ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

COLLEGE OF NATURAL SCIENCES

Problematic Sub-Grade Soil Reinforcement Using Local Natural Fibers on Selected Road Section from Wolaita, South Western Ethiopia

“A Thesis Submitted to

The School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Sciences in Geological Engineering (Engineering Geology)”

By

Tirfu Maja

May 2018

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

COLLEGE OF NATURAL SCIENCES

Problematic Sub-Grade Soil Reinforcement Using Local Natural Fibers on Selected Road Section from Wolaita, South Western Ethiopia

"A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Sciences in Geological Engineering (Engineering Geology)"

By

Tirfu Maja

May 2018

Signature page

Addis Ababa University

School of Graduate Studies

This is to certify that the thesis prepared by Tirfu Maja, entitled: *Problematic Sub-Grade Soil Reinforcement Using Local Natural Fibers on Selected Road Section from Wolaita, South Western Ethiopia*: Submitted in partial fulfillment of the requirements for the Degree of Master of Science in Geological Engineering (Engineering Geology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Examiner: ________________ Signature _______________ Date ________________

Examiner: __________________ Signature _______________ Date ________________

Advisor: Dr. Zeeman Geremew Signature ___________ Date ________________

____

Chair of School or Graduate Program Coordinator

Research Title: - Problematic Sub-Grade soil Reinforcement Using Local Natural Fibers in Selected Road Section from Wolaita, South Western Ethiopia. By Tirfu Maja. AAU, 2018

Abstract

A road is very important for the community, because it is base for the socio-economic interaction among people. Based on road life and its economic considerations, road pavement designs mainly need good sub-grade materials or reinforcement of existing problematic soil. Natural fibers have capability to reinforce problematic soils such ranging from clay to silty sand. Wolaita (project area) is one of the highly populated area in Ethiopia and its land is almost completely covered by farm and house. The soil in wolaita area is lateritic clay. However, road construction site's soil does not fulfill the sub-grade soil requirements economically. Hence hundreds of millions metric cube soil is needed for sub-grade layer and the same volume of soil is cut to drop site in one road project. This research work come up with mechanism, mechanical conjugation of random distributed local natural fibers and soil, in order to reinforce the problematic sub-grade soil.

In general the research work comprises the tasks such as characterization and selection of fibers, representative problematic soils and soil-fiber mixtures. Method of characterization is done as per AASHTO and ASTM test methods which are recommended in Ethiopian Road Authority. Accordingly the characterization of the worst problematic soil and selected fibers (Enset ventricosum and Teff straw fibers) is done before conjugating them. The effect of fibers percentage by weight and of fiber length in the soil on CBR, surcharged swell, dry density, moisture content and their optimum improvements are discussed in this paper. The percentage of individual fiber in the soil is taken as 0%, 0.25%, 0.5%, 0.75%, 1%, and 1.25% by air dry weight. The result show that MDD is decreased and OMC is increased with increased fibers percent while CBR value is increased until 1% for Enset fiber and 0.75% for Teff straw fiber with fiber length of 6 cm. However, the degree of improvement of fiber mixed soil is 157 and 133 times greater than the soil without the fiber respectively. One point unsoaked CBR test shows that the value increased from 57% to 62%. 4.54kg surcharged swell value of teff straw fiber conjugated soil is decreased from 5 to 3 as percent of fiber increased from 0% to 0.75%, respectively and decreased from 5 to 3.5 as fiber increased from 0% to 1% respectively for Enset fiber. According to improvement, change in road pavement design as per ERA manual and its subsequent benefits are also discussed in this paper. Finally, appropriate recommendations are written according to the finding.

Keywords: - Reinforce, Problematic soil, CBR, Natural fibers, Enset fiber, Teff straw, Sub-grade

Acknowledgement

First of I would like to Praise God, who provides me peace and health during the present research work.

I give my special thanks to my Advisor Dr. Zemenu Geremew for his encouragement, guidance and support. I want to say thank you very much for all.

I would like to give my thanks to Addis Ababa University, School of Earth Sciences for their financial support for this study.

I would like to express my special thanks to Ethiopian Road Authority southern district and HHRBC for permissions to use their collaborative soil laboratory.

Also, I would like to give my special thanks to Wondewosen Kifile- principal consultant of Hunan Huandan Road and Bridge Corporation China (HHRBCC) Design and Build road project; Mesfin Tehilku- vice consultant of the project; Sercalem Tewolde- material engineer of the project and Cheramlak Hibdo- quantity supplier and laboratory technician; for their consult during laboratory work.

I would like to thank Wolaita Zone Farm and Natural Resources Department, and water, mine and energy department for their providing valuable data.

At last, regardless of order, I would like to say also thanks to all of my family, friends and classmates who directly or indirectly helped me in this research.

Table of contents

List of tables

Table No. **particulars** **pages**

List of figures

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Soil reinforcement is a technique to improve the engineering characteristics of soils. The process of soil reinforcement help to improve the required engineering properties in a soil needed for the construction work.

Some structures built on problematic soils such as expansive soils, organic soils, peats, and marshy land are crack at different parts due to structural failure (Aqeel AL-Adili, 2011). Expansive soils are major geotechnical hazards that pose several problems on engineering structures causing billions of dollars of damage in many parts of the world especially at places where there are significant climatic differences between dry and wet periods (Gourley et al., 1993; Nelson and Miller, 1992). The most known remedial measurements used to improve those damaged structures are moisture controlling, using alternative type of foundation and soil stabilization/reinforcement. Since the frequent objectives of the soil stabilization/reinforcement are to improve soil strength, to decrease permeability and water absorption and/or to improve bearing capacity and durability according to predefined structure life.

Soil reinforcement by fiber material is considered as an effective ground improvement method because of its cost effectiveness, easy adaptability and reproducibility. According to Badavath (2004), and Hussein Shaia et.al (2016) natural fibers such as Jute can improve several weak soils like black cotton soil, organic soils, peats, clays depart from soils in marshy land and water logged area.

The pavement construction on black cotton soil, organic soils and peats roads has always been problematic since their bearing capacity is low. For such roads sub-grade soil improvement is recommended. Also according to Hejazi et. al (2012), natural and synthetic fibers have different applications and benefits. In his review he commented that the use of natural and synthetic fiber in geotechnical engineering is feasible in six fields including pavement layer, retaining wall and railway embankment, protection of slopes, earth quakes and soil foundation engineering.

According to ERA manual (2002), the strength of the road sub-grade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and it is dependent on the type of soil, its density, and its moisture content. After estimating the sub-grade moisture content for design, it is then necessary to determine a representative density at which a design CBR value will be selected. To specify densities during construction, it is recommended that the top 25 cm of all Sub-grades should be compacted to a relative density of at least 100% of the maximum dry density achieved by ASTM test Method D 698 (light or standard compaction). Alternatively, at least 93% of the maximum dry density achieved by ASTM Test Method D 1557 may be specified.

The ERA Site Investigation Manual (2002), recommends as a first step to conduct standard compaction tests (ASTM D 698) and to measure the CBR on samples molded at 100% MDD and OMC (standard compaction), to guide in the selection of homogeneous sections of a road project. Other useful correlations for assessing qualitatively the sub-grade strength include: a correlation between the nature of the soils (as given in the Unified Soil Classification System, USCS, described in ASTM Method D2487) and typical design CBR values; and the use of the AASHTO classification.

Different countries use different local natural fibers to reinforce problematic soils. For example jute and coconut fibers is used in India, China, Thailand and coconut and sisal fiber are used in India, Bangladesh, Brazil etc.(Dimpa Moni Kalita et.al, 2016). Unconfined compressive strength of a red soil in Assam, India, increased by 91%,100%, 126% and 143% due to addition of 0.25%, 50%, o.75% and 1% of coconut coir fiber respectively (Kalita et,al.). Also according to Babu and Vasudevan (2008), the fiber reinforced soil achieved an increase of strength 3.3 times that of non reinforced soil.

Agriculture is the mainstacy of Ethiopia's economy, which supports more than 85% of the population. This sector directly or indirectly forms an important component of the livelihoods of more than 70 million for food and as a source of income (Olango et al.2014). From agricultural product teff is the famous one in Ethiopia.

Enset is cultivated only in its native indigenous farming systems of South and South-Western Ethiopia but later it get great attention to prevail in Ethiopia because of its great medicinal value and drought resistance (Cheeseman, 1947).

Enset *ventricosum fiber* commonly known as katcha, and teff stem (chid) fibers are the byproducts of false banana and teff respectively. The by-products are left over after harvesting enset and teff and can be used as natural fiber.

1.2. Statement of the problem

A road is a very important infrastructure because it is base for the socio-economic interaction among peoples. Any rehabilitating or newly constructing roads' lifespan and quality are depend on the quality of road sub grade soil, quality of construction materials and appropriate pavement design and design constraints.

In wolaita zone, wolata sodo to Hawassa via dimtu raod project, almost all of the soil does not fulfill the sub-grade soil requirements considerably. Indeed HHRBC, contractor of Wolata Sodo to Hawassa via Dimtu raod project, decided to remove all the existing in-situ sub-grade soil and infill it with suitable soil (cupping) from community faraway. But the project area community is one of highly populated area in Ethiopia and their land is almost completely covered by farm but hundred millions meter cube of soil is needed and the same volume of soil is discarded to drop site for the project.

Hence, in order to get sub-grade soil excavation site (selected material cut site), peoples are displaced from their localities, crops are destroyed, and local geomorphology (landscapes) can be changed. Project risk owners are also faced to high cost expenditures such as compensation cost for displaced peoples and destroyed crops for drop sites and excavation site, transportation cost for discarding and backfilling soil and site excavation cost.

A number of researches have been carried out on road sub-grade soil reinforcement using chemicals: limes, cements, etc. (discussed in literature review). According to those studies, soil reinforcement using chemicals is coasty and not environmentally friend. The use of locally available natural fibers as a reinforcement material can potentially be cost effective and non detrimental to the environment.

1.3. Objectives

1.3.1. General objective

The general objective of the present study is to evaluate the engineering performance of the reinforced problematic sub-grade soil using natural fibers (teff straw and enset ventricosum).

1.3.2. Specific objectives

The present study is aimed to achieve the following objectives

- To identify and characterize problematic sub-grade soils of the selected road section.
- To select and characterize the properties of natural fibers which are locally available.
- To determine the fiber treatments processes and apply it.
- To determine the engineering properties of the fiber treated and untreated problematic sub-grade soil.
- To identify the optimum reinforcement parameters related to fiber length, contents ant types.

1.4. Methodology and materials used

1.4.1. Desk study

In any research work, data is very crucial because any scientific research use data as a bench mark to get full information. During desk study preliminary works are done. Since preliminary investigation is indoor study of the research, it emphasize on secondary data. The secondary data are gathered from literature reviews and soil test reports from Ethiopia Road Authority Sodo district and HHRBC road project etc. The activities engaged in the desk study are listed as follows.

- ❖ To analyze the results and elaborate conclusions and recommendations.
- ❖ Topography of the area where the road alignment pass through.
- ❖ General engineering and agricultural properties of the soil
- ❖ General and specific geology of the study area
- ❖ General physiography, accessibility, demography, climate and hydrogeology
- ❖ Some characteristics of local natural fibers
- ❖ Related literature review of fiber soil conjugations and others

1.4.2. Detail study

1.4.2.1. Primary data

Since this research is experimental, the primary data were obtained after undertaking detailed site investigations and/after from laboratory tests.

1.4.2.2. Field work

Two major aspects of field works are done during detailed site investigations. Firstly, correlating the data obtained from literature reviews with existing data in the ground. Secondly, sampling and sample collection from the road site.

By following along road alignment of the project, which is from Bitena - Mayo Kote - Zalal Yesus-Sodo and MayoKote-Delbo Junction to Alaba -Sodo road" which comprise 48.3 kms, the segment of selected area is from Mayo Kote to Zalal Yesus which has about 5 kms. Mayo Kote to Zalal Yesus is selected for detail investigation because the physical properties of the soil is most likely represent major coverage of soil in study area community and the volume of fills from this area higher than other segments of project area.

The sample is sampled from Mayo Kote community for fiber conjugation with GPS (UTM) point X= 372187, Y= 761381 and Z= 2148 and survey station of 94+320 (Mayo Kote local area). There are other sampling sites for testing for checking the accuracy of secondary data and to find the soil segment which has poorest engineering characteristics.

The sample was taken by pitting because pitting method is more appropriate for discrete data rather continuous. The pit has depth about 2 m because the average depth of road cut is about 2m from the surface regardless of topgraphic survey leveling. Using plastic bag the sample was taken to soil laboratory sit in Badesa, owned by HHRBCC.

To select fiber for the research work different factors such as comparatively easily accessibility, tensile strength of the fiber by observation, the agricultural productivity of fiber on problematic soil and abundance of by-product are used. By considering these factors the two fibers are selected and research experiments are conducted. Finally enset ventricusum (kacha) and teff straw (chid) fibers were selected for the experiment.

1.4.2.3. Laboratory work

After the field work and soil and fiber sampling, characterization of natural sub-grade soil, determination of engineering properties of soil-fibers mixtures were done in the laboratory.

a) Characterization of natural sub-grade soil

In order to characterize the soil, the road segment, was selected from proposed road project. The selected road segment has poor engineering soil properties according to ERA manual, 2002. Later then the soil samples were collected by pitting from the localities and following tests were done in the laboratory.

- Soil classification test
- surcharge swell test
- Standard Proctor compaction test
- strength test interims of California bearing ratio (CBR) Soil

b) Characterization of fibers

Fibers have their unique characteristics rather than soil that can vary the soil properties when I mixed it with fibers. Therefore physical characteristics of fibers were determined in the laboratory. These properties are:- flexibility of teff straw in dry, room temperature and wetted condition, water absorption capacity of fibers, bending angle just before breaking in dry condition for teff straw fibers, color of fibers, average length, average thickness of fibers and average thickness of hallow space of pseudo-stem for teff straw.

c) Determination of engineering properties of soil-fibers mixture

The content of fiber in the air dried soil is prepared as 0, %, 0.25%, 0.5%, 0.75%, 1% and 1.25 % by weight for both fibers. Weight of fibers is taken drying wetness after saturation of fibers. Then after obtaining high improving ratio of soil-fiber conjugation, the effect of fiber length is determined for both fibers. The different tests conducted after mixing of soil and fibers by eliminating combinations of test parameters with fiber ratio in order to get optimum improvements are:-

- Moisture content
- Standard Proctor compaction test
- Surcharge swell test
- California bearing ratio(CBR)

1.5. Scope of the research and its limitations

This research is done on problematic sub-grade soil improvement by using natural fiber conjugation with soil in order to know the degree of improvement according to highway pavement design parameters. The improvement of selected soil is checked by conducting some tests; that may give me information for highway pavement design parameters and scientific synthesis and analysis.

The design parameters needed for in this research are referred from ERA manuals and manuals, methods, and anther materials referred in ERA manuals because degree of improvement is calculated based on road construction practices in Ethiopia. Coast benefits and socio-political merits according to consequence of sub-grade improvement are evaluated according to ERA manual.

This research does not address the durability of local natural fibers under road pavement. The research has showed positive output, therefore question about durability and chemicals, materials and mechanisms those increase the durability of fibers would be a further study. Since the degree of improvement of soil-fiber conjugation with materials or chemicals are different from soil-fiber conjugation alone.

The effect of biological components of fibers such as lignite, cellulose etc. is not determined. The effect of such components weather improving or not have not addressed. Due to that case the curing period of conjugation not addressed in this paper.

1.6. Significance of the study

Since natural fibers are biodegradable, it is eco-friend. Using natural fibers is very important soil improving method because they are cheap, reproductive, taken from localities, etc. conjugation of fibers with problematic soil has significant improvement on engineering properties of soil.

According to result obtained from this research there are merits to road projects which are constructing and will be constructed over soil like in the project area. The findings show that there is significant reduction of coast using natural fibers to improve sub-grade soils because it minimize the cost of road projects which will be constructed such sub-grade soils.

Using local natural fibers such as teff straw and enset ventricosum fiber can minimize the cost of sub-grade replacement such as excavation cost of problematic sub-grade soil and capping soil, transportation cost of problematic sub-grade soil and capping soil, can be used to reduce environmental impact etc. Using them also show significant change in thickness of pavement layer in different class of flexible pavement catalogue, subsequently this reduce the demerits related to road projects.

By itself using natural fibers, to improve sub-grade soil, is important to community and science world because it gives alternative improving mechanism for problematic soils and it give clues to science world as well as community serving approach in geological and geotechnical research.

Fiber improved soils may have different application areas such as bearing capacity improvement, low income house foundation and wall improvement, as infilling material behind retaining wall, in railway embankment, in dam embankment, erosion control etc.

.

CHAPTER TWO - LITERATURE REVIEW

2.1. Soil Reinforcement Mechanism

Reinforcing mechanism in soil is the technique where fibers are placed in the soil to improve stability and control deformation (Kumar, 2015). According to the author, strains in the soil mass generate strains and tensile loads in the reinforcements. These tensile loads act to restrict soil movements and thus impart additional shear strength. This result in the composite soil reinforcement system having significantly greater shear strength than the soil mass alone (Kumar, 2015)

Kumar (2015) has identified three methods of soil reinforcements. 1 - Physical methods such as vibration, thermo-electrical, freeze and thaw. 2 - Mechanical method using fibrous materials from Geo-synthetic family (Geo-grid, Geo-textile, Geocomposite, Geo-net, and Geo-cell) and natural fiber groups. 3 - Chemical method using conventional materials, enzymes & polymeric resins. The different soil reinforcement methods are shown in Figure 2.1

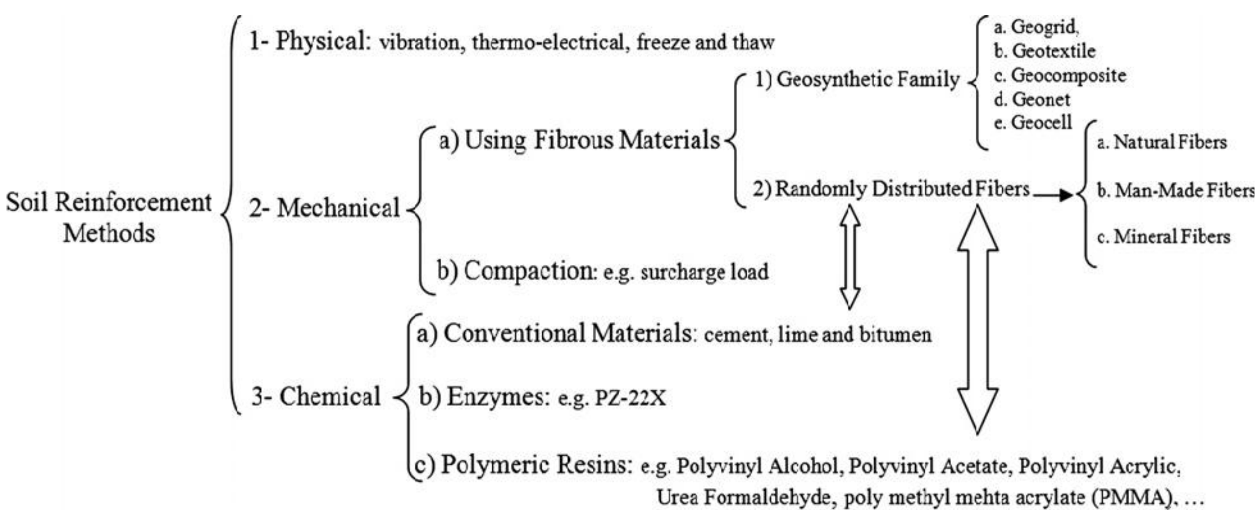


Fig. 2.1. Different procedures of soil reinforcement, after Dhiraj Kumar, 2015

2.2. Mechanical soil reinforcement

Mechanical soil reinforcement method uses improvement by the mechanism of compaction and conjugating with fibrous materials such as geo-synthetic families and randomly distributed fibers such as natural fibers (enset fiber, jute fiber, sisal fiber, etc.,), manmade fibers, and/or mineral fibers (see fig. 2.1).

Natural and synthetic fibers have different applications and benefits. In his review he commented that natural and synthetic fiber in geotechnical engineering is feasible in six fields including pavement layer, retaining wall, and railway embankment, protection of slopes, earth quakes and soil foundation engineering (Hejazi et. al 2012).

Soil reinforcement by fiber material is considered as an effective ground improvement method because of its cost effectiveness, easy adaptability and reproducibility.

2.2.1. Natural fibers

Natural fibers are byproducts and found naturally. When these fibrous materials randomly distributed in composite soil, they can reinforce problematic composite soils mechanically. Use of natural fiber in civil engineering for improving soil properties is advantageous because they are cheap, locally available, biodegradable and eco-friendly. The natural fiber reinforcement causes significant improvement in tensile strength, shear strength, and other engineering properties of the soil (Kumar, 2015). When fibers randomly mixed with soil they increase the cohesion among the soil particles. In addition the interaction of the fibers among themselves and the fibers' flexibility makes them behave as a structural mesh that holds the soil together increasing the soil structural integrity.

Natural fibers such as Jute can improve several weak soils like black cotton soil, organic soils; peats and other clays soils in marshy land and water logged area. The pavement construction on these roads has always been problematic since their bearing capacity is low. For such roads sub-grade soil improvement is recommended (Badavath, 2004).

Advantages of using natural fibers are: there are several different natural fibrous materials that can be used to reinforce the soil, the machinery required is minimal, the fibers can be inexpensive and environmentally friendly, and it can be implemented in all types of soils. This characteristic of the reinforcement method allows it to be easily implemented in large areas (Babu& Vasudevan, 2008).

2.2.1.1. Coconut coir fiber

Coconut coir fiber is one of natural fiber which is used to reinforce problematic soil when mixed with the soil.

The coconut coir fibers are normally 50–350 mm long and consist mainly of lignin, tannin, cellulose, pectin and other water soluble substances. Due to its high lignin content, coir degradation takes place much more slowly than other natural fibers. So, the fiber is also very long lasting, with infield service life of 4–10 years. The water absorption of coir fiber is about 130–180% and diameter is about 0.1–0.6 mm (Rowell M, et, al. 200.). The degradation of coir depends on the medium of embedment, the climatic conditions.

According to Rowell et, al (2000), the diameter of the fibers ranges 10-20 micro meter with specific gravity of 1.15-1.13g/cm and its ultimate tensile strength reaches up to 250 MPa. It retains much of its tensile strength when wet, and it has low tenacity but high elongation.

As Rowell et, al (2000) study, Coconut coir used in black cotton and lateritic soil. After experimental analysis the coir-soil composite soil shows that fibers decrease the maximum dry density of composite soil and it retain 80% of its tensile strength after 6 months of embedment in clay

Coir fiber shows better resilient response against synthetic fibers by higher coefficient of friction. For instance, findings show that coir fiber exhibits greater enhancements (47.5%) in resilient modulus or strength of the soil than the synthetic one (40.0%) (Chauhan et.al, 2008).

According to Ravishankar and Raghavan (2005), a lateritic soil's, maximum dry density (MDD) decreases with addition of coir and its optimum moisture content (OMC) increases with an increase in percentage of coir.

The compressive strength of the coir fiber reinforced soil increased with increasing content of coir fiber up to 1% (by dry weight) While further increase in coir content resulted reduction in the compressive strength (Chauhan et al, 2005).

Khedari et al (2005) introduced a new type of soil–cement block reinforced with coir fibers with low thermal conductivity. Black cotton soil treated with 4% lime and reinforced with coir fiber shows ductility behavior before and after failure. An optimum fiber content of 1% (by weight) with aspect ratio (a ratio of length to diameter) 20 for fiber was recommended for strengthening the black cotton soil (Ramesh et.al, 2010,).

Hejazi et al (2012), studied the suitability of using coir waste as stabilizer for improving the sub-grade characteristics of an expansive soil (LL=52%, PI=24%). The result showed that the CBR value of stabilized soil increased more than 4 fold as compared to untreated soil.

2.2.1.2. Sisal fiber

Sisal fiber is also one of natural fiber used in enforcements of weak soils. According to Mishra et.al (2014), the diameter of sisal fiber is ranges 25-400 µm with specific gravity 1.2-1.45 g/cm and has ultimate tensile strength of 560 MPa. Sisal fiber keeps its 80% of tensile strength after 6 months embedment in clay. Traditionally sisal fibers used as reinforcement for gypsum plaster sheet generally in Brazil, Indonesia and East African countries (Mishra et.al 2014) like enset ventricosum fiber used in Ethiopia.

Ghavami et al (1999) found out that inclusion of 4% sisal, or coconut fiber, imparted considerable ductility and slightly increased the compressive strength of their mixed soil. It also reported that introduction of bitumen emulsion did not improve the bonding between the soil and fibers; but did significantly improve soil durability.

Prabakar and Siridihar (2002) used 0.25%, 0.5%, 0.75% and 1% of sisal fibers by weight of raw soil with four different lengths of 10, 15, 20 and 25 mm to reinforce a local problematic soil. They concluded that sisal fibers reduce the dry density of the soil. The increase in the fiber length and fiber content also reduces the dry density of the soil. As well it was found that the shear stress is increased non-linearly with increase in length of fiber up to 20 mm and beyond, where an increase in length reduces the shear stress. The percentage of fiber content also improves the shear strength. But beyond 0.75% fiber content, the shear stress reduces with increase in fiber content.

Finally, the above researchers conclude that fiber improves the ductility and compressive strength of composite soil fiber mix. The shear strength of composite soil is increased non linear with increase length of fiber up to 20mm as optimum length and 0.75% as optimum fiber content by dry weight of the soil.

2.2.1.3. Palm fibers

Palm fiber is one of natural fiber which has filament textures with special properties such as low costs, plenitude in the region, durability, lightweight, tension capacity and relative strength against deterioration (Yusoff et. al, 2010).

Unconfined compression strength (UCS), California Bearing Ratio (CBR) and compaction tests were performed on neat and palm fiber reinforced soil samples by Marandi et al (2007). They reported that at a constant palm fiber length, with increase in fiber inclusion (from 0% to 1%), the maximum and residual strengths were increased, while the difference between the residual and maximum strengths was decreased. A similar trend was observed for constant palm fiber inclusion and increase in palm fiber length (from 20 mm to 40 mm).

The results of a study conducted by Islam et al (2009) about fiber reinforcement using date palm fibers performed on a silty-sand soil clearly indicated that in the reinforced specimens where the soil grains are replaced by fibers, the fibers control the behavior of the specimen. There was a direct relationship between the fiber length and content and the bearing capacity of the soil. In the study a California Bearing Ratio (CBR) test was performed on 12 different wet samples: two control groups (unreinforced soil) and ten combinations of one of two different fiber lengths (20 mm and 40 mm) and one of five different fiber contents (0.25%, 0.50%, 0.75%, 1.00% and 1.50%). The result shows that there is an increase in CBR value with increasing fiber content in composite soil until the fiber percentage reach to 1%.

Jamellodin et al (2010), noted a significant improvement in the failure deviator stress and shear strength parameters (C and U) of a soft soil reinforced with palm fibers can be achieved. It is observed that the fibers act to interlock particles and group of particles in a unitary coherent matrix thus increasing the strength properties of the soil.

Ahmad et al (2010) mixed palm fibers with silty sand soil to investigate the increase of shear strength during triaxial compression. The specimens were tested with 0.25% and 0.5% content of palm fibers of different lengths (i.e. 15 mm, 30 mm and 45 mm). Reinforced silty sand containing 0.5% coated fibers of 30 mm length exhibited approximately 25% increase in friction angle and 35% increase in cohesion compared to those of unreinforced silty sand. In addition, palm fibers coated with acrylic butadiene styrene thermoplastic increased the shear strength of silty sand much more compared to uncoated fibers.

Sallehan and Yaacob (2010), found that the addition of 3% palm fibers improve the compressive strength of composite bricks. Water absorption test results indicated a small increase in water absorption with the increase in the palm fiber content.

2.2.1.4. Jute fiber

Jute is abundantly grown in Bangladesh, China, India and Thailand. Jute fibers are extracted from the fibrous bark of jute plants which grow as tall as 2.5 m with the base stem diameter of around 25 mm. There are different varieties of jute fibers with varying properties (Swamy N, 1984)

Jute is mainly environmental-friendly fiber that is used for producing porous textiles which are widely used for filtration, drainage, and soil stabilization. For instance, GEOJUTE_ is the commercial name of a product woven from jute fibers used for soil stabilization in pavement engineering (http://www.beltonindustries.com/erosion_short.html.)

Aggarwal and Sharma (2010) used different lengths (5–20 mm) of jute fibers in different percentages (0.2–1.0%) to reinforce soil. Bitumen was used for coating fibers to protect them from microbial attack and degradation. They concluded that jute fiber reduces the MDD while increases the OMC. Maximum CBR value is observed with 10 mm long and 0.8% jute fiber, an increase of more than 2.5 times of the plain soil CBR value.

Islam and Iwashita (2010) showed that jute fibers are effective for improving the mortar strength as well as coherence between block and mortar. Experimental study was conducted by Badavath(2010) on locally available (Doimukh, Itanagar, Arunachal Pradesh, India) soil(44% sand,52% silt, and 4% clay SG 2.6, LL 26, MDD 17.3 and OMC 16.45) reinforced with Jute fiber. In his study the soil samples were prepared at its maximum dry density corresponding to its optimum moisture content in the CBR mould with and without reinforcement (Badavath, 2004)

Badavath (2004) used the percentage of Jute fiber by dry weight of soil as 0.25%, 0.5%, 0.75% and 1%. The fiber lengths were taken as 30 mm, 60 mm and 90 mm and two different diameters, 1 mm and 2 mm were considered for each fiber length. The laboratory CBR values of soil and soil reinforced with Jute fiber were determined. The effects of lengths and diameters of fiber on CBR value of soil were also investigated. Tests result indicates that CBR value of soil increases with the increase in fiber content. It was also observed that increasing the length and diameter of fiber further increases the CBR value of reinforced soil and this increase is substantial at fiber content of 1 % for 90 mm fiber length having diameter 2 mm. Thus there is significant increase in CBR value of soil reinforced with Jute fiber and this increase in CBR value will substantially reduce the thickness of pavement sub-grade.

2.2.1.5. Flax

Flax is one of the natural fiber used in many countries. According to Segetin et al (2007) the ductility of the soil–cement composite is improved with the addition of flax fibers. An enamel paint coating was applied to the fiber surface to increase its interfacial bond strength with the soil. Fiber length of 85 mm along with fiber content levels of 0.6% was recommended by them.
Due to improving potential of flux after research finding, ‘‘Uku’’ is product of flax fiber-reinforced, stabilized and rammed earth walled housing system that has been recently designed as a building material.

2.2.1.6. Barely straw

Barley straw is widely cultivated and harvested once or twice annually in almost all rural areas in all over the world and could be used in producing composite soil blocks with better characteristics. It is important to know that during the Egyptian times, straws or horse hairs were added to mud bricks, while straw mats were used as reinforcements in early Chinese and Japanese housing construction (Bainbridge B, and Athene S,) <http://www.osbbc.ca>. According to them, from the late 1800s, straw was also used in the United States as bearing wall elements. Bouhicha et al (2005) proved the positive effects of adding straw in decreasing shrinkage, reducing the curing time and enhancing compressive strength if an optimized reinforcement ratio is used. Flexural and shear strengths were also increased and a more ductile failure was obtained with the reinforced specimen.

Natural fibers including wheat straw, barley straw and wood shavings were used by Ashour et al.(2010) to make a novel plaster material composed of cohesive soil and sand. They noted thatwhile fibers have remarkable effect on the strength and ductility of plasters, their effects on the elastic modulus of plasters are relatively small. Abtahi et al. (2010) showed that barley straw fibers are effective on the shear strength of the soil. The optimized fiber content was 1%.

2.2.1.7. Bamboo fiber

Bamboo fiber is important because the root rhizomes of bamboo are excellent soil binders which can prevent erosion (Lin et al, 2010)**.** Bamboo fibers are remarkably strong in tension but have low modulus of elasticity about 33–40 KN/mm^2 and high water absorption about 40–45% (Kozlowski, 2011). The tests undertaken by Coutts (1995) showed that the bamboo fiber is a satisfactory fiber for incorporation into the cement matrix of soil.

2.3. Origin and Formation of Residual Soils

Residual soils are derived from the in situ weathering and decomposition of rock which has not been transported from its original location. Particles of residual soil often consist of aggregates or crystals of weathered mineral matters that breakdown and become progressively finer if the soil is manipulated (Blight, 1997). Residual soils are affected by mainly Weathering process, Climate and Topography

Weathering process

Residual soils are formed by the in situ weathering of rocks, through Physical, Chemical and Biological processes. Most commonly, residual soils are formed from igneous or metamorphic parent rocks, but residual soils formed from sedimentary rocks are not uncommon. Chemical processes tend to predominate in the weathering of igneous rocks, whereas physical weathering are so closely interrelated that one process never proceeds without some contribution by the other (Blight,1997).

Physical weathering includes the effect of such mechanical process as abrasion, expansion and contraction. Physical weathering produces end products consisting of angular blocks, cobbles, gravel, sand, silt and even clay sized rock flour. The mineral constituents of all these products are exactly like those of the original rock. Chemical weathering, on the other hand, results in the decomposition of rock and the formation of new minerals.

The chemical changes operating in primary minerals of the rocks in temperate or semitropical zones tend to produce end products consisting of clay minerals predominately represented by kaolinite and occasionally by Halloysite and by hydrated or dehydrous Oxides
of Iron and Aluminum

Chemical weathering is favored by warm humid climates, by the process of vegetation and by gentle slope. Thus, tropical and subtropical regions of low relief with abundant rainfall and high temperature are the most susceptible to chemical alterations. Deep, strongly leached red,brown and yellow profiles are manifestations of the effects of sever chemical weathering. Under conditions favorable to tropical weathering, the weathering processes may be so intense and may continue so long that even the clay minerals, which are primarily hydrous aluminum silicates, are destroyed. In the continued weathering the silica is leached and what remains consists merely of Aluminum Oxide such as Gibbsite, or of Hydrous Oxide such as Limonite or Goethite derived from the Iron. This process is known as laterization.

Climate

Climate exerts a considerable influence on the rate of weathering. Physical Weathering is more predominant in dry climates while the extent and rate of chemical weathering is largely controlled by the availability of moisture and by temperature. The clay minerals of the soils of the world changed in predictable way with distance from the equator.

Climate has a further effect on the properties of tropical residual soils. In sub humid tropical and subtropical areas water tables are often deeper than 5 to 10 m and the effects of unsaturation, desiccation and seasonal or longer term rewetting have to be taken into account in geotechnical design.

Topography

Topography controls the rate of weathering by partly determining the amount of available water for each zone of weathering. Precipitation will tend to run off hills and accumulate soils in valleys and hollows. Soil profiles developed from basic Igenous Rocks on hillsides the depth of weathering increase down the slope where as Kalioite / Hallosite are the predominant clay minerals at the top of the slope and Smectite at the bottom of the slope (Blight, 1997).

2.3.1. The engineering characteristics of lateritic soils

In many countries of Africa and Asia, lateritic soils are the traditional materials for road and airfield construction. Though a good deal of literature is available on lateritic soils and several excellent reviews have been prepared on lateritic soils (Lyon, 1971)

The available data on lateritic soils gives the impression that the red color seems to have been accepted by most authors as the most important property by which these soils could be identified. Other obviously significant basic physical properties such as texture, structure, consistency, etc., often were ignore . It is also noted that the lack of uniformity in pretreatment and testing procedures (resulting from association with different standards in different parts of Africa) makes it difficult to compare even textural data on the same soils. It is noted that three major factors influence the engineering properties and field performance of lateritic soils. These are; 1, Soil forming factors (e.g. parent rock, climate vegetation conditions, and topography and drainage conditions). 2, Degree of weathering (degree of laterization) and texture of the soils, genetic soil type, the predominant clay mineral type and depth of sample. (Lyon, 1971).

Climate and topography influences the rate of weathering. Physical weathering is more pronounced in dry climates, while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature. Topography on the other hand, controls the rate of weathering by partly determining the amount of available water and the rate at which it moves down through the zone of weathering. It also controls the effective edge of the profile by controlling the rate of erosion of a weathered material from the surface. Hence deeper profiles will generally be found in valleys and on gentle slopes rather than high ground or steep slopes (Blight, 1997).

2.3.2. Chemical, mineralogical and physico- chemical characteristics

A distinctive feature of laterite and lateritic soils is the higher proportion of Sesquioxide of Iron and/or Aluminum relative to the other chemical components. The amount of Alumina or Iron Oxides is an important factor in differentiating Aluminous and Ferruginous varieties. The base (alkalis and alkaline earths) is almost absent in lateritic horizons, except in some Ferruginous crusts developed in alluvium and some concretionary horizons in Ferruginous tropical soils. Other lateritic constituents are Manganese, Titanium, Chromium and Vanadium Oxides.

The mineralogical constituents can be divided in two major elements, which are essential to laterization, and minor elements, which do not affect the laterization process. The major constituents are Oxides and Hydroxides of Aluminum and Iron, with clay minerals and, to a lesser extent, Manganese, Titanium and Silica. The minor constituents are residual remnants or elastic material. The clay mineral most common in lateritic soils is Kaolinite. Halloysite is also reported. Illite and Montimorillonite are rare. The secondary minerals resulting mainly from the laterization process are Gibbsite, Goethite, Limonite and Hematite. Neither Manganese nor Titanium minerals were observed in significant amounts.

3. CHAPTER THREE - GENERAL ASSESSMENT AND OVERVIEW OF THE STUDY AREA

3.1. Location of the study area

The study area is located in Wolaita Zone, southern Ethiopia, and West of Hawassa town. This zone is bounded by Kambata Tambaro and Hadiya Zones in the North, by Gamo Gofa zone in the South, by Sidama zone in the East and by Dawuro zone in the West. It falls within coordinates of 37 N 0303495-37 N 04044577.86 and UTM 0718632.96-UTM0794863 &/or 6^{o}30'18.3"-7^{o}11'19.3"N and 37^{o}13'16.11"-38^{o}08'00.87"E; and the total area of the zone is 4511.66 km^2.

To go to Wolaita from Addis Ababa, it has two options of roads access; 1) Addis Ababa - Ziway-Shashamene - Wolaita Soddo (380 kms) and 2) Addis Ababa -Butajira- Hawassa- W/Soddo (330kms) are alternative ways that leads to the project areas.

In the Wolaita, the project area is located West direction from Wolaita Sodo town, to Hawasa. The project by itself named as Moricho-Dimtu-Bitena-Sodo Design and Build Road Project. Main contractor- Hunan Huandan Road and Bridge Corporation China (HHRBCC) and minor contract, Bitena-Mayo Kote-Zalal Yesus-Sodo and MayoKote-Delbo Junction to Alaba -Sodo road which comprise 48.3 Kms.

A selected road section for investigation is selected from minor contractor area (Bitena-Mayo Kote-Zalal Yesus-Sodo and MayoKote-Delbo Junction to Alaba -Sodo) is Mayo Kote-Zalala Yesus, green rout I. (fig. 3.1, 3.2 and 3.3).

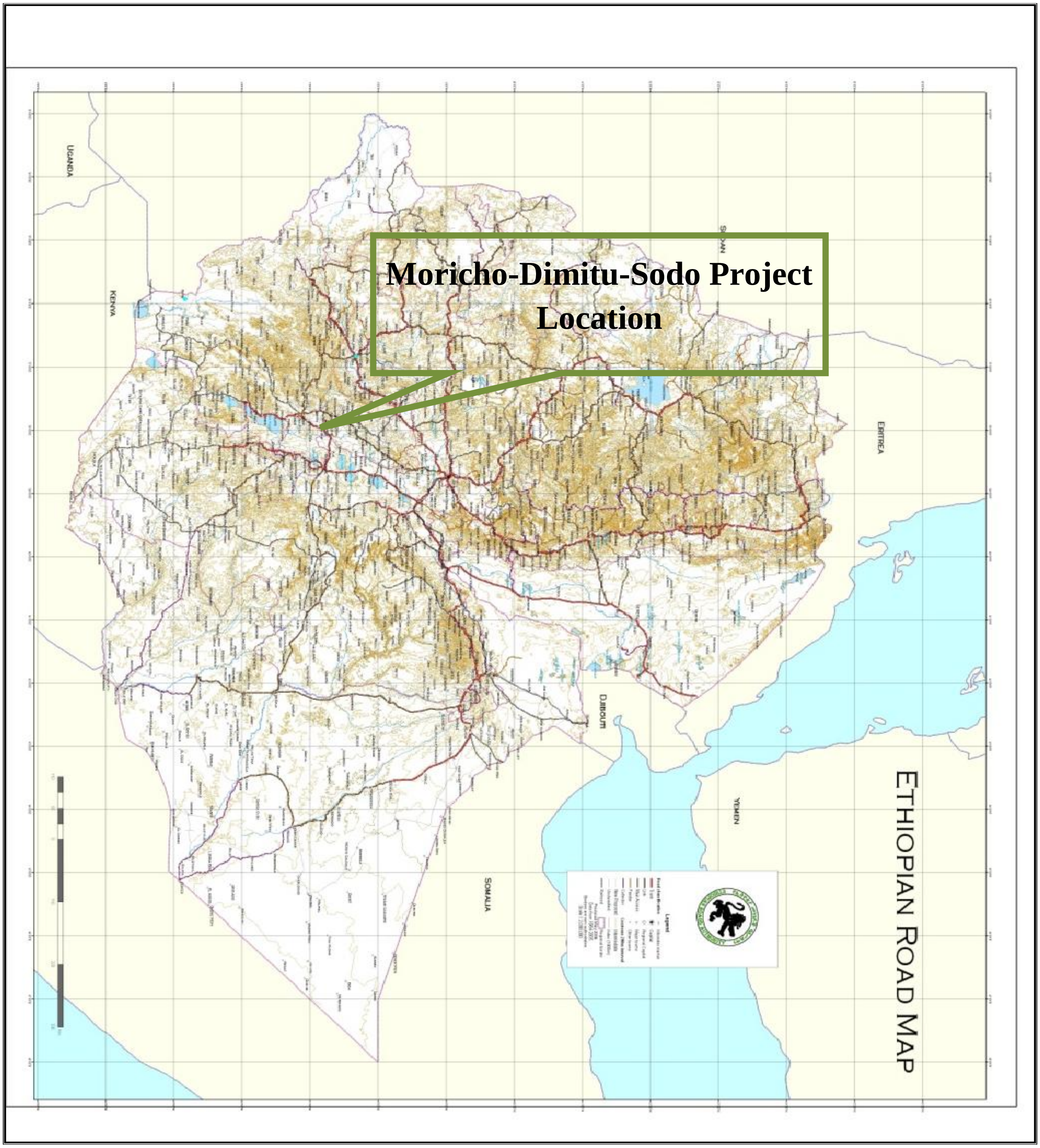


Fig. 3.1. Project location map

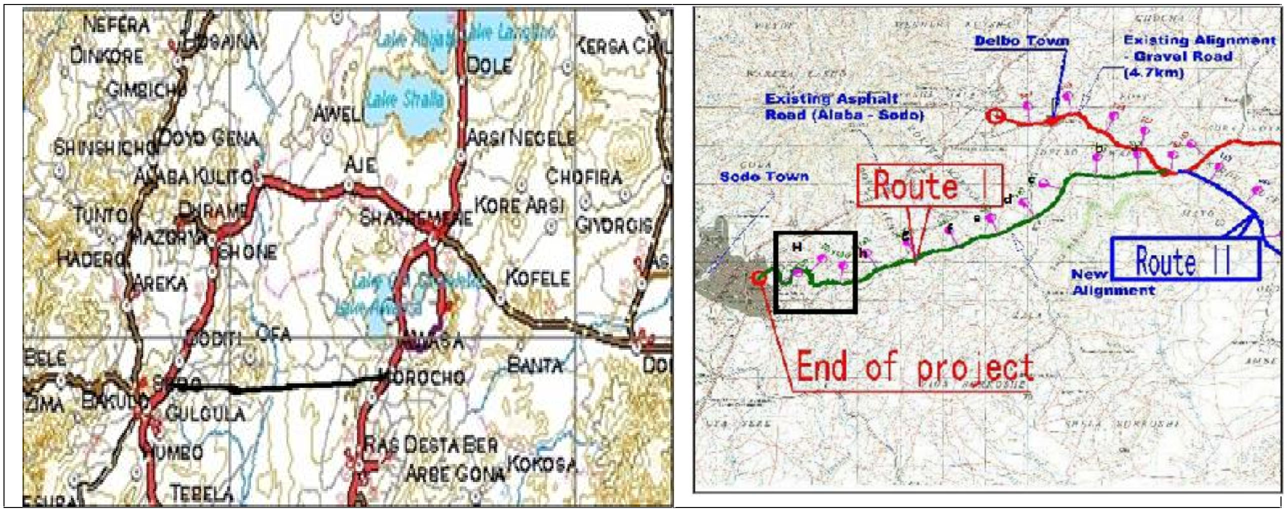


Fig. 3.2. Project location map, a) crop cut from b) hand sketch from fig.3.1.

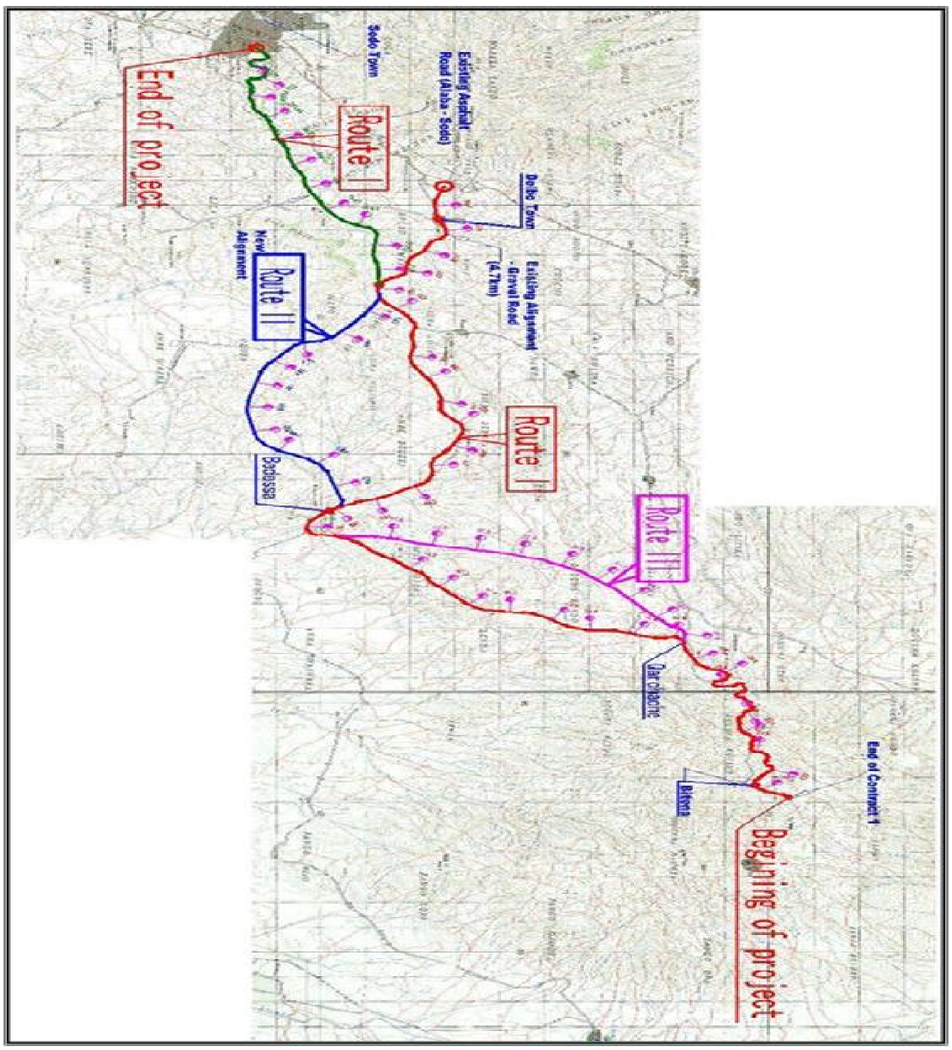


Fig. 3.3 Project road route sketch(from Soddo to Hawasa)

3.2. Regional geology

MER (main Ethiopian rift) extends in NNE /NE-SSW/SW direction from southern Afar rift (9º30'N) to (5º15'N) in southern Ethiopia (Gabriel, 1999). It is closed lakes basin of Awassa, Abaya- chamo, and chew bahir. The dominant geology of this part of the main Ethiopian rift consists of almost all types of volcanic rocks.

The Precambrian basement rocks in the region is out cropped in south of Amaro and Burji. These out crops are biotite, hornblende, gneiss and quartz feldsphatic gneiss. Tertiary formations include trachytes of Damot mount skewing to North West of the study area, rhyolites outcropping to west of Lake Abaya, basalts on southwestern margins of Gidole–Chencha-Wajifo-Humbo, and southeastern margins of Ageremariam-Cheleclectu-Yirgachefe–Dilla areas and, ignimbrites covering around Agereselam- Aleta wondo and Hosanna areas. (Wolde Gabriel., 1999)

As Wolde Gabriel (1999) discussion, Quaternary formations with in southern main Ethiopian rift valley includes Pleistocene basalts around Lake Abaya and Chamo, volcano sedimentary rocks and lacustrine deposits covering rift floor, ignimbrites around Humbo- Sodo –Boditti- Hossana areas and recent rhyolites in Bilate and Gidabo basins and Hossana areas, and pumices of rift floor between Aje, Alaba to NNW-SSE direction.

3.2.1. Geology of the selected road section area

Though several researchers in the region have carried out some regional geological studies, locally no detail works are present. However some geological information is taken from regional scale works of Raunet, 1978, Kazmin, 1979, G.Wolde Gabriel, (1999).

Main lithologic units in the project area range in the age from Tertiary to Holocene. They include: alkali basalts of trap series (Solko mount top), Pliocene trachyte of Damot top, Pliestocene ignimbrites, rhyolitic flows, lacustrine deposits and fissured alkali basalts with associated cones, and Holocene rhyoloitic flows, obsidian and pumices. Correlation of the rocks of the catchments with that of regional is given below (Table 3.1).

Table 3.1 correlation of regional geology with the catchments (after Abriham Asha, 2008)

Regional geology	**Local geology**
Holocene formations	Hobicha acidic flows
Pleistocene basalts	Fissured basalts of lowlands
Pliestocene lacustrine deposits	Lacustrine deposits of Abela
Pliestocene ignimbrite	Ignimbrites of soddo and Humbo
Pleistocene rhyolites	Hobicha rhyolites
Pliestocene pumice	
Tertiary trachyte	Damota trachytes
Tertiary rhyolites	
Tertiary basalts	Solko mount basalts
Tertiary ignimbrites	
Precambrian rocks Gneiss and schist	

Trap series alkali basalts

Trap series basalts in the area is the pre- rift basic volcanic rock unit correlates with the same series basalts of chencha, and yirgachefe area within the Abaya-Chamo Lakes basin (Raunet, 1978).

Trachyte lava

This unit covers the most highland peak at altitude of above 2908masl that overlooks the town of soddo and is the unit in the most recharging part of the catchments. Damot Mountain is the dome like structure formed by piling of two types of trachytes (Yodit Tefera, 2005) and ignimbrite unit exposed at eastern and southeastern foot of the mountain due to the road cut. The northwest and west skewing of the dome is probably due to dominant flow of trachytes to one side. The trachyte lava extends about 6kms from the top of the mountain towards northeast and along the regional western margin of the MER and 2kms towards the study area. Yodit Tefera, 2005, also analyzed the unit from mountain top as, two types based on plagioclase, quartz, and k-feldspar contents and the matrix is constituted by fine-grained plagioclase set in the minerals of olivine and pyroxene. But western part of the foot of the mountain and southern part are covered by ignimbrites (G.wolde Gabriel, 1999). He also presents the analysis results of the unit as silica rich with SiO_2 of more than 76%.

Ignimbrites

Ignimbrites of early Pleistocene cover wide area of northern, western, eastern and southern parts of the study area along highly cultivated Humbo-Soddo – Boditti regions with red soils underlying it on hilly landform. The formation is light colored and hard consolidated in areas where no secondary fractures occurred.

The flow took place into pre-existing valleys of the escarpment and also it climbs to mountains revealing that they are occurred after trap series (Rauneth, 1978). The formation is roughly stratified and prismatic with great many quartz grains appearing on the surface.

From geophysical survey of VES 1 and 2(refer to VES points on hydrogeological map), this unit is underline by thick clay soil of >35meters thick around highlands. The clay soil thickness decreases up to <1meter in lowlands near Humbo (Abriham Asha 2008). As to the information from VESes, formation is intercalated with clays, tuff, breccias and pumice.

Rhyolitic flow

This unit outcrops around calderaic collapse of Hobicha ridge. Berhane *et al*., (1978) described it as the remnant wall of the volcano tectonic sub-circular collapse of the Pleistocene age. From field observation, the rolling topography from soddo Damot towards Abaya Lake is interrupted by the rhyolitic flow of the Hobicha and Wanche ridges, indicating that this formation occurred latter. It is compact, porphyritic rhyolitic lava flow in association with obsidian intrusion and pumice ejecta and formed mainly from minerals such as pyroxene, olivine and apatite (Gezahagn Y, 1980).

Lacustrine deposits

A lacustrine deposit consists of deposits left behind by Lake Abaya when it occupied larger area and higher level (Gezahagn Y, 1980) 4-5kms from Humbo town on soddo–Arbaminch asphalted road. It hasn't been affected by Holocene tectonic activity; and covers area of about 40-60km^2 where there is intensive agricultural practice. This deposit is observed at deep and straight gullies to be vertically exposed with sections of silty clay, weathered pumice mixture rounded gravels, scoracious fall and others indicating that it is of detrital and volcano lacustrine.

Fissured alkali basalts and associated scoria cones

They are recent basaltic flow outcropped on the southern lowlands of the study area at the adjacent sides of the rift floor that form southeastern boundary of the catchments. These are younger basalts that differ from Tertiary basalts in that they are unweathered and cut by Holocene tectonics trending NNE-SSW (Gezahagn Y, 1980). The assemblages of the unit are mainly olivine, clinopyroxene and apatite (Gezahagn Y, 1980). Vesicular basalt separates from the underlying massive basalt by 2-meters thick scoracious material. Friable scoria that is the last activity of the basaltic volcanism covers wide area in lowlands. The extremely abundant cones around lowlands, indicating linear trend along NNE-SSW observed to be older than Holocene tectonics that split the area and also some of the scoria cones

Recent acidic lava flows of Hobicha and associated pumice fall.

The recent acidic volcanism forming well defined mountainous massifs of Hobicha are result of pilling of viscous acid flow of rhyolites and obsidians with associated pumice ejecta. The flow ends in steep slopes towards Lake Abaya at south of the massifs covering the wonji fault belt as observed in the field.

3.2.2. Tectonics

The Tertiary Quaternary tectonic system known as the east African rift system is one of the largest structural features of the earth’s crust extending for a distance of about 600kms from Mozambique to Syria. The African rift system is most typically developed in Ethiopia in the section known as Main Ethiopian Rift (MER) (Mohr, 1964), which extends from Lake Chamo in south to Afar in north. MER system extending from Afar (NE/NNE) at 9º30’in North to Konso highlands SW/SSW 5º15’in South. It is divided into three geographical features represented by northern (Fentale to Nazreth), central (Nazreth to Awassa), and southern (Awassa to Konso) sectors (G. WoldeGabriel et al, 1999). Northwestern part of Lake Abaya basin is with in southern part of the MER where the study catchment is located.

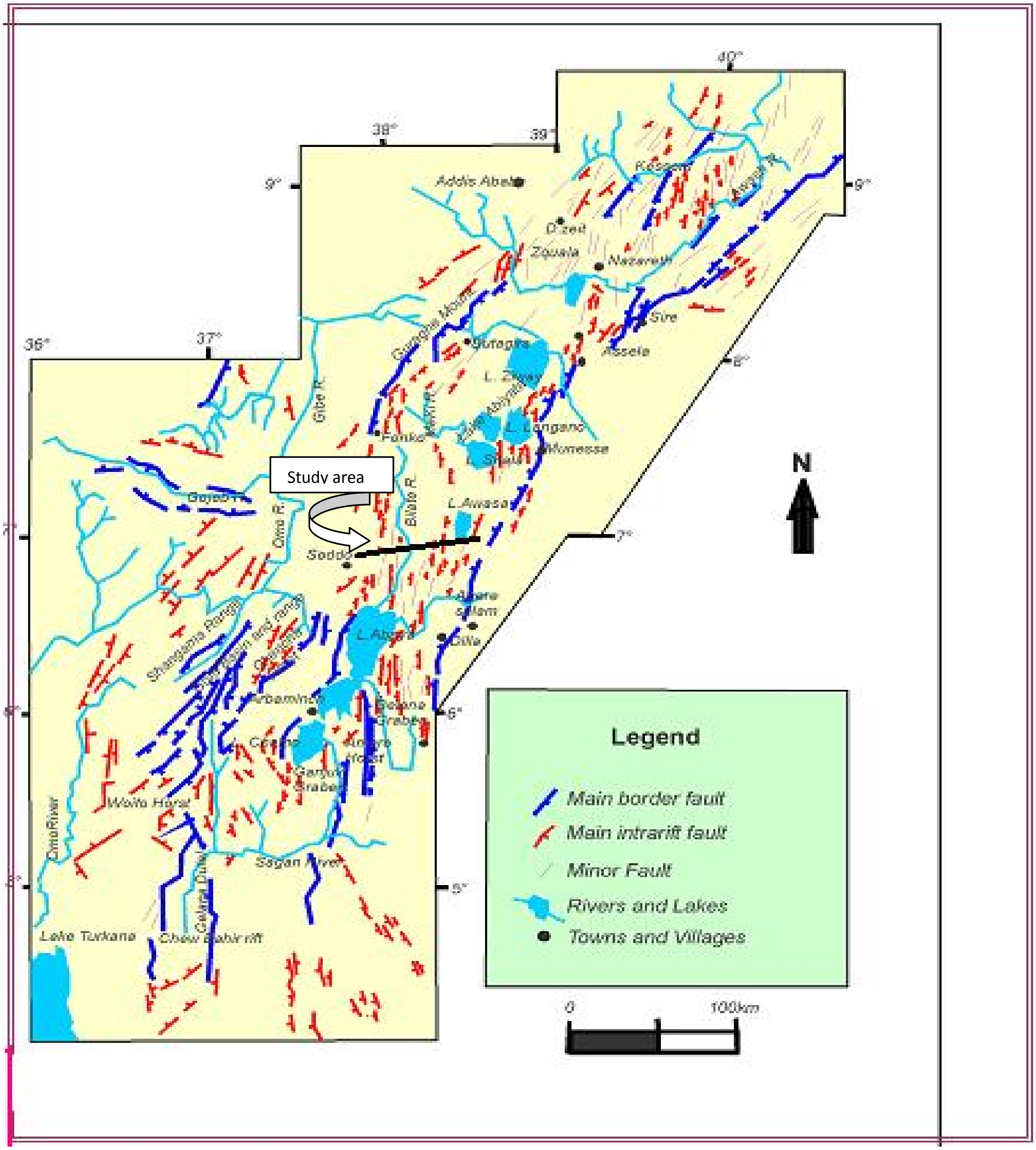


Fig. 3.4. Structural map of MER (after Boccalet et. al,1998 in Abriham Asha, 2008)

There are two distinct fault systems occurring in the MER recognized by long time; they are: 1) Tertiary boarder fault systems that define rift margin extending mainly NNE-SSW 2) Right stepping en-echelon faults constituting the so called “wonji fault belt”(Mohr, 1960,1967;Mohr and Wood, 1976; Gabriel et al, 1990).

The wonji fault belt affects the rift floor branching -off from the eastern rift margins and affecting the Quaternary volcanic products and is the recent tectonic systems of the MER (Boccaletti et al, 1998) (fig 3.4).

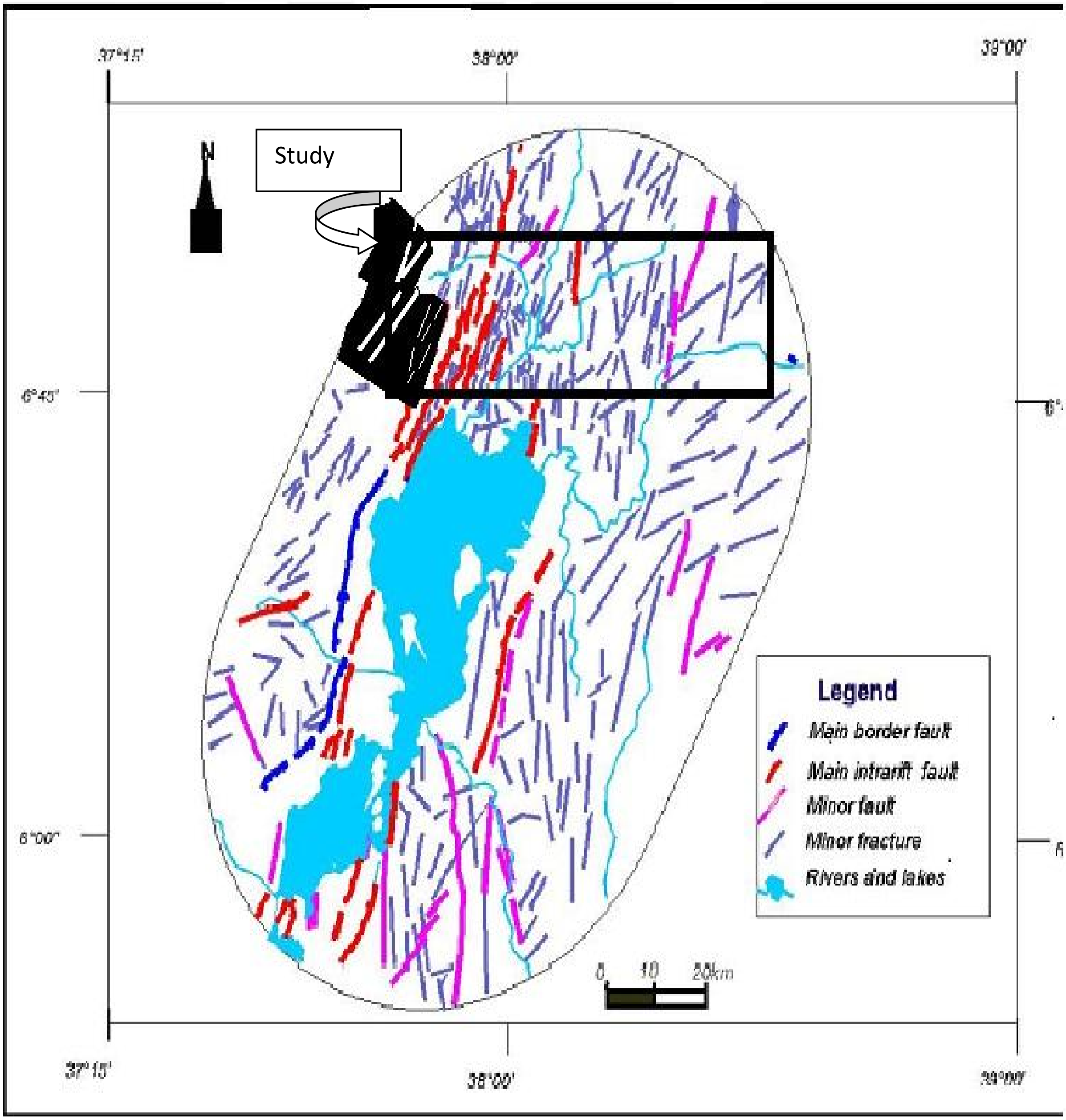


Fig 3.5 Structural map of lake Abaya area (after Bekele Abebe et al, 1992).

Accordingly, tectonics with in and around the boundary of the catchments is of two types; that are end Tertiary and Quaternary tectonic systems.

Tertiary tectonics in the area includes long faults, running NNE-SSW, which are sometimes parallel between mountain relief and plains which go down to lakes. This long fault passes through Chencha, Boreda, Soddo with some interruptions around wajifo, and passes to south of Hosanna with E-W fault system occurring to SE of Wagabeta calderas; and margin rift fault continues towards Guraghe highlands with interruption around Butajira town to west of lake ziway. From Soddo town, with direction of NE-SW or E-W towards Duguna Mountain, some minor faults and fractures of Tertiary tectonics is forming northern boundary of the catchments.

Quaternary tectonic system in the area includes sub-circular caldaria collapses and wonji fault en-echelon swarm fault series. The sub-circular collapses are observed in two areas within the study area: the first is the one that forms NE boundary of the catchments, faces to east with northern rim of Duguna mountain which is out of the study area and southern rim Hobicha rhyolitic ridge of the same series. This sub-circular collapse cuts the Pleistocene ignimbrites with the displacement about 60-200meters with a diameter of 12kms, and the second is within the median part of the catchments which has NE rim at south of Hobicha and SW rim ends at eastern face of the Humbo (Solko mountain) which is clearly seen standing from southwestern part in the field (refer to geologic map). This structure faces towards south and passes through southern Hobicha–north of Humbo town cutting the asphalt road to east of Solko Mountain.

3.2.3. Regional Hydrogeology

Wolaita zone has two river basins Blate and Omo river basins. Bilate basin is covered by volcanic rocks that have different Hydrological properties due to different in their texture, lithology, primary and secondary geological structures hence the geological formation that exists in this area have different water bearing capacities (Abriham Asha, 2008).

In Bilate basin ground water leaves the aquifer formations in subsurface in the form of spring's pumpage from wells evapo-transpiration and out flow from this river to Lake Abaya. Many springs discharge ground water to land surfaces from mainly along the fault and fracture zones at higher rates in the escarpments and most are scattered along fault scarps in west and north of the Soddo area across the project road alignment.

According to department of water, mine and energy, ground water and natural spring assessment study shows shallow ground water discharge is featured by the springs on the slopes and foot of adjacent escarpments as well as hand dug wells. On other hand, in Omo river basin the ground water resource is mainly focused different springs. For example kindo koyisha and kindo didaye woredas, lower zones of Omo river basin, are rich in spring resource. Fractured ignimbrite and basalts are the aquifers of these springs.

3.2.4. Physiographic, Drainage, and Climate

Physiography: The study areas are composed of rugged, undulating mountain, rolling hills, plateaus and plains, gorges that extend up and dawn to low land of Humbo - Fango -Gelechecha area (project area) and Bolso Bombe of Mole settlements Boloso Sore in Afama Bancha, Korke Dog keble (Near to project area) . Damot Gale ,Damote Sore and Soddo zuriya Woredas are dominated by flat lands, plains, midlands and some parts with gorges.

Climate and rainfall: According to weather condition this zone receives maximum rainfall from July to September and it ranges from 801-1600 mm while the average temperature varies from minimum 15.1 ^{0}c to maximum 31 ^{0}c. Wolaita zone is categorized under rift valley and in terms of agro ecology the area is 14% highland (Dega), 56% is mid land (wein adega) and 30% lowland (kola).The altitude ranges from lowest at the foot Omo river 501m.a.s.l. to highest 2950 m.a.s.l at peak of mounta in Damota.

Climate plays a great role in influencing moisture contents of sub-grade and sub-base soil. parameters such as rainfall, temperature, relative humidity, evapotranspiration and wind speed, which are very important to evaluate the sub-base soil is soaked by infiltration water or increased ground water table.

The rainfall pattern in the project area is bimodal, that is because Ethiopia is situated under the influence of Inter Tropical Convergence Zone (ITCZ). When the ITCZ just moves from South to North the small "Belg" (March-April) rains prevail (be happening) in the project area. When the ITCZ zone is beyond the Northern boundary heavy "Kiremt" rains prevail. The rainfall levels on average of 1300mm/year and frequently reaching values as high as 1800-2000mm/year, around the mountainous area.

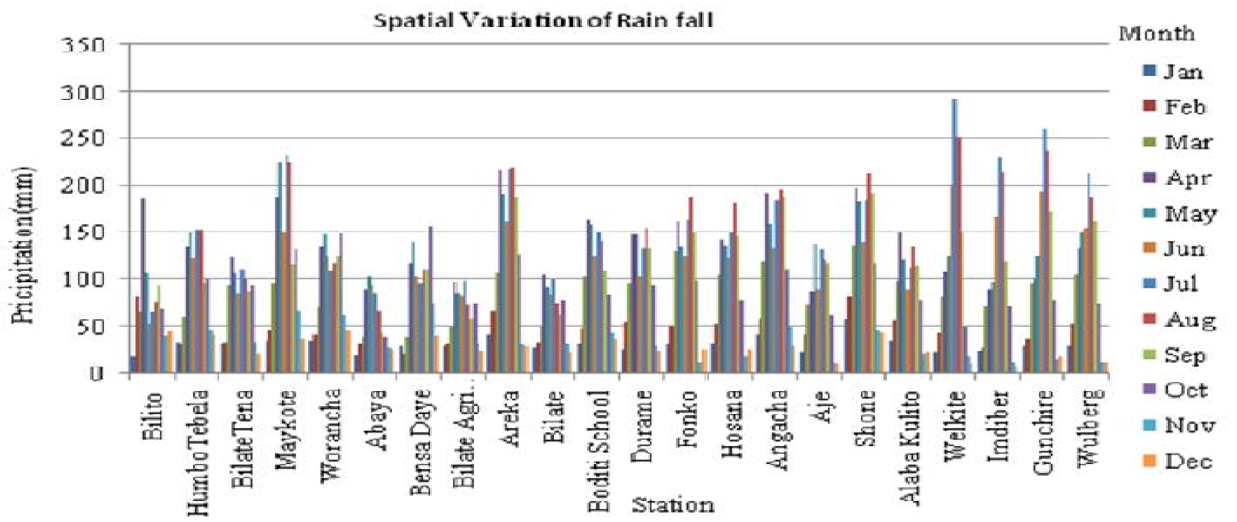


Fig. 3.5 Mean monthly precipitations in the study area and nearby meteorological stations Tesfaye Tesema, 2010.

Based on altitude and temperature of Ethiopian, Mapping Agency classified five climatic zones. Table below shows classification of climate zone based on Altitude and Temperature presented by Ethiopian mapping Agency (1981) in the National Atlas of Ethiopia, p14.

Table 3.2 classification of climatic zone, from National Atlas of Ethiopia, p14

No	Altitude (m.a.s.l)	Temperature (^{o}c)	Climate Zone
1	Below 500	30-40	Desert (Bereha)
2	500-1500	About 30	Tropical (Kolla)
3	1500-2300	15-20	Sub Tropical (Weina Dega)
4	2300 -3300	10-15	Temperate (Dega)
5	3300 & above	10 or Less	Alpine (Kur)

Based on the above classification, Wolaita has (three**)** climatic zones such as Tropical/Kolla (Abaya lake, Bele, Bedesa, Bombe Towns areas etc), Sub Tropical /Weina Dega (the plateau areas of the zone) and Temperate/Dega (Mount Damot & other mountainous Areas).

Drainage: Wolaita zone mainly comprises two basin systems. These are Omo and Bilate basin. The Omo drainage system is controlled by geological structures. In the zone most of the Streams and/or rivers are originated from Mount Damot and some streams flow towards Rift valley Basin via project area to (Abaya Lake) and some others flow towards Omo River Basin.

And the Bilate River basin (project area acrosses) flows from the Gurage Mountain in the north towards the south in to the Lake Abaya. It is perennial rivers such as Bilate, Hamasa .Bisare Gelana that flow in to the Lake Abaya. Generally many small streams drain towards Abaya Lake along With Bilate River. Most of its tributaries as well as large volume of water comes from, Wolaita zone high lands of the catchment. The increase downstream could be influenced by the corresponding low rainfall, high evapotranspiration, relatively slow drainage and thermal springs that join the river downstream. The drainage density is high in the plateau and escarpment area and very low in the rift floor.

Land Use, and Land Cover

Large area of the land of Wolaita is intensively cultivated. These areas are used to grow cereal crops like teff, false banana (Enset) and cash crops like coffee, and cereal crops and others.
The growth of vegetation, whether natural or cultivated, depends on the availability favorable soil conditions and sufficient soil moisture. Generally the natural dense vegetation cover in the study areas is very poor and most of mountainous steep slope areas are exposed to serious erosion problem (Especially mount Damot).

Presently in the study area the high lands and mid highlands consists scarcely scattered Eucalyptus trees, Bushes, while scattered acacia and scrubs cover the lowland areas (Bedessa Area).

According to the information taken from the elders living in the study area before a few years ago most of the mountainous areas were covered with lush (green) vegetation, but now man is destroyed it. Generally the vegetation cover is decreasing from time to time and now it is in a very dangerous condition. The main causes for destruction of forests in the study area are:- Cleaning in order to farm (largely), Cutting and using woods for furniture and for fuel in household level (less), and Over grazing(least). This is due to having high population density and increasing time to time. Hence luck of farm land, competition for nature is increasing.

3.3. Soil of selected road section

The road section is selected from the project road and different tests and visual characterstics are done for the current research work. A selected road section for investigation is selected from minor contractor area (Bitena-Mayo Kote-Zalal Yesus-Sodo and MayoKote-Delbo Junction to Alaba -Sodo) is Mayo Kote-Zalala Yesus, green rout I (figure 3.6)

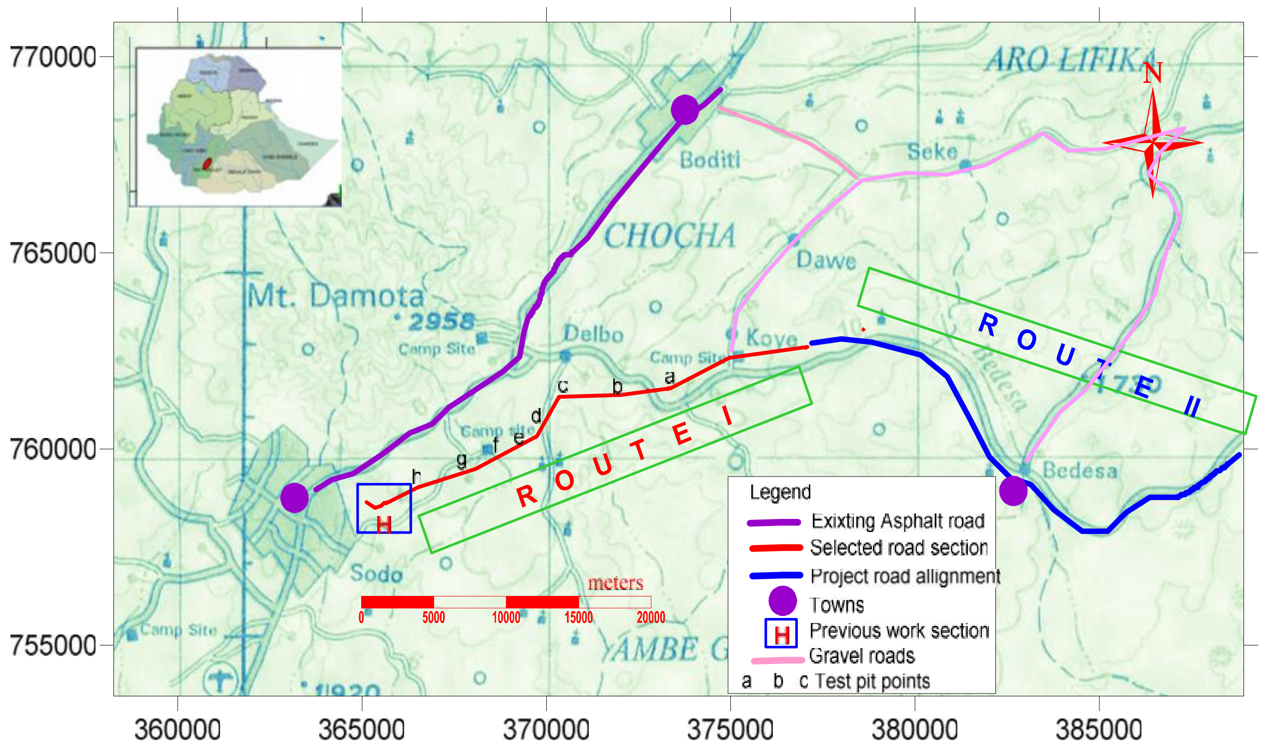


Fig. 3.6. Sketch map of selected road sections and sample location (crop cut from fig.3.1)

Rout I is the selected road section for the research work. The sample was collected from pit sites **a, b, c, d, e, f, g** and **h.** Pit point **d** (the worst problematic soil) is selected for soil-fiber mix investigation. From **H** different index, chemical and design parameters are collected as secondary data.

Physical characteristics of soil

The color of soil stady area is red brown in dry condition while dark red brawn in wet condition. Visually inspected almost similar soil color, dominantly red brown soil, start from the nearby town Bodity (370km far from Addis) dominantly covers Soddo – Houssan , Soddo – Chida, Gamo Goffa and Sodo –Hawasa (current project area) road direction. A color of the soil is shown in figure 3.7.

Figure 3.7 road cut and its color

In the red brown lateritic soil, there is 0.5m thick, brownish white, horizon intercalation in depth from 0-4m from the surface across road alignment. This intercalated soil has good engineering characters tics in relation to the red brown horizon. It has LL 42%, PL 31, PI 12, MDD 1.46g/cc, OMC 18, Swell 3% and CBR at 95% MDD 5. This soil is the product of pyroclastic Pliestocene pumice which is correlated with regional geology rocks. This layer is pinch out in lower area toward to the sodo town.

At foots of Damota mountain and its surrounding, dark reddish brown and reddish brown clay soil are developed on recent volcanic deposits of trachyte, ignimbrite and ash, which form the gently undulating plain characteristics of the large area. The thickness of these soils ranges from 5m to 100 m at the foot of mountains and river valleys.

The soil type is closely related to soil parent material and its degree of weathering. The main parent materials are Trachyte, Rhyolite, Basalt, Ignimbrite and Volcanic Ash (Mengesha et al., 1996)

Fig. 3.8 Weathered pyroclastic Pliestocene pumice intercalation.

According to Hanna (2008), the soil of the project area is lateritic. Residual soils are derived from the in situ weathering and decomposition of rock which has not been transported from its original location. Particles of residual soil often consist of aggregates or crystals of weathered mineral matters that breakdown and become progressively finer if the soil is manipulated (Blight, 1997).

Residual soils are affected by: Weathering process, Climate, Topography. The dominant weathering process can be obtained by area climate data (average annual rain fall and temperature). As mentioned in previously, the project area has average mean annual temperature 23 c^o and average mean annual rain fall about 130 cm. By using the figure 3.9 the dominant weathering process is identified as transitional zone from moderate to strong chemical weathering (fig. 3.6).

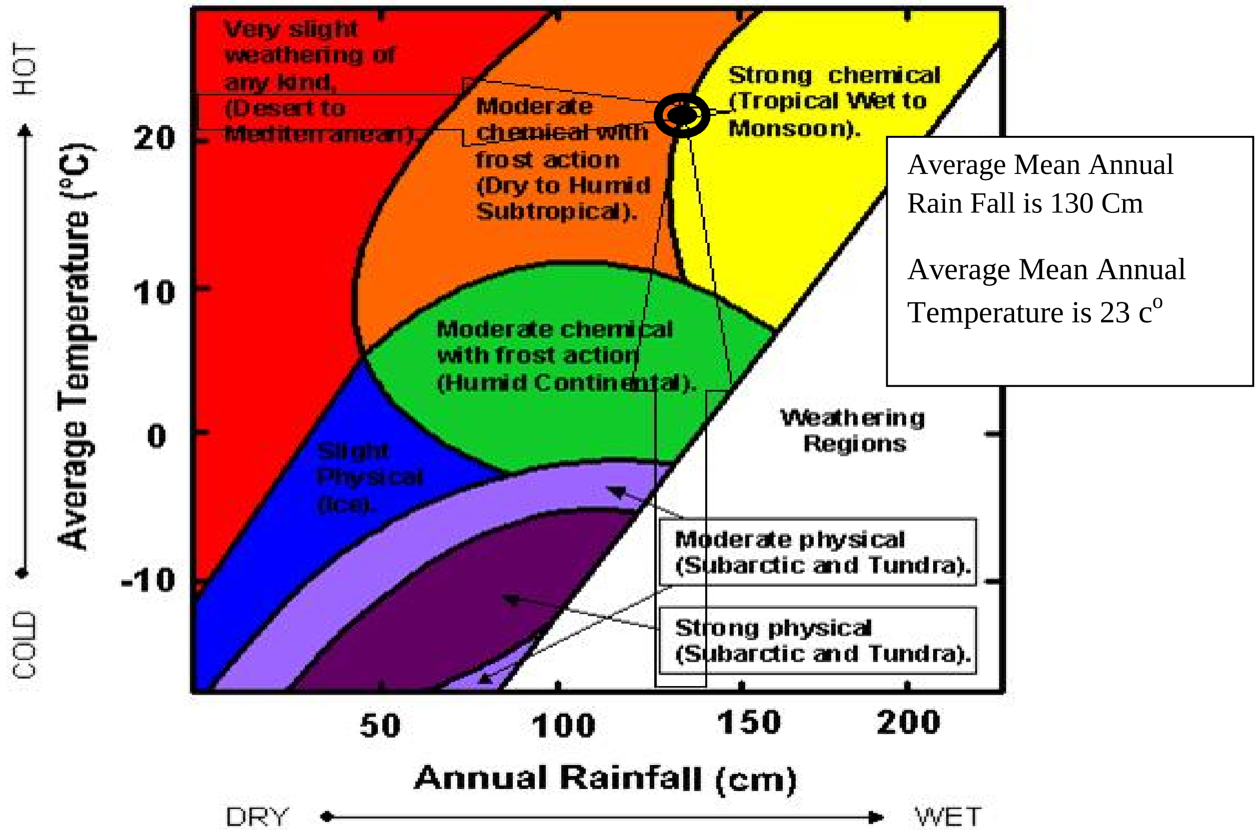


Figure 3.9 dominant weathering type of the project area.

According to Hanna (2008), in the area **H** (in fig. 3.6)**,** the mineralogical weathering products of parental rock and oxide composition of soils are given in figure 3.10 and table 3.3.

TP5	-1.50 m	Quartz low Pyrophyllite	SiO_2 $Al\ (Si_2O_5)(OH)$
TP5	-2.00m	Albite calcian low Kaolinte Quartz low Aluminiar Hematite	$(Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O_8)$ $Al_2(Si_2O_5)(OH)_4$ SiO_2 $(Fe_{0.86}\ Al_{0.14})_2O_3$

Figure 3.10 mineralogical composition of soil in the area H (see figure 3.6)

Table 3.2. Oxide compositions of soils in study area H, after Hanna,2008

Test	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	k_2O	MnO	H_2O	LOI	Ti_2O	P_2O_5	SiO_2/R_2O_3
P1	42	23	16	0.36	<0.01	0.69	1.2	0.2	4.3	10	1.5	0.1	1.1
P2	41	22	16	0.46	<0.01	0.52	1.2	0.3	6.2	10	1.6	0.1	1.1
P3	45	22	12	0.42	<0.01	0.25	1.27	0.2	9.6	10	1.4	0.1	1.3

Table 3.3. Index properties obtained from H (see figure 3.6), after Hanna (2008) is summarized as:

Pit in H	W	LL	PL	PI	Ac	SR	Free swell	SG	AASHTO CLS.	UCS CLS.
1	36	66	39	27		17	35	2.8	A-7-5	MH
2	36	62	34	28	0.48	14	33	2.8	A-7-5	MH
3	34	63	37	26	0.44	27	38	2.8	A-7-6	MH

W= moisture content, Ac = clay-size fraction (i.e., percent by weight finer than 0.002 mm in size). Activity designated by "Ac" is defined as Ac = PI /C Where C is the percent of clay - size fraction by weight, SG= specific gravity.

The properties of the soils obtained from **a, b, c, d, e and f** are conducted by the researcher and summarized as in table 3.4.

Table 3.4. Laboratory results of sample pit from selected road section.

Pit point	LL	PL	PI	MDD g/cc	OMC	SWELL%	CBR%
a	60	39	21	1.42	38	5	2.6
b	63	40	23	1.39	37	6	2.4
c	42	31	12	1.46	18	3	5
e	66	32	24	1.30	35	6	2.2
f	55	32	23	1.46	37	4	2.7
g	61	40	21	1.45	35	5	2.4

The properties of 'd' are described in chapter 4. The soil selected from pit d is taken to fiber-soil mixture (see fig. 3.6).

CHAPTER FOUR

4. CHARACTERIZATION OF FIBERS AND SOIL

4.1. Selection and Characterization of Fibers

There are many natural fibers in wolaita area. For example enset ventricusum fiber (kacha), bananas stem fiber, barely straw fiber, sisal fiber, wheat straw fiber, teff straw fiber, etc. These natural fibers are by-products and they can be simply available locally.

To select fibers for research work, the researcher considered different factors such as availablity, tensile strength, suitability of soil for fiber production and abundance of by-product. Hence based on the above factors the researcher selected two fibers to proceed the research experiment. These fibers are enset ventricusum fiber (kacha) and teff straw (chid).

4.1.1. Enset ventricusum fiber (kacha)

Enset is cultivated only in its native indigenous farming systems of South and South-Western Ethiopia but later it get great attention to prevail in all Ethiopia because of its great medicinal value and drought resistance (Cheeseman, 1947). Wolaita, is located in southern nation nationality and regional state, has highest prevail of enset plantation.

Enset grow up to 6 m height (stem height is up to 2.5m stem) and thickness can rich up to 0.7 m in diameter (fig. 4.1). Its stem is overlapped fold by fold. This plant is main source of food in the southern region of Ethiopia especially the Guarage, Wolaita, Sidama, Kambata, Hadiya and Dawro people. One of the well known food is “kocho”, a solid staple a bit like heavy bread, processed from enset plant, which is eaten with milk, cheese, cabbage, meat and/or coffee. This plant is also a major source for fiber; the people call the fiber as “kacha”. They use it to make rope and a mat.

Figure 4.1 Enset plant and its internal fold

The extraction of the fiber is not the main objective for the local people rather it as a byproduct. The main reason for extraction process is searching for food which is kocho. There are steps to isolate enset ventricosum fiber from the kocho.

The enset fiber is generally white in color, and it has 2m in length and also it has averagely 0.02mm diameter for single fiber (read by caliper).see fig. 4.2.

Figure 4.2 Enset ventricosum fiber

For the purpose of research, the enset fiber is purchased from local market and it has the following properties.

- White in color
- Average length of single fiber reaches up to 2m
- Average diameter of single fiber is 0.02mm
- It absorbs water from 50-60% (soaked for after 24 hours) compared to the weight of its natural dry mass.
- Density of the fiber is 690 Kg/m^3 which indicate that it has light density.
- Single fiber snap force required is 15.4 which indicate that it has strong tensile strength.

The organic compositions of ensect ventricosum fibers and their descriptions are written in the table 4.1.

Table 4.1 Organic components of the Enset fiber.

Fiber properties	**Test result**	**Implication**
Cellulose (%)	62%	complex carbohydrate
Hemi cellulose (%)	19%	
Moisture content (%)	15.47%	Absorbent
Lignin (%)	5%	UV protective and non-decomposable

Source Eshetu Esayas et al, 2018

4.1.2. Teff straw fiber (chid)

Agriculture is the mainstay of Ethiopia's economy, which supports more than 85% of the population. This sector directly or indirectly forms an important component of the livelihoods of more than 70 million for food and as a source of income (Olango et al.2014).

Teff (*Eragrostis tef (Zucc.Trotter*) is a small-grained cereal that has been grown as food crop in East Africa for thousands of years (D'Andrea, 2008). It is a staple food for the majority of the population in Ethiopia and Eritrea. Teff is adapted to a large variety of environmental conditions and widely grown from sea level up to 2800m above sea level (a.s.l.) under various rainfall, temperature, and soil conditions (Seyfu, 1997). It is cultivated in Ethiopia on about 2.59* 10^6 ha and occupies about 28% of the total crop area allocated to cereals (D'Andrea, 2008) delivering about 20% of the total cereal grain production and 17% of cereal crop residues production annually (FAO 1987). The average teff grain yield of 1228 -3500 kg/ha (FAO 2010) is low compared to other cereals, but by-product (teff stem/chid) is huge.

Teff grown on Ethiopian Vertisols (montimorrilonite rich clay soil) to which it is ecologically well adapted due to its tolerance to water logging (Efrem, 2001). Vertisols comprise 2.5% of the world's total land area, with major areas in India, Africa and Australia. They occupy about 105*10^6 ha in Africa and about 12.6*10^6 ha in Ethiopia (Debele, 1985). Around 5.9*10^6ha is in use by farming systems in which teff is an important crop (Bull 1988). Vertisols are dark, montmorillonite-rich clay soils with characteristic shrinking and swelling properties. They have high clay content (43% to at least 50cm depth from the surface) and when dry they show cracks of at least 1cm wide and 50cm deep (FAO 2000).

Wolaita is predominantly covered with vertisols and followed by nitosoils (FAO,2000). Teff is the predominant cereal crop produced in wolaita. Teff is produced twice in a year and large volume of teff straw is produced in every year.

The teff straw fiber, purchased from local farmer, has the following properties

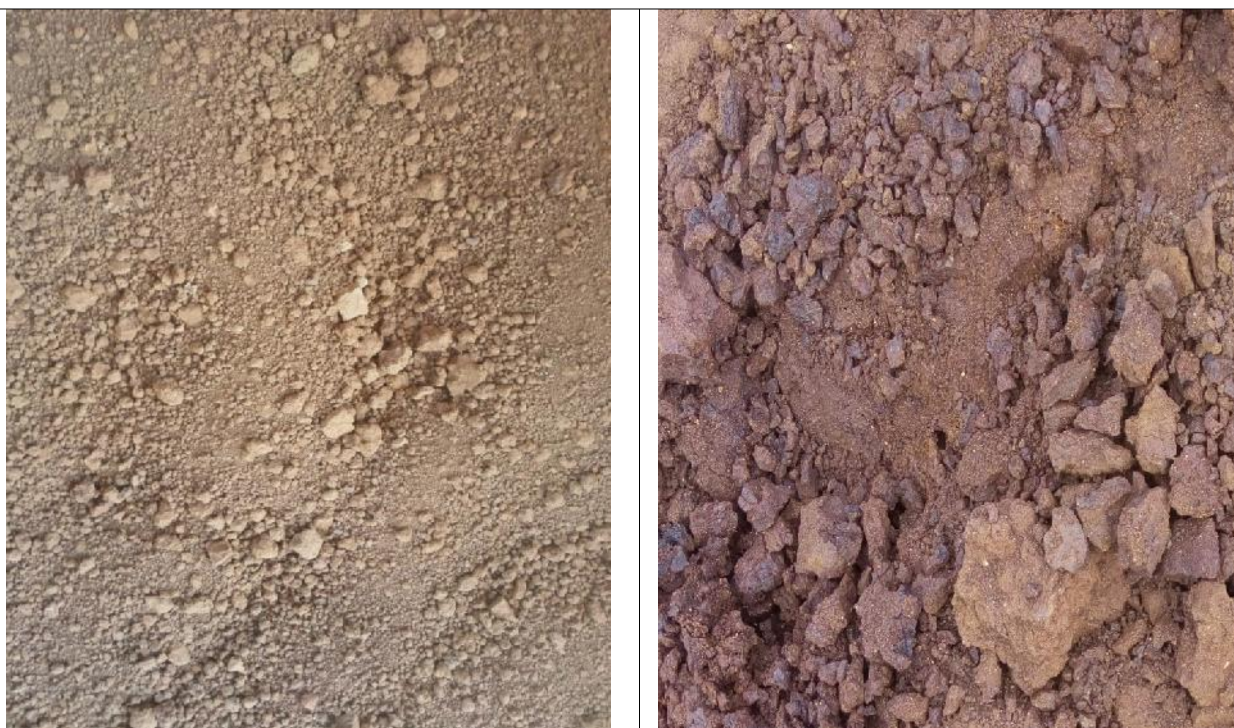
- White and reddish brown in color.
- It absorbs water from 40-50% (soaked for 24 hours) compared to the weight of its natural dry mass.
- It has average length 5cm and average thickness of 1mm with average hollow space (distorted or undistorted) of 0.3 mm.
- In dry condition, it breaks when bend about 270- 360 degree
- It attains high flexibility when wet.

4.2. Characterization of sub-grade soils

Representative soil is selected for laboratory tests in order to answer hypotheses. First question to the researcher in to select representative soil is "where is the worst problematic soil in the Wolaita especially from the HHRBC road project? To answer this question the researcher went to different organizations and company to get data. The soaked CBR data, collected from different woreda in the zone indicates that problematic soil is found the whole in the wolaita zone woredas. Much of data is found from Moricho-Dimtu-Bitena-Sodo Design and Build Road Project. Main contractor- Hunan Huandan Road and Bridge Corporation China (HHRBCC) and minor contract, Bitena-Mayo Kote-Zalal Yesus-Sodo and MayoKote-Delbo Junction to Alaba -Sodo road which comprise 48.3 kms. This project is employed by Federal Democratic Republic of Ethiopia, Ethiopian Road Authority. The volume of cut and fill data is assessed with its location is correlated with their soaked CBR data. Their data indicates that over 84% of soil along road alignment has soaked CBR value less than 5% in 1 inch penetration load.

The soil is sampled in test pit (depth 2m, surface area $4m^2$) from station 94+320 or 'd' (between Mayo Kote and Zalal Yesus) where there is high volume cut and fill material and soaked CBR data taken from the project area, has around 2%. Using plastic bag the sample is taken to soil laboratory in planted Badesa town, owned by HHRBCC and Federal Democratic Republic of Ethiopia, Ethiopian Road Authority.

Physical characteristics of the sampled soil- The soil has reddish brown color when it dried but it becomes darker reddish brown when wetted. When wetted it also show black shiny lustering inclusions in the soil mass. The following figure 4.3 shows the color of the dry soil sample.



a- air dried soil

b- insitu soil(undried)

Figure: 4.3 soils sampled for laboratory test.

Soil grade

Soil grading is done by using ASTM sieving method. The percent passing from total mass of the sample is recorded as shown in the table 4.2.

Table: 4.2. ASTM soil grading for AASHTO M145-91-table-2 soil classification requirements

Grading			
ASTM Sieve No.	10	40	200
Diameter f mm	2	0.425	0.075
% Passing from total mass	96.0	72.0	51.0

Liquid limit (LL %) of the soil

Liquid limit (LL %), three point Casagrande's grooving tool experiment is done as per AASHTO T-89. The water content is determined under controlled number of blows/ groove (22-28). After trial and error the water content determined as 60%, 62.7%, and 64.9% to corresponding number of blows 28, 26, and 22 respectively.

Table 4.3 the relationship between number of blows in Casagrande and water contents of the soil.

Water Content %	60.0	62.7	64.9	---
Number of Blows	28	26	22	25

According to AASHTO T-89 specification, the averaged slope line is drawn by using water content and number of blows. Tangential point on the line above 25 blows and corresponding water content is taken as liquid limit of the soil. Therefore the following graph uses to estimate liquid limit of the soil. The following figure indicates that the water content corresponding to 25 blows is about 62.5 %.

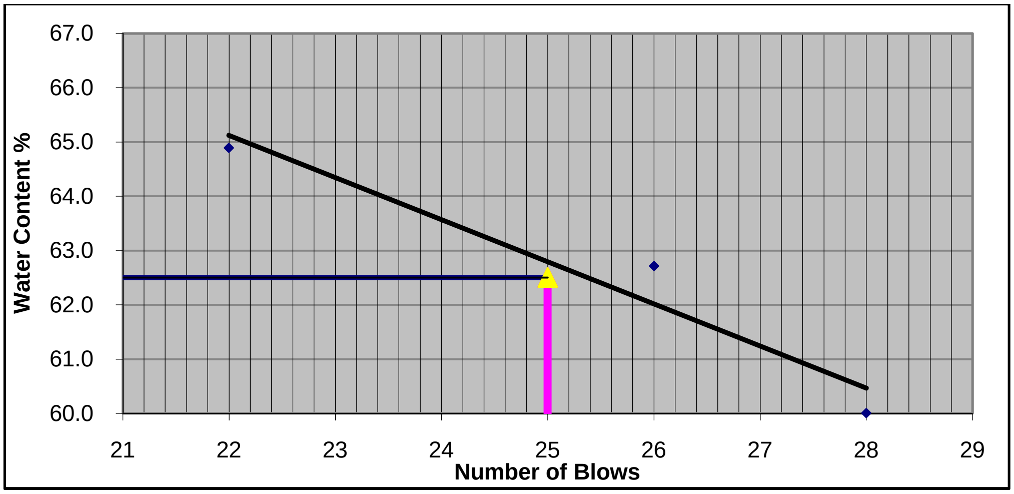


Figure 4.4 indicates water content at 25 blows (LL %)

Plastic limit of the soil

Plastic limit (WP %), is done by bimodal rolling method as per AASHTO T-90-96. The soil is squeezed and mixed with moisture (water) in order to get 5.2 mm (1/8 inch) diameter thread after rolling over the smooth glass using fingers. These threads are broken in to eight and six pieces and inserted in 2 tares. Then the weight is measured before and after oven dry. To increase accuracy it is done two times to take average value of moisture contents (figure 4.5).

Weight of water	2.47	2.58
Weight of Dry soil	8.64	8.50
Water Content %	28.59	30.35
Averaged water contents or Wp	***29.5***	

Figure 4.5 determination of WP in progress and results

Plasticity index (PI). PI is the difference between the liquid limit and the plastic limit. Therefore plastic index (PI) simply calculated from the value obtained from liquid limit and plastic limit (62.5-29.5=33).

Classification of the soil

The soil is classified according to AASHTO M145-91 specification. To classify the soil, the specification use LL, PI, and percent pass of soil through ASTM sieve no. 200 (0.075 mm), 10 (2mm), and 40(0.425mm) according to AASHTO M145-91-table-2 requirements.

Percent pass of the soil through the ASTM sieve number (10-96%, 40-72% and 200-51%), PI-33, and the difference between LL and 30 is greater than 30. Therefore the soil is classified as A-7-6. The grading and Attenbergs limit tests are summarize as follow (see annex).

According to AASHTO description Subgroup A-7-6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high-volume change.

Compaction test

Compaction is densification of soils by mechanical manipulation. Soil densification entails expelling air out of the soil, which improves the strength characteristics of soils, and also reduces compressibility and permeability. Using a given compaction energy, the density of soil varies as a function of moisture content. This relationship is known as the moisture-density curve, or the compaction curve. The energy inputs to the soil have been standardized and are generally defined by Standard Proctor (ASTM D 698 and AASHTO T 99) and Modified Proctor (ASTM D 1557 and AASHTO T 180) tests. These tests are applicable for cohesive soils since the soil is lateritic clay. In order to find moisture –density relationship, Modify Proctor compaction test is performed to find out the optimum moisture content (OMC) and maximum dry density (MDD) as per AASHTO T-180 (recommended by ERA manual, 2002). Four trial compactions are done by adding the constant increasing amount of moisture. The following graph shows the optimum moisture content and maximum dry density of the soil. Figure 4.6 presents MDD is 1.478 and OMC is 23.8% (shown in figure 4.6)

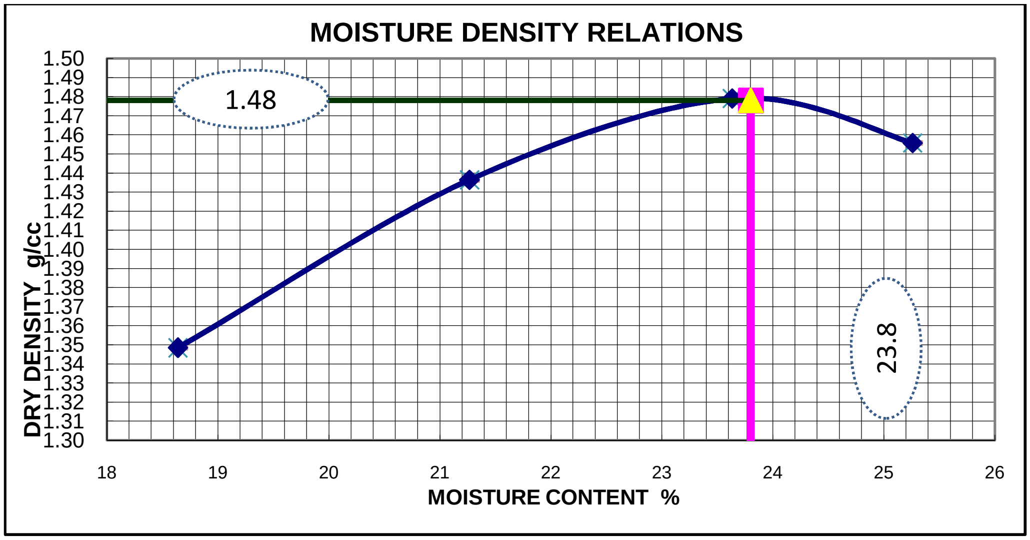


Figure 4.6 shows OMC MDD of the soil

California Bearing Ratio (CBR)

The experiment is done using test method as per AASHTO T-193. According to this method three compactive efforts (10, 30, and 65 blows) are used to compact soil at OMC and the Californian Bearing Ratio (CBR) shall be determined at 95% of the maximum dry density.

The wolaita area has high ground water occurrences, high annual rain fall depth and durational and peak of precipitation (discussed in chapter 3). The CBR value is determined by considering high severity (see figure 4.7 and annex).

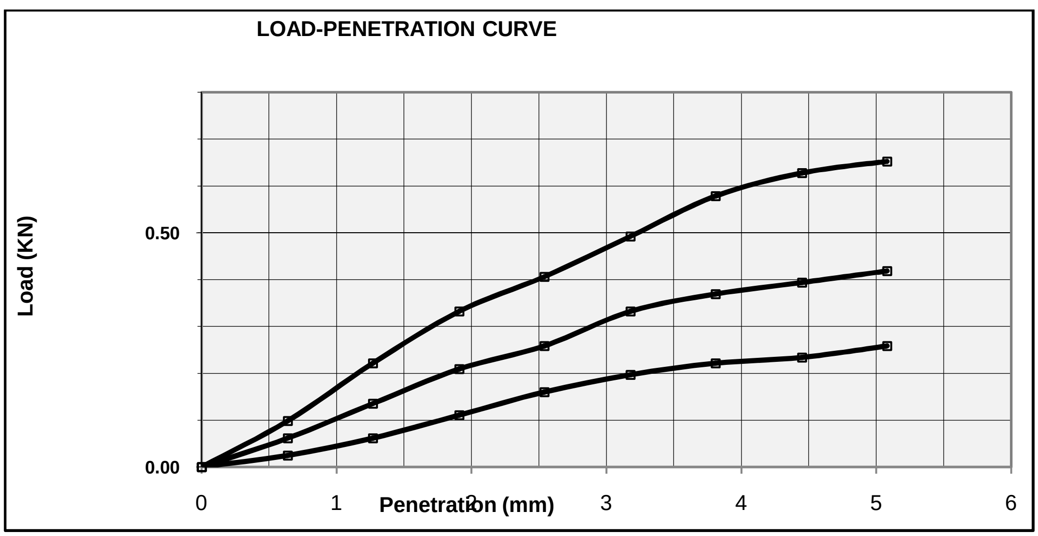


Figure 4.7 Load - penetration curve

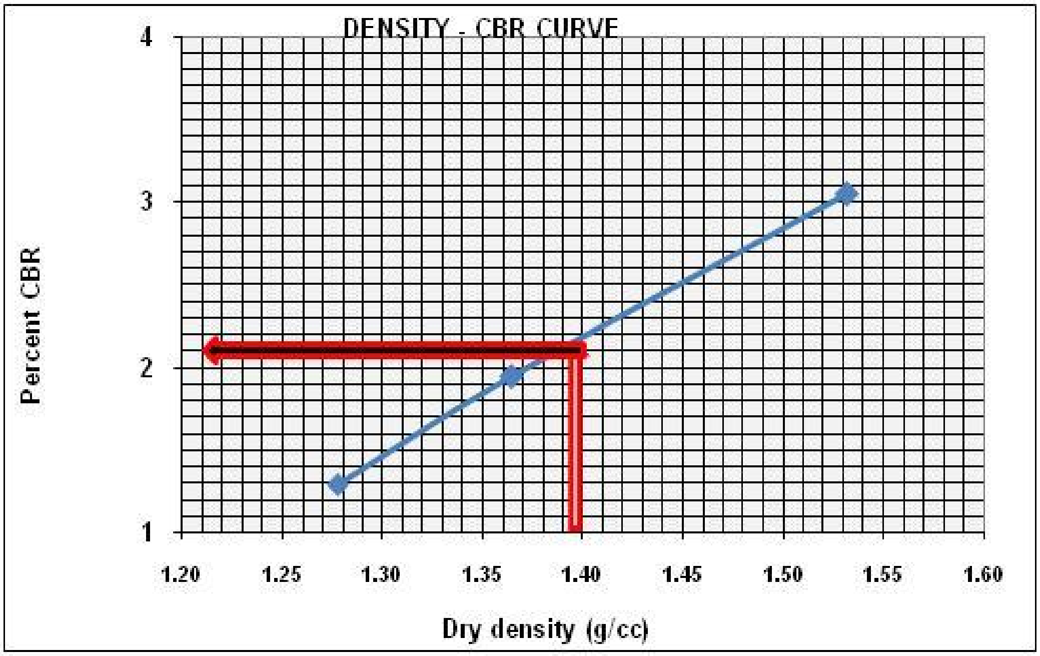


Figure 4.8 density-CBR curve of the soil

The CBR value of the soil is obtained by plotting dry density, got from blows of three compaction effort versus percent CBR of 2.54 mm penetration of each dry density. Therefore the CBR value at 95% MDD (1.40 g/cc) is 2.1%.

Percent Swell

Before soaking, all data are measured and dial tripod is attached on top of mold in order to measure swell after soaking. The height of specimen in the mold is 116.43 mm before soaking. The three effort compacted soil with molds are surcharged with 4.54 kg are soaked in water for about 4 days. Then the percent swell of soil/conjugate soil is calculated by change in height (mm) of soil/conjugated soil before and after soaking is divided by height of mold (height of soil/conjugated soil before soaking).

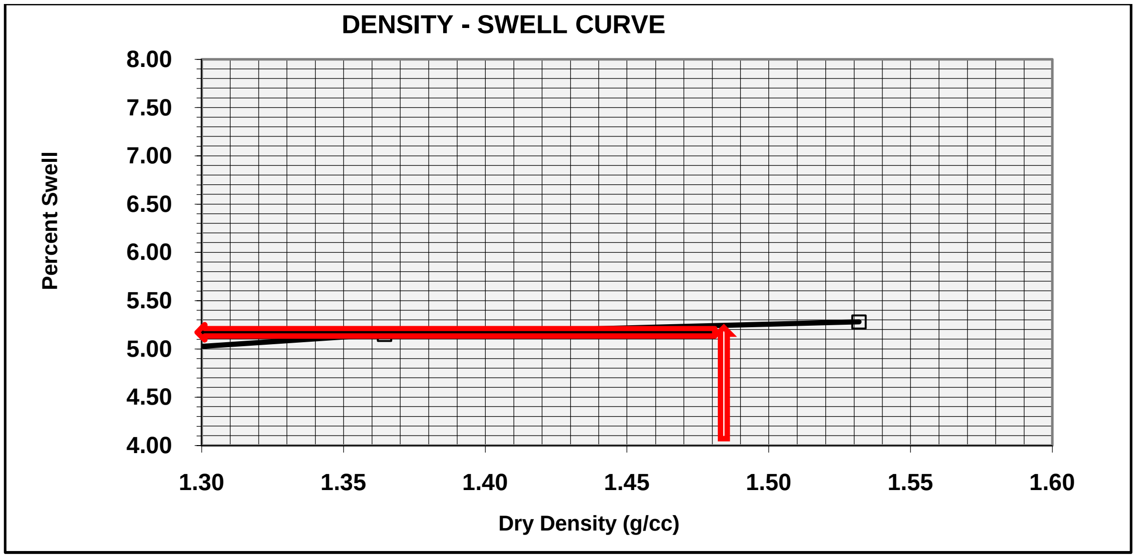


Figure 4.9 dry density-swell curve of the soil.

The above tables and graph shows swelling slightly increase with increasing compactive effort, decreasing moisture contents and increasing CBR.

4.3. Preparation Fiber/soil Ratio and Conducting Experiment

The designed ratio of fibers and naturally moisture soil by their weight is prepared **as 0.25%, 0.5%, 0.75%, 1%, 1.25** and **1.5%** for each fiber. Interval of increasing fiber percent is assumed according to papers which done previously on natural fibers (discussed in chap. 3, literature riview). This ratio is prepared after fiber attains its optimum flexibility and maximum water absorption by submerging in water and drying on sun light until it loose its wetness. After preparation of fiber-soil ratio, compaction is carried out immediately after mixing for 10 blow mold and other two molds are done in 10 minute intervals one by one.

The average length of teff straw fiber is about 6 cm and its length is taken as 6 cm for each teff straw-soil ratio. The experiment is done for only 6 cm length because it has a challenge to users to chop to smaller length due to its irregular interconnection of straw fibers.

The average length of enset ventricosum fiber is more than 2m and it elongated regularly. Fiber is chopped in to 4 cm and 6 cm. The comparison of effect of 4 cm and 6cm length is done on 0.75% of fiber content. But there is no difference on CBR value between them. According to literature review the CBR value is increasing with fiber length but here there is no change in

CBR value at different length. This may show there is highest length limitation after which no change in improvement even if there is change in fiber length.

4.3.1. Enset fiber reinforced soil

After preparation of enset fiber and soil mixture, the same test methods are used like those were used for characterization of the soil previously. The data are compiled for **0.25%, 0.5%, 0.75%, 1%, 1.25** enset fiber content and each of them is proceed with 6cm fiber length. Compiled laboratory results are given in table 4.4 and annex

Table 4.4 Laboratory test results of enset fiber- soil mixtures

% FIBER	MDD	OMC	SWELL AT 100% MDD	CBR At 95% MDD
0	1.478	23.8	5	2.1
0.25	1.47	24	4.5	2.8
0.5	1.468	24.8	4.4	4.2
0.75	1.454	25.2	3.2	4.7
1	1.439	25.7	3.5	5.4
1.25	1.425	26	4	5

4.3.2 Teff straw reinforced soil

After preparation of teff straw fiber and soil conjugation, the same test methods are used those was used for characterization of the soil and enset-soil conjugation previously. The experiment was done for designed fiber-soil ratio of soil until to find optimum ratio. The test was conducted for fiber ratio 0.25%, 0.5%, 0.75% and 1%. Compiled laboratory data is given in table 4.5 and annex.

Table 4.5 Laboratory test results of teff straw fiber- soil mixtures

% FIBER	MDD	OMC	SWELL AT 100% MDD	CBR At 95% MDD
0	1.476	23.8	5.0	2.1
0.25	1.472	24.2	4.6	2.6
0.5	1.465	24.6	3.3	3.9
0.75	1.452	25.8	3.0	4.7
1	1.435	26	3.2	4.4

Unsoaked CBR

Finally unsoake CBR test is conducted by using high improving ratio of fiber soil mixture to justify the improvement. This is done by one point CBR (56 below by modified compactor) on 6 cm length and 1% enset fiber reinforced soil at 100% MDD. The result is summarized in the table 4.6

Table 4.6 unsoaked CBR value with and without fiber in 1% content of enset fiber

Penetration (mm)	Dial Rdg		Load (Kn)		Unsoaked CBR %	
	Without fiber	With fiber	Without fiber	With fiber	Without fiber	With fiber
2.54	600	650	7.39	8.00	57	62
5.08	930	1209.00	11.45	14.88	59	76

5. CHAPTER FIVE -RESULTS AND DISCUSSION

5.1. Introduction

The soil used in this study was collected from the HHRBC highway construction site, which is under construction along Hawasa-Wolaita Soddo via Dimtu Bilate. The sampling site is located near to Wolaita Sodo along Badessa-Soddo road. The various index properties and compaction properties (maximum dry density and optimum moisture content), CBR, and surcharge swell of soil were determined in the laboratory (described in chapter 3). The properties of soil are summarized as following.

- Liquid limit of the soil (LL%)…………………………..….62.5
- Plastic limit of the soil(WP%)…………………………..….29.5
- Plasticity index of the soil (PI)……………………………..…33
- Percent passing through ASTM sieve no. 200……………..…51
- AASHTO soil classification………………………………A-7-6
- Maximum dry density of the soil…………………….....1.478 g/cc
- Optimum moisture contents of the soil………………….23.8 %
- surcharge (2.47 kg) swell at 100% MDD of the soil………..5%
- Soaked CBR % at 95% MDD……………………………..…2.1
- One point load un soaked CBR……………………………...57

According to ERA (2002), design of Pavement thickness is depends on CBR values of sub-grades, sub-bases, capping and sub-coarse aggregates, hydrological/hydrological or meteorological and vehicle axel load under given design life. The CBR value has direct relationship with shear strength, compressive strength and strain resistance of the soil and it inversely correlated with LL, PI, and swell properties.

5.2. Effect of Fibers on MDD and OMC of the soil

5.2.1. Effect of Enset Ventrecusom Fiber on MDD and OMC of the Soil

It is observed that optimum moisture content (OMC) increases and maximum dry density (MDD) reduces with addition of Enset ventrecusom fiber in sub-grade soil (figure 5.1). With mixing of 0.25% of enset ventricosum fiber having 6 cm length, the optimum moisture content increases from 23% to 24% and the maximum dry density reduces from 1.478 /cc to 1.470 gm/cc. Whereas there is an increase in OMC from 24% to 26% with inclusion of 0.25% to 1.25 % of enset ventricosum fiber in the subgrade soil respectively and the MDD reduces from 1.470 gm/cc (with 0.25% enset ventricosum fiber) to 1.425 gm/cc (with 1.25 % of enset ventricosum fiber) respectively. The following table and graphs show the behavior of Dry Density and Moisture Content of the soil in different amount of enset ventricosum fiber.

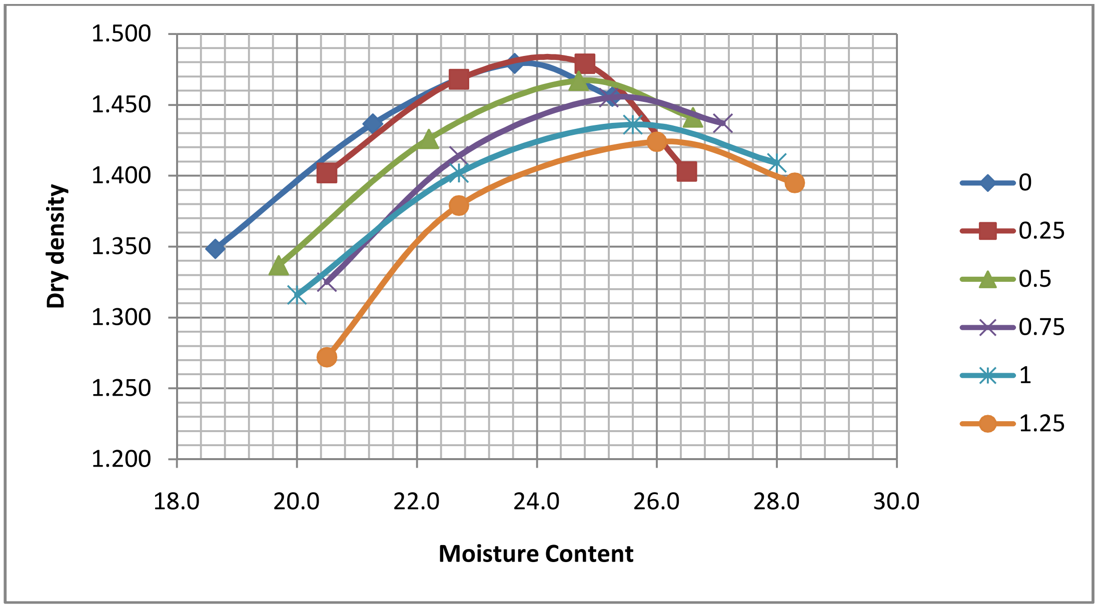


Figure 5.1The relationship between dry density and moisture content at different enset fiber contents.

The figure 5.1 and shows dry density versus moisture content, shows increasing of moisture content and decreasing of dry density with increasing fiber percent.

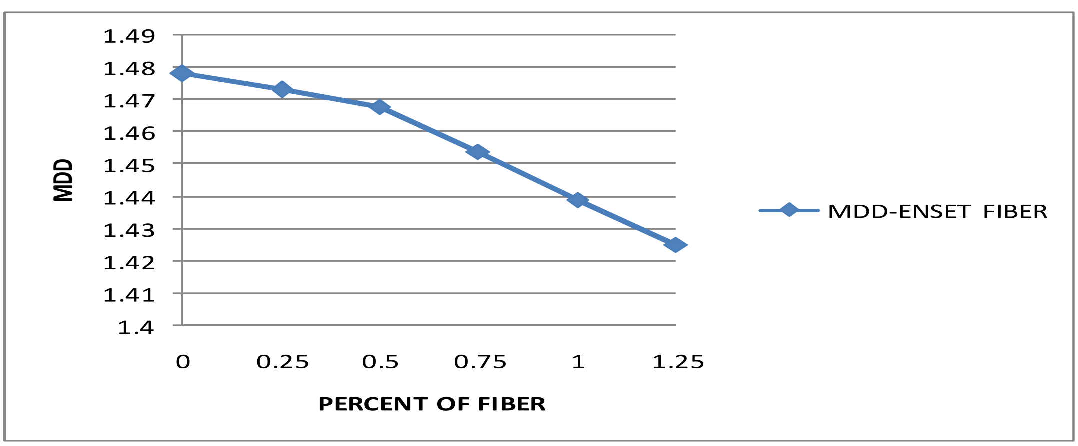


Figure 5.2 decreasing of MDD with increasing percent of enset ventricusum fiber.

Maximum Dry Density of conjugate soil is decreasing from 1.486 to 1.425 as fiber increasing from o% to 1.25% respectively. The above graph shows that dry density of soil is greater than dry density of enset fiber and change in amount of water absorbed by replaced fiber. It is true that, in a constant volume, the replacement of some amount soil with the fiber lowers dry density of the conjugated soil with fiber.

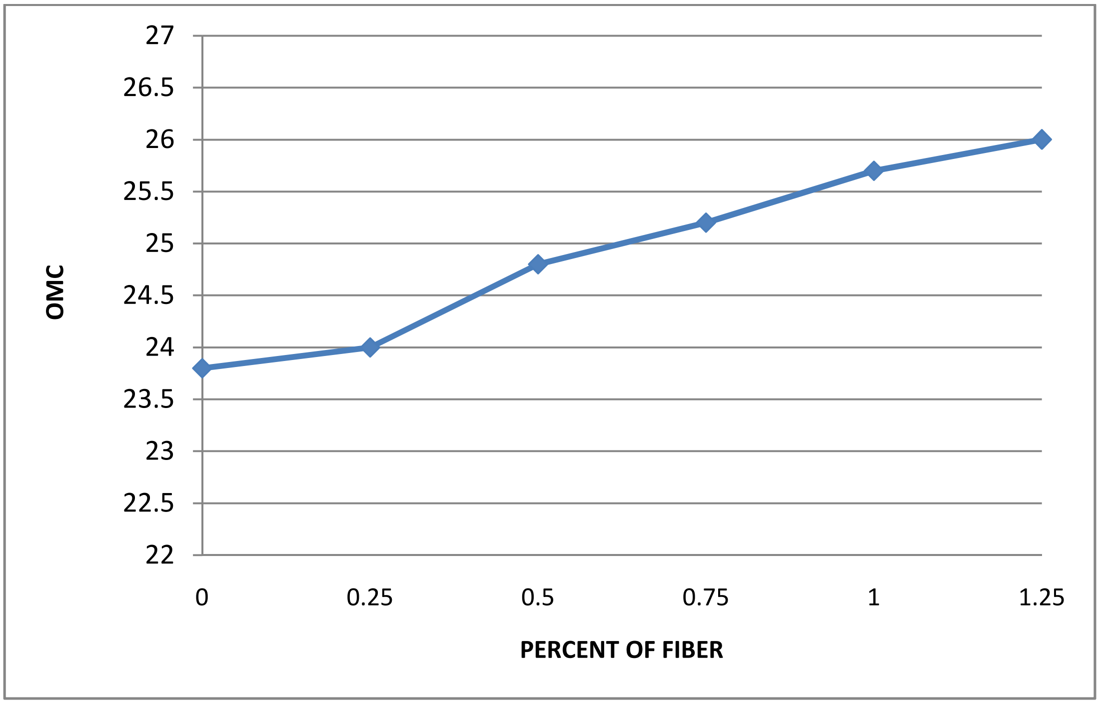


Figure 5.3 increasing of OMC with increasing percent of enset ventricusum fiber

This graph (fig.5.3) shows OMC increasing with fiber content (%). Optimum Moisture Content is increasing from 23.8 to 26 as fiber increasing from 0% to 1.25% respectively. It indicates that moisture/water absorption capacity of enset fiber is greater than that of soil replaced by fiber in the compaction mold. The change in density of water absorbed by fiber and equivalent occupied soil in the mold, and change in dry density of soil and fiber can affect dry density of the conjugated soil.

5.2.2. Effect of Teff straw fiber on MDD and OMC of the soil

It is also observed that optimum moisture content (OMC) increases and maximum dry density (MDD) reduces with addition of teff straw fiber in sub-grade soil. With mixing of 0%, 0.25%, 0.5%, 0.75% and 1% of straw fiber, the optimum moisture content increased from 23.8% to

24.2%, 24.6%, 25.8% and 26% respectively and the maximum dry density reduces from 1.478g/cc, 1.472g/cc,1.465g/cc,1.452g/cc and 1.435g/cc respectively. Whereas there is an increase in OMC from 24% to 26.4% with inclusion of 0.25% to 1.25 % of straw fiber in the subgrade soil respectively and the MDD reduces from 1.470 gm/cc (with 0.25% fiber) to 1.45 gm/cc (with 1 %) respectively. The following figure 5.4 and annex show the behavior of Dry Density and Moisture Content of the soil in different amount of fiber.

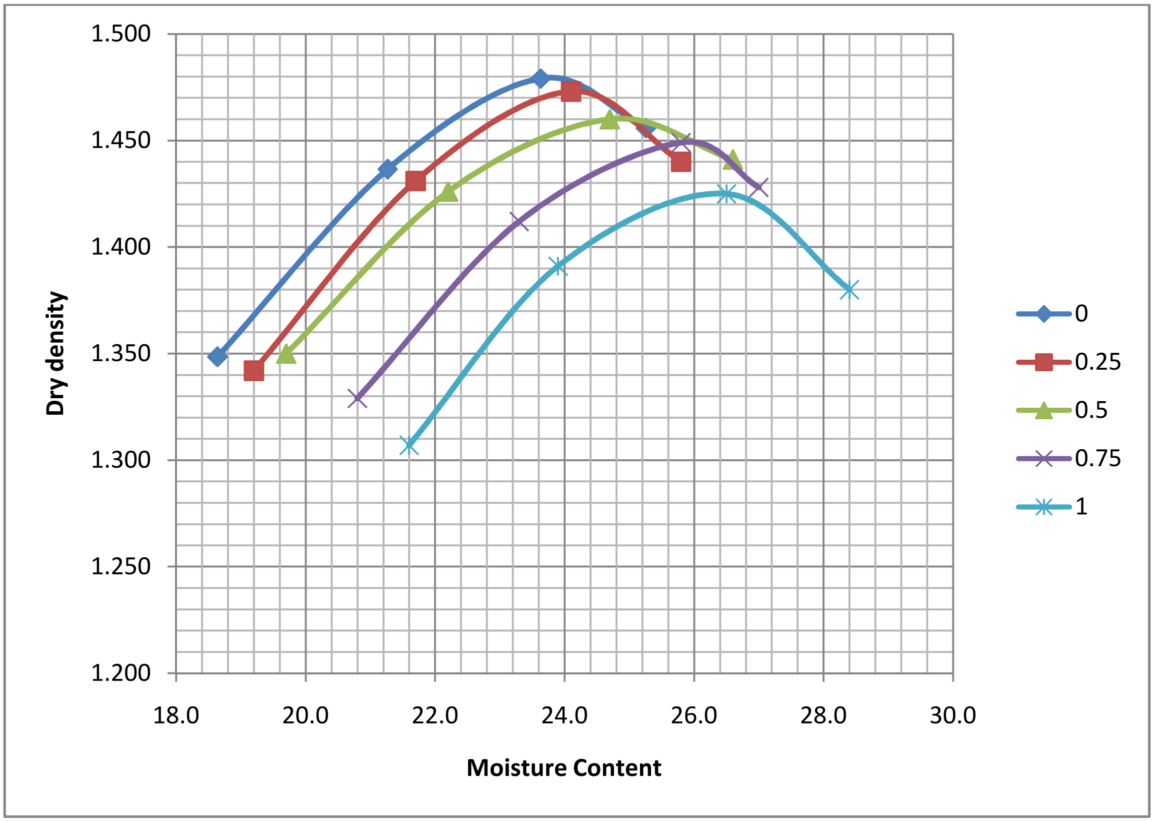


Figure 5.4 the relationship between dry density and moisture content at different teff straw fiber contents

The above figure 5.4, like for enset fiber, dry density versus moisture content, also shows increase of moisture content and decrease of dry density with increasing teff straw fiber percent. The peak of each graph projectile indicates maximum dry densities(y-axe) and optimum moisture contents (x-axe) of the conjugated soil.

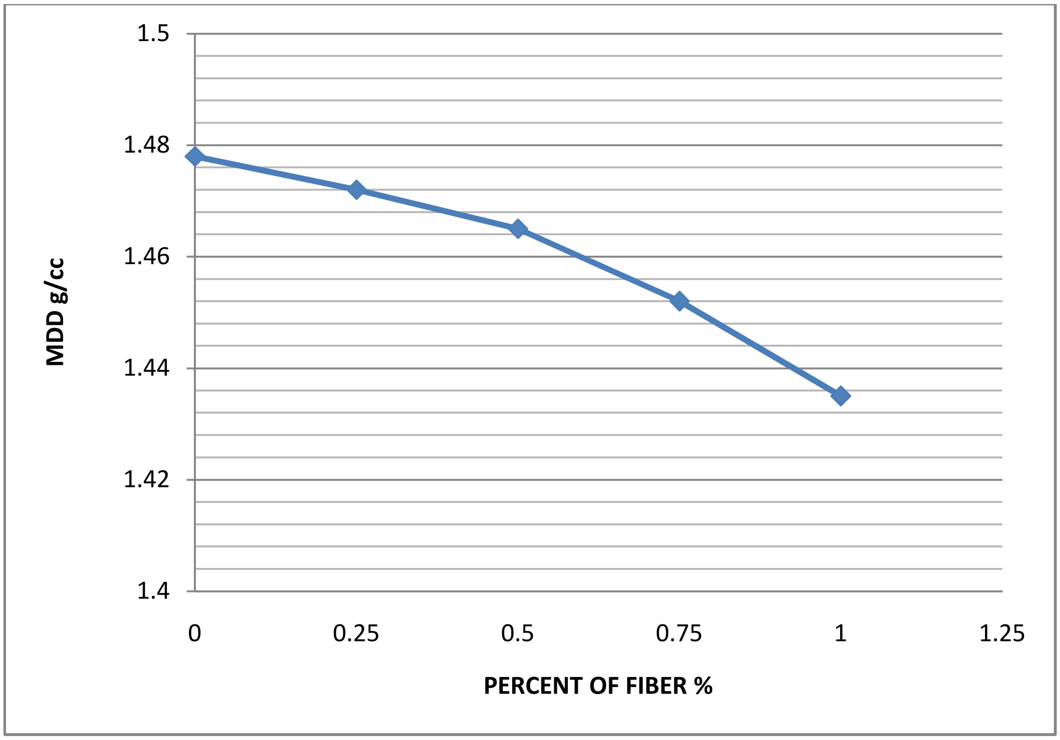


Figure 5.5 MDD vs. percent teff straw fiber.

The above graph also shows that dry density of soil is greater than dry density of teff straw fiber. It is true that, in a constant volume (mold), when we replace some amount teff straw fiber (%) with the soil we can record lower dry density of the conjugated soil with teff straw fiber.

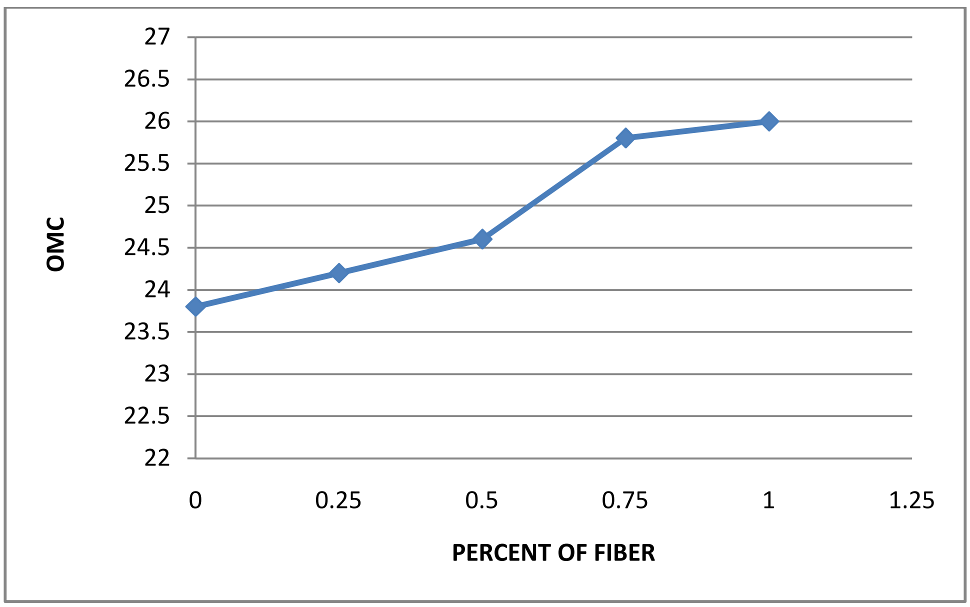


Figure 5.6 OMC vs. percent of teff straw fiber

This figure 5.6 also shows OMC increasing with fiber content (%). It indicates that moisture/water absorption capacity of teff straw fiber is greater than that of soil replaced by fiber in the compaction mold. The change in density of water absorbed by teff straw fiber and equivalent occupied soil in the mold, and change in dry density of soil and fiber can also affect dry density of the conjugated soil.

5.3. Effects of fibers on surcharge swell

5.3.1. Effects of enset ventercosum fibers on surcharge swell

Before soaking, all data are measured and dial tripod (swell measuring gauge) is attached on top of mold in order to measure swell after soaking. The height of specimen in the mold is 116.43 mm before soaking. The percent swell of fiber mixed soil is calculated by change in height (mm) mixed soil before and after soaking is divided by height of mold (height of compacted soil in the mold before soaking) as discussed in chapter 4

The swell, change in height of sample before and after soaking, with 4.54 kg surcharge weight is measured for each fiber contents per three compactive effort blows. The figure 5.7 and annex shows the swelling properties of fiber mixed soils.

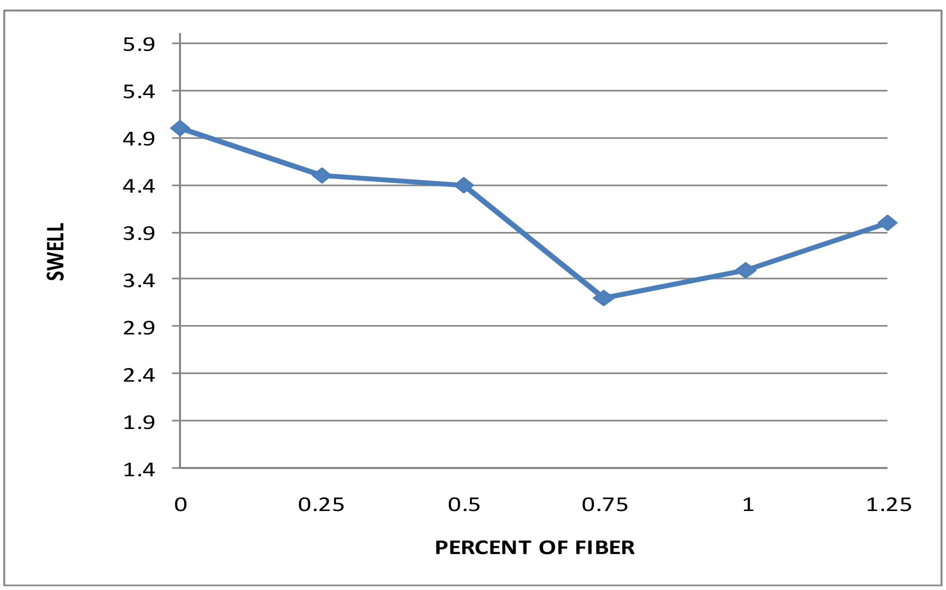


Figure 5.7 swell property of conjugate soil with increasing content of enset ventricosum fiber.

The above graph shows that percent swell of conjugated soil is decreasing from 5 to 3.2 as percent of fiber increasing from o to 0.75 respectively. Then percent swell is increasing from 3.2 to 4 as enset ventricosum fiber increasing from 0.75% to 1.25% respectively.

5.3.2. Effects of teff straw fibers on surcharge swell

In the same way as we do in effects of enset ventercosum fibers on surcharge swell, effects of teff straw fibers on surcharge swell is the same regardless of comparison. Figure 5.8 shows that percent swell of conjugated soil is decreases from 5 to 3 as percent of fiber increasing from o to 0.75 respectively. Then percent swell decreased as teff straw fiber increases from o.75% to 1%.

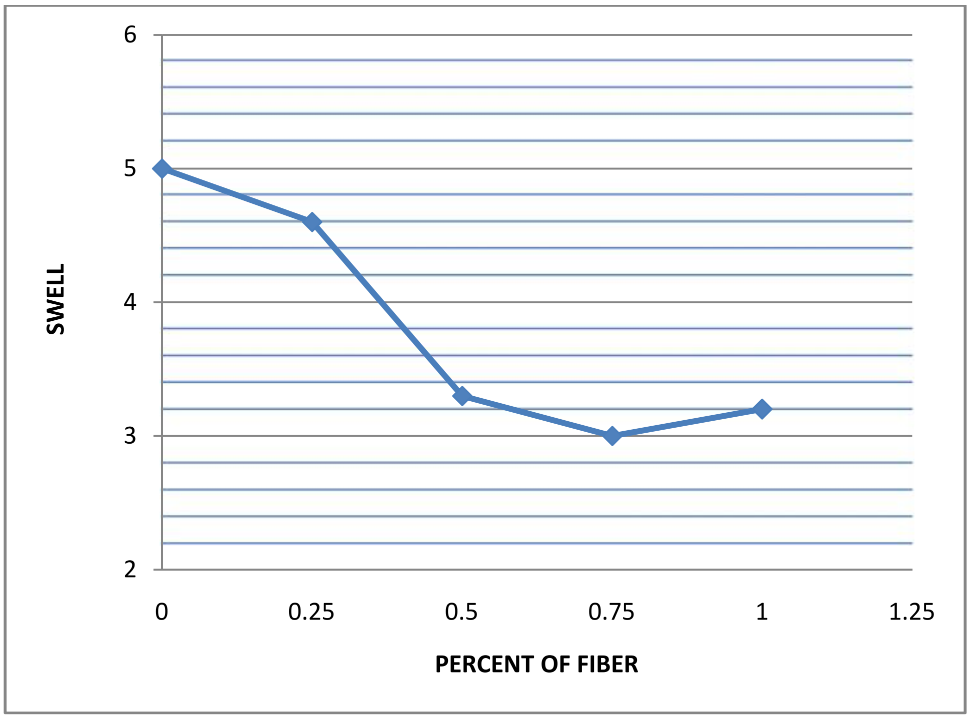


Figure 5.8 the relationship b/n swell and percent of fiber in the conjugate soil

5.4. Effects of fibers on CBR value

5.4.1. Effects of Enset Ventricosum Fibers on CBR Value

The effect of 0.25, 0.5, 0.75, 1 and 1.25 percent of enset ventricosum fiber increase CBR % of 33,100,123 and 157% greater than the CBR value of the natural soil. The optimum CBR value is obtained with 1% of the fiber content (see figure 5.9).

Table 5.1 CBR and MDD of enset conjugated soil

Percent of fiber	**0**	**0.25**	**0.5**	**0.75**	**1**	**1.25**
MDD	1.478	1.473	1.468	1.454	1.439	1.425
95% MDD	1.404	1.409	1.395	1.379	1.367	1.354
CBR at 95% MDD	2.1	2.8	4.2	4.7	5.4	5
Increase in CBR%	0	33	100	123	157	138

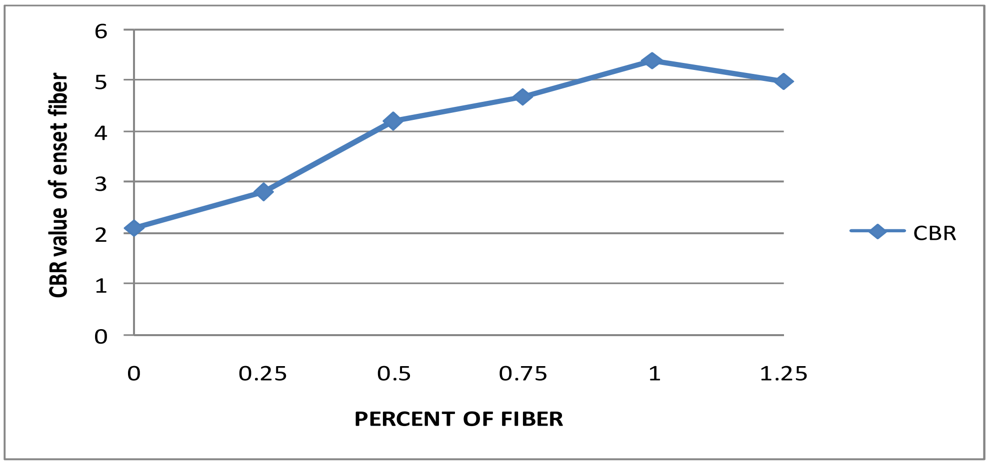


Figure 5.9 Graph of CBR vs percent of enset fiber

5.4.2. Effects of teff straw fibers on CBR value

The effect of 0.25, 0.5, 0.75 and 1 percent of teff straw fiber increased CBR % value by 24,85,133 and 109 % CBR value of the natural soil. The maximum CBR value is obtained from 0.75% of teff straw fiber (see figure 5.10).

Table 5.2 CBR and MDD of teff straw conjugated soil

Percent of fiber	**0**	**0.25**	**0.5**	**0.75**	**1**
MDD	1.478	1.472	1.465	1.452	1.435
95% MDD	1.404	1.398	1.392	1.379	1.366
CBR at 95% MDD	2.1	2.6	3.9	4.7	4.4
Increase in CBR%	0	24	85	133	109

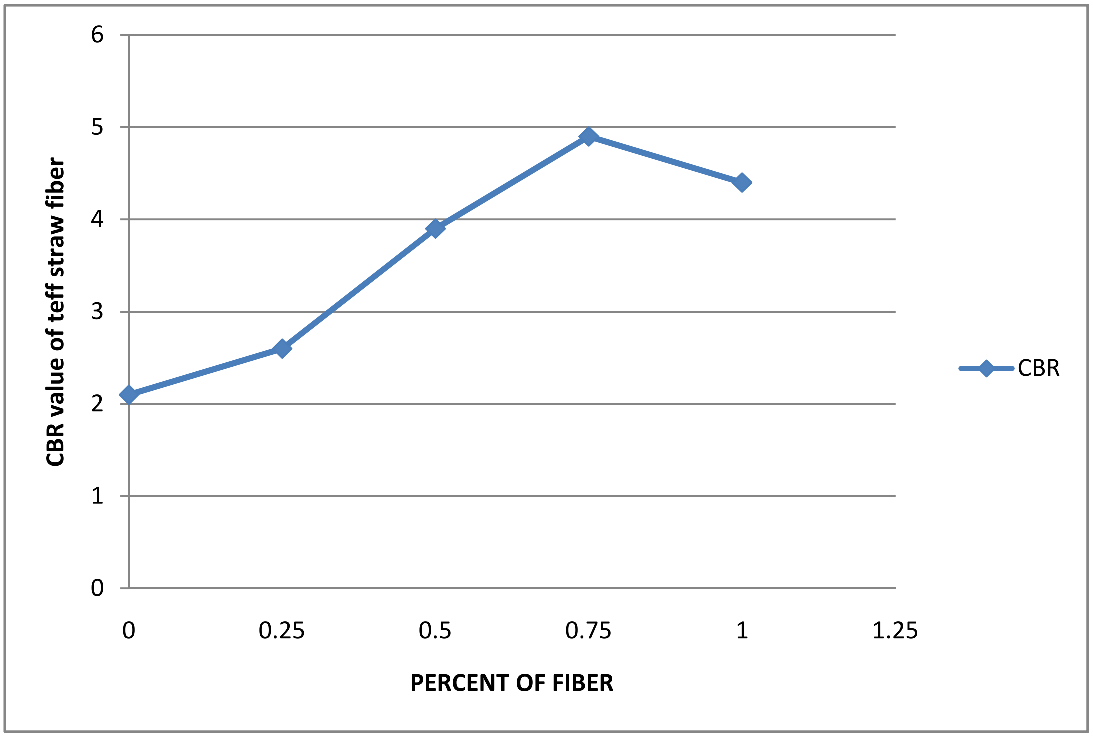


Figure 5.10 Graph of CBR vs percent of teff straw fiber

CBR value of the soil is increasing with the increasing of percent fiber. Generally the effect of fibers (teff strawfiber and enset ventricosum) is the same regardless of their degree of improvement.

In general MDD and CBR have direct relation to each other. However, using fibers, MDD decreases with increasing CBR value. The effect of fiber is keeping CBR increasing even if the MDD is decreasing. This effect may be like the act of roots in the soil, binding soil particles by increasing shear strength among soil particles and fibers. These fibers act to interlock particles and group of particles in a unitary coherent matrix thus increasing the strength properties of the soil as palm fiber do (discussed in literature review).

5.5. Comparisons of fibers on degree of improvement

Fibers may not have the same improving capacity. It is true that the improvement of the soil is not from simply using the fiber assuming as volume fulfillment but its degree of improvement depends on the type and characteristics. Therefore fibers act as improving material as well as sub-grade soil.

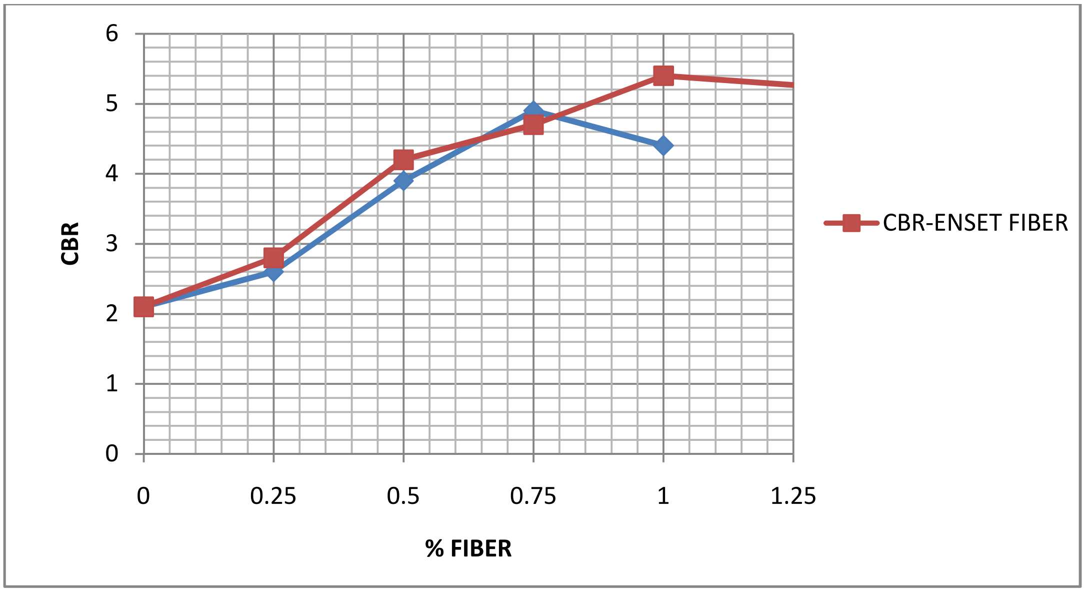


Figure 5.11. Graphical CBR comparison of enset and teff straw fibers.

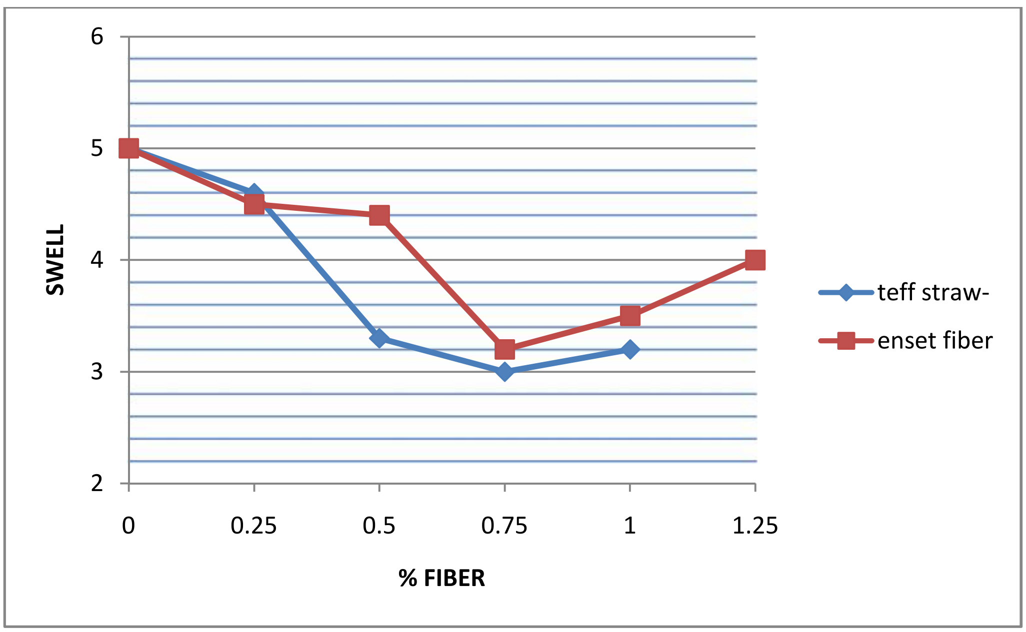


Figure 5.12 graphical swell comparison of enset and teff straw fibers.

As shown in figure 5.12 generally enset vetricosum fiber has higher tendency to be swell in the soil than teff straw fiber. This may indicate that moisture/water absorption capacity of enset fiber is higher than teff straw in a given compaction effort and surcharge load in submerged mold.

On other hand, inset fiber resulted higher ability to increase in CBR value than teff straw with the same percent of fiber contents. This indicates the rate of decreasing/increasing CBR and swell of Enset fiber is higher than that Teff straw after/before maximum point of CBR and swell are obtained because enset fiber is higher flexible and making good matrix of bondage with soil under compaction mold. Therefore it attains different elongation shape in the compacted soil and it has higher absorption capacity under unloading/compaction effort.

In Enset fiber reinforced soil's CBR value is stay increasing specifically with swell at 0.75% of fiber content. 0.75% of enset fiber is the turning point from decreasing to increasing in swell but one more interval of fiber content to decrease in CBR value. This means the effect of swelling is insignificant to decrease CBR value at 0.75% of enset fiber content. The graph line of curvature is not smooth, which aggravate the turning point as wider.

The length of enset fiber is 6cm and the diameter is 0.02mm, hence the diameter of enset fiber nearly compatible in segregation in the soil particles thus increase shear strength between silt and clay sized soil particles.

5.6. Effect of fibers on road pavement design

We have seen that using fibers in problematic soil improves engineering characteristics of the soil such as California bearing ratio and surcharge swelling. According to Hejazi et. al (2012), natural and synthetic fibers have different applications and benefits when we blending them with problematic soils. In his review he commented that natural and synthetic fiber in geotechnical engineering is feasible in six fields including pavement layer, retaining wall, and railway embankment, protection of slopes, earth quakes and soil foundation engineering.

Improving engineering characteristics of soil corresponds to structural road layer feasibility and subsequent benefits of economical, social as well as political considerations. According to ERA manual, 2002 vol.1, pavement layer structural catalogue is designed under traffic classes and socked CBR values of sub grade soils. There are 8 structural catalogs in ERA manual, 2002 vol.1. Those are Granular road-base/ surface dressing; Composite road base (unbounded and cemented)/surface dressing; Granular road base/semi-structural surface; Composite road base/semi structural surface; Granular road base/structural surfacing; Composite road base/ structural surface; Bituminous road base/semi-structural surface and Cemented road base/surface dressing. This structural catalogue is classified based on cumulative number of vehicles and CBR value of sub grade soil.

Traffic classes are calculated after survey of equivalent standard axels (ESAs) from different vehicle types. To estimate ESAs annual average daily traffic method has been using in Ethiopia. Annual average daily traffic, traffic volume in two directions is given as:

$$AADT_1 = AADT_0\ (1+I)^{X}$$

Where $AADT_1$ is Annual average daily traffic, traffic volume in two directions; $AADT_0$ is initial traffic volume by counting by following traffic counting methods and techniques;' I' is annual growth rate of the vehicles; and 'X' is number of years between traffic survey and road opening. Cumulative number of vehicles (T or 10^6 ESAs) over chosen design period is given as:

$$T = 365\ AADT1\ [(1 + I)^{N} - 1]$$

Where T is Cumulative number of vehicles in 10^6 ESAs, N is design period of the road.

There are 8 traffic classes (10^6 ESAs) name as T1, T2, T3, T4, T5, T6, T7 and T8. The table shows their ranges.

Table 5.3: Traffic Classes for Flexible Pavement Design

Traffic classes	**Range (10^6 ESAs)**
T1	<0.3
T2	0.3-0.7
T3	0.7-1.5
T4	1.5-3
T5	3-6
T6	6-10
T7	10-17
T8	17-30

Source: ERA manual, 2002, volume 1

As we seen in the above structural catalogue for pavement layer design is prepared by using traffic classes and sub grade soil CBR value. CBR value of sub grades also has classes to form combinations with traffic classes. These classes are S1, S2, S3, S4, S5 and S6 (table 5.8).

Table 5.4: Sub-grade strength classes for Flexible Pavement Design after ERA,2001, VOL.1.

Sub-grade strength	Range of CBR%
S1	2
S2	3 and 4
S3	5-7
S4	8-14
S5	15-29
S6	30+

As we seen the optimum percent of enset ventricosum fiber and teff straw fiber, used in this paper, are 1 and 0.75 respectively. Using enset ventricosum fiber increases the CBR value from 2.1 %(sub-grade) to 5.4 and teff straw fiber increase from 2.1 % to 4.4. This indicates enset ventricosum fiber transforms S1 sub-grade CBR classes to S3 while teff straw changes from S1 to S2. Therefore, when sub-grade CBR value increase from one class to the upper class, the thicknesses of pavement layer decreases in a given structural catalogue because the resistance to vertical and tangential wheel load of the pavement layers is increased.

The following tables show the thickness minimization of pavement layers and alternative geological pavement construction materials due to improvements of local natural fibers for the different types of pavement layer according to structural catalogue of ERA specifications.

The current road project is designed as ‘Granular Road Base/Semi-structural surfacing’ with T6 traffic class having two traffic lanes for 10year design life which has 10m width. As example the effect of fibers on road pavement design of the project (49 km) is give in table 5.10. From the road rout, about 90 % of soil has the same physical characters with the soil was taken for laboratory investigations. General estimation of volume of soil can be minimized by using those natural fibers as considering another design parameters are constant (table 5.5). total effect of fibers in on thicknesses of pavement layers for all road type/ S-classes / T-classes is summarized in annex

Table 5.5 rough estimation of pavement layer volume can be reduced by using fibers

Fibers	Sub-grade soil (in cubic meter)	Granular road base(in cubic meter)
Enset fiber	49,000*10*0.3=147,000	49,000*10*0.05= 2,4500
Teff straw	49,000*10*0.1= 49,000	49,000*10*0.025=12250

Table 5.6 effect of fibers on "Granular road base/semi-structural surface" for T6

S/T in mm	**Vertical profile**	**Pavement type**	**T6**	**ΔT6**
S1- Sub-Grade Soil		Flexible bitumineous surface	50	
		Granular road base GB1-3	200	
		Granular road base Gs	325	
		Subgrade / capping	300	
S2=Soil Improved By Teff Straw		Flexible bitumineous surface	50	0
		Granular road base GB1-3	200	0
		Granular road base Gs	300	25
		Subgrade / capping	200	100
S3=Soil Improved By Enset Fiber		Flexible bitumineous surface	50	0
		Granular road base GB1-3	200	0
		Granular road base G5	275	50
		Subgrade / capping	-	300

Source: ERA manual, 2001, vol.1

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

During overview of study area, due to high population density and high population growth, Wolaita people face land shortage problems. In Wolaita area there is little bare land. Land is covered by economic plants, crops and cereals. They need another land for agriculture because they experienced their life on agriculture only.

In the research area soil is problematic for road pavement construction but it is very important to the agriculture. Enset and teff grow well in such soils. Therefore treating the soil by its product (enset fiber and teff straw fiber) is may be good conservation practice in the communities.

Based on the meteorological and hydro geological data of project area, the soil can be affected by surfaceand sub-surface water if pavement is not well drained. Since this soil is problematic, it need high cost for road pavement that accommodate the problem or it need replacing sub-grade soil with suitable (higher CBR value) soil. In the study area road is constructed by replacing unsuitable sub-grade soil with suitable soil. However, it true that the population growth is increasing, and the need for asphalt road is increasing but the cut and fill sites and new road alignments (bare lands) are decreasing.

This paper comes up with mechanical reinforcement or improvement using local natural fibers. So, local natural fibers selected according to different factors such as easily accessibility, tensile strength of the fiber by observation and simple hand test, the agricultural productivity of fiber on problematic soil and abundance of by-product. By considering above factors, two fibers are selected and research experiment is proceeded. These fibers are enset ventricusum fiber (kacha) and teff straw (chid).

The Enset fiber has the following properties: white in color, average length of single fiber riches up to 2m, average thickness of single fiber is 0.02mm and percentage of water absorbance is about 50-60% (soaked for 1 day in accumulation) compared to the weight of its natural dry mass, dry density is about 690kg/m^3, snap force of a single fiber is 15.4. Organic compositions of the fiber are cellulose families and lignin.

The teff straw fiber has also the following properties; it attain its high flexibility after wetting it in water certain hours, it absorbs water from 40-50% (soaked for 1 day in accumulation) compared to the weight of its natural dry mass. in dry condition, it break when bending from 270- 360 degree, it's average length rich up to 5cm and average thickness is 1mm with average diameter 0.3 mm hollow space (it is pseudo stem) and the color is white and reddish brown due to as their genesis difference.

The sampled soil for soil-fiber mix is selected and tested in the soil laboratory, has the following characteristics: maximum dry density of the soil - 1.478 g/cc; optimum moisture contents (OMC) - 23.8 %, Average percent surcharge (2.47 kg) swell - 6.26 %; surcharge (4.54 kg) swell at 100% MDD - 5%; Soaked CBR % at 95% MDD - 2.1; un soaked CBR value- 57%; Liquid limit (LL%) - 62.5; Plastic limit (WP%) - 29.5; Plasticity index (PI) - 33; Percent passing through ASTM sieve no. 200 - 51 and AASHTO soil classification - A-7-6.

New method and procedure is determined to obtain optimum CBR value of soil and fiber mixture. There was a challenge to mix fibers homogeneously in the soil due to relatively low density of fibers compared to soil. To make a mixture random distributed and homogeneous, firstly soil is sieved by sieve number 200. Second, the soil passed through sieve no. 200 is mudded with proportional fiber content using plastic limit amount of water. When soil is muddy fibers simply mixed with mud, and get random elongational directions in the soil-fiber mixture. After air drying of mixed mud, CBR test is being proceeded as per AASHTO T-180 method D.

Enset ventricosum fiber (qacha) and teff straw fiber (chid) has positive effects on improving engineering characteristics of problematic soil. There is significant change on mainly surcharge swell, California bearing ratio (CBR) and road pavement layers design requirements.

It is observed that optimum moisture content (OMC) is increasing and maximum dry density (MDD) is decreasing with increasing the percentage of both Enset ventrecusom and teff straw fiber in sub-grade soil. An increase in content of enset ventricosum fiber from 0.25% to 1.25 % in the sub-grade soil increases OMC of mixed soil from 24% to 26% respectively and the MDD reduces from 1.470 gm/cc (with 0.25% enset ventricosum fiber) to 1.425 gm/cc (with 1.25 % of enset ventricosum fiber) respectively. Mixing of 0%, 0.25%, 0.5%, 0.75% and 1% of straw fiber, the OMC increases from 23.8%, 24.2%, 24.6%, 25.8% and 26% respectively and MDD reduces from 1.478g/cc, 1.472g/cc,1.465g/cc,1.452g/cc and 1.435g/cc respectively.

It also observed that the property of 4.54 kg surcharge swell is decreasing with increasing percent fibers until percent fiber rich optimum point for CBR value. Percent swell of fiber conjugated soil is decreasing from 5 to 3 as percent of fiber increasing from 0 to 0.75 respectively and is increasing from 0.75% to 1% of teff straw fiber. The turning point (0.75) is fiber percent where optimum CBR is obtained. Percent swell of enset ventricosum fiber conjugated soil is decreasing from 5 to 3.3 as percent of fiber increasing from o to 0.75 respectively and is increasing from around 0.75% to 1.25% of enset ventricosum fiber.

The CBR value of fiber-soil conjugation is concluded that inclusion of percent fiber of enset ventricosum fiber by weight as 0.25, 0.5, 0.75, 1 and 1.25 are increases CBR % 33,100,123 and 157 times the CBR value of sub-grade soil only respectively while the inclusion of teff straw fiber as 0.25, 0.5, 0.75 and 1 increases CBR % value as 24, 85,133 and 109 times the CBR value of the sub-grade soil only. The optimum percentage of improvement for enset ventricosum and teff straw were obtained by mixing 1 and 0.75 percent respectively.

Also it has seen that degree of improvement of enset ventricosum fiber is greater than that of teff straw fiber. Enset ventricosum fiber transforms sub- grade class from S1 to S3 while teff straw fiber transform from S1 to S2.

Therefore the following recommendations are proposed based on the scope of the research work.

1. There are many natural fibers in wolaita as well as Ethiopia but we has been not yet look along that way of practices to improve soils using local natural fibers. Therefore I highly recommend making intensive researches and subsequently using fibers accordingly because fibers used in this paper have potential to improve problematic soils regardless of fibers durability.
2. I recommend for researchers for further study on durability of local natural fibers under road pavement; chemicals, materials and mechanisms those can increase the durability of fibers; biological components of the fibers and their effects; prevention of microbial attacks of fibers; curing period; effect of aspect ratio (ratio of fiber length to woven or single fiber thickness) of fibers.

REFERENCES

Abtahi M, Okhovat N, Pourhosseini R, Hejazi M.(2010) Improvement of soil strength by natural fibers. From res to des Europ prac, Bratislava,Slovak Republic; 15-42

Abriham Asha (2006), integrated hydro geological investigation in Hamessa water catchment in wolaita zone, unpublished MSc. Theses.

Aggarwal P, Sharma B.(2010) Application of jute fiber in the improvement of subgrade characteristics. In: Proc of int conf on adva in civ eng,Trabzon Turkey; pp. 27–30

Ahmad F, Bateni F, Azmi M. Performance evaluation of silty sand reinforced with fibers. Geotext Geomembr ;28:93–9.

Ashour T, Bahnasawey A, Wu W. (2010), Compressive strength of fiber reinforced earth plasters for buildings. AJAE 1:86 92.

Aqeel Al Adil, Rafig Azzam, Giovanni Spagnoli and Joerg Schrader(2011), Strength of soil reinforced with fiber materials (Papyrus), Soil Mechanics and Foundation Engineering, 2012, Volume 48, Number 6, Page 241

ASTM, 2004. Special Procedures for Testing Soil and Rock for Civil Engineering Purpose,U.S. America.

Ayyar R, Krishnaswamy R, Viswanadham S. Geosynthetics for foundations on a swelling clay. Int work on geotex, Bangalore, India; 1989.

Bainbridge B, Athene S. Plastered straw bale construction. The Canelo project report, Canelo, Arizona, USA.<http://www.osbbc.ca>.

Blight G.E., 1997. Mechanics Of Residual Soils, A.A Balkema, the Netherlands

Bell, F.G. (2007). Engineering Geology, 7th ed., Elsevier Butterworth-Heinemann Linacre House, London,: 61-76.

Boccaletti, M. Bonini, M.. Mazzouli, R., Abebe, B., Piccardi, L. and Tortorici, L. (1997) Quaternary oblique extensional tectonics in the Ethiopian Rift (Horn of Africa). *Tectonophysics 287: 97-116.*

Bouhicha M, Aouissi F, Kenai S.(2005), Performance of composite soil reinforced with barley straw. Cement Concrete Compos vol.27: 617–21.

Bryan gaw and sofia Zamora (2010). Soil reinforcement with natural fibers for low income housing communities, Worcester polytechnic institute, BSc. Theses, England.

Cheah J, Morgan T. UKU: (2009)concept to construction using flax-fibre reinforced stabilised rammed earth. In: 11th Int confe non-conv mat and tech; 6–9 September, Bath, UK.

Chauhan S,Mittal S,Mohanty B.(2008),Performance evaluation of silty sand subgrade reinforced with fly ash and fiber.Geotext Geomembr vol. 26:429–35.

Coutts P.(1995), Autoclaved bamboo pulp fiber reinforced cement. Cement Concrete Compos vol.17: 99–106.

C.S. Bandavath (2004), Application of jute geotextile sub-grade soil improvement, MSc. Thesis institute of technology, roorkee-247667, india.

Dimpa moni kalita (2016), comparative study of soil reinforcement with natural fibers, synthetic fibers, and waste material. International journal of latest trend in engineering and technology (IJLTET), 6: 284-290

Eshetu Esayas et al (2018), Development of Wall Construction Material Stabilized with Enset Vegetable Fibers for Rural Housing Units.American Journal of Civil Engineering and Architecture, Vol. 6, No. 2, 54-62. doi:10.12691/ajcea-6-2-2

ERA (2002), pavement design manual, vol, 1 and 2, flexible pavements and gravel roads, Addis Ababa Ethiopia.

Ghavami K, Filho R, Barbosa P.(1999), Behaviour of composite soil reinforced with natural fibers. Cement Concrete Compos 21: 39-48.

Gourley, C., Newill, D. and Schreiner, H.D.,1993. Expansive soils: TRL's research strategy, First International Symposium on Engineering Characteristics of Arid Soils. Overseas Centre, Transport Research Laboratory, Crowthorne, Berkshire, UK., City University, London.

Habtamu Solomon (2012), chemical stabilization of expansive sub-grade soil performance evaluation on selected road section in northern Addis Ababa. MSc thesis, AAU, Addis Ababa, Ethiopia.

Hanna Tibebu, (2008), Study of Index Properties and shear Strength Parameters of Laterite soils in Southern Part of Ethiopia in the case of Wolayita – Sodo, AAU

Harriette L. The potential of flax fibers as reinforcement for composite materials. Eindhoven (the Netherlands): Eindhoven University Press; 2004.

H.M. hejazi, M .Sheikhzadeh, S.M. Abtahi and A.Zadhoush (2012), simple review of soil reinforcement by using natural and synthetic fibers. Journal of construction and building materials, vol. 3

Hussein Shaia, Haider H. Aodah, and Basim H. AL-Hameidawi (2016) Improvement of Sub-grade Soil using Natural Jute Fiber Sheet at Various Layers

Islam M, Iwashita K.(2010), Earthquake resistance of adobe reinforced by low cost traditional materials. J Nat Disas Sci 32:1–21.

Jamellodin Z, Talib Z, Kolop R, Noor N. (2010), The effect of oil palm fibre on strength behaviour of soil. In: 3rd SANREM conf, kota kinabalu, Malaysia; 3–5

KazminV, (1979), Explanation of the geological map of Ethiopia. Bulletin no.1 Geological survey of Ethiopia, Addis Ababa, PP. 14

Khedari J, Watsanasathaporn P, Hirunlabh J. (2005),Development of fiber-based soil– cement block with low thermal conductivity. Cement Concrete Compos .27:.111–6.

Kozlowski R.(2011), Handbook of natural fibers: processing and applications, vol.2. UK: Cambridge,USA.

Lin D, Huang B, Lin S.(2010), 3-D numerical investigations into the shear strength of the soil–root system of Makino bamboo and its effect on slope stability. Ecol Eng.; 36: 992–1006.

Lyon Association Inc. 1971.“Lateritic and Laterite Soil and Other Problematic Soils of Africa” Kumasi, Ghana.

Marandi M, Bagheripour H, Rahgozar R, Zare H.(2008), Strength and ductility of randomly distributed palm fibers reinforced silty-sand soils. Am J, Appl Sci 5: 209–20.

Mansour A, Srebric J, Burley J.(2007) Development of straw-cement composite sustainable building material for low-cost housing in Egypt. J Appl Sci Res 3:1571–80.

Mishra S, Mohanty K, Drzal T, Misra M, Hinrichsen G.(2004) A review on pineapple leaf fibers, sisal fibers and their biocomposites. Macromol Mater Eng , 289:955–74.

Nelson, J.D. and Miller, D.J.,1992. Expansive Soils Problems and Practice in Foundation and Pavement Engineering. John Wiley &Sons, Inc.

Olngo (2014), indigenous knowledge, use and on farm management of enset diversity in wolaita, southern Ethiopia. Journal of ethinobiology and ethinomedicine, ministry of agriculture, Addis Ababa, Ethiopia 1:10-41

Prabakara J, Sridhar R.(2002) Effect of random inclusion of sisal fiber on strength behavior of soil. Construct Build Mater 16:123–31.

Ramesh N, Krishna V, Mamatha V.(2010) Compaction and strength behavior of limecoir fiber treated Black Cotton soil. Geomech En 2:19–28

Raunet, M., (1978) Geographical and morpho-pedological survey, Lake Abaya and Chamo western catchment, sothern rift valley, Ehtiopia. Indian Institute of Technology; 1989.

Ravishankar U, Raghavan S.(2004) Coir stabilised lateritic soil for pavements. In: Indian geotech conf, Ahmedabad, India; 2004.

Rowell M, Han S, Rowell S.(2000) Characterization and factors effecting fiber properties. Nat Polym Agr Compos 115–34.

Salehan I, Yaacob Z.(2011) Properties of laterite brick reinforced with oil palm empty fruit bunch fibers. Pertanika J Sci Technol 19:33–43.

Segetin M, Jayaraman K, Xu X.(2007) Harakeke reinforcement of soil–cement building materials: manufacturability and properties. Build Environ 2007;42:3066–79.

Subaida A, Chandrakaran E, Sankar N. Laboratory performance of unpaved roads reinforced with woven coir, Geotext Geomembr 27:204–10.

Swamy N. New reinforced concretes. Surry University Press; 1984.

Viswanadham S. Bearing capacity of geosynthetic reinforced foundation on a swelling clay master of technology dissertation. Madras (India):Indian Institute of Technology; 1989.

WoldeGabriel,G.,Walter,R.C.,Hart,W.K.,Mertizmann,S.A.andAronson,J.L,(1999). Temporal relations and geochemical features of felsic volcanism in the central sector of main Ethiopian rift .Acta Vulca no.l

Yodit Tefera, (2005), Evaluation of Land degradation and landslides around wolaita –shone using remote sensing and GIS methods.Msc thesis, A.A.U

Yusoff M, Salit M, Ismail N, Wirawan R.(2010), Mechanical properties of short random oil palm fiber reinforced epoxy composites. Sains Malay .39:87–92.

ANNEX

9. Moisture density relationship of the soil

Moisture contents %	18.6	21.3	23.6	25.4
Dry density of the soil g/cc	1.348	1.436	1.479	1.456
Natural moisture content %	9.5			

10. AASHTO M145-91-table 2-classification of soil and soil aggregate mixtures.

Table 2—Classification of Soils and Soil-Aggregate Mixtures

General Classification	Granular Materials (35 Percent or Less Passing 75 µm)							Silt-Clay Materials (More Than 35 Percent Passing 75 µm)			
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, A-7-6
Sieve analysis, percent passing:											
2.00 mm (No. 10)	50 max	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max	50 max	51 min	—	—	—	—	—	—	—	—
75 µm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid limit	—		—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to Good							Fair to Poor			

[a] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30. (See Figure 2.)

11. grading, Attenberg's limits and classifications of the soil

Grading				Atenberg's limit				AASHTO Classification (M145-91)
ASTM SIEVE No.	10	40	200	LL	WP	PI (LL-WP)	LL-30	
Diameter f mm	2	0.425	0.075	*62.5*	*29.5*	*33*	***32.5***	***A-7-6***
% Passing from total mass	*96.0*	*72.0*	*51.0*					

12. CBR value using three compactive efforts and two penetrations

Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.22	0.32	1.7	1.6
30	0.36	0.53	2.7	2.6
65	0.46	0.65	3.4	3.3

13. After conducting the test the following results are obtained.

Blow in modified proctor	Dry density (g/cc)	CBR %
10	1.34	1.7
30	1.45	2.7
65	1.55	3.4
MDD	1.48	
95% of MDD :	1.404	
CBR at 95% of MDD :	2.10	

14. percent swell of the soil

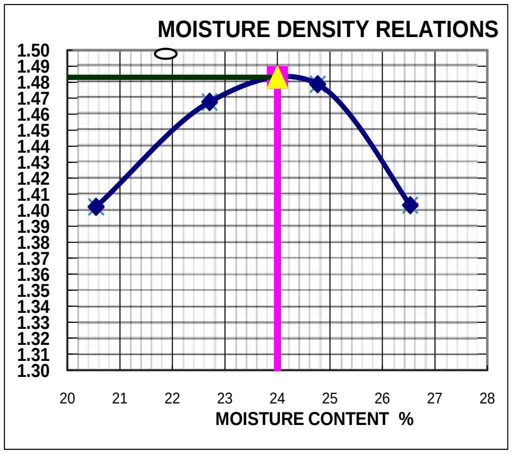
No.of blows	10	30	65
Dial reading (before soaking)mm	0	0	0
Dial resding (after soaking)mm	6.15	6.00	5.80
Percent Swell	4.98	5.15	5.30
percent swell at 100% MDD (1.48 g/cc)	5.0		

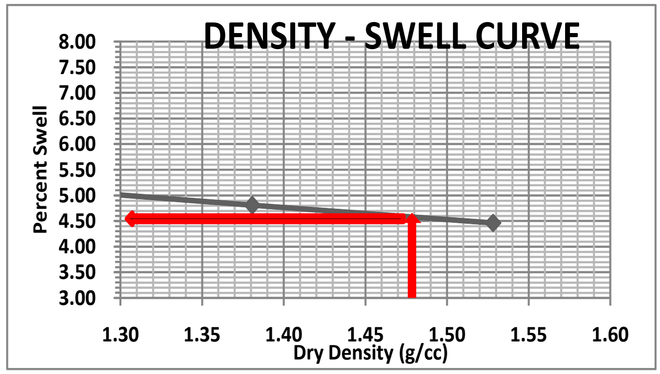
15. SOIL LABORATORY REPORTS OF DIFFERENT SOIL- FIBER RATIOS

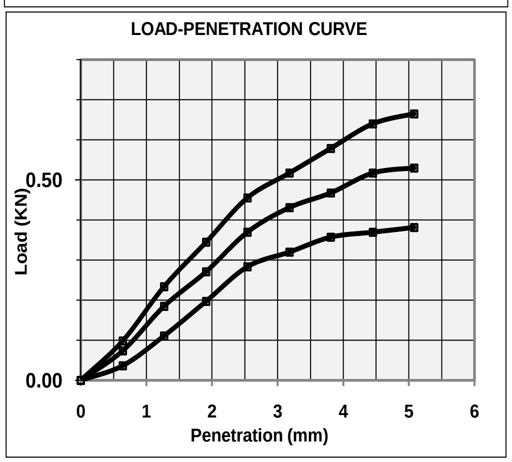
A. compiled soil laboratory data obtained from 0.25 enset fiber conjugated soil

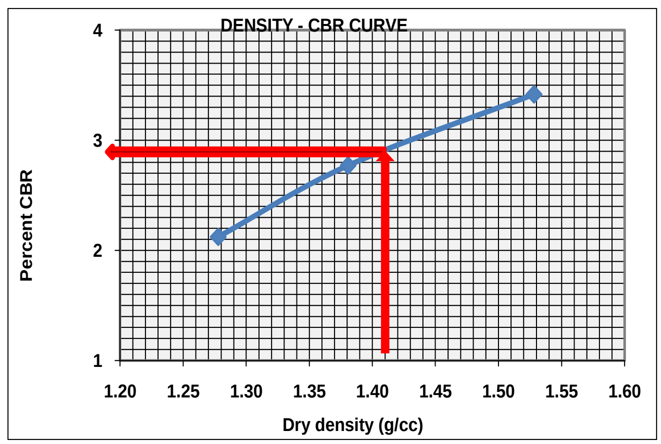
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.483
OMC (%) :	24.0

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.28	29.25	1.26	40.51
30	1.38	28.89	1.38	41.29
65	1.53	24.15	1.49	36.86









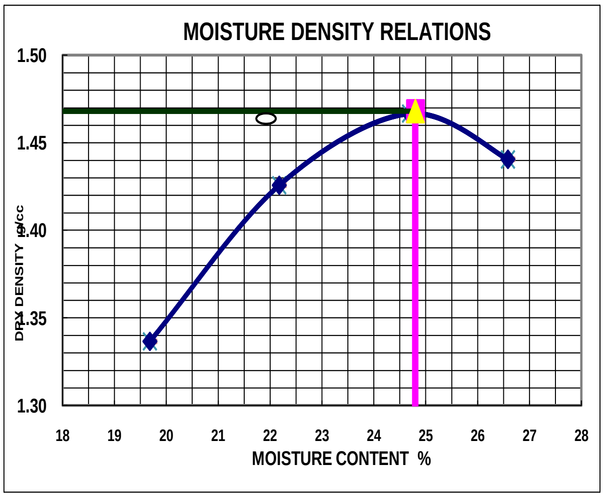
Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.28	0.38	2.1	1.9
30	0.37	0.53	2.8	2.6
65	0.46	0.66	3.4	3.3

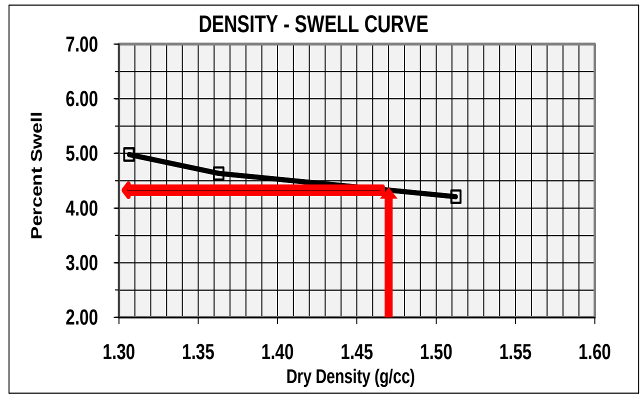
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.28	2.1	5.07
30	1.38	2.8	4.81
65	1.53	3.4	4.47
95% of MDD :	1.409		
CBR at 95% of MDD :	2.80		

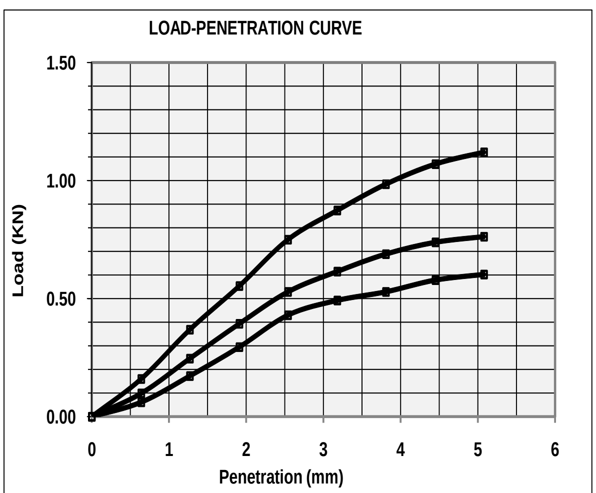
B. Compiled soil laboratory data obtained from 0.5 enset fiber conjugated soil

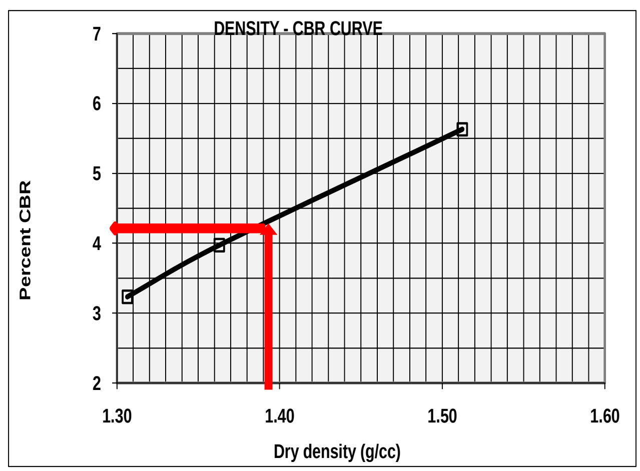
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.468
OMC (%) :	24.8

Blows	Before Soaking DD (g/cc)	Before Soaking Moisture (%)	After Soaking DD (g/cc)	After Soaking Moisture (%)
10	1.31	28.63	1.29	42.74
30	1.36	29.33	1.35	41.51
65	1.51	26.73	1.47	36.75







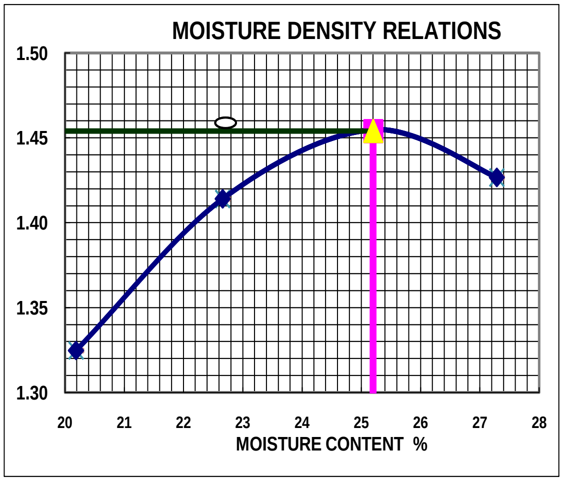


Blow	LOAD (KN) 2.54mm	LOAD (KN) 5.08mm	CBR (%) 2.54mm	CBR (%) 5.08mm
10	0.43	0.60	3.2	3.0
30	0.53	0.76	4.0	3.8
65	0.75	1.12	5.6	5.6

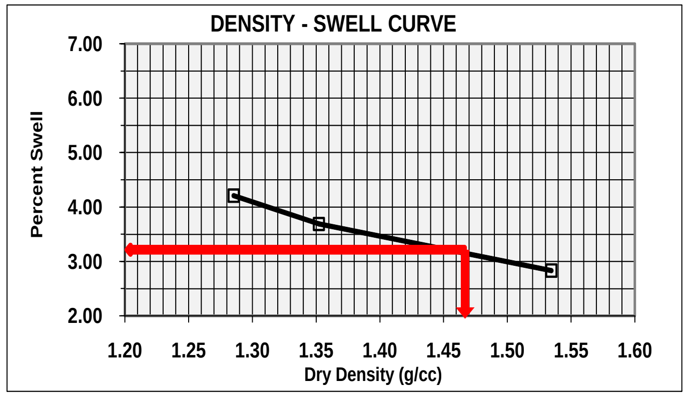
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.31	3.2	4.98
30	1.36	4.0	4.64
65	1.51	5.6	4.21
95% of MDD :	1.395		
CBR at 95% of MDD :	4.20		

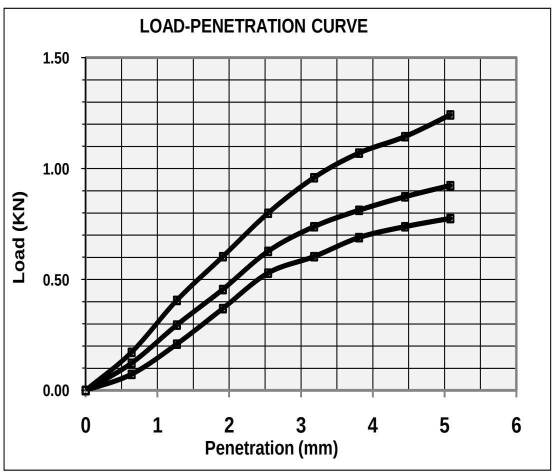
C. Compiled soil laboratory data obtained from 0.75 enset fiber conjugated soil

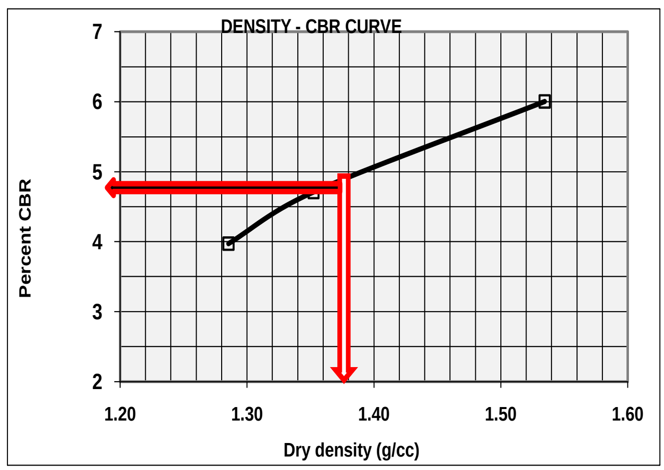
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.452
OMC (%) :	25.2



Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.29	25.92	1.28	34.61
30	1.35	31.19	1.34	34.77
65	1.53	23.24	1.49	35.42







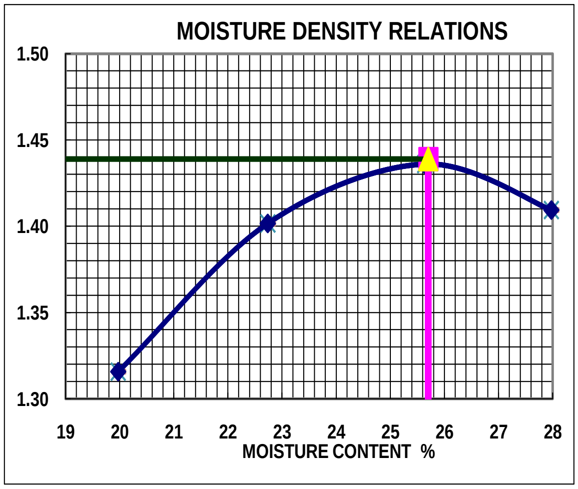
Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.53	0.78	4.0	3.9
30	0.63	0.92	4.7	4.6
65	0.80	1.24	6.0	6.2

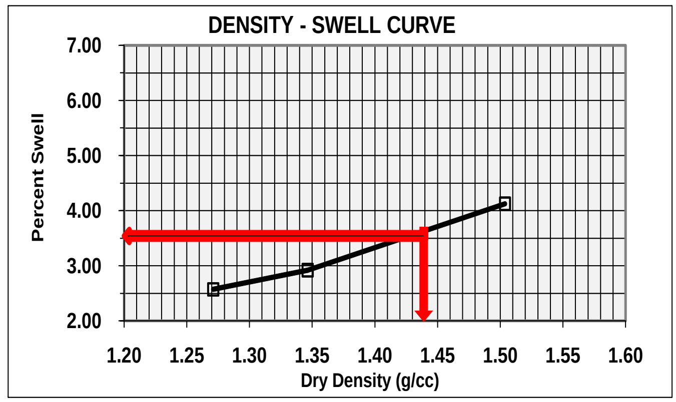
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.29	4.0	4.21
30	1.35	4.7	3.69
65	1.53	6.0	2.83
95% of MDD :	1.379		
CBR at 95% of MDD :	4.70		

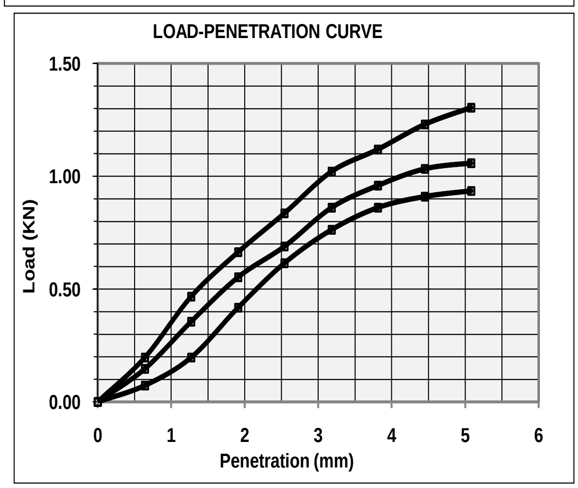
D. Compiled soil laboratory data obtained from 1% enset fiber conjugated soil

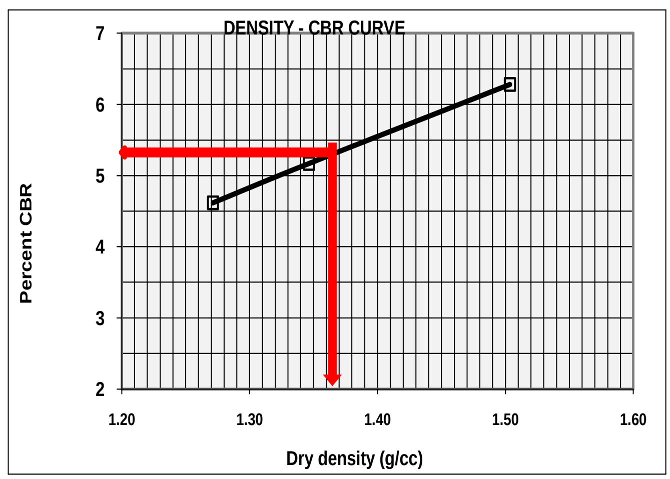
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.439
OMC (%) :	25.7

Blows	Before Soaking DD (g/cc)	Before Soaking Moisture (%)	After Soaking DD (g/cc)	After Soaking Moisture (%)
10	1.27	25.19	1.25	28.15
30	1.35	31.48	1.33	35.92
65	1.50	23.09	1.48	34.41









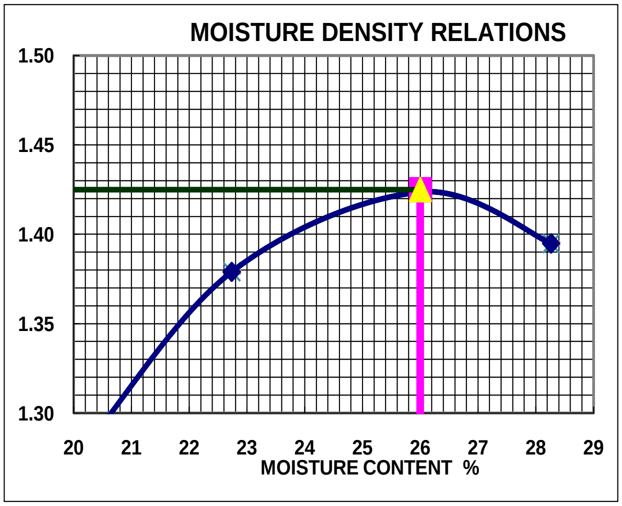
Blow	LOAD (KN) 2.54mm	LOAD (KN) 5.08mm	CBR (%) 2.54mm	CBR (%) 5.08mm
10	0.62	0.94	4.6	4.7
30	0.69	1.06	5.2	5.3
65	0.84	1.30	6.3	6.5

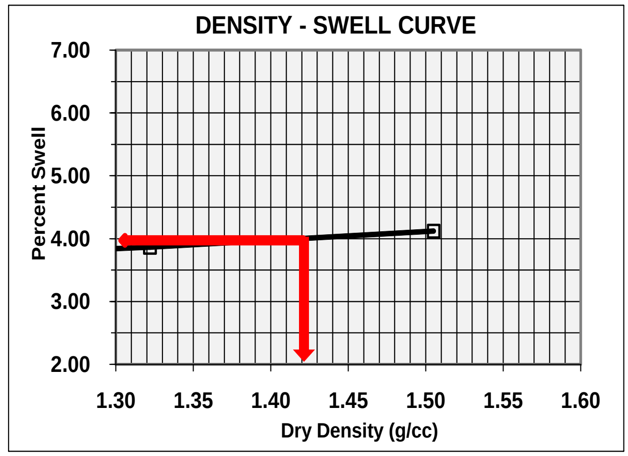
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.27	4.6	2.58
30	1.35	5.2	2.92
65	1.50	6.3	4.12
95% of MDD :	1.367		
CBR at 95% of MDD :	5.40		

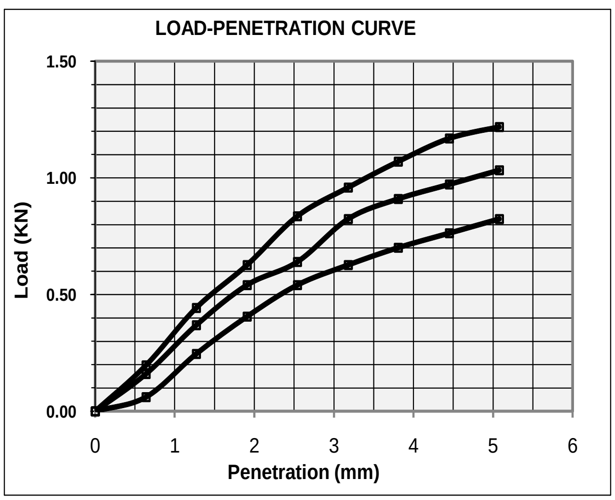
E. Compiled soil laboratory data obtained from 1.25% enset fiber conjugated soil

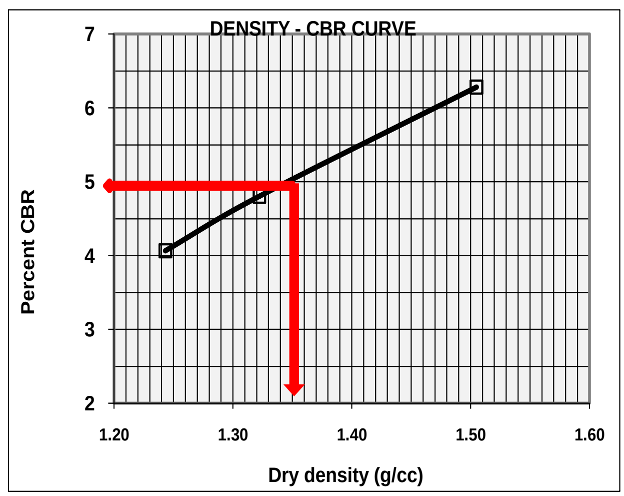
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.425
OMC (%) :	26.0

Blows	Before Soaking DD (g/cc)	Before Soaking Moisture (%)	After Soaking DD (g/cc)	After Soaking Moisture (%)
10	1.24	23.53	1.22	37.67
30	1.32	23.93	1.32	33.08
65	1.50	23.76	1.49	31.34









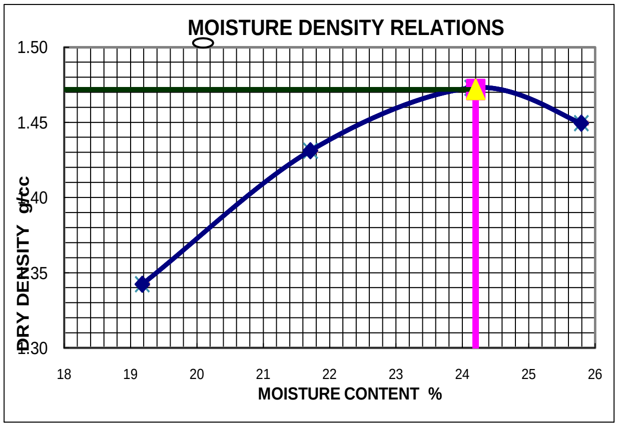
Blow	LOAD (KN) 2.54mm	LOAD (KN) 5.08mm	CBR (%) 2.54mm	CBR (%) 5.08mm
10	0.54	0.82	4.1	4.1
30	0.64	1.03	4.8	5.2
65	0.84	1.22	6.3	6.1

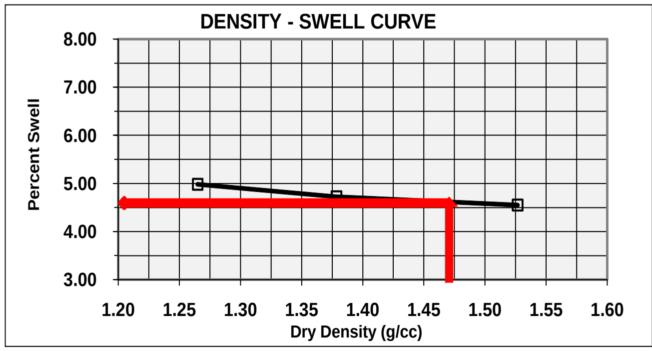
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.24	4.1	3.78
30	1.32	4.8	3.86
65	1.50	6.3	4.12
95% of MDD :	1.354		
CBR at 95% c	5.00		

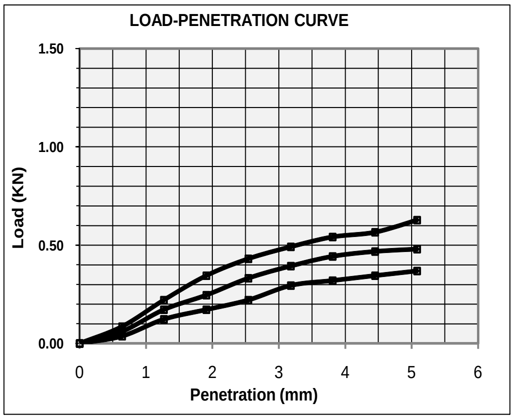
F. Compiled soil laboratory data obtained from conducting 0.25% teff fiber conjugated soil.

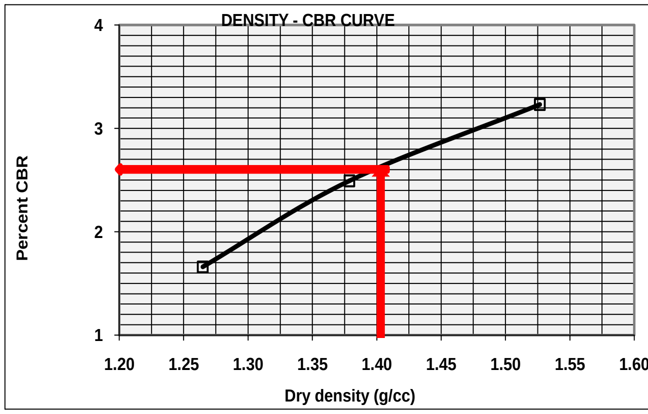
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.472
OMC (%) :	24.2

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moistur (%)
10	1.26	22.46	1.25	36.90
30	1.38	23.29	1.37	32.26
65	1.53	23.66	1.52	29.32









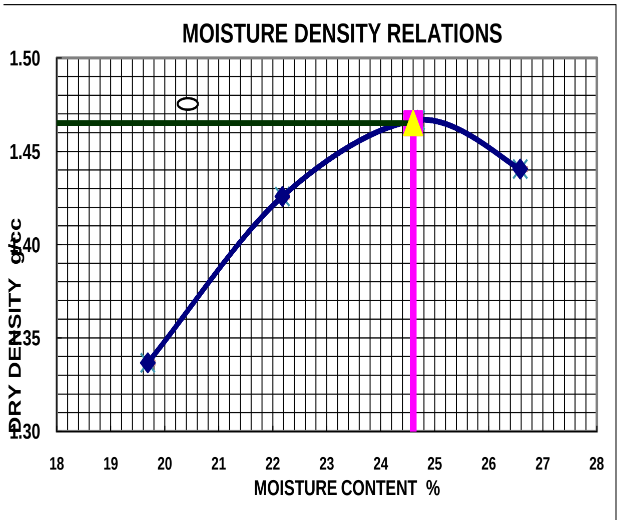
Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.22	0.37	1.7	1.8
30	0.33	0.48	2.5	2.4
65	0.43	0.63	3.2	3.1

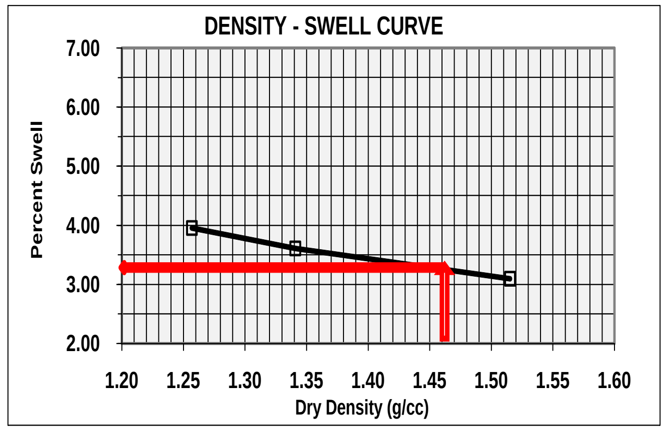
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.26	1.7	4.98
30	1.38	2.5	4.72
65	1.53	3.2	4.55
95% of MDD :	1.398		
CBR at 95% of MDD :	2.60		

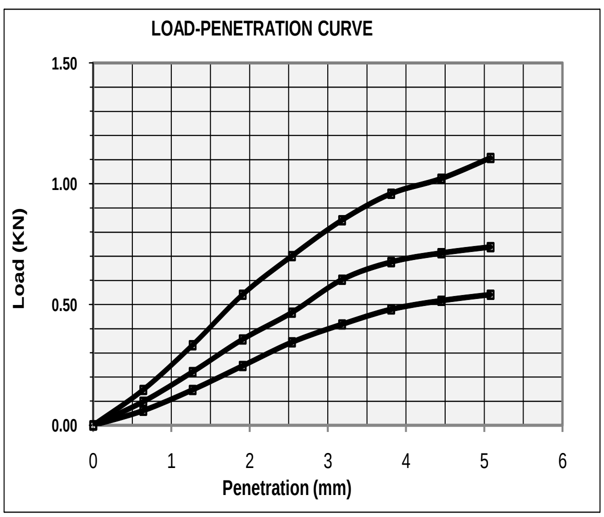
G. Compiled soil laboratory data obtained from conducting 0.5% teff fiber conjugated soil

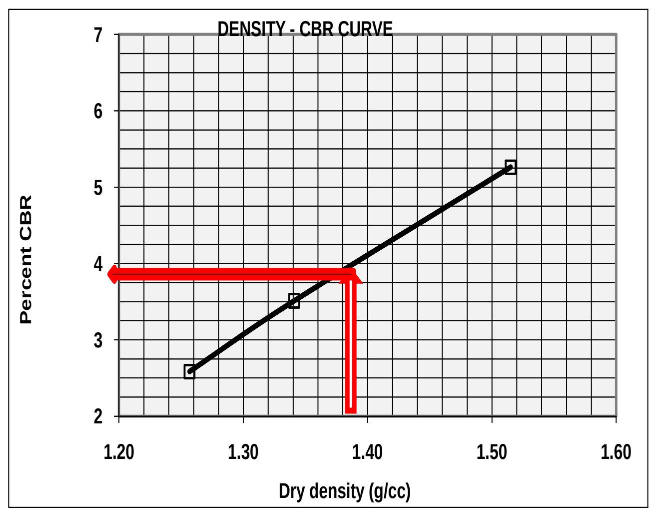
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.465
OMC (%) :	24.6

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.26	22.84	1.25	34.49
30	1.34	24.08	1.34	33.33
65	1.52	24.01	1.47	31.41









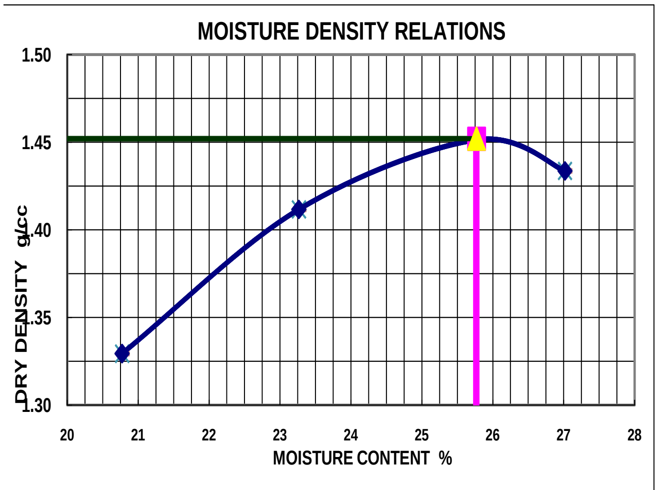
Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.34	0.54	2.6	2.7
30	0.47	0.74	3.5	3.7
65	0.70	1.11	5.3	5.5

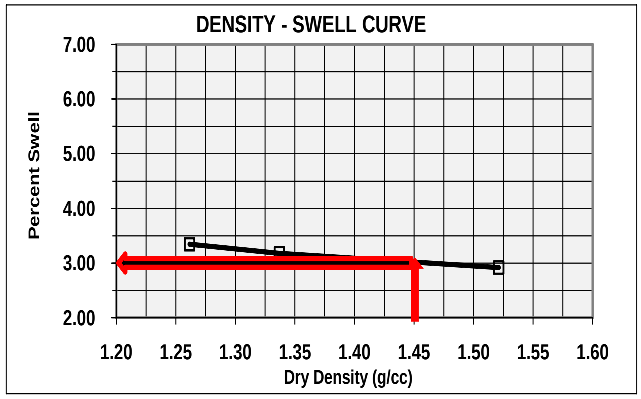
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.26	2.6	3.95
30	1.34	3.5	3.61
65	1.52	5.3	3.09
95% of MDD :	1.392		
CBR at 95% of MDD :	3.90		

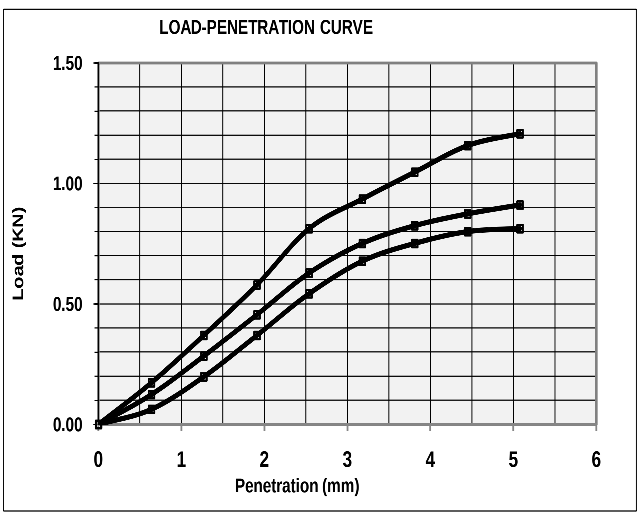
H. Compiled soil laboratory data obtained from conducting 0.75% teff straw fiber conjugated soil

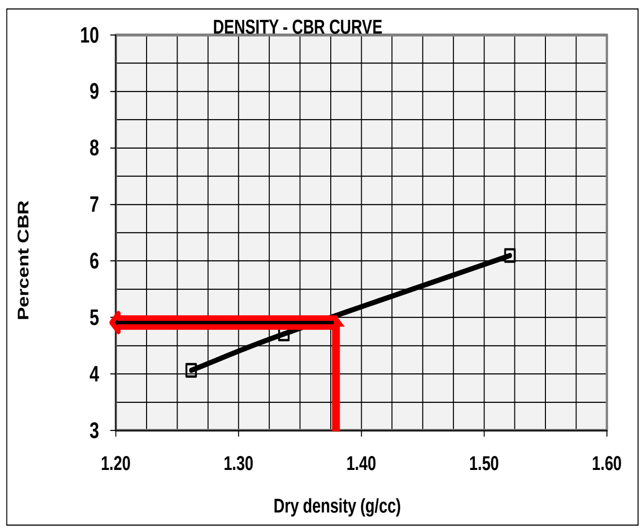
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.452
OMC (%) :	25.8

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.26	23.17	1.26	35.55
30	1.34	24.91	1.33	34.35
65	1.52	24.52	1.50	34.56









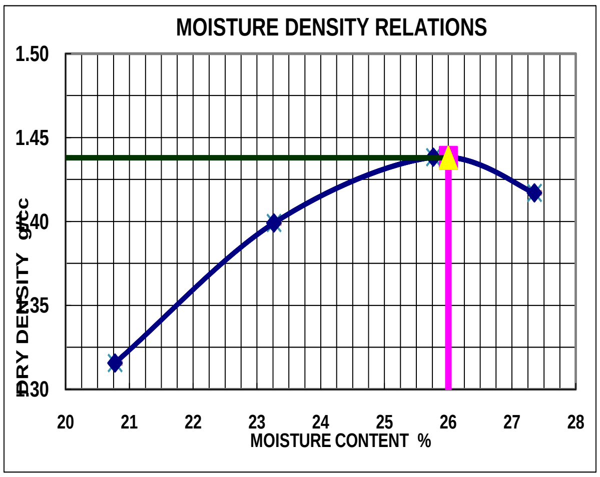
Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.54	0.81	4.1	4.1
30	0.63	0.91	4.7	4.6
65	0.81	1.21	6.1	6.0

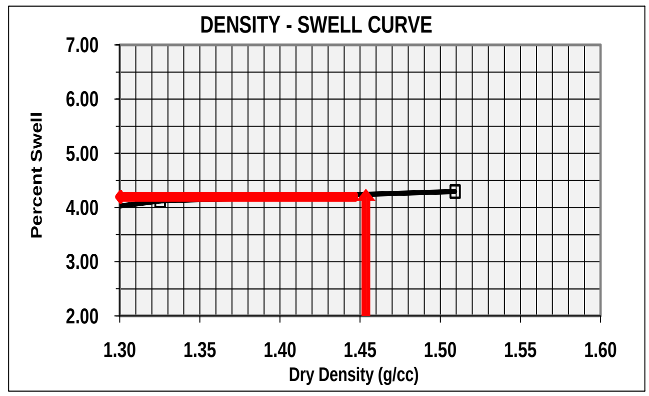
Blow	Dry density (g/cc)	CBR %	Swell %
10	1.26	4.1	3.35
30	1.34	4.7	3.18
65	1.52	6.1	2.92
95% of MDD :	1.379		
CBR at 95% of MDD :	4.90		

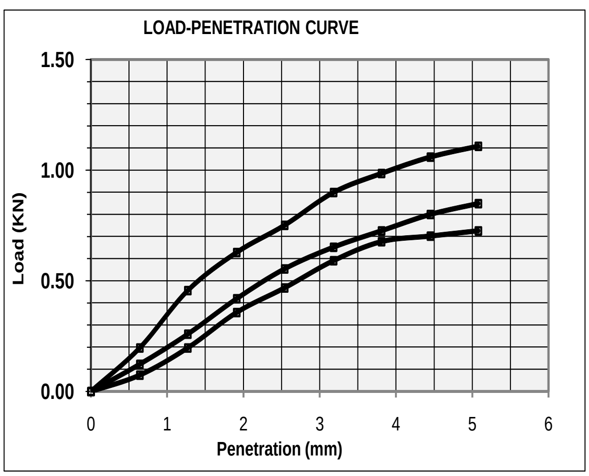
I. **Compiled soil laboratory data obtained from conducting 1% teff straw fiber conjugated soil**f

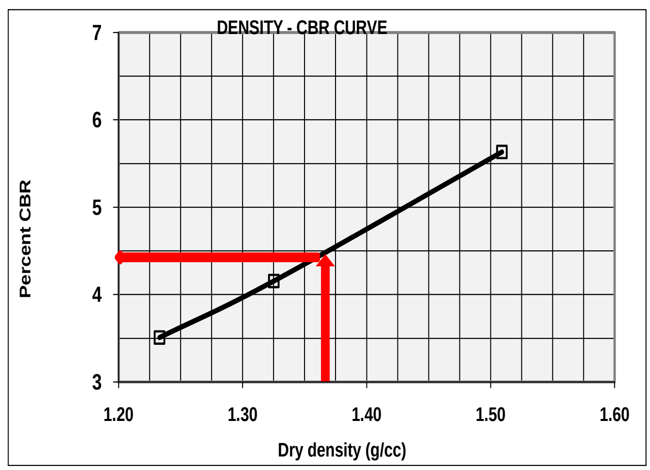
MODIFIED PROCTOR : T-180, METHOD D	
MDD (g/cc) :	1.438
OMC (%) :	26.0

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.23	22.22	1.22	41.14
30	1.33	22.14	1.32	41.84
65	1.51	21.32	1.50	46.93









Blow	LOAD (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	0.47	0.73	3.5	3.6
30	0.55	0.85	4.2	4.2
65	0.75	1.11	5.6	5.5

Blow	Dry density (g/cc)	CBR %	Swell %
10	1.23	3.5	3.78
30	1.33	4.2	4.12
65	1.51	5.6	4.29
95% of MDD :	1.366		
CBR at 95% of MDD :	4.40		

J. Proctor compaction value of enset ventricusom conjugated soil

Fiber content (%)	**0**	**0.25**	**0.5**	**0.75**	**1**	**1.25**
MDD	1.478	1.470	1.468	1.454	1.439	1.425
OMC	23.8	24	24.8	25.2	25.7	26

K. Proctor compaction value of teff straw conjugated soil

Fiber content (%)	0	0.25	0.5	0.75	1
MDD	1.478	1.472	1.465	1.452	1.435
OMC	23.8	24.2	24.6	25.8	26

L. Swell property of conjugate soil with increasing content of enset ventricosum fiber.

Percent of fiber	**0**	**0.25**	**0.5**	**0.75**	**1**	**1.25**
Percent swell of soil on 100% MDD	5	4.5	4.4	3.2	3.5	4
Percent decrease in swell	0	10	12	36	30	20

M. swell property of conjugate soil with increasing of teff straw fiber.

Percent of fiber	**0**	**0.25**	**0.5**	**0.75**	**1**
Percent swell of soil on 100% MDD	5	4.6	3.3	3	3.2
Percent decrease in swell	0	8	34	40	36

16. EFFECTS OF FIBERS ON ROAD PAVEMENT THICKNESSES

A. effect of fibers on "granular road-base/ surface dressing"

S/T in mm	Vertical profile	Pavement type	T1	T2	T3	T4	T5	T6
S1- Sub-Grade Soil		Surface dressing	Sd	Sd	sd	Sd	Sd	Sd
		Granular subbase1	150	150	200	200	200	225
		Granular sub-base 2	175	225	200	250	300	325
		Sub-grade / capping	300	300	300	300	300	300
S2=Soil Improved By Teff Straw		Surface dressing	Sd	Sd	sd	Sd	Sd	Sd
		Granular subbase1	150	150	200	200	200	225
		Granular sub-base 2	150	200	175	225	275	300
		Sub-grade / capping	200	200	200	200	200	200
S3=Soil Improved By Enset Vetricosum Fiber		Surface dressing	Sd	Sd	sd	Sd	Sd	Sd
		Granular subbase1	150	150	200	200	200	225
		Granular sub-base 2	200	250	225	275	325	350
		Sub-grade / capping	0	0	0	0	0	0

Sd = surface dressing

B. effect of fibers on “Composite road base (unbounded and cemented)/surface dressing”

<table>
<tr><th>S/T in mm</th><th>Vertical profile</th><th>Pavement type</th><th>T1</th><th>T2</th><th>T3</th><th>T4</th><th>T5</th><th></th><th>T6</th><th>T7</th></tr>
<tr><td rowspan="5">S1- SUB-GRADE SOIL</td><td></td><td>Surface dressing</td><td>Sd</td><td>Sd</td><td>sd</td><td>Sd</td><td>Sd</td><td></td><td>Sd</td><td>Sd</td></tr>
<tr><td></td><td>Granular subbase1</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td></td><td>150</td><td>150</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Granular subbase 2</td><td rowspan="2">150</td><td rowspan="2">175</td><td rowspan="2">200</td><td rowspan="2">225</td><td rowspan="2">275</td><td>Sub grade</td><td>125</td><td>125</td></tr>
<tr><td>GB2</td><td>150</td><td>175</td></tr>
<tr><td></td><td>Sub grade / capping</td><td>300</td><td>300</td><td>300</td><td>300</td><td>300</td><td></td><td>300</td><td>300</td></tr>
<tr><td rowspan="5">S2=SOIL IMPROVED BY TEFF STRAW</td><td></td><td>Surface dressing</td><td>Sd</td><td>Sd</td><td>sd</td><td>Sd</td><td>Sd</td><td></td><td>Sd</td><td>Sd</td></tr>
<tr><td></td><td>Granular subbase1</td><td>125</td><td>150</td><td>150</td><td>150</td><td>150</td><td></td><td>150</td><td>150</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Granular subbase 2</td><td rowspan="2">150</td><td rowspan="2">150</td><td rowspan="2">175</td><td rowspan="2">200</td><td rowspan="2">250</td><td>Sub grade</td><td>125</td><td>125</td></tr>
<tr><td>GB2</td><td>125</td><td>150</td></tr>
<tr><td></td><td>Subgrade / capping</td><td>200</td><td>200</td><td>200</td><td>200</td><td>200</td><td></td><td>200</td><td>200</td></tr>
<tr><td rowspan="5">S3=SOIL IMPROVED BY ENSET VETRICOSUM</td><td></td><td>Surface dressing</td><td>Sd</td><td>Sd</td><td>sd</td><td>Sd</td><td>Sd</td><td></td><td>Sd</td><td>Sd</td></tr>
<tr><td></td><td>Granular subbase1</td><td>125</td><td>125</td><td>150</td><td>150</td><td>150</td><td></td><td>150</td><td>150</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Granular subbase 2</td><td rowspan="2">150</td><td rowspan="2">150</td><td rowspan="2">150</td><td rowspan="2">175</td><td rowspan="2">225</td><td>Sub grade</td><td>125</td><td>125</td></tr>
<tr><td>GB2</td><td>125</td><td>150</td></tr>
<tr><td></td><td>Subgrade / capping</td><td>100</td><td>125</td><td>125</td><td>150</td><td>150</td><td></td><td>150</td><td>150</td></tr>
</table>

C. effect of fibers on "Granular road base/semi-structural surface"

S/T in mm	Vertical profile	Pavement type	T3	T4	T5	T6
S1- SUB-GRADE SOIL		Flexible bitumineous surface	50	50	50	50
		Granular road base GB1-3	175	175	175	200
		Granular road base Gs	200	300	300	325
		Subgrade / capping	300	300	300	300
S2=SOIL IMPROVED BY TEFF STRAW		Flexible bitumineous surface	50	50	50	50
		Granular road base GB1-3	175	175	175	200
		Granular road base Gs	175	225	275	300
		Subgrade / capping	200	200	200	200
S3=SOIL IMPROVED BY ENSET VETRICOSUM FIBER		Flexible bitumineous surface	50	50	50	50
		Granular road base GB1-3	175	175	175	200
		Granular road base G5	150	200	250	275
		Subgrade / capping	-	-	-	-

GS= granular sub- base; GB (1,2..)= granular road base classes

D. effect of fibers on "Composite road base/semistructural surface"

S/Tin mm	**Vertical profile**	**Pavement type**	**T3**	**T4**	**T5**	**SPLIT /T6**	**T6/SPLIT**	**T7**	**T8**
S1- SUB-GRADE SOIL		Flexible bitumineous surface	50	50	50		50	50	50
		GB1-GB2	150	150	150		150	150	150
		CB2	175	250	250	CB1	125	125	150
						CB2	125	250	150
		Sub grade / capping	300	300	300		300	300	300
S2=SOIL IMPROVED BY TEFF STRAW		Flexible bitumineous surface	50	50	50		50	50	50
		GB1-GB2	150	150	150		150	150	150
		CB2	175	200	225	CB1	125	125	150
						CB2	125	150	150
		Sub grade / capping	200	200	200		200	200	200
S3=SOIL IMPROVED BY ENSET VETRICOSUM FIBER		Flexible bitumineous surface	50	50	50	50		50	50
		GB1-GB2	150	150	150	150		150	150
		CB2	150	150	200	250	CB1	125	150
							CB2	125	125
		Sub grade / capping	125	150	150	150	150	150	150

GB1 & GB2 = Granular road base classes; CB2 = cement or lime stabilized road base class 2.

E. effect of fibers on "Granular road base/structural surfacing"

S/T in mm	Vertical profile	Pavement type	T6	T7	T8
S1- SUB-GRADE SOIL		Flexible bitumineous surface	100	125	150
		GB1-GB2	200	225	250
		Granular sub-base	250	225	250
		GC2	350	350	350
S2=SOIL IMPROVED BY TEFF STRAW		Flexible bitumineous surface	100	125	150
		GB1-GB2	200	225	250
		Granular sub-base	225	225	2250
		GC2	200	200	200
S3=SOIL IMPROVED BY ENSET TRICOSUM FIBER		Flexible bitumineous surface	100	125	150
		GB1-GB2	200	225	250
		Granular sub-base	250	250	275
		GC2	-	-	-

GC (1,2,3,4) Granular capping or sub-grade fill classes

F. effect of fibers on “Composite road base/ structural surface”

S/T in mm	Vertical profile	Pavement type	T6	T7	SPLIT	T8
S1- SUB-GRADE SOIL		Flexible bitumineous surface	100	125		150
		GB1-GB3	150	150		150
		CB2	200	250	Sub-grade	125
					CB2	125
		Sub grade / capping	350	350		350
S2=SOIL IMPROVED BY TEFF STRAW		Flexible bitumineous surface	100	125		150
		GB1-GB2	150	150		150
		CB2	200	250	Sub-grade	125
					CB2	125
		Sub grade / capping	200	200		200
S3=SOIL IMPROVED BY ENSET VETRICOSUM FIBER		Flexible bitumineous surface	100	125		150
		GB1-GB2	150	150		150
		CB2	175	200		225
		Sub grade / capping	125	125		125

CB2= cement or lime stabilized road base class 2; CS = cement or lime stabilized sub-base

G. effect of fibers on “Bituminous road base/semi-structural surface”

S/T in mm	Vertical profile	Pavement type	T4	T5	T6	T7	T8
S1- SUB-GRADE SOIL		SD/bitumineous	SD	50	50	50	50
		Bitumineous road base	150	125	150	175	200
		Granular sub-base G5	200	225	225	225	250
		Subgrade / capping	350	350	350	350	350
S2=SOIL IMPROVED BY TEFF STRAW		SD/bitumineous	SD	50	50	50	50
		Bitumineous road base	150	125	150	175	200
		Granular sub-base G5	200	225	225	225	250
		Subgrade / capping	200	200	200	200	200
S3=SOIL IMPROVED BY ENSET VETRICOSUM FIBER		SD/bitumineous	SD	50	50	50	50
		Bitumineous road base	150	125	150	175	200
		Granular sub-base G5	250	250	275	275	275
		Subgrade / capping	-	-	-	-	-

Sd =surface diressing; Gs=class of granular sub base.

H. effect of fibers on “Cemented road base/surface dressing”

S/T in mm	**Vertical profile**	**Pavement type**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
S1- SUB-GRADE SOIL		SD	SD	SD	SD	SD	SD	SD
		CB2	150	150	175	200	200	200
		CS	150	175	175	200	225	250
		Subgrade / capping	350	350	350	350	350	350
S2=SOIL IMPROVED BY TEFF STRAW		SD	SD	SD	SD	SD	SD	SD
		CB2	150	150	175	200	200	200
		CS	150	175	175	175	225	275
		Subgrade / capping	225	225	225	225	225	225
S3=SOIL IMPROVED BY ENSET VETRICOSUM FIBER		SD	SD	SD	SD	SD	SD	SD
		CB2	150	150	175	200	200	200
		CS	150	150	150	275	200	225
		Subgrade / capping	125	125	125	125	125	125

Sd = surface dressing; CB2= cement or lime stabilized road base class 2; CS = cement or lime stabilized sub-base