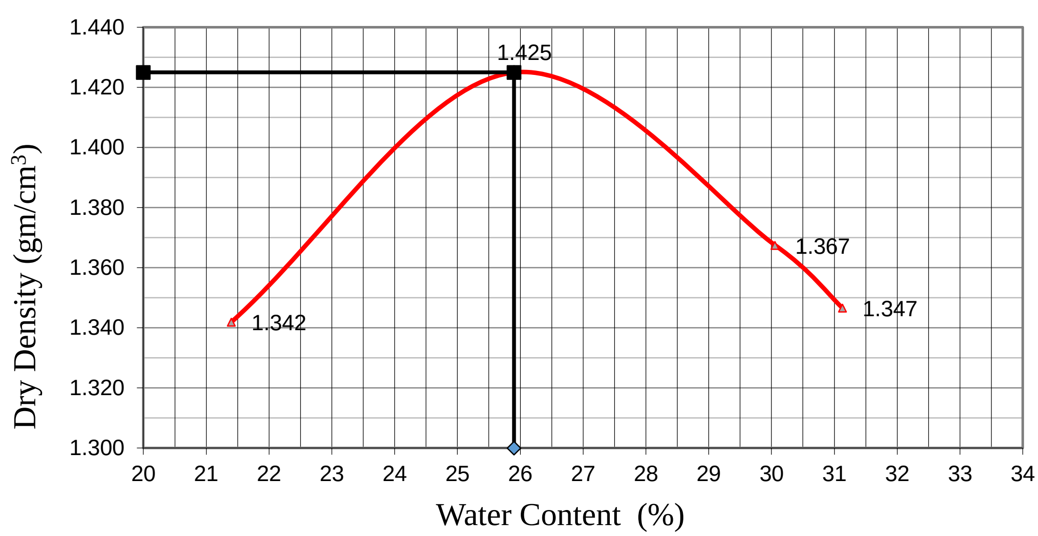


Figure E-11 Compaction Curve of Reinforced Soil with 1% of 35mm+15% Sand

Table E-12 Moisture-Density relations of Stabilized Soil with 1% of 35mm +20% Sand

| Test Method | ASTM- D 1557 | | | |
|---|---|---|---|---|
| Lab.test No. | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
| Water in cc | - | - | - | - |
| Wt.of mould + Wet sample(g) | 4490.4 | 4676.9 | 4709.3 | 4681.8 |
| Wt.of mould (g) | 3001.8 | 3001.8 | 3001.8 | 3001.8 |
| Wt.of wet soil(g) | 1488.6 | 1675.1 | 1707.5 | 1680.0 |
| Volume of mould cm3 | 944 | 944 | 944 | 944 |
| Wet Density gm /cm3 | 1.58 | 1.77 | 1.81 | 1.78 |
| **Moisture content** | | | | |
| Wet soil + tin (g) | 146.90 | 153.60 | 118.60 | 145.10 |
| Dry soil + tin (g) | 130.10 | 130.90 | 95.60 | 110.50 |
| Wt of tin (g) | 32.7 | 33.1 | 16.8 | 10.4 |
| Wt of Water (g) | 16.80 | 22.70 | 23.00 | 34.60 |
| Wt of Dry soil (g) | 97.4 | 97.8 | 78.8 | 100.1 |
| Moisture content % | 17.25 | 23.21 | 29.19 | 34.57 |
| Dry Density gm /$cm^3$ | 1.3449 | 1.4402 | 1.4001 | 1.3225 |

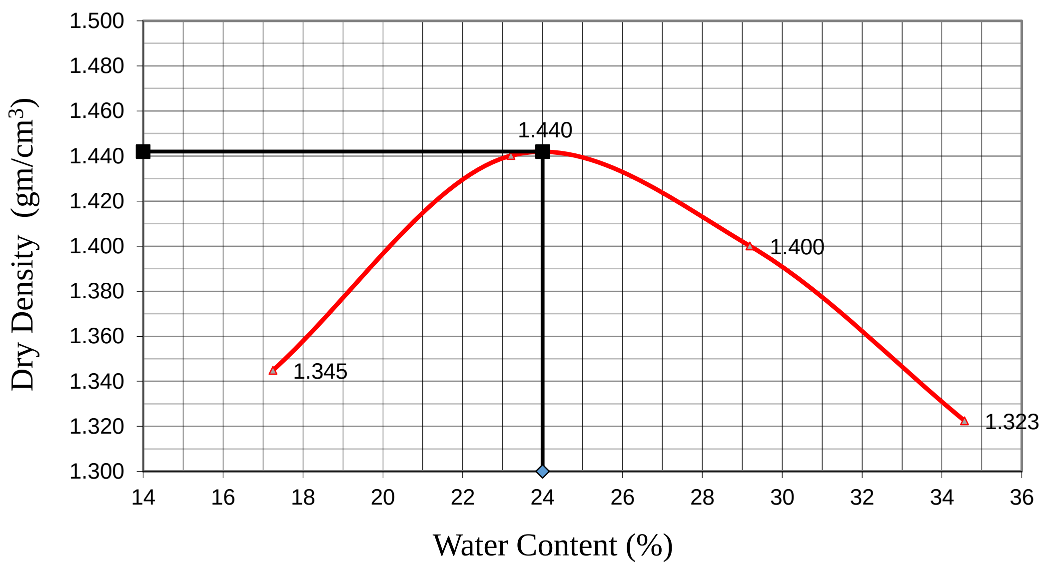


Figure E-12 Compaction Curve of Reinforced Soil with 1% of 35mm+20% Sand

# Appendix-F

# California Bearing Ratio (CBR) Test Results

Table F-1 CBR Test Data

| | |
|---|---|
| Plunger Area | 1935 $mm^2$ |
| Rammer Weight | 4.54 kg |
| Blows/ Layer | 56/5 |
| Diameter of mould | 152.4 mm |
| Volume of mold | 2124 cm |
| Ring Calibration Factor | 46.367 N/division |

All the CBR tests were conducted based on the above data provided and compacted at OMC and MDD of each soil sample.

Table F-2 CBR and Swell of Reinforced Soil with 0.5% of 20mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | | | |
| 0.64 | 4 | " | 0.19 | Gauge reading | Initial | Final |
| 1.27 | 6 | " | 0.28 | | 1223.000 | 2082.000 |
| 1.91 | 7.5 | " | 0.35 | Swell (%) | 6.76 | |
| 2.54 | 8.5 | " | 0.39 | | | |
| 3.81 | 10 | " | 0.46 | | | |
| 5.08 | 11 | " | 0.51 | | | |
| 7.62 | 12 | " | 0.56 | | | |
| | | | 0.00 | | | |

| Penetration in mm | Load ,kN | Standard Load, KN | CBR, % | % Swell |
|---|---|---|---|---|
| 2.54 | 0.39 | 13.2 | 2.99 | 6.76 |
| 5.08 | 0.51 | 20.0 | 2.55 | |

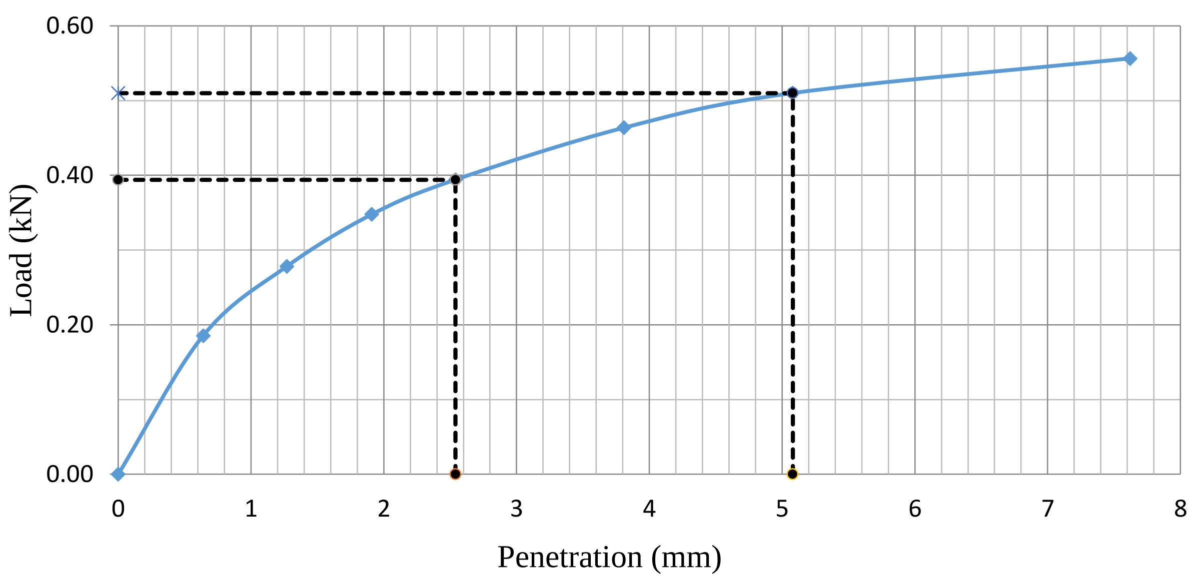


Figure F-1 Load versus Penetration curve of Reinforced soil with 0.5% of 20mm fiber

Table F-3 CBR and Swell of Reinforced Soil with 0.5% of 35mm fiber

| Test Method | ASTM-D1883 | | | | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 4 | " | 0.19 | | Initial | Final |
| 1.27 | 6.5 | " | 0.30 | | 1770.000 | 2569.000 |
| 1.91 | 8 | " | 0.37 | Swell (%) | 6.29 | |
| 2.54 | 9.0 | " | 0.42 | | | |
| 3.81 | 10 | " | 0.46 | | | |
| 5.08 | 11 | " | 0.51 | | | |
| 7.62 | 12 | " | 0.56 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load ,kN | Standard Load, kN | CBR, % | % Swell |
| 2.54 | 0.42 | 13.2 | 3.16 | 6.29 |
| 5.08 | 0.51 | 20.0 | 2.55 | |

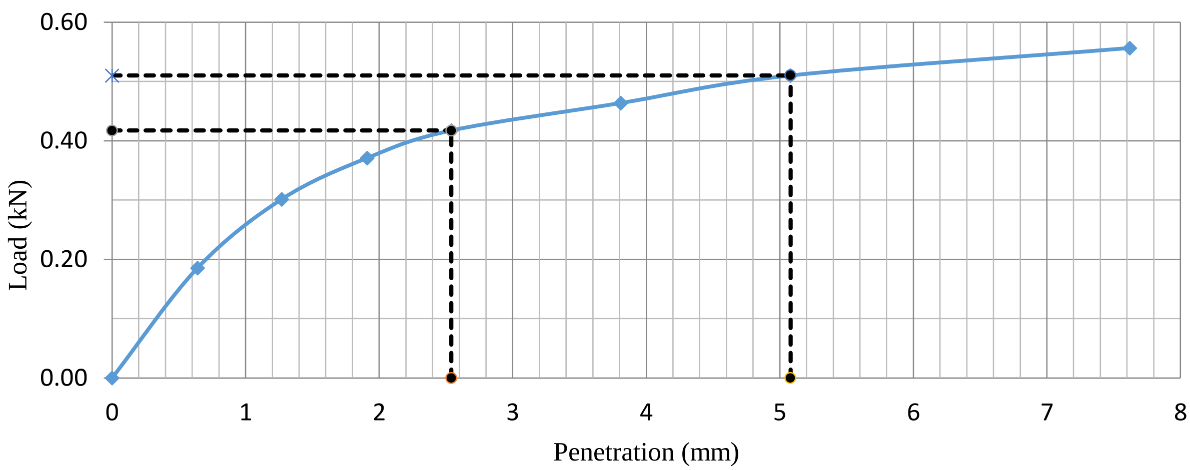


Figure F-2 Load versus Penetration curve of Reinforced soil with 0.5% of 35mm fiber

Table F-4 CBR and Swell of Reinforced Soil with 0.5% of 50mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 3.5 | " | 0.16 | | Initial | Final |
| 1.27 | 5.5 | " | 0.26 | | 960.000 | 1736.000 |
| 1.91 | 7 | " | 0.32 | Swell (%) | 6.11 | |
| 2.54 | 8.5 | " | 0.39 | | | |
| 3.81 | 9.5 | " | 0.44 | | | |
| 5.08 | 10.5 | " | 0.49 | | | |
| 7.62 | 11 | " | 0.51 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load ,kN | Standard Load, kN | CBR, % | % Swell |
| 2.54 | 0.39 | 13.2 | 2.99 | 6.11 |
| 5.08 | 0.49 | 20.0 | 2.43 | |

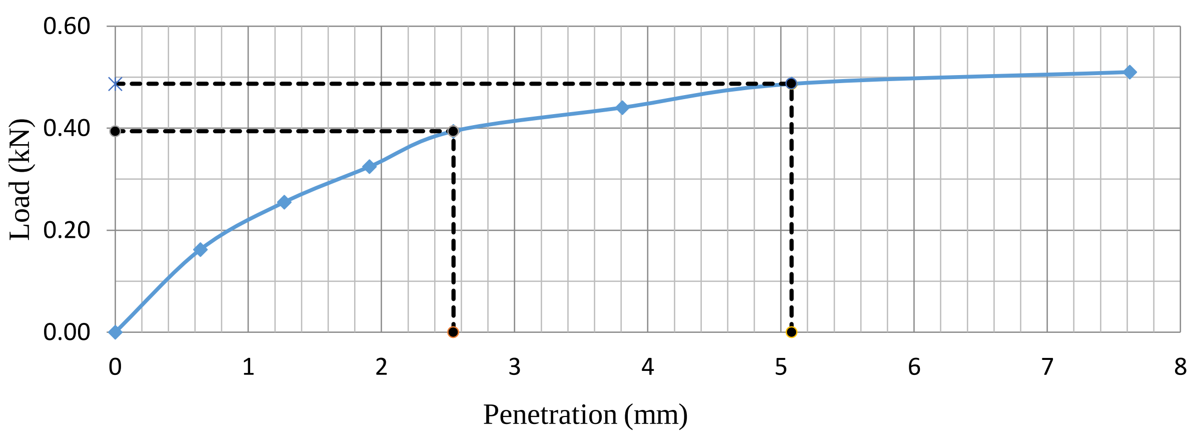


Figure F-3 Load versus Penetration curve of Reinforced soil with 0.5% of 50mm fiber

Table F-5 CBR and Swell of Reinforced Soil with 1% of 20mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | | | |
| 0.64 | 5.5 | " | 0.26 | Gauge reading | Initial | Final |
| 1.27 | 8.5 | " | 0.39 | | 651.000 | 1324.000 |
| 1.91 | 11 | " | 0.51 | Swell (%) | 5.30 | |
| 2.54 | 12.5 | " | 0.58 | | | |
| 3.81 | 13.5 | " | 0.63 | | | |
| 5.08 | 14.5 | " | 0.67 | | | |
| 7.62 | 15 | " | 0.70 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (KN) | Standard Load (Kn) | CBR (%) | % Swell |
| 2.54 | 0.58 | 13.2 | 4.39 | 5.30 |
| 5.08 | 0.67 | 20.0 | 3.36 | |

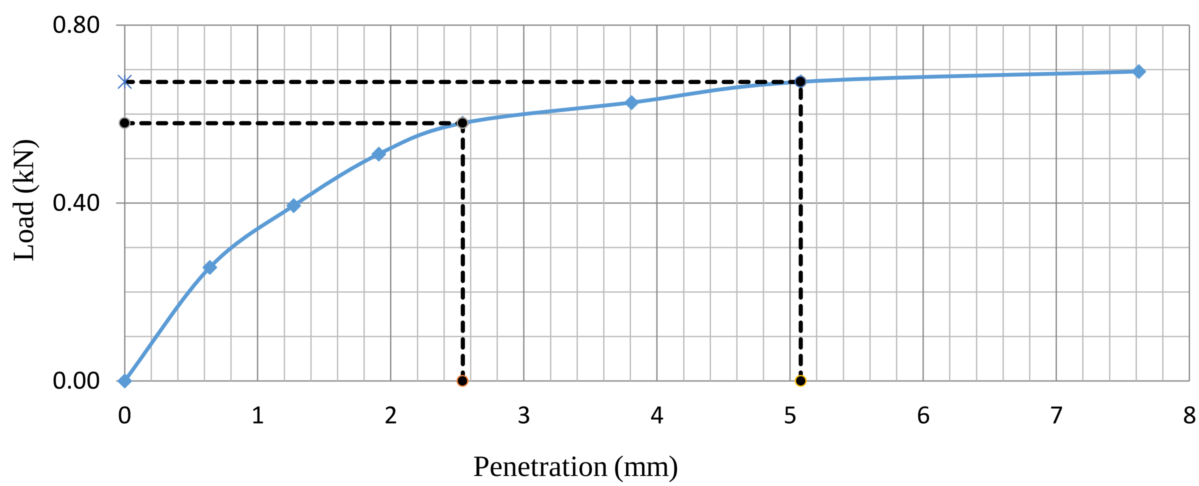


Figure F-4 Load versus Penetration curve of Reinforced soil with 1% of 20mm fiber

Table F-6 CBR and Swell of Reinforced Soil with 1% of 35 mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration (mm) | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 6 | " | 0.28 | | Initial | Final |
| 1.27 | 10 | " | 0.46 | | 514.000 | 1156.000 |
| 1.91 | 13 | " | 0.60 | Swell(%) | 5.06 | |
| 2.54 | 14.5 | " | 0.67 | | | |
| 3.81 | 15.5 | " | 0.72 | | | |
| 5.08 | 16.5 | " | 0.77 | | | |
| 7.62 | 17 | " | 0.79 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR (%) | % Swell |
| 2.54 | 0.67 | 13.2 | 5.09 | 5.06 |
| 5.08 | 0.77 | 20.0 | 3.83 | |

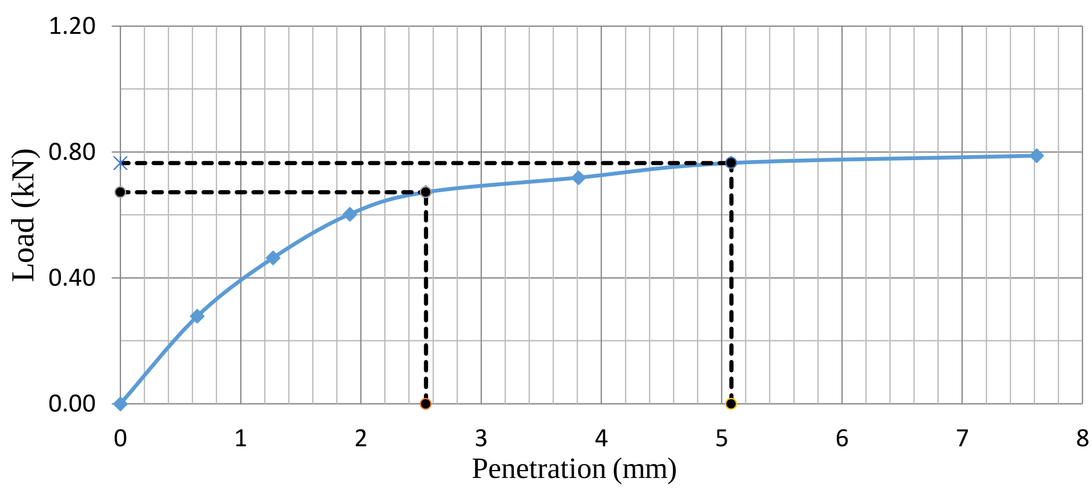


Figure F-5 Load versus Penetration curve of Reinforced soil with 1% of 35 mm fiber

Table F-7 CBR and Swell of Reinforced Soil with 1% of 50 mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 4 | " | 0.19 | | Initial | Final |
| 1.27 | 7 | " | 0.32 | | 1449.000 | 2171.000 |
| 1.91 | 9 | " | 0.42 | Swell(%) | 5.69 | |
| 2.54 | 10.5 | " | 0.49 | | | |
| 3.81 | 12 | " | 0.56 | | | |
| 5.08 | 13.5 | " | 0.63 | | | |
| 7.62 | 14 | " | 0.65 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR, % | % Swell |
| 2.54 | 0.49 | 13.2 | 3.69 | 5.69 |
| 5.08 | 0.63 | 20.0 | 3.13 | |

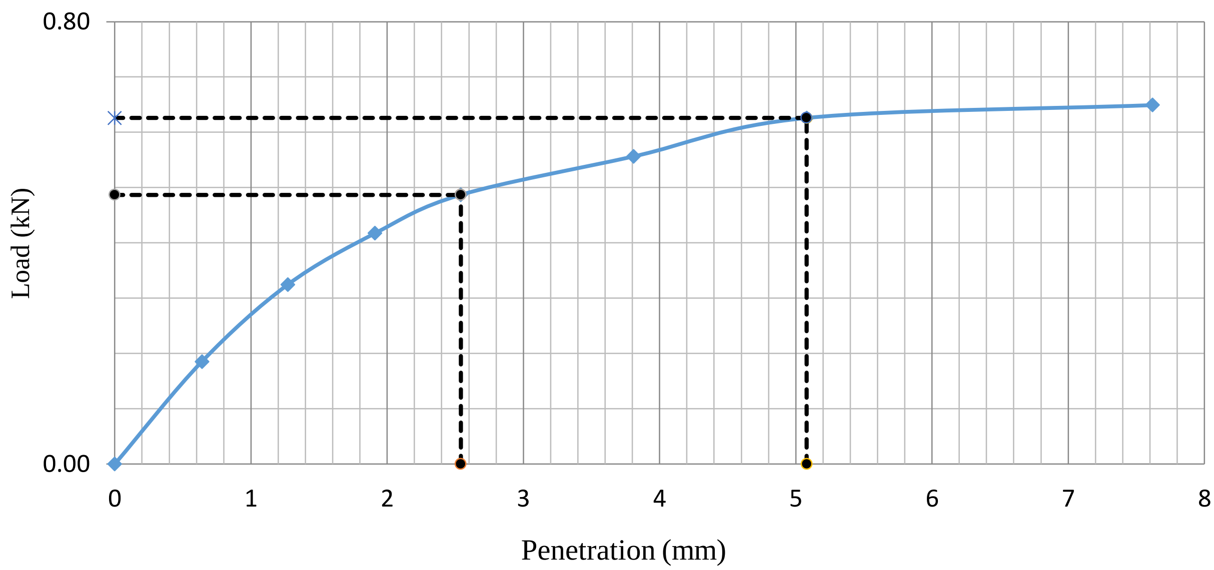


Figure F-6 Load versus Penetration curve of Reinforced soil with 1% of 50 mm fiber

Table F-8 CBR and Swell of Reinforced Soil with 1.5% of 20 mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 4.5 | " | 0.21 | | Initial | Final |
| 1.27 | 7 | " | 0.32 | | 1536.000 | 2275.000 |
| 1.91 | 8.5 | " | 0.39 | Swell(%) | 5.82 | |
| 2.54 | 9.5 | " | 0.44 | | | |
| 3.81 | 10.5 | " | 0.49 | | | |
| 5.08 | 11.5 | " | 0.53 | | | |
| 7.62 | 12 | " | 0.56 | | | |
| | | | 0.00 | | | |

| Penetration (mm) | Load ,kN | Standard Load, kN | CBR, % | % Swell |
|---|---|---|---|---|
| 2.54 | 0.44 | 13.2 | 3.34 | 5.82 |
| 5.08 | 0.53 | 20.0 | 2.67 | |

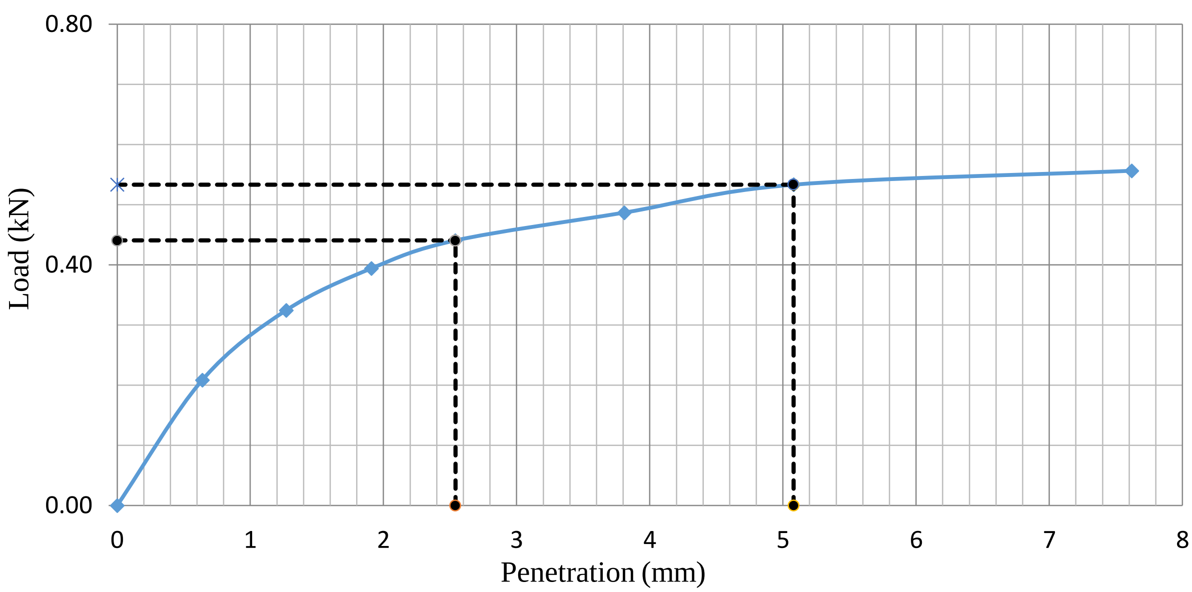


Figure F-7 Load versus Penetration curve of Reinforced soil with 1.5% of 20 mm fiber

Table F-9 CBR and Swell of Reinforced Soil with 1.5% of 35 mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | | | |
| 0.64 | 4 | " | 0.19 | Gauge reading | Initial | Final |
| 1.27 | 6 | " | 0.28 | | 1467.000 | 2238.000 |
| 1.91 | 7.5 | " | 0.35 | Swell(%) | 6.07 | |
| 2.54 | 8.5 | " | 0.39 | | | |
| 3.81 | 9.5 | " | 0.44 | | | |
| 5.08 | 10.5 | " | 0.49 | | | |
| 7.62 | 11 | " | 0.51 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR (%) | % Swell |
| 2.54 | 0.39 | 13.2 | 2.99 | 6.07 |
| 5.08 | 0.49 | 20.0 | 2.43 | |

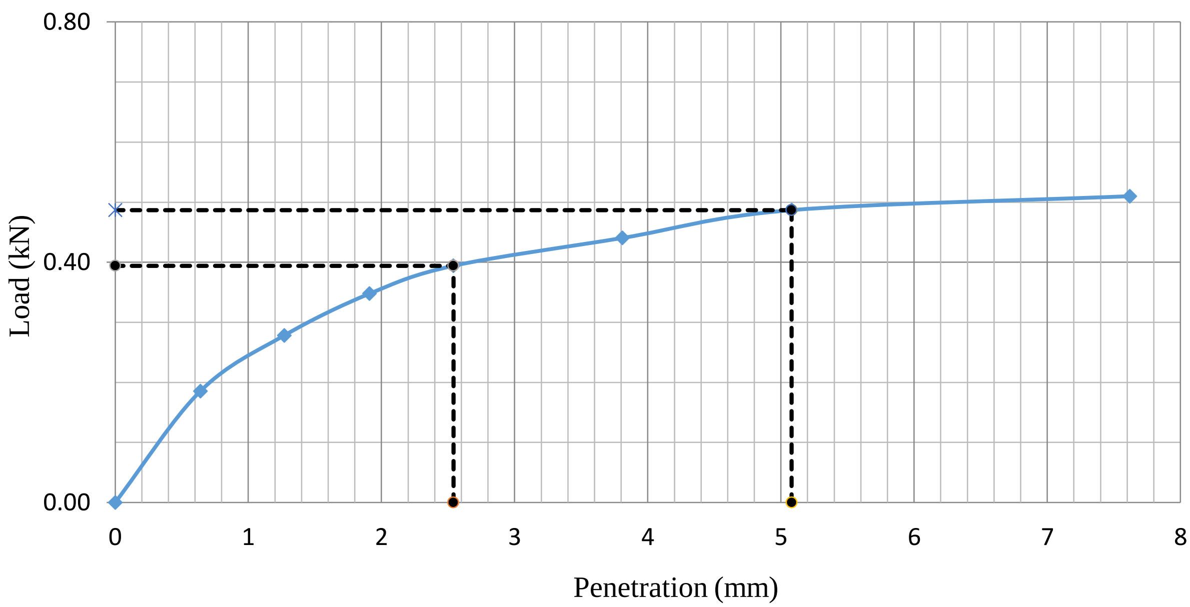


Figure F-8 Load versus Penetration curve of Reinforced soil with 1.5% of 35 mm fiber

Table F-10 CBR and Swell of Reinforced Soil with 1.5% of 50 mm fiber

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.361 | 0.00 | Gauge reading | | |
| 0.64 | 3 | " | 0.14 | | Initial | Final |
| 1.27 | 5 | " | 0.23 | | 1093.000 | 1891.000 |
| 1.91 | 6.5 | " | 0.30 | Swell(%) | 6.28 | |
| 2.54 | 7.5 | " | 0.35 | | | |
| 3.81 | 8.5 | " | 0.39 | | | |
| 5.08 | 9.5 | " | 0.44 | | | |
| 7.62 | 11 | " | 0.51 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR ( %) | % Swell |
| 2.54 | 0.35 | 13.2 | 2.63 | 6.28 |
| 5.08 | 0.44 | 20.0 | 2.20 | |

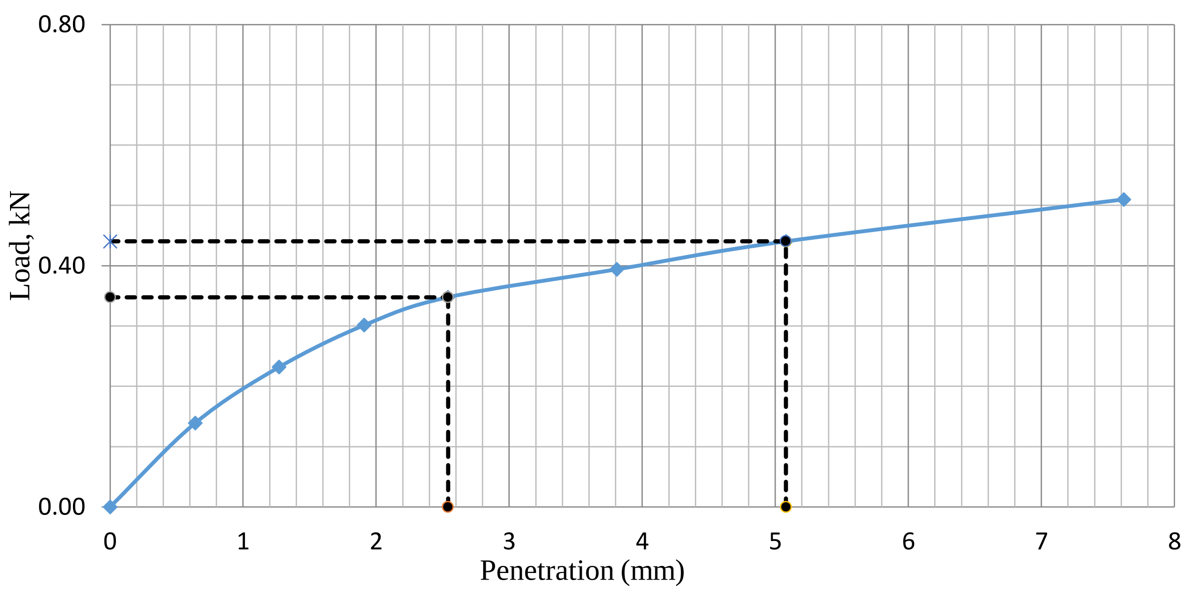


Figure F-9 Load versus Penetration curve of Reinforced soil with 1.5% of 50 mm fiber

Table F-11 CBR and Swell of Stabilized Soil with 1% of 35 mm fiber+ 10% sand

| Test Method | | | | | ASTM-D1883 | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 6 | " | 0.28 | | Initial | Final |
| 1.27 | 9.5 | " | 0.44 | | 1195.0 | 1843.0 |
| 1.91 | 13 | " | 0.60 | Swell(%) | 5.10 | |
| 2.54 | 15.0 | " | 0.70 | | | |
| 3.81 | 16.5 | " | 0.77 | | | |
| 5.08 | 18 | " | 0.83 | | | |
| 7.62 | 19 | " | 0.88 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (KN) | Standard Load (KN) | CBR (%) | % Swell |
| 2.54 | 0.70 | 13.2 | 5.27 | 5.10 |
| 5.08 | 0.83 | 20.0 | 4.17 | |

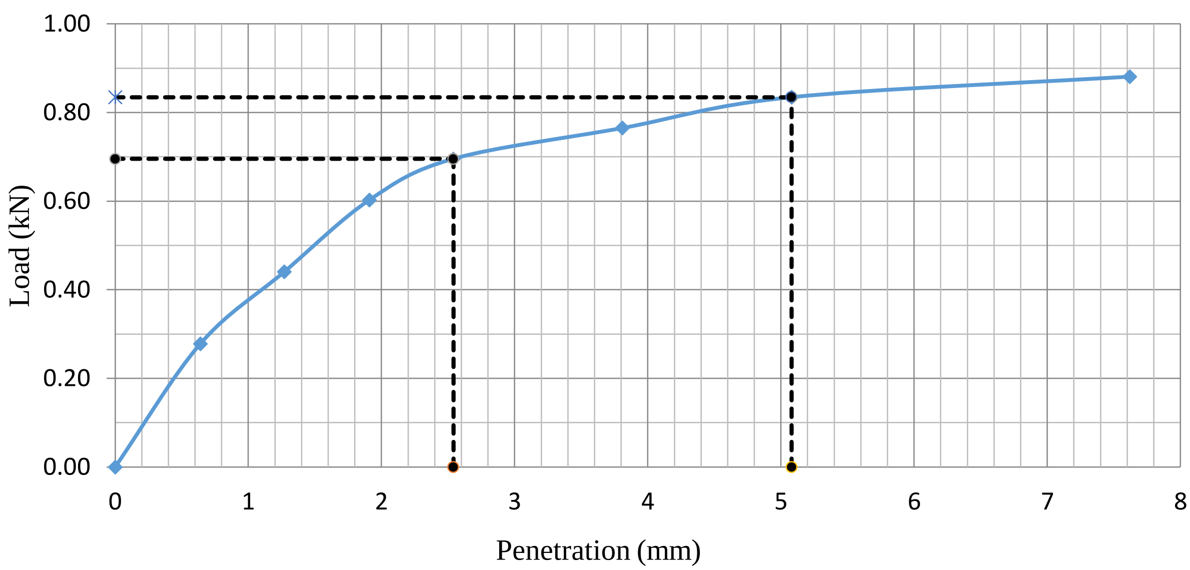


Figure F-10 Load versus Penetration curve of Stabilized Soil with 1% of 35mm fiber +10% Sand

Table F-12 CBR and Swell of Stabilized Soil with 1% of 35 mm fiber+15% Sand

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 6 | " | 0.28 | | intial | final |
| 1.27 | 9.5 | " | 0.44 | | 870.000 | 1502.000 |
| 1.91 | 13 | " | 0.60 | Swell(%) | 4.98 | |
| 2.54 | 15.5 | " | 0.72 | | | |
| 3.81 | 16.5 | " | 0.77 | | | |
| 5.08 | 18 | " | 0.83 | | | |
| 7.62 | 19.5 | " | 0.90 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (KN) | Standard Load (KN) | CBR (%) | % Swell |
| 2.54 | 0.72 | 13.2 | 5.44 | 4.98 |
| 5.08 | 0.83 | 20.0 | 4.17 | |

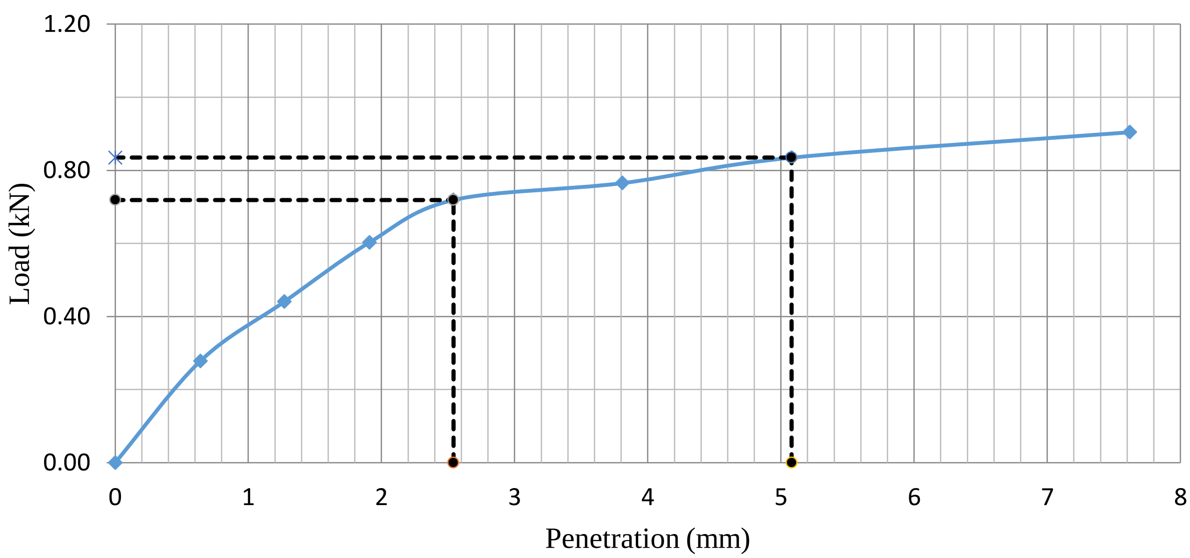


Figure F-11 Load versus Penetration curve of Stabilized Soil with 1% of 35mm fiber +15% sand

Table F-13 CBR and Swell of Stabilized Soil with 1% of 35 mm fiber+20% Sand

| Test Method | | | ASTM-D1883 | | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 8 | " | 0.37 | | Initial | Final |
| 1.27 | 12 | " | 0.56 | | 1350.000 | 1959.000 |
| 1.91 | 15 | " | 0.70 | Swell(%) | 4.80 | |
| 2.54 | 17.0 | " | 0.79 | | | |
| 3.81 | 18.5 | " | 0.86 | | | |
| 5.08 | 19.5 | " | 0.90 | | | |
| 7.62 | 20.5 | " | 0.95 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (KN) | Standard Load (kN) | CBR (%) | % Swell |
| 2.54 | 0.79 | 13.2 | 5.97 | 4.80 |
| 5.08 | 0.90 | 20.0 | 4.52 | |

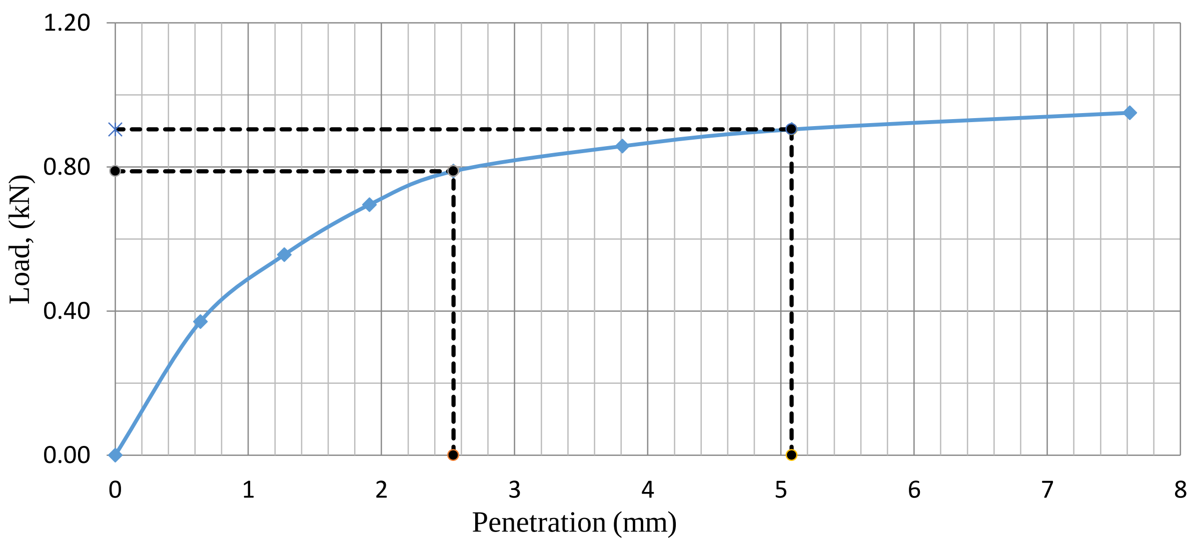


Figure F-12 Load versus Penetration curve of Stabilized Soil with 1% of 35mm fiber +20% Sand

Table F-14 CBR and Swell of Stabilized Soil with 1% of 35 mm fiber+ 1st sand layer

| Test Method | | | | | | ASTM-D1883 |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | | | |
| 0.64 | 7.5 | " | 0.35 | Gauge reading | Initial | Final |
| 1.27 | 12 | " | 0.56 | | 463.000 | 972.000 |
| 1.91 | 16 | " | 0.74 | Swell(%) | 4.01 | |
| 2.54 | 19.0 | " | 0.88 | | | |
| 3.81 | 25 | " | 1.16 | | | |
| 5.08 | 30 | " | 1.39 | | | |
| 7.62 | 31 | " | 1.44 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR (%) | % Swell |
| 2.54 | 0.88 | 13.2 | 6.67 | 4.01 |
| 5.08 | 1.39 | 20.0 | 6.96 | |

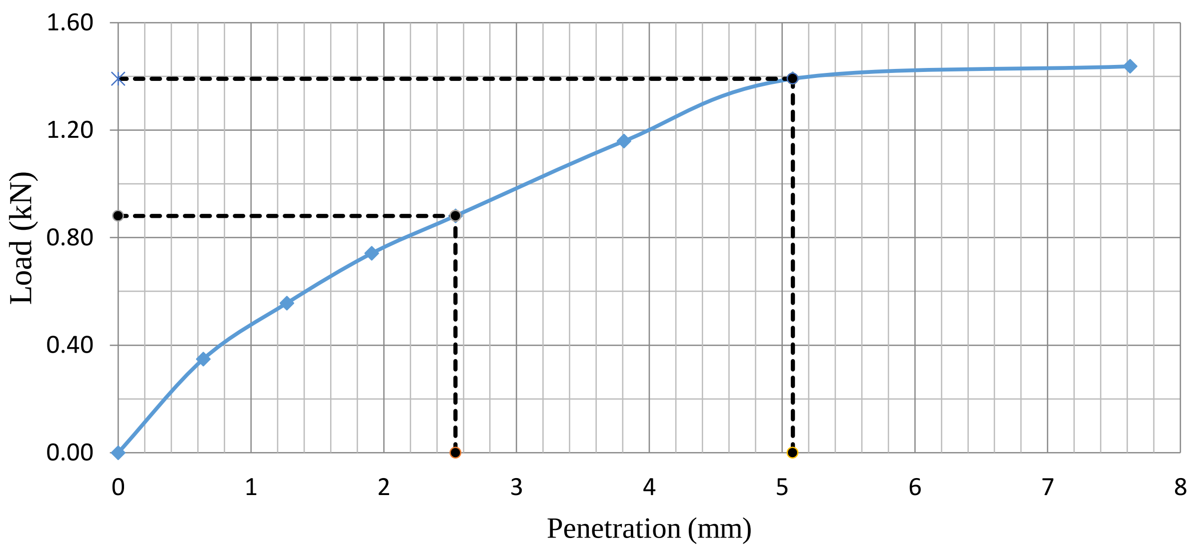


Figure F-13 Load versus Penetration curve of Stabilized Soil with 1% of 35mm fiber+1st sand layer

Table F-15 CBR and Swell of Stabilized Soil with 1% of 35 mm fiber+ 2nd sand layer

| Test Method | | | ASTM-D1883 | | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 7.5 | " | 0.35 | | Initial | Final |
| 1.27 | 12 | " | 0.56 | | 414.000 | 956.000 |
| 1.91 | 15.5 | " | 0.72 | Swell(%) | 4.27 | |
| 2.54 | 19.0 | " | 0.88 | | | |
| 3.81 | 24 | " | 1.11 | | | |
| 5.08 | 28 | " | 1.30 | | | |
| 7.62 | 29.5 | " | 1.37 | | | |
| | | | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR (%) | % Swell |
| 2.54 | 0.88 | 13.2 | 6.67 | 4.27 |
| 5.08 | 1.30 | 20.0 | 6.49 | |

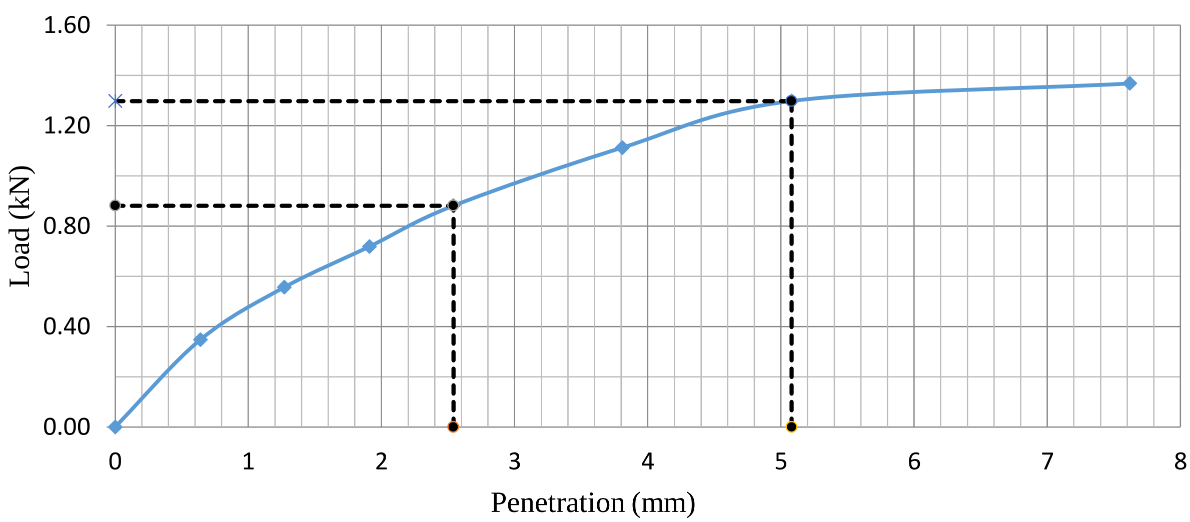


Figure F-14 Load versus Penetration curve of Stabilized Soil with 1% of 35mm fiber+2nd Sand layer

Table F-16 CBR and Swell of Stabilized Soil with 1% of 35 mm fiber+ 3rd sand layer

| Test Method | | | | ASTM-D1883 | | |
|---|---|---|---|---|---|---|
| Penetration mm | Load dial divs. | Ring Factor N/div | Load (kN) | Swell Data | | |
| 0 | 0 | 46.367 | 0.00 | Gauge reading | | |
| 0.64 | 7 | " | 0.32 | | Initial | Final |
| 1.27 | 12 | " | 0.56 | | 524.000 | 1122.000 |
| 1.91 | 15.5 | " | 0.72 | Swell(%) | 4.71 | |
| 2.54 | 17.5 | " | 0.81 | | | |
| 3.81 | 19 | " | 0.88 | | | |
| 5.08 | 20 | " | 0.93 | | | |
| 7.62 | 22 | " | 1.02 | | | |
| | | " | 0.00 | | | |

| CBR Results | | | | |
|---|---|---|---|---|
| Penetration (mm) | Load (kN) | Standard Load (kN) | CBR, % | % Swell |
| 2.54 | 0.81 | 13.2 | 6.15 | 4.71 |
| 5.08 | 0.93 | 20.0 | 4.64 | |

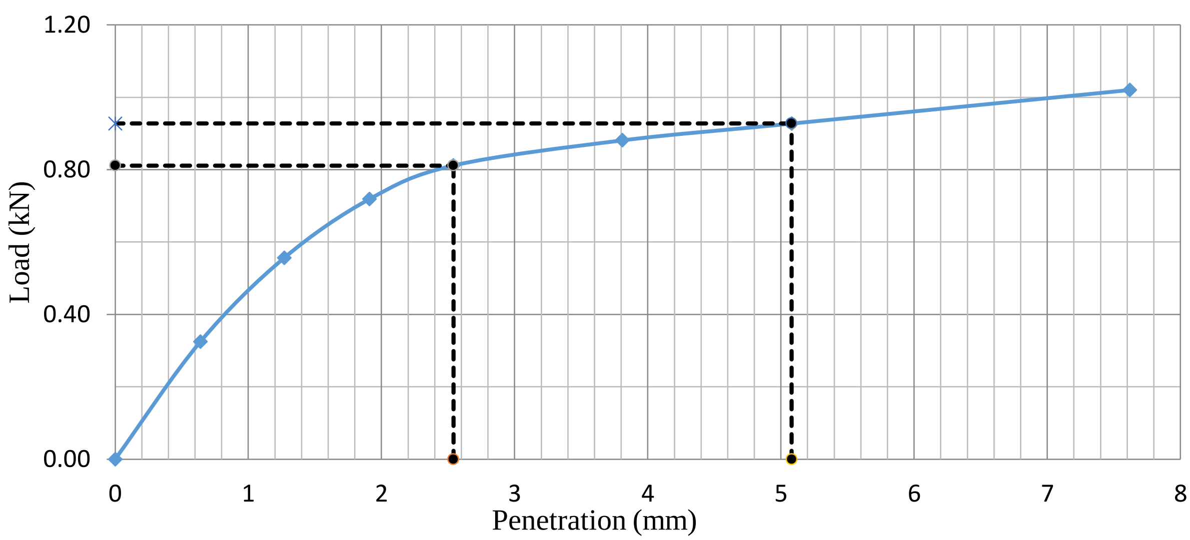


Figure F-15 Load versus Penetration curve of Stabilized Soil with 1% of 35mm fiber+3rd sand layer

# APPENDEX G

## Unconfined Compressive Strength (UCS) Test Results

The following data is constant for all UCS tests that were conducted for this study

Table G-1 UCS test data

| Specimen Data | |
|---|---|
| Diameter (mm) | 37 |
| Lenth (mm) | 74 |
| Area ($A_O$) ($mm^2$) | 1075.86 |
| Volume ($mm^3$) | 79575.86 |
| Rate (mm/min) | 1.50 |
| Ring Factor (kN/div) | 0.00205 |

Table G-2 UCS of Soil Sample 1(pit 1)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Moisture content | | | | | | | |
| Wet Sample + Container(gm) | | | 144.90 | | Volume, (mm$^3$) | 79575 | |
| Dry Sample + Container(gm) | | | 111.30 | | Bulk density(gm/cm$^3$ | 1.821 | |
| Wt. Of Water(gm) | | | 36.30 | | Drydensity(gm/cm$^3$) | 1.399 | |
| Wt. Of Container (gm) | | | 0.00 | | | | |
| Wt of Dry Sample (gm) | | | 111.30 | | | | |
| Water Content (%) | | | 30.19 | | | | |
| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL(mm) | Strain (ε) | % Strain | Corrected Area A' | Load (kN) | Stress (kPa) |
| 0 | 0.0 | 0.00 | 0.00 | 0.000 | 1075.350 | 0.000 | 0.00 |
| 20 | 82.0 | 0.20 | 0.003 | 0.270 | 1078.256 | 0.168 | 155.90 |
| 40 | 105.0 | 0.40 | 0.005 | 0.541 | 1081.162 | 0.215 | 199.09 |
| 60 | 125.0 | 0.60 | 0.008 | 0.811 | 1084.069 | 0.256 | 236.38 |
| 80 | 145.0 | 0.80 | 0.011 | 1.081 | 1086.975 | 0.297 | 273.47 |
| 100 | 155.0 | 1.00 | 0.014 | 1.351 | 1089.881 | 0.318 | 291.55 |
| 120 | 164.0 | 1.20 | 0.016 | 1.622 | 1092.788 | 0.336 | 307.65 |
| 140 | 168.0 | 1.40 | 0.019 | 1.892 | 1095.694 | 0.344 | 314.32 |
| 160 | 169.0 | 1.60 | 0.022 | 2.162 | 1098.600 | 0.346 | 315.36 |
| 180 | 169.0 | 1.80 | 0.024 | 2.432 | 1101.507 | 0.346 | 314.52 |
| 200 | 168.0 | 2.00 | 0.027 | 2.703 | 1104.413 | 0.344 | 311.84 |
| 220 | 167.0 | 2.20 | 0.030 | 2.973 | 1107.319 | 0.342 | 309.17 |
| 240 | 166.0 | 2.40 | 0.032 | 3.243 | 1110.226 | 0.340 | 306.51 |
| 260 | 166.0 | 2.60 | 0.035 | 3.514 | 1113.132 | 0.340 | 305.71 |
| 280 | 166.0 | 2.80 | 0.038 | 3.784 | 1116.038 | 0.340 | 304.92 |
| 300 | 166.0 | 3.00 | 0.041 | 4.054 | 1118.945 | 0.340 | 304.13 |
| 320 | 166.0 | 3.20 | 0.043 | 4.324 | 1121.851 | 0.340 | 303.34 |
| 340 | 166.0 | 3.40 | 0.046 | 4.595 | 1124.757 | 0.340 | 302.55 |
| 360 | 166.0 | 3.60 | 0.049 | 4.865 | 1127.664 | 0.340 | 301.77 |
| 380 | 166.0 | 3.80 | 0.051 | 5.135 | 1130.570 | 0.340 | 301.00 |
| 400 | 165.0 | 4.00 | 0.054 | 5.405 | 1133.477 | 0.338 | 298.42 |
| 420 | 165.0 | 4.20 | 0.057 | 5.676 | 1136.383 | 0.338 | 297.65 |
| 440 | 165.0 | 4.40 | 0.059 | 5.946 | 1139.289 | 0.338 | 296.90 |
| 460 | 165.0 | 4.60 | 0.062 | 6.216 | 1142.196 | 0.338 | 296.14 |

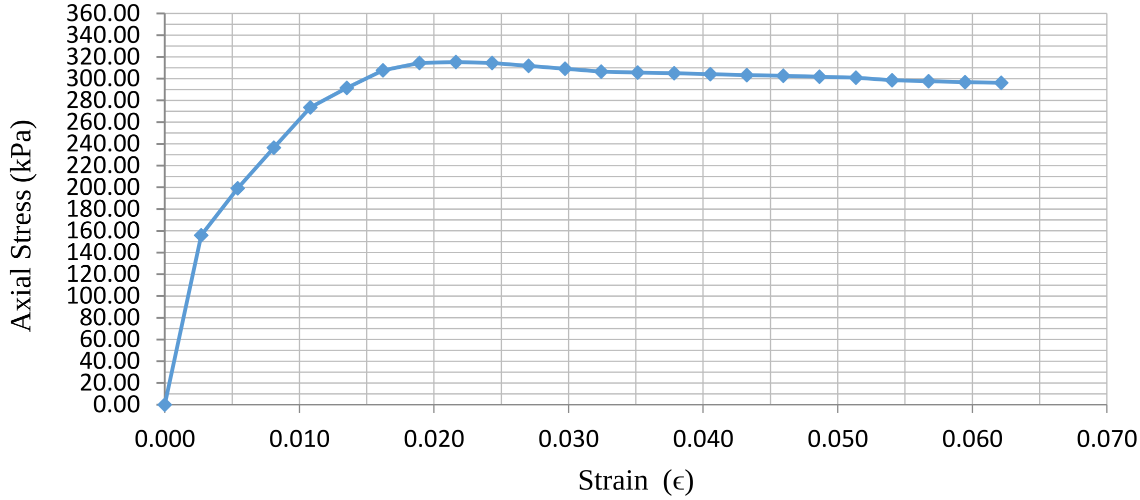


Figure G-1 Stress-strain curve of the natural soil Sample 1(pit 1)

Table G-3 UCS of Reinforced Soil by 1%, 35mm Katcha fiber

| Moisture Content | | | | | | | |
|---|---|---|---|---|---|---|---|
| Wt of Wet Sample + Container(gm) | | | 142.00 | | Volume, (mm$^3$) | 79575.86 | |
| Wt of Dry Sample + Container(gm) | | | 106.60 | | Bulk density(gm/cm$^3$) | 1.784 | |
| Wt. Of Water(gm) | | | 35.40 | | Dry density(gm/cm$^3$) | 1.342 | |
| Wt. Of Container (gm) | | | 0.00 | | | | |
| Wt of Dry Sample (gm) | | | 106.60 | | | | |
| Water Content (%) | | | 33.21 | | | | |
| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL(mm) | Strain (ε) | % **Strain** | Corrected Area A' | Load (kN) | Stress (kPa) |
| 0 | 0.0 | 0.00 | 0.00 | 0.000 | 1075.350 | 0.000 | 0.00 |
| 20 | 55.0 | 0.20 | 0.003 | 0.270 | 1078.256 | 0.119 | 110.18 |
| 40 | 74.0 | 0.40 | 0.005 | 0.541 | 1081.162 | 0.160 | 147.84 |
| 60 | 92.0 | 0.60 | 0.008 | 0.811 | 1084.069 | 0.199 | 183.31 |
| 80 | 108.0 | 0.80 | 0.011 | 1.081 | 1086.975 | 0.233 | 214.61 |
| 100 | 124.0 | 1.00 | 0.014 | 1.351 | 1089.881 | 0.268 | 245.75 |
| 120 | 140.0 | 1.20 | 0.016 | 1.622 | 1092.788 | 0.302 | 276.72 |
| 140 | 154.0 | 1.40 | 0.019 | 1.892 | 1095.694 | 0.333 | 303.59 |
| 160 | 167.0 | 1.60 | 0.022 | 2.162 | 1098.600 | 0.361 | 328.35 |
| 180 | 180.0 | 1.80 | 0.024 | 2.432 | 1101.507 | 0.389 | 352.97 |
| 200 | 191.0 | 2.00 | 0.027 | 2.703 | 1104.413 | 0.413 | 373.56 |
| 220 | 202.0 | 2.20 | 0.030 | 2.973 | 1107.319 | 0.436 | 394.03 |
| 240 | 210.0 | 2.40 | 0.032 | 3.243 | 1110.226 | 0.454 | 408.57 |
| 260 | 220.0 | 2.60 | 0.035 | 3.514 | 1113.132 | 0.475 | 426.90 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 280 | 228.0 | 2.80 | 0.038 | 3.784 | 1116.038 | 0.492 | 441.28 |
| 300 | 234.0 | 3.00 | 0.041 | 4.054 | 1118.945 | 0.505 | 451.71 |
| 320 | 240.0 | 3.20 | 0.043 | 4.324 | 1121.851 | 0.518 | 462.09 |
| 340 | 246.0 | 3.40 | 0.046 | 4.595 | 1124.757 | 0.531 | 472.42 |
| 360 | 251.0 | 3.60 | 0.049 | 4.865 | 1127.664 | 0.542 | 480.78 |
| 380 | 255.0 | 3.80 | 0.051 | 5.135 | 1130.570 | 0.551 | 487.19 |
| 400 | 258.0 | 4.00 | 0.054 | 5.405 | 1133.477 | 0.557 | 491.66 |
| 420 | 260.0 | 4.20 | 0.057 | 5.676 | 1136.383 | 0.562 | 494.20 |
| 440 | 262.0 | 4.40 | 0.059 | 5.946 | 1139.289 | 0.566 | 496.73 |
| 460 | 264.0 | 4.60 | 0.062 | 6.216 | 1142.196 | 0.570 | 499.25 |
| 480 | 266.0 | 4.80 | 0.065 | 6.486 | 1145.102 | 0.575 | 501.75 |
| 500 | 268.0 | 5.00 | 0.068 | 6.757 | 1148.008 | 0.579 | 504.25 |
| 520 | 270.0 | 5.20 | 0.070 | 7.027 | 1150.915 | 0.583 | 506.73 |
| 540 | 271.0 | 5.40 | 0.073 | 7.297 | 1153.821 | 0.585 | 507.32 |
| 560 | 273.0 | 5.60 | 0.076 | 7.568 | 1156.727 | 0.590 | 509.78 |
| 580 | 275.0 | 5.80 | 0.078 | 7.838 | 1159.634 | 0.594 | 512.23 |
| 600 | 276.0 | 6.00 | 0.081 | 8.108 | 1162.540 | 0.596 | 512.81 |
| 620 | 277.0 | 6.20 | 0.084 | 8.378 | 1165.446 | 0.598 | 513.38 |
| 640 | 278.0 | 6.40 | 0.086 | 8.649 | 1168.353 | 0.600 | 513.95 |
| 660 | 280.0 | 6.60 | 0.089 | 8.919 | 1171.259 | 0.605 | 516.37 |
| 680 | 281.0 | 6.80 | 0.092 | 9.189 | 1174.165 | 0.607 | 516.93 |
| 700 | 282.0 | 7.00 | 0.095 | 9.459 | 1177.072 | 0.609 | 517.49 |
| 720 | 284.0 | 7.20 | 0.097 | 9.730 | 1179.978 | 0.613 | 519.87 |
| 740 | 285.0 | 7.40 | 0.100 | 10.000 | 1182.884 | 0.616 | 520.42 |
| 760 | 286.0 | 7.60 | 0.103 | 10.270 | 1185.791 | 0.618 | 520.97 |
| 780 | 287.0 | 7.80 | 0.105 | 10.541 | 1188.697 | 0.620 | 521.51 |
| 800 | 289.0 | 8.00 | 0.108 | 10.811 | 1191.604 | 0.624 | 523.87 |
| 820 | 291.0 | 8.20 | 0.111 | 11.081 | 1194.510 | 0.629 | 526.21 |
| 840 | 293.0 | 8.40 | 0.114 | 11.351 | 1197.416 | 0.633 | 528.54 |
| 860 | 295.0 | 8.60 | 0.116 | 11.622 | 1200.323 | 0.637 | 530.86 |

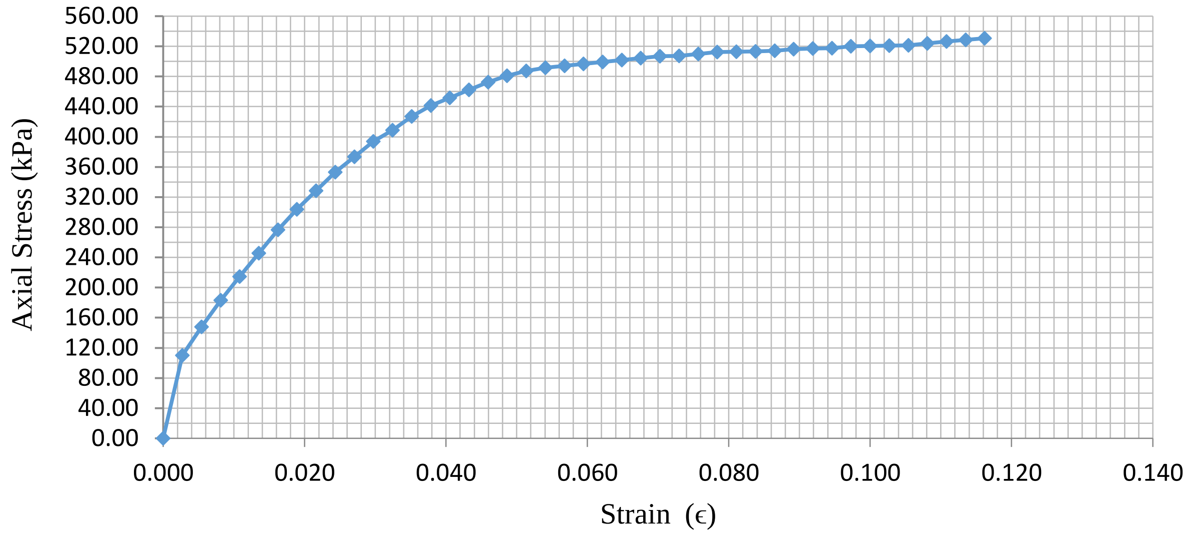


Figure G-2 Stress-Strain curve of Reinforced Soil by 1%, 35mm Katcha fiber

Table G- 4 UCS of Reinforced Soil by 1%, 35mm Katcha fiber blended with 20% sand

| Moisture Content | | | | | | | |
|---|---|---|---|---|---|---|---|
| Wt of Wet Sample + Container(gm) | | | 144.30 | | Volume, (mm$^3$) | 79575.86 | |
| Wt of Dry Sample + Container(gm) | | | 116.20 | | Bulk density(gm/cm$^3$) | 1.813 | |
| Wt. Of Water(gm) | | | 28.1 | | Dry density(gm/cm$^3$) | 1.460 | |
| Wt. Of Container (gm) | | | 0.00 | | | | |
| Wt of Dry Sample (gm) | | | 116.20 | | | | |
| Water Content (%) | | | 24.18 | | | | |
| Deformation Dial Reading | Load Dial Reading | Sample Deformation, ΔL(mm) | Strain(ε) | % Strain | Corrected Area A' | Load (kN) | Stress (kPa) |
| 0 | 0.0 | 0.00 | 0.00 | 0.000 | 1075.350 | 0.000 | 0.00 |
| 20 | 67.0 | 0.20 | 0.003 | 0.270 | 1078.256 | 0.137 | 127.38 |
| 40 | 97.0 | 0.40 | 0.005 | 0.541 | 1081.162 | 0.199 | 183.92 |
| 60 | 127.0 | 0.60 | 0.008 | 0.811 | 1084.069 | 0.260 | 240.16 |
| 80 | 158.0 | 0.80 | 0.011 | 1.081 | 1086.975 | 0.324 | 297.98 |
| 100 | 171.0 | 1.00 | 0.014 | 1.351 | 1089.881 | 0.351 | 321.64 |
| 120 | 182.0 | 1.20 | 0.016 | 1.622 | 1092.788 | 0.373 | 341.42 |
| 140 | 192.0 | 1.40 | 0.019 | 1.892 | 1095.694 | 0.394 | 359.22 |
| 160 | 200.0 | 1.60 | 0.022 | 2.162 | 1098.600 | 0.410 | 373.20 |
| 180 | 210.0 | 1.80 | 0.024 | 2.432 | 1101.507 | 0.431 | 390.83 |
| 200 | 215.0 | 2.00 | 0.027 | 2.703 | 1104.413 | 0.441 | 399.08 |
| 220 | 220.0 | 2.20 | 0.030 | 2.973 | 1107.319 | 0.451 | 407.29 |
| 240 | 222.0 | 2.40 | 0.032 | 3.243 | 1110.226 | 0.455 | 409.92 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 260 | 224.0 | 2.60 | 0.035 | 3.514 | 1113.132 | 0.459 | 412.53 |
| 280 | 226.0 | 2.80 | 0.038 | 3.784 | 1116.038 | 0.463 | 415.13 |
| 300 | 228.0 | 3.00 | 0.041 | 4.054 | 1118.945 | 0.467 | 417.71 |
| 320 | 232.0 | 3.20 | 0.043 | 4.324 | 1121.851 | 0.476 | 423.94 |
| 340 | 234.0 | 3.40 | 0.046 | 4.595 | 1124.757 | 0.480 | 426.49 |
| 360 | 238.0 | 3.60 | 0.049 | 4.865 | 1127.664 | 0.488 | 432.66 |
| 380 | 242.0 | 3.80 | 0.051 | 5.135 | 1130.570 | 0.496 | 438.81 |
| 400 | 244.0 | 4.00 | 0.054 | 5.405 | 1133.477 | 0.500 | 441.30 |
| 420 | 246.0 | 4.20 | 0.057 | 5.676 | 1136.383 | 0.504 | 443.78 |
| 440 | 248.0 | 4.40 | 0.059 | 5.946 | 1139.289 | 0.508 | 446.24 |
| 460 | 250.0 | 4.60 | 0.062 | 6.216 | 1142.196 | 0.513 | 448.70 |
| 480 | 252.0 | 4.80 | 0.065 | 6.486 | 1145.102 | 0.517 | 451.14 |
| 500 | 254.0 | 5.00 | 0.068 | 6.757 | 1148.008 | 0.521 | 453.57 |
| 520 | 256.0 | 5.20 | 0.070 | 7.027 | 1150.915 | 0.525 | 455.99 |
| 540 | 258.0 | 5.40 | 0.073 | 7.297 | 1153.821 | 0.529 | 458.39 |
| 560 | 260.0 | 5.60 | 0.076 | 7.568 | 1156.727 | 0.533 | 460.78 |
| 580 | 262.0 | 5.80 | 0.078 | 7.838 | 1159.634 | 0.537 | 463.16 |
| 600 | 264.0 | 6.00 | 0.081 | 8.108 | 1162.540 | 0.541 | 465.53 |
| 620 | 266.0 | 6.20 | 0.084 | 8.378 | 1165.446 | 0.545 | 467.89 |
| 640 | 268.0 | 6.40 | 0.086 | 8.649 | 1168.353 | 0.549 | 470.23 |
| 660 | 270.0 | 6.60 | 0.089 | 8.919 | 1171.259 | 0.554 | 472.57 |
| 680 | 272.0 | 6.80 | 0.092 | 9.189 | 1174.165 | 0.558 | 474.89 |
| 700 | 274.0 | 7.00 | 0.095 | 9.459 | 1177.072 | 0.562 | 477.20 |
| 720 | 276.0 | 7.20 | 0.097 | 9.730 | 1179.978 | 0.566 | 479.50 |
| 740 | 278.0 | 7.40 | 0.100 | 10.000 | 1182.884 | 0.570 | 481.79 |
| 760 | 280.0 | 7.60 | 0.103 | 10.270 | 1185.791 | 0.574 | 484.07 |
| 780 | 282.0 | 7.80 | 0.105 | 10.541 | 1188.697 | 0.578 | 486.33 |
| 800 | 284.0 | 8.00 | 0.108 | 10.811 | 1191.604 | 0.582 | 488.59 |
| 820 | 284.0 | 8.20 | 0.111 | 11.081 | 1194.510 | 0.582 | 487.40 |
| 840 | 282.0 | 8.40 | 0.114 | 11.351 | 1197.416 | 0.578 | 482.79 |

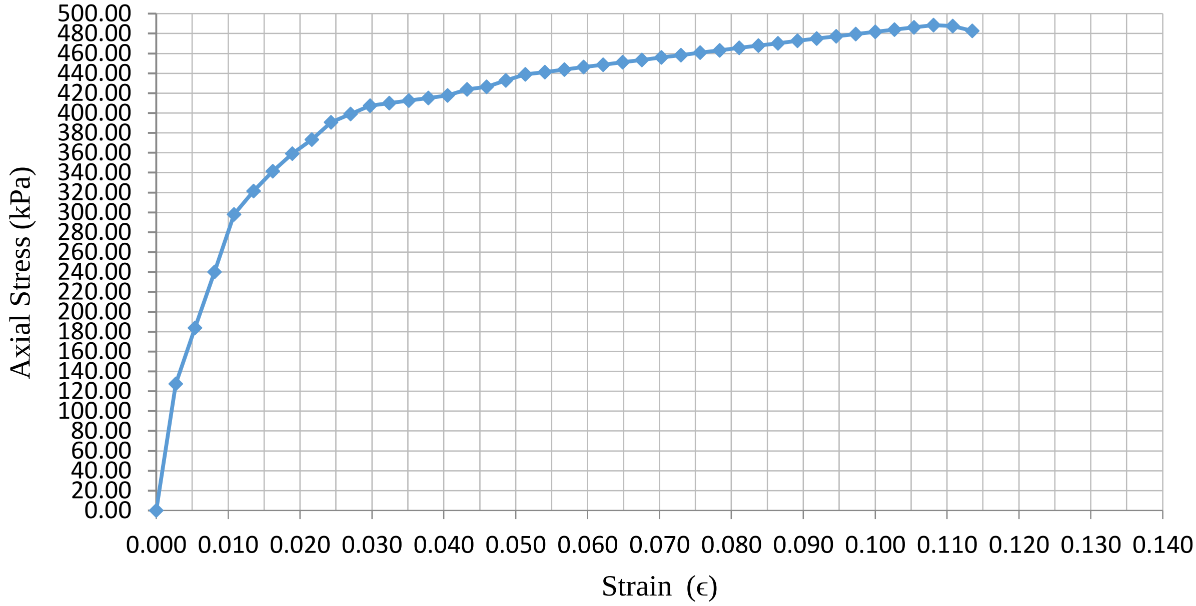


Figure G-3 Stress-Strain curve of Reinforced Soil by 1%, 35mm Katcha fiber + 20% sand