Addis Ababa University

Addis Ababa Institute of Technology

School of Graduate Studies

School of Civil and Environmental Engineering

Bamboo as Temporary Soil Reinforcement

A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Civil Engineering under Geotechnical Engineering.

By:

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October, 2015

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ABSTRACT

Now-a-days, the high cost and lack of reinforcing steel in many parts of the world has directed to increasing interest in the possible use of other locally accessible materials for the construction. For this reason the main objective of this research is to undertake the use of bamboo as temporary soil reinforcement which is inexpensive and local available material in Ethiopia. For the thesis study Shimal bamboo (Oxytenanthera abyssinica) was used as reinforcement. This bamboo is found in Benishangul–Gumuz Regional State and it is covered the area of 440, 000 hectares. The primary purpose of reinforcing the soil is to improve stability, to increase modulus of rigidity and to increase the strength of lateritic soil which is found in Assosa region.

The tests were carried out to find the use of bamboo as temporary soil reinforcement material. Accordingly ASTM, several laboratory tests were conducted. Atterberg limits (PI, LL, and PL), washed sieve analysis, hydrometer analysis and specific gravity on the air dried soil; standard compaction tests and unconfined compression tests on the molded soil –bamboo sample were conducted. The soil specimens were molded in cylindrical form of 38mm diameter and 76mm height while the bamboo specimens were trimmed in to square plates of 24mm size and 3mm thickness. The trial soil specimens are: soil specimen without bamboo specimen (0 bamboo), soil specimen with one bamboo specimen in the center (1 bamboo), soil specimen with one bamboo specimen on top and one at the bottom (2 bamboos) and soil specimen with one bamboo specimen on top, center and bottom (3 bamboos).

A lateritic soil classified as A-7-5 under AASHTO soil classification system was reinforced with 0, 1, 2 and 3 bamboo specimens at laboratory trial level to evaluate its unconfined compressive strength (UCS) and modulus of rigidity. From the bamboo laboratory test result, the dry density of the molded soil specimen decreased from 1.41g/cm^3 at 0 bamboo specimen to 1.35g/cm^3 at 3 bamboo specimens, the UCS increased from 278.96kN/m^2 at 0 bamboo specimen to 381.71kN/m^2 at 3 bamboo specimens. Also, for each of the four percentage strains (0.01, 0.02, 0.03 and 0.04%) considered, the modulus of rigidity increased with bamboo specimens.

Key Words: - Bamboo; Modulus of rigidity; Optimum moisture content; Friction

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TABLE OF CONTENTS

LIST OF FIGURES……………………………………………………………..viii
LIST OF TABLES………………………………………………………………x
LIST OF ACRONYMS…………………………………………………………1
Symbols…………………………………………………………………………2
1 INTRODUCTION……………………………………………………………3
1.1 Background 3
1.2 Statement of the Problem 4
1.3 Objective of the study 5
1.4 Methodology 5
1.5 Structure of the thesis 6
2 LITERATURE REVIEW……………………………………………………..7
2.1 Introduction 7
2.2 Properties of Bamboo 8
2.2.1 Physical Properties of bamboo.. 8
2.2.2 Mechanical properties of bamboo... 8
2.2.3 Physical and mechanical properties of lowland bamboo of Benishangul Gumuz Region State 10
2.3 Soil reinforcement 10
2.3.1 Bamboo as reinforcement 10
2.4 Bamboo as Construction Material... 11
2.5 The use of bamboo as soil reinforcement from different researches 16
3 SAMPLING AREA DESCRIPTION………………………………………..28
3.1 General information 28
3.2 Land cover and land use 29
3.3 Geology 29
3.4 Climate 29
3.5 Soil Characteristics of Assosa 30
4 SAMPLING AND LABORATORY TEST RESULTS………………………31
4.1 Collection and preparation of soil sample.. 31
4.2 Collection and preparation of bamboo specimens 31
4.3 Laboratory test results and discussions 32

4.3.1 Identification of sensitivity to test procedures ... 32
4.3.2 Loss of water of hydration ... 32
4.3.3 Disaggregation of clay-size particles on mixing ... 32
4.3.4 Drying and wetting ... 33
4.4 Characteristics of the soil ... 33
4.4.1 Moisture Content Determination ... 33
4.4.2 Index properties of soil ... 34
4.4.3 Soil classification ... 35
4.4.4 Compaction Test ... 37
4.5 Characteristics of the soil-bamboo specimen in comparison with pure soil sample ... 38
4.5.1 Dry Densities ... 38
4.5.2 Unconfined compressive strength (UCS) ... 39
4.5.3 Modulus of Rigidity ... 41
5 CONCLUSIONS AND RECOMMENDED AREA OF FURTHER STUDY ... 44
5.1 Conclusion ... 44
5.2 Recommended area of further study ... 45
6 REFERENCES ... 46
APPENDIX-A ... 49
Index properties test results ... 49
[A] Natural moisture content ... 49
[B] Specific gravity ... 49
Calibration of pycnometer ... 49
Specific gravity determination ... 50
[C] Grain size analysis ... 50
Sieve Analysis ... 50
Hydrometer analyses ... 51
[D] Atterberg Limits ... 53
APPENDIX – B ... 54
Standard Compaction Test results ... 54
APPENDIX –C ... 55
The amount of water added and mass of soil compacted ... 55
APPENDIX –D ... 57
MD Vs. No of bamboo test result ... 57

APPENDIX –E…………………………………………………………………58
UCS Vs. No of bamboo test result…………………………………………………...58
APPENDIX – F……………………………………………………………...59
Unconfined Compression Strength Test Results…………………………………….59
[A] UCS with zero bamboo reinforcement test results 59
[B] UCS with one bamboo reinforcement test results 61
[C] UCS with two bamboo reinforcement test results 63
[D] UCS with three bamboo reinforcement test results 65
APPENDIX-G……………………………………………………………………..68
MR Vs. No of bamboo test result……………………………………………………68

LIST OF FIGURES

Figure 1: Bamboo specimen 4
Figure 2: Remolding equipment 4
Figure 3: Soil specimens with 0, 1, 2 and 3 bamboo specimens 5
Figure 4: Lowland bamboo natural forest in Assosa area........ 8
Figure 5: Bamboo poles & bamboo firewood on sale in an open market in Assosa town . 8
Figure 6: Intensive bamboo use for housing in rural clustered rural villages in Assosa .. 12
Figure 7: Common bamboo pit latrine structures used in Assosa rural settlements........ 12
Figure 8:Use of lowland bamboo in scaffolding, and formwork in local flour mills in Assosa town 13
Figure 9: Furniture made from lowland bamboo on sale in an open market day at Assosa town........ 13
Figure 10: Use of bamboo as a fencing and bridge material 14
Figure 11: Bamboo as a building and construction material for grain storage granary in Assosa 14
Figure 12: Front elevation and roof of the traditional-modern house in Assosa 15
Figure 13: Product of bamboo floor tiles at the bamboo star agro-forestry plc........ 15
Figure 14:Top view of placement of reinforcement and sample preparation........ 16
Figure 15:The view of valley and hill side[24]........ 17
Figure 16:Disposal of debris in hilly area[24] 17
Figure 17: Construction of pine logs to protect the hill slopes under the Bhutan Rural Access Project[24] 18
Figure 18: Bamboo terracing, bamboo crib walls, and bamboo knitting were developed to suit the requirements of each slope [24]. 19
Figure 19:Plantting of bamboo over the bamboo structures to complete the process of slope stabilization........ 20
Figure 20: Construction of bamboo knitting structures and the planting of local species of flora in progress 20
Figure 21: The bioengineering works remained stable even during fierce monsoon rains in 2007 20
Figure 22: Conventional methods of protecting the cutting of the hillside the road 21
Figure 23:Cross sections of retaining wall (gabion and crib) constructed at Kusunti, Lalitpur[28] 23
Figure 24:Before and after construction photographs, Kusunti, Lalitpur [28] 23
Figure 25:The vegetated bamboo crib wall just after construction (November 2006) and after one year of construction (Kusunti, Lalitpur, November, 2007) 24
Figure 26:Before and after construction photographs, Kali Khola, Pokhara (June 2007) 24

Figure 27:Before and after construction photographs, Pulchowk Campus, Lalitpur (December, 2007) ... 25
Figure 28:Before and after construction photographs, Sarangkot landslide, Pokhara (January, 2008) ... 25
Figure 29:Vegetated bamboo crib wall construction in Thankot [30] ... 27
Figure 30: location of the research area, Assosa town, on the map of Ethiopia ... 28
Figure 31:A square plate of bamboo specimens ... 31
Figure 32: Grain size distribution curve ... 35
Figure 33: Dry density vs. moisture content graph ... 38
Figure 34: Change in dry density with number of bamboo specimen ... 39
Figure 35: Variation of UCS with the number of bamboo specimens ... 40
Figure 36: Stress relationship for specimens at 0, 1, 2, and 3 bamboo specimens ... 42
Figure 37: Variation of modulus of rigidity with No. of Bamboo specimen ... 43
Figure 38:Grain size distribution curve ... 52
Figure 39:Water content Vs. No of blow curve ... 53
Figure 40:dry density vs. moisture content graph ... 54
Figure 41:Change in dry density with number of bamboo specimen ... 57
Figure 42:Variation of UCS with the number of bamboo specimens ... 58
Figure 43:Axial stress Vs. % Axial Strain with zero bamboo enforcement ... 61
Figure 44:Axial stress Vs. % Axial Strain with one bamboo enforcement ... 63
Figure 45:Axial stress Vs. % Axial Strain with two bamboo enforcement ... 65
Figure 46:Axial stress Vs. % Axial Strain with three bamboo enforcement ... 67
Figure 47: Variation of modulus of rigidity with No. of Bamboo specimen ... 69

LIST OF TABLES

Table 1: Typical materials properties of bamboo compared with mild steel, concrete and timber [18] 9
Table 2: Index properties of the soil 34

LIST OF ACRONYMS

AASHTO: American Association of State Highway and Transportation Officials

ASTM: American Society for Testing and Materials.

BCB: Bitumen Coted Bamboo Mesh

CBR: California Bearing Ratio

d/B: Depth / Breadth

FPRDI: Forest Products Research and Development Institute

g: gram

km: kilometer

kN : Kilo Newton"s

LL: Liquid limit

MDD: Maximum Dry Density

MN: Mega Newton"s

MPa: Mega Pascal

m: metres

mm: millimetres

NMC: Natural moisture content

N: Number of Reinforcing Layer

OMC: Optimum Moisture Content

PWD: Public Works Department

PL: Plastic limit

PI: Plasticity Index

RH: Relative Humidity

SG: Specific gravity

UCS: Unconfined Compressive Strength

WP: Waste Plastics

WTR: Waste Tyre Rubber

Symbols

Designation	unit
A: Cross-section area	m2
γw : Density of water	kg/m3
Wn: Existing or natural moisture content of dry soil	%
LL : Liquid limit	%
Wo : Optimum moisture content	%
PI : Plasticity index	%
PL: Plastic limit	%
M: Mass	kg
γmax : Maximum dry density of soil	kg/m3
γd : Mass of dry soil	kg/m3
V : Volume of water to be added	m3

1 INTRODUCTION

1.1 Background

Soil reinforcement is defined as a technique to improve the engineering characteristics of soil. In this way, using natural fibers to reinforce soil is an old and ancient idea. Consequently, randomly distributed fiber-reinforced soils have recently attracted increasing attention in geotechnical engineering for the second time.

Currently, the scarcity and high cost of reinforcing steel in many countries have enforced to increasing interest in the possible use of other available local materials for the construction.

One natural material which has great appeal in terms of availability and ease of use in the rural and farming communities in the developing world is bamboo. Bamboos occur mostly in tropical and subtropical areas, from sea level to snow-capped mountain peaks, with a few species reaching into temperate areas. They are most abundant in south-eastern Asia, with some species in the Americas and Africa and none in Australia. One of the major applications of bamboo is for construction and housing. It is estimated that one billion people live in bamboo houses. For ages bamboo has been used in construction and currently they are used as props, foundations, framing, scaffolding, flooring, walls, roofs and trusses. Bamboos are tied together to make grid reinforcement and placed in soft clay to solve deformation problems in embankments [1]. It is encouraged that bamboo be used as reinforcement material for construction of walls in place of mud walls since they have quite higher strength and they are environmentally sustainable.

For the thesis, study Shimal bamboo (Oxytenanthera abyssinica) was used and it is found in Benishangul–Gumuz National Regional State. The bamboo in this region is majorly used as: firewood, food, house construction material (walls, structural work, ceiling, partitioning, floor, scaffolding, formwork, etc.), fencing, pit latrines, simple bridges, animal houses, the construction of grain storage structures and furniture making.

Bamboo is also used in the making of various implements (e.g. ladders) used at construction sites. Bamboo Star Agro-forestry PLC factory that is found in Benishangul–Gumuz National Regional State produces bamboo flooring and bamboo sticks at export standard level.

Bamboo has been used in many applications in construction works for hundreds of years because of its high strength-to-weight ratio and its relative ease of use. Bamboo has high tensile strength and is relatively light in weight. It is therefore an attractive material for engineering purposes and has had many applications in construction works for hundreds of years. Its properties are such that it also has the potential for reinforcing weaker materials [2].

Soil can often be regarded as a combination of four basic types: gravel, sand, clay, and silt. It generally has low tensile and shear strength and its characteristics may depend strongly on the environmental conditions (e.g. dry versus wet) [3]. On the other hand, reinforcement consists of incorporating certain materials with some desired properties within other material which lack those properties [4]. Therefore, soil reinforcement is defined as a technique to improve the engineering characteristics of soil in order to develop the parameter such as shear strength, compressibility, density; and hydraulic conductivity [5]. Mainly, reinforced earth is a composite material consisting of alternating layers of compacted backfill and man-made reinforcing material [6].

So, the primary purpose of reinforcing soil mass is to improve its stability, to increase its bearing capacity, and to reduce settlements and lateral deformation [7].

1.2 Statement of the Problem

Several constructions in Ethiopia have been failing due to lack of use of soil with adequate engineering strength. Thus the need for improvement of the engineering properties of soil has been a paramount concern to the geotechnical engineers. The engineers have been reinforcing the soil to improve its stability, to increase its bearing capacity, to reduce settlement and lateral deformation by using different material.

In recent times, the high cost and general shortage of reinforcing steel in many parts of the world has led to increasing interest in the possible use of alternative locally available materials for the construction. For this reason the main objective of the thesis is to undertake the use of bamboo as temporary soil reinforcement which is cheaper and locally available material in Ethiopia.

1.3 Objective of the study

The general objective of this research is;

- ❖ to undertake the use of bamboo as temporary soil reinforcement because of its cheapness and local availability in Ethiopia.

The specific objectives of this research are:

- ❖ to improve soil stability.
- ❖ to improve the engineering property of the lateritic soil or
- ❖ to improve the strength and stiffness of the lateritic soil found in Assosa region by using bamboo reinforcement.

1.4 Methodology

1. Materials**:**
   - ❖ The soil was air dried and pulverized appropriately.
   - ❖ Shimal bamboo (Oxytenanthera abyssinica) which was collected from Benishangul–Gumuz Regional State. The bamboo specimens were cut and trimmed into a square plate of 24mm size and 3mm thickness shown in Figure -1. The smooth surfaces of the bamboo specimens were roughened to increase the friction between the specimen and the soil.

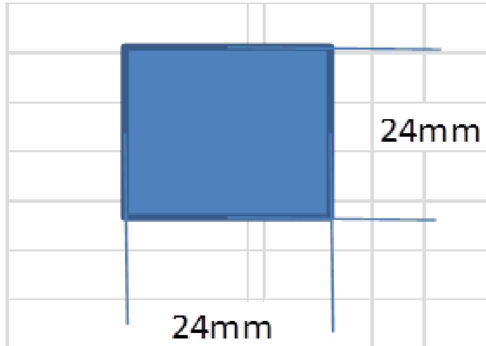

Figure 1: Bamboo specimen

2. Tests including liquid limit, plastic limit, washed sieve analysis, hydrometer analysis and specific gravity were performed on the air dried soil.
3. Compaction test was also carried out on the soil to determine its optimum moisture content (OMC) and maximum dry density (MDD).
4. Unconfined compressive strength (UCS) of its specimen was molded in a cylindrical mold of diameter 38mm and height of 76mm by using the equipment shown in the Figure 2. These are soil specimen without bamboo specimen and soil specimen with bamboo specimen (soil+1bamboo, soil+2bamboo, soil+3bamboo) as shown in Figure 3.

Figure 2: Remolding equipment

The soil was air dried and pulverized appropriately. Then the soil was sieved using sieve No 4 or 4.75 mm sieve size for remolding purpose with bamboo and without bamboo. 30ml amount of water and 122.4 g mass of the soil were needed for remolding. For easy referencing, this detail calculation is attached in the APPENDIX-C

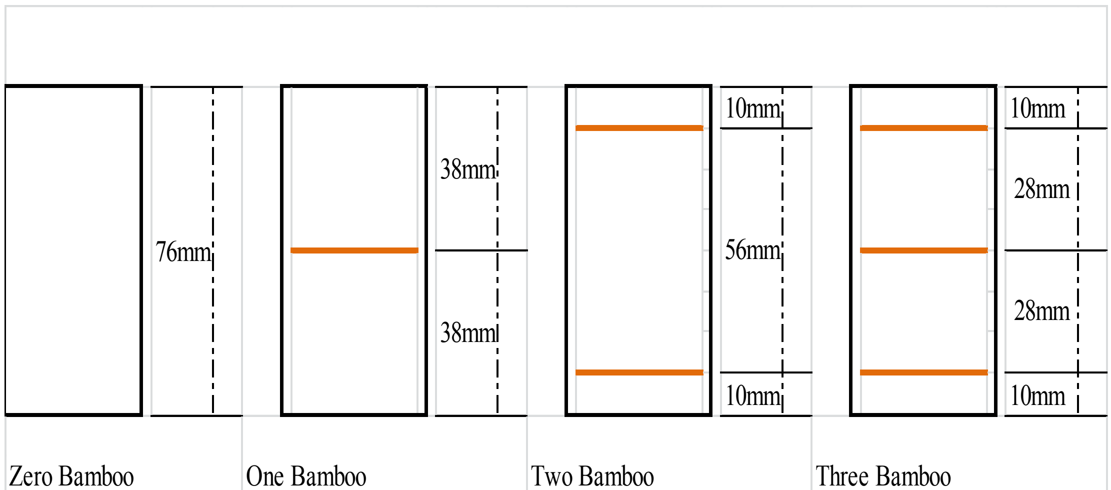

Figure 3: Soil specimens with 0, 1, 2 and 3 bamboo specimens

5. In all tests, the bamboo specimen was placed horizontally in the layers. The same compaction effort was applied to all soil-bamboo specimen system. During compaction, the bulk density and molding moisture contents were determined.
6. The UCS test was then conducted on all the soil-bamboo specimens and its failure stresses as well as the stress-strain relationship of each of the specimen systems determined.
7. Plot change in dry density vs. number of bamboo specimen, variation of UCS vs. the number of bamboo specimens, variation of modulus of rigidity vs. number of bamboo specimen and stress-strain relationship for soil specimens and soil-bamboo specimens.
8. Finally interpret the result from the plot graphs. Prove the use of bamboo as temporary soil reinforcement instead of steel or other reinforcement material**.**

1.5 Structure of the thesis

This thesis is organized in six chapters. Chapter one deals with the general introduction, statement of the problem, objective of the study and methodology. Chapter two gives the literature review on general introduction about bamboo, bamboo as soil reinforcement and the use of bamboo as soil reinforcement from different researches. Chapter three gives an overview on sampling area description like general information, land cover and land use, geology, climate, and soil characteristics of Assosa. . Chapter four gives an overview on sampling and laboratory test results like collection and preparation of soil sample and bamboo specimens, remolding of soil with and without bamboo specimens, identification of sensitivity to test procedures ,characteristics of the soil and characteristics of the soil-bamboo specimen in comparison with pure soil sample (dry densities, Unconfined compressive strength (UCS), modulus of rigidity). Chapter five gives conclusion and recommendation area of further study. Finally in chapter six lists of the references are included.

2 LITERATURE REVIEW

2.1 Introduction

Bamboo is the strongest and fastest growing perennial grass species that belongs taxonomically to the subfamily of Bambusoideae under the family of Pocaceae (8) . More than 1,500 species and 90 genera of bamboo are found in the world, covering 36 million (ha) of land which is distributed in the tropical and sub-tropical belt between 46^0 North and 47^0 South latitude at elevations as high as 4000m above sea level and is commonly found in Africa, Asia and Central and South America [9].

About 43 species and 11 genera bamboo are found in Africa, covering an estimated area of 2.7 million hectare. About 93% of Africa bamboo species are found only in Madagascar [9]. In terms of area coverage, 67 % of the African and more than 7% of the world bamboo resource is found in Ethiopia[10].This indicates that Ethiopia has the greatest bamboo resources in Africa representing a significant proportion of Africa‟s total bamboo resources.

Ethiopia has two bamboo species namely, the highland bamboo, Yushania alpine, (k.Schum) and the lowland bamboo, Oxytenanthera abyssinica (A. rich). It covers one million hectares of highland and lowland bamboo resources, which accounts for about 15% and 85 % respectively [10]. For the thesis study we will use Shimal bamboo (Oxytenanthera abyssinica) which is found in Benishangul–Gumuz Regional State and which is covering an area of 440, 000 hectare [11].

Bamboo used as to reinforce the soil which is found in Assosa town. There are some investigation have been done on Assosa town soil. Researchers have investigated that the Assosa town soil is classified as lateritic soil [12].

Figure 4: Lowland bamboo natural forest in Assosa area

Figure 5: Bamboo poles & bamboo firewood on sale in an open market in Assosa town

2.2 Properties of Bamboo

2.2.1 Physical Properties of bamboo

The amount of moisture in bamboo varies within and between the species, height and age of the living culm. The moisture content has a similar influence on the strength of the bamboo as it has in timber. Generally, in dry conditions the strength is higher than in the green condition. For some Malaysian bamboos, moisture content is about 30% to 130%. However the density of bamboo varies from about 0.5g/cm^3 to 0.9g/cm^3 with the outer culm having a far higher density than the inner part [13].

2.2.2 Mechanical properties of bamboo

The strength of bamboo depends on the species and on its age, moisture content, density and culm height. The mechanical properties of bamboo vary with the age of the bamboo and the height of the culm, as mentioned by [14]. However, higher moisture content will decrease the strength of bamboo. The strength of this material is also related to its density. The density of bamboo varies approximately from 0.5 to 0.9 g/cm^3 but can differ considerably within the culm (increase with the height of the culm) and between species [15].

As bamboo becomes older, the strength properties increase. This is probably due to the hardening of the culm walls as the bamboo matures in about 3 to 5 years, by which time it would reach its maximum strength [16].On the other hand,[14] states that culms take 2 to 6 years to mature which depends on the species. According to [15] young bamboo with higher moisture content shows greater increase in strength on drying than the older culms.

[17] presented a comparison between bamboo and the more common engineering materials, as tabulated in Table- 1. It was found that bamboo is very strong in tension, with a few species having tensile strength as high as that for mild steel. The ratio of tensile to compressive strength of bamboo can be as high as seven times. According to

[2] the tensile strength of bamboo is relatively high and can reach 370MPa. This makes bamboo an attractive alternative to steel in tensile loading applications. This is because the ratio of tensile strength to specific weight of bamboo is six times greater than that of steel [18].

Table 1: Typical materials properties of bamboo compared with mild steel, concrete and timber [18]

Material	Ultimate Strength (N/mm^2)		Tensile-Compressive Strength ratio, σ_t / σ_c	Modulus of Elasticity (kN/mm^2)
	Tension, σ_t	Compression, σ_c		
Mild Steel	480	-	1 .0	210
Concrete	2-4	25-55	0.1	10-17
Timber	20-1 10	50-100	1.1	8-13
Bamboo	180-440	38-65	4.8-7.1	7-20

[2] found the strength distribution at the bottom of the bamboo culm to be more uniform than at the top. The strength of bamboo also increases with age and the maximum strengths are realized at age 3-4years, after which strength begins to decrease [19]. In the nodes, the average fracture toughness is lower than the minimum value of the entire culm. Hence the fibers in the nodes do not contribute any fracture resistance. [15], also studied the mechanical properties of bamboo. They concluded that both physical and mechanical characteristics vary with respect to diameter, length, age, type, position along culm and moisture content of bamboo. Different bamboo species perform differently for the same set of test [20]. Bamboo will perform differently depending on the specie and maturity. Unlike steel rods, bamboo can raise many issues with respect to durability. Bamboo may contain high nutrients to foster fungi growth and insect attack. It needs to be protected from several conditions including temperature, moisture and pest.

2.2.3 Physical and mechanical properties of lowland bamboo of Benishangul Gumuz Region State

Samples of oxytenanthera abyssinica bamboo were tested on April 5-15, 2010 by the Physical and Mechanical Properties Section, Forest Products Research and Development Institute (FPRDI) of the Philippines to determine their physical and mechanical properties. Three samples were taken for testing with ages 1 year, 2 years and 3 years [21].

The table below shows the result of the laboratory test regarding the physical and mechanical properties of the lowland bamboo of Benishangul Gumuz Region:

The strength of bamboo increases with its age‟s. According to literature, at age three the bamboo can be harvested and be used for its possible ends. The results showed that the one year old can be used for medium construction like furniture and the three year old for heavy construction because of its strength classification which is based on wood (21).

Statistical analysis showed that age is important for relative density, fiber stress at proportional limit, modulus of rupture and shear at nodal portion. It means that age matters on the strength of bamboo. The height level (butt, middle & top) is not important may be due to limited descriptive samples [21].

2.3 Soil reinforcement

2.3.1 Bamboo as reinforcement

Bamboo reinforcement has been well documented by [22]. To begin with, unlike steel, the properties of bamboo are not consistent but cover a wide range. This is because they depend on a considerable number of variables including such obvious ones as; species of bamboo, age of the bamboo culm, moisture content and pre-treatment (i.e. how the bamboo is stored and weathered) but also on less obvious factors such as time of harvest, method of harvesting and soil in which it is grown

As a result, the properties of bamboo vary a great deal. Much academic research has been devoted to measuring the properties of bamboos under a very wide range of conditions; but, despite this, the detailed situation is not very clear because test methods have not been standardized and insufficient research has been done. Nevertheless, the broad range of likely values for the key variables of elastic modulus and tensile strength are well documented and therefore, realistic and safe values can probably be assumed for design purposes,, subject to checks made on samples of bamboo that it is proposed to use [22].

2.4 Bamboo as Construction Material

It has been found through research that some species of bamboo have ultimate tensile strength same as that of mild steel at yield point. Experimentally it has been found that the ultimate tensile strength of some species of bamboo is comparable to that of mild steel and varies from 140N/mm^2- 280N/mm^2. Bamboo is a versatile material because of its high strength-to-weight ratio, easy workability and availability. Bamboo needs to be chemically treated due to its low natural durability. It can be used as bamboo trusses, bamboo roof skeleton, bamboo walling/ceiling, bamboo doors and windows, bamboo flooring, reed boards, scaffolding [21].

Because of its high tensile strength, it is used as concrete reinforcement for slab, beam, column and concrete pavement and as soil reinforcement for soft clay soil under unpaved road, slope stability [2].

For the thesis study Shimal bamboo (Oxytenanthera abyssinica) was used as temporary soil reinforcement. This bamboo is found in Benishangul–Gumuz National Regional State. The bamboo in this region is mainly used as: firewood, food, house construction material (walls, structural work, ceiling, partitioning, floor, scaffolding, formwork, etc) fencing, pit latrines, simple bridges, animal houses, the construction of grain storage structures and furniture making. Bamboo is also used in the making of various implements (e.g. ladders) used at construction sites. Bamboo Star Agro-Forestry plc.

factory is found in Benishangul–Gumuz National Regional State produces bamboo flooring and bamboo sticks at export standard level. According to [11] some of the uses of bamboo in this region are shown in Figure 6, 7, 8, 9, 10, 11, 12 and 13.

Figure 6: Intensive bamboo use for housing in rural clustered rural villages in Assosa

Figure 7: Common bamboo pit latrine structures used in Assosa rural settlements

Figure 8:Use of lowland bamboo in scaffolding, and formwork in local flour mills in Assosa town

Figure 9: Furniture made from lowland bamboo on sale in an open market day at Assosa town

Figure 10: Use of bamboo as a fencing and bridge material

Figure 11: Bamboo as a building and construction material for grain storage granary in Assosa

Figure 12: Front elevation and roof of the traditional-modern house in Assosa

Figure 13: Product of bamboo floor tiles at the bamboo star agro-forestry plc.

2.5 The use of bamboo as soil reinforcement from different researches

In this part of the work literatures related to bamboo as soil reinforcement is reviewed. In Ethiopia, unlike geotechnical engineering stream less related researchs had done on bamboo as reforecement in structural engineering stream.Some related studiest to the present work ,however, were conducted in the past for academic purposes.

The study was done on the effect of bamboo reinforcement installed below different square footing resting on sandy soil. The soil sample was placed for CBR test. Bamboo reinforcement having 0.5 inch diameter and 12 inch long was placed into the soil at different depth. The bamboos were horizontally spaced at 1.75 inch interval to each. Density/degree of compaction was ensured by Standard Proctor Test. The experiment was executed on different layer system of bamboo reinforcement in different depth (i.e. 0.75 inch, 1.5 inch, 2.25 inch) and also by changing the footing dimensions (i.e. 3x3 inch, 3.5x3.5 inch, 4x4 inch). The orientation of the layer system was parallel – perpendicular –parallel [23].

Figure 14:Top view of placement of reinforcement and sample preparation

From experimental result the load bearing capacity of soil was increased when the bamboo reinforcement was placed within the depth of failure envelope. The load bearing capacity was increased up to 1.77 times for single layer reinforced soil and 2.02 times for multiple layer reinforced soil system than the load bearing capacity of unreinforced condition of soil. Improvement in load bearing capacity was observed considerable in reinforced soil over the unreinforced soil. For single layer system, load bearing capacity was touched maximum and settlement was also stretched minimum when the reinforcement layer was placed at 0.30B. For multilayer system, BCR increases with increasing number of reinforcing layer (N). The BCR was reached maximum for N=3 but the percentage increase in BCR for N=3 over N=2 was very small (4%).In multi-layer reinforcing system, settlement was considerably decreased with the increasing number of reinforcing layer [23].

The Mizoram State Roads Project (2011**)** employed innovative bioengineering techniques that was used the abundantly available local bamboo to stabilize the hill slopes above and below the road at a fraction of the cost of conventional methods that use concrete structures for the purpose [24].

Figure 15:The view of valley and hill side[24]

Figure 16:Disposal of debris in hilly area[24]

Using locally available bamboo to terrace the hill slopes for cultivation was a well-known and old practiced in Mizoram. Bringing in significant technical was known-how from the Rural Access Project (RAP) in Bhutan, the World Bank team was introduced the new concept of using this bamboo to bind and stabilize the hill slopes on both the hill and valley side of the road, as well as on debris disposal sites. This combined the traditional techniques were long employed by the local people with new ideas about how to expand their use [24].

In Bhutan, the RAP project was used pine logs to create crib walls and other bioengineering measures to protect the slopes. In Mizoram, given the local people"s traditional were known-how and ease in handling bamboo, the World Bank team was adapted the techniques employed in Bhutan to suit local conditions by using the abundantly available bamboo [24].

Figure 17: Construction of pine logs to protect the hill slopes under the Bhutan Rural Access Project[24]

Bamboo terracing, bamboo crib walls and bamboo knitting were developed to suit the requirements of each slope as well as for debris disposal sites. The Mizoram State Public Works Department (PWD), the project implementing authority, as well as World Bank staff and the supervision consultants together were devised their own method of bamboo matting, working out as they were gone along the exact dimensions that were suitable for a particular slope [24].

Implementation was assigned to local village councils. The local people was retained the traditional skills of working with bamboo; they were also known where to collect the raw material from as they were known where the bamboo forests were located. The new bioengineering techniques were demonstrated to them on small trial patches. Drawings/sketches were made of the various types of work needed at a particular site. Given their familiarity with the materials, the local laborers were employed in the trial patches adapted these methods to suit particular conditions. They were then taken to other sites along the route to demonstrate these new methods to local groups working near their own villages [24].

Figure 18: Bamboo terracing, bamboo crib walls, and bamboo knitting were developed to suit the requirements of each slope [24].

The abundantly available bamboo seeds were then planted over the bamboo structures to complete the process of slope stabilization quickly and cheaply over large areas. Special care was also taken to provide chute drains to avoid erosion when the saplings were young and their roots shallow. The quick-growing local flora was ensured that the slopes became green very soon [24].

Figure 19:Plantting of bamboo over the bamboo structures to complete the process of slope stabilization

Figure 20: Construction of bamboo knitting structures and the planting of local species of flora in progress

Figure 21: The bioengineering works remained stable even during fierce monsoon rains in 2007

The bioengineering works were also helped retain the productivity of the hill slopes whereas masonry works would not have done so. This was one of major importance to local communities, given that agriculture is the predominant land use along the project corridor. Where the bioengineering works have been completed, communities have been able to resume their traditional „jhum" cultivation [24].

Figure 22: Conventional methods of protecting the cutting of the hillside the road

The performance of bamboo by reinforcing lateritic soil with 0, 1, 2 and 3 bamboo specimens at laboratory trial level has been studied to evaluate its unconfined compressive strength (UCS) and modulus of rigidity. The soil specimens were molded in cylindrical form of 38mm diameter and 76mm height while the bamboo specimens were trimmed in to circular plates of 34mm diameter and 3mm thickness. The trial soil specimens were: soil specimen without bamboo specimen (0 bamboo), soil specimen with one bamboo specimen in the center (1 bamboo), soil specimen with one bamboo specimen on top and one at the bottom (2 bamboos) and soil specimen with one bamboo specimen on top, center and bottom (3 bamboos). Though, the dry density of the molded soil specimen was decreased from 1.638Mg/m^3 at 0 bamboo to 1.470Mg/m^3 at 3 bamboos, the UCS increased from 226KN/m^2 at 0 bamboo to 621KN/m^2 at 3 bamboos. Also, for each of the 3 percentage strains (0.5, 1.0 and 1.5%) was considered, the modulus of rigidity increased with bamboo specimens. This idea is similar to the study except the shape of the bamboo [25].

The performance of reinforced gravel subbase layer with different materials, such as Bitumen Coated Bamboo Mesh (BCBM), Waste Plastics (WP) and Waste Tyre Rubber

(WTR) in model flexible pavement construction laid on expansive soil subgrades has been studied. Cyclic load tests were carried out by placing a circular metal plate directly on the flexible pavement laid on expansive subgrades. The load carrying capacity was substantially increased for reinforced BCBM, which exhibits high load carrying capacity followed by WP and WTR stretches [26].

Bamboo culms which were strong, light weight and durable were used to make foundation mats. Rubble mound break water was constructed with bamboo mats placed on the sea floor first, and the gabion baskets were set up on the mats and filled with stones. The armour units were placed on the sea ward side of the structure to form the seaward slope. The armour units were granite quarry rocks [27].

Field monitoring was conducted quarterly for 2 years just after completion of construction to investigate the foundation settlement. The maximum total settlement was limited to 15.0 cm, no settlement was observed after 16 months after completion of construction which indicates the primary settlement was completed by that time. Number of differential settlement was observed in the breakwater which shows the integrity of the foundation mats [27].

The study had focused on field investigations to develop technical standards of soil bioengineering systems instead of conventional method used in road side slope stabilization work in Nepal. For the implementation of the research project works, four sites were selected (Kusunti, Lalitpur; Kali Khola, Pokhara; Pulchowk campus, Kathmandu; Sarangkot-Road, Pokhara). A vegetated bamboo crib wall was compared with a conventional slope stabilization method (gabion) by means of different parameters, which results that this kind of system is a suitable alternative for solving slope stability problems or for road embankment protection in Nepal from a technical as well ecological and economical point of view. A direct arrangement was shown that a bioengineering system (crib wall made of bamboos) is 4-times cheaper than a conventional civil engineering structure (gabion) and offers the same factor of technical safety [28].

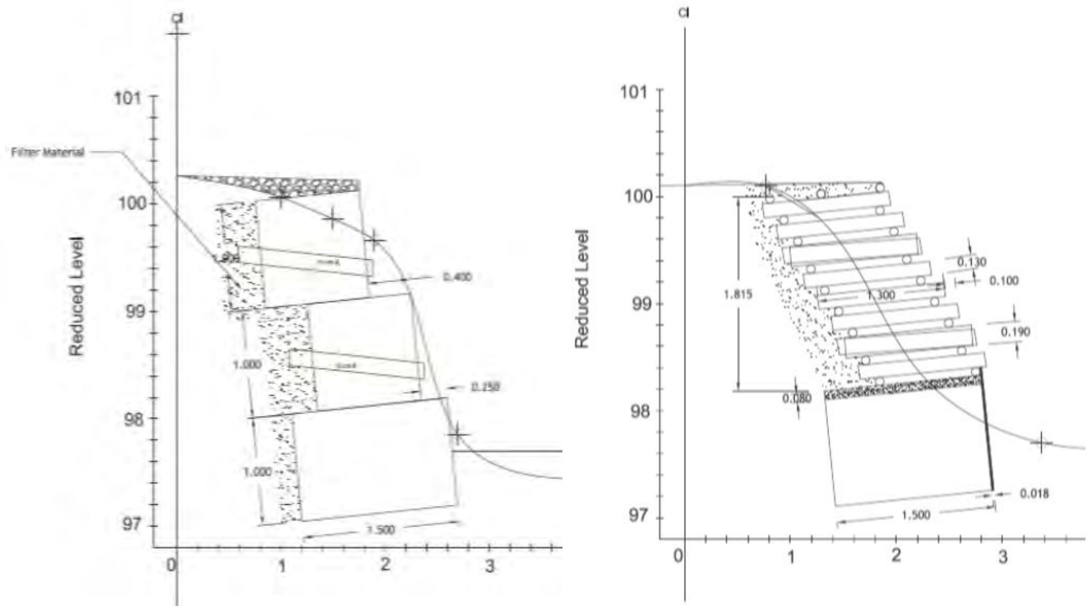

Figure 23:Cross sections of retaining wall (gabion and crib) constructed at Kusunti, Lalitpur[28]

Figure 24:Before and after construction photographs, Kusunti, Lalitpur [28]

Figure 25:The vegetated bamboo crib wall just after construction (November 2006) and after one year of construction (Kusunti, Lalitpur, November, 2007)

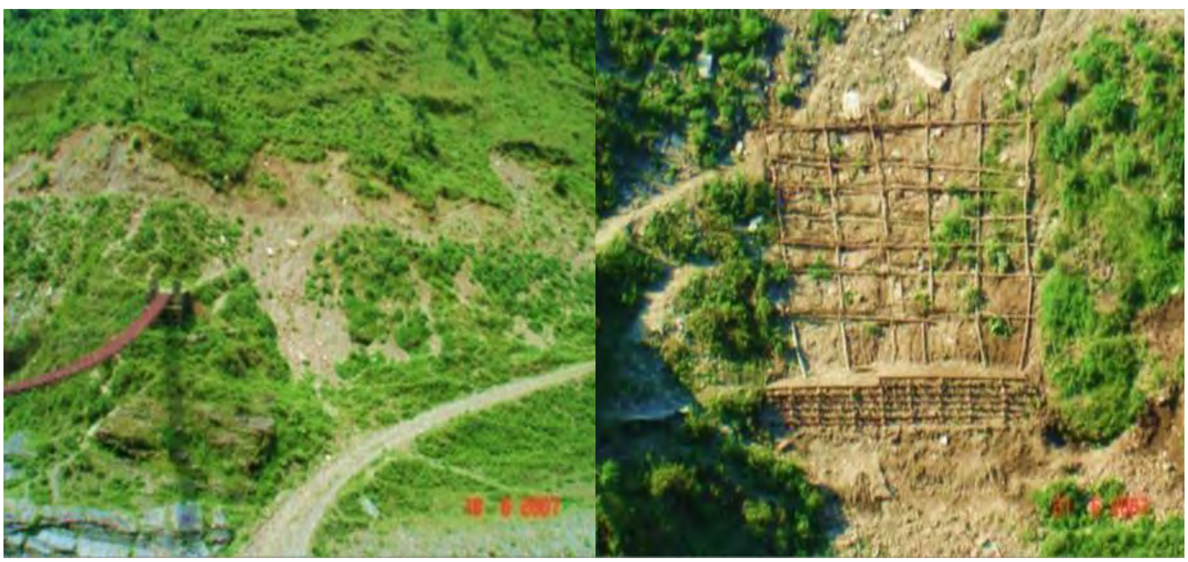

Figure 26:Before and after construction photographs, Kali Khola, Pokhara (June 2007)

Figure 27:Before and after construction photographs, Pulchowk Campus, Lalitpur (December, 2007)

Figure 28:Before and after construction photographs, Sarangkot landslide, Pokhara (January, 2008)

The onsite load test was carried out against the bamboo net with every different binding material and interval of bamboo net to evaluate the stress per condition deformation behaviour. Maximum load of bamboo net was measured to be in the range of 2.10kN - 11.02kN depending on its interval, showing bigger maximum load at shorter interval- the typical tendency, when the displacement was in the range of 181mm-604mm [29].

In the test under the same interval of bamboo net (1.0x1.0m) but with different binding material used for the joint, it was measured to be 3.66kN, 268kN and 2.10kN in case of steel wire, tie cable and poly propylene band showing less binding force, resulted from the area jointed with bamboo member getting loose at the time of loading [29].

Completely new type of construction in Nepal has been devloped together with the local people. In Nepal it is not possible to use anchor logs as auxiliary material for a crib wall. So a new method was developed which uses bamboo trees as construction element for a vegetated crib wall. Three bamboo elements were tied together with wire. These elements aimed to stabilize the structure until the soil was mechanically reinforced by the root system of the plans. Rooted plants were placed between the horizontal bamboo elements. So no experience was yet available on the mechanical effects and durability of bamboo. In Nepal, bamboo was used as alternative to timber [30].

Figure 29:Vegetated bamboo crib wall construction in Thankot [30]

Laboratory pullout tests were used to investigate the bond coefficient of bamboo reinforcement embedded in weathered Bangkok clay to compare the pullout resistance of the reinforcement with or without transverse members. Three pullout tests were done in each test setup. The applied normal pressures for each of the three series were: 10, 30, 50; 50, 70, 90 and 90,110, 130kPa, respectively. Four large scale direct shear test were made in each setup with applied normal pressures of 10, 50, 90,130kPa. The pullout rate and the direct shear rate of 1mm/min were adopted for all tests [31].

3 SAMPLING AREA DESCRIPTION

3.1 General information

The area studied is located in western Ethiopia; Benishangul Gumuz Regional State. Assosa Town is the capital city of Benishangul Gumuz Regional State located at 675km from Addis Ababa, the capital of Ethiopia, in southwest direction. It is 96km from the Ethio-Sudan border. The town has a flat terrain with latitudes of 10^{o}04'N, and longitudes of 34^{o}31'E and elevation of 1570m above mean sea level. Location of the research area on the map of Ethiopia is shown in Figure 30

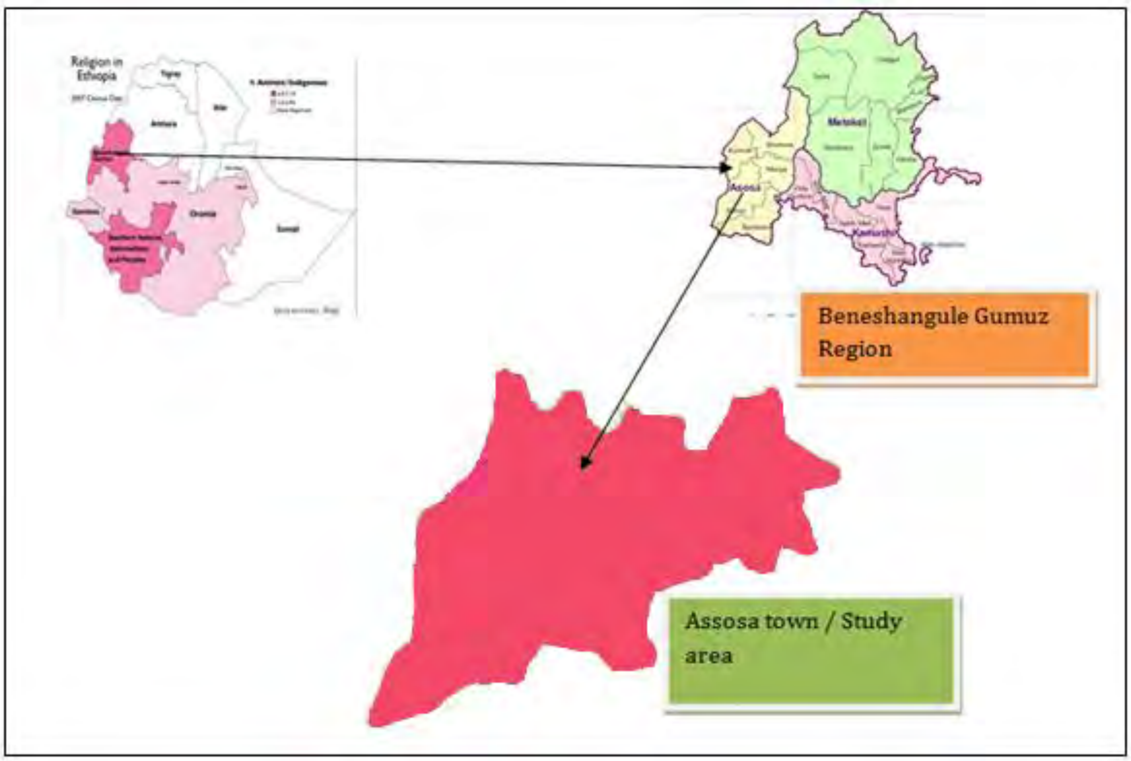

Figure 30: location of the research area, Assosa town, on the map of Ethiopia

(Source: Beneshangul Gumuz National Regional State, Assosa of Finance and Economic Development, 2013)

3.2 Land cover and land use

Assosa area is a flat terrain with fertile land .The area is covered with bamboo tree and grasses stretching up to 4m height. Most of the area is cultivated following the route connecting Assosa to central Ethiopia and Ethio-Sudan boarder.

3.3 Geology

The Geological formation of Assosa town and the surrounding are: flood basalt. These rocks have been subjected to very deep and intensive weathering processes, and rock exposures are mainly evident only in the areas underlain by granite and gneiss. Moreover, all of the urban roads are almost earth roads of red to brown sandy silty clay soil with a considerable amount of dark to gray soils [32].

3.4 Climate

According to the climatic classification of Assosa town is warm (“Kola”) with a temperature greater than 20^oC (Very warm), which is most of the times uncomfortable. It has a moisture index ranging from 50 to 100 (intermediate or moist), i.e.; potential evapotranspiration is mostly greater than precipitation.

The climate of the Assosa town is tropical humid with seasonal variations associated with the oscillation of inter- tropical convergence zone /ITCZ/. Between June and September, the ITCZ is located north of Ethiopia and an area is under the influence of Atlantic equatorial westerly and southern winds from the Indian Ocean. This south - westerly winds ascend over the south-western highlands of Ethiopia to produce the main rainy season. About 80% of the mean annual rainfall occurs during the period of these four months. Although the location is in tropics, temperatures are mild. Only occasionally does the temperature exceed 30°C or drop below 10°C. The area lies in the medium to high rain fall area with an average annual rain fall of around 1600mm [34]

3.5 Soil Characteristics of Assosa

According to [12] the town has a flat terrain with an elevation of around 1570m above mean sea level. All of the urban roads are almost earth roads of red to brown sandy silty clay soil with a considerable amount of dark to gray soils. The natural ground water table is located at 7m minimum and 35m maximum with almost the same soil type up to 1.0m and changing in grain size for soils is relatively stiff at 2m below the ground for most locations. The Geological formation of Assosa town and the surrounding are formed from basalt.

All lateritic soils require minimum rainfall of 750mm for their formation with hot periods and soil geology of mostly basaltic rock as a parent material. It is known that the rate of chemical weathering is controlled by moisture and temperature (other conditions being constant, chemical reaction rates approximately double for each 10^{o}c rise in average temperature). Generally based on the soil forming conditions and the actual situation of the water table observed, one can classify Assosa soil as hydrated form of laterite soil with high natural water content, high laboratory liquid limit changes irreversibly up on drying [12].

4 SAMPLING AND LABORATORY TEST RESULTS

4.1 Collection and preparation of soil sample

The soil in this research was a lateritic soil collected from Assosa town at 1.5m depth by using method of disturbed sampling. The soil was air dried and pulverized appropriately for compaction and remolding of soil with bamboo and without bamboo.

4.2 Collection and preparation of bamboo specimens

The bamboo used for this study was collected from Benishangul–Gumuz Regional State, Assosa. Scientific name of bamboo is Shimal bamboo (Oxytenanthera abyssinica) which is covering an area of 440, 000 hectares in the region.

The bamboo specimens were cut and trimmed into a square plate of 24mm size, 34mm diagonal and 3mm thickness as shown in the Figure 31. The smooth surface of bamboo specimens was roughened to increase the friction between the specimen and the soil.

Figure 31:A square plate of bamboo specimens

4.3 Laboratory test results and discussions

Most of the laboratory tests were carried out in accordance with the ASTM procedures for soil testing [35]. The soil classification was carried out using AASHTO classification [36]. The laboratory tests conducted are explained in the following sections.

4.3.1 Identification of sensitivity to test procedures

In order to identify susceptibility of lateritic soils to the effect of clay mineral aggregation, to drying and to re-wetting (dehydration of sesquioxides), bulk sample at its natural moisture content should be tested in laboratory. The following tests should be conducted [37].

4.3.2 Loss of water of hydration

Two test portions should be prepared for moisture content determinations. One should be oven dried at 105^{o}c until successive test weightings show that no further weight loss is taking place, and the moisture content should be then determined. The other sample should be air-dried or oven dried at no more than 50^{o}c until successive test weightings show no further weight loss, and the moisture content then determined. The two results should be compared. A.B. Fourie recommends the moisture variation 4-6% or more indicates that structural water is present [38]. If this is confirmed by repeated tests then the oven drying temperatures for the subsequent programme of tests should be changed to an appropriate value or reduce the difference from moisture content tested conventionally.

4.3.3 Disaggregation of clay-size particles on mixing

As A.B. Fourie [38]suggests five air dried test portions should be mixed with water to give the range of water contents suitable for liquid and plastic limit determinations. The mixing time should be no more than 5 minute, and the mixed samples should be left to cure overnight before testing. After determining the moisture content for each test point on a part of each test portion, the reminder should then be mixed for a further 25 minutes before again determining the liquid limit. A.B. Fourie suggests a "> 5%" difference between the liquid limits of the specimens 5 minutes and 30 minutes mixing times indicate a breakdown of the aggregations of clay sized particles within the material [38]. If this disaggregation is confirmed by further tests, the main test programme should include the following instructions.

1. limit the mixing times (no more than 5 minutes)
2. Use fresh material for each moisture content point in compaction tests, for liquid and plastic limit determinations.

4.3.4 Drying and wetting

Some guidance may be obtained by comparing the Atterberg limits of soil prepared from natural moisture content with those of oven dried soil rewetted to the point of test. With no further research, it indicates the preparation of laboratory specimens should simulate sensibly the likely field procedures with respect to wetting and / or drying of the soil prior to compaction.

4.4 Characteristics of the soil

4.4.1 Moisture Content Determination

Moisture contents of the soil samples were determined in the laboratory according to ASTM D 2216; Blight, 1997; CIRIA 1995. Drying oven temperatures of 105^{o}c and 50^{o}c with maximum relative humidity (RH) 30% were used to dry the samples. From laboratory test result, natural moisture content at 50^{o}c is 285% and at 105^{o}c is 31.5%, so the difference between these values is 3.4%.

As pointed out in section 5.1.1 moisture variations 4 - 6 % or more indicate that loosely bound molecular water is present. From the test results, one can see that the differences in moisture contents for the site under consideration are below 4%, which means that the soil under investigation does not contain loosely bound water of hydration. Hence for subsequent tests in need of moisture content determinations for the thesis work, oven drying at 105^{o}c can be used.

4.4.2 Index properties of soil

Soil is a complex material. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solids, liquid and gases, where in many instances the solid particles also vary in size. Furthermore the relative quantities of solid, liquid and gases in a given soil is found to change due to any physical cause such as loading, seasonal variation and change of temperature which makes the situation further complicated [39].

The behavior of soils should thus be understood by conducting tests on physical attributes of the soil particle and soil aggregate constituents [40].The physical properties of soils which serve mainly for identification and classification purpose are commonly known as index properties which can be determined by simple laboratory tests. Index property tests are grain size analysis, Atterberg limits, free swell and specific gravity. Under this research index property test has conducted such as grain size analysis, Atterberg limits and specific gravity. For easy referencing, ASTM testing analysis is attached in the APPENDIX-A

The results of the index properties, standard compaction and grain size analysis summary are shown in Table 2 and Figure 32 respectively.

Table 2: Index properties of the soil

Description	SG	LL (%)	PL (%)	PI (%)	NMC (%)	MDD (g/cm^3)	OMC (%)	AASHTO
Values	2.75	60	39	21	31.4	1.42	35.5	A-7-5

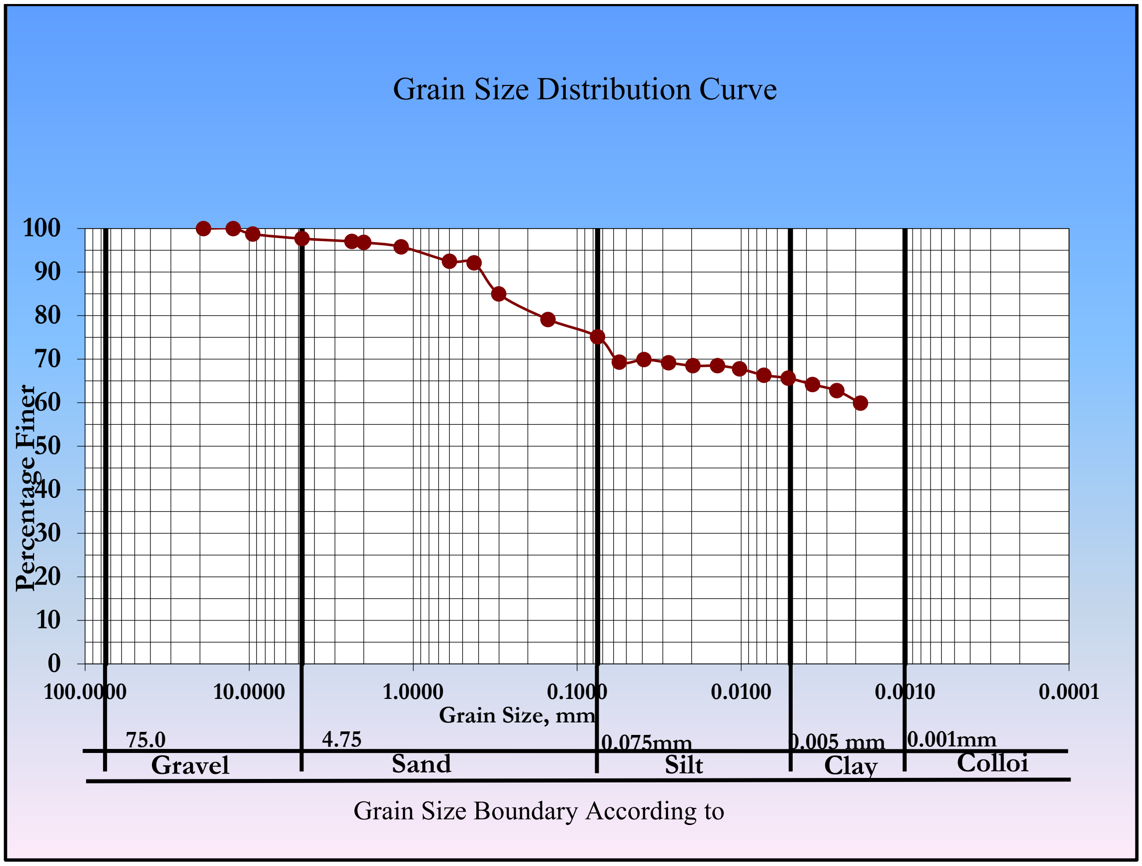

Figure 32: Grain size distribution curve

4.4.3 Soil classification

Though different disciplines find a soil classification based purely on particle-size classification satisfactory for their professional needs, the Civil Engineer requires a classification that has engineering applications. The demand led to the development of a number of engineering soil classifications. All widely used engineering soil classifications involve a combination of particle size and measures of plasticity and texture.

Engineering soils are subdivided into two main groups as a function of their predominant sizes and associated plasticity. The coarse-grained soils are composed of sand size and larger particles. They are separated into size ranges by sieving of materials up to cobble size. Except for minor fractions of plastic fines, they characteristically are non-plastic.

The fine grained soils consist predominantly of silt and clay-sized particles with differing degrees of plasticity measured by their Atterberg limits rather than by sieving and settling velocity methods.

The most widely used classification schemes are those that divide soils into an orderly, easily remembered system of groups, or classes, that have similar physical and engineering properties and that can be identified by simple and inexpensive tests. These groups ideally provide estimates of both the engineering characteristics and performance of soils for design and construction engineers. The descriptions of soils within the groups of a given classification typically are represented by alphabetical or alphanumeric symbols for rapid identification in written material, graphic boring logs, and on engineering drawings. The continued use of a few engineering soil classification systems is the result of the provision in each for the needs of the Civil Engineer as well as the adaptability of the classification to the variety of soils encountered in engineering practice.

Here classification was made based on the two most popular engineering soil classifications: AASHTO, soil grouping based on their mineralogical composition and soil grouping on their genetic basis and soil forming factors is also made.

It is a textural-plasticity classification that uses sieved fractions and atterberg limits for assignment of soils to seven main groups and several subgroups. The classification is more specific than the USC system. In the limits placed on silt-clay (fine-grained) soils as required by soil gradations, rather than using the No.4 sieve (4.75 mm) of the USC system as the upper limit of the sand-size range, the AASHTO classification uses the No. 10 sieve (2.0 mm) as the upper size limit of sand. However, the No. 200 sieve (0.075 mm) used in the USC system is retained to separate the finer fractions from sand [36].

The increased number of soil groups in the AASHTO classification compared with the USC system as well as the different upper size limits of sand makes comparisons of the two systems difficult [36].

The results of the grain size distribution and other index properties above showed that the soil classified under A-7-5 sub-group according to AASHTO soil classification system.

There are some investigation have been done on Assosa town soil. The researchers have been investigated that the Assosa town soil classified as lateritic soil [12].And also according to the reconnaissance survey made by this research the Assosa town soil classified as lateritic soil.

4.4.4 Compaction Test

Compaction places soils in a dense state and hence decreases further settlement, increases shear strength and decreases permeability. Water plays an important role during compaction. If a small amount of water is added to a soil that is then subjected to compaction by a given amount of energy, the soil will be compacted to a certain unit weight. If the moisture content of the same soil is gradually increased and the compaction is done in the same way, the dry unit weight of the soil will gradually increase. The moisture content at which the maximum dry unit weight is obtained is referred to as the optimum moisture content. Adding water beyond optimum value reduces density. Water replaces soil particles and the curve more or less straight and parallel to zero - void line. Zero - void line is a line drawn with proctor curve to check the acceptability of the test. It represents the relationship of water content to dry density for 100% degree of saturation.

From the test result, the maximum dry density (MDD) and optimum moisture content (OMC) of the soil compacted at standard compaction test is 1.42 g/cm3 and 35.5% respectively as shown in Figure 33. For easy referencing, ASTM testing analysis is attached in APPENDIX-B

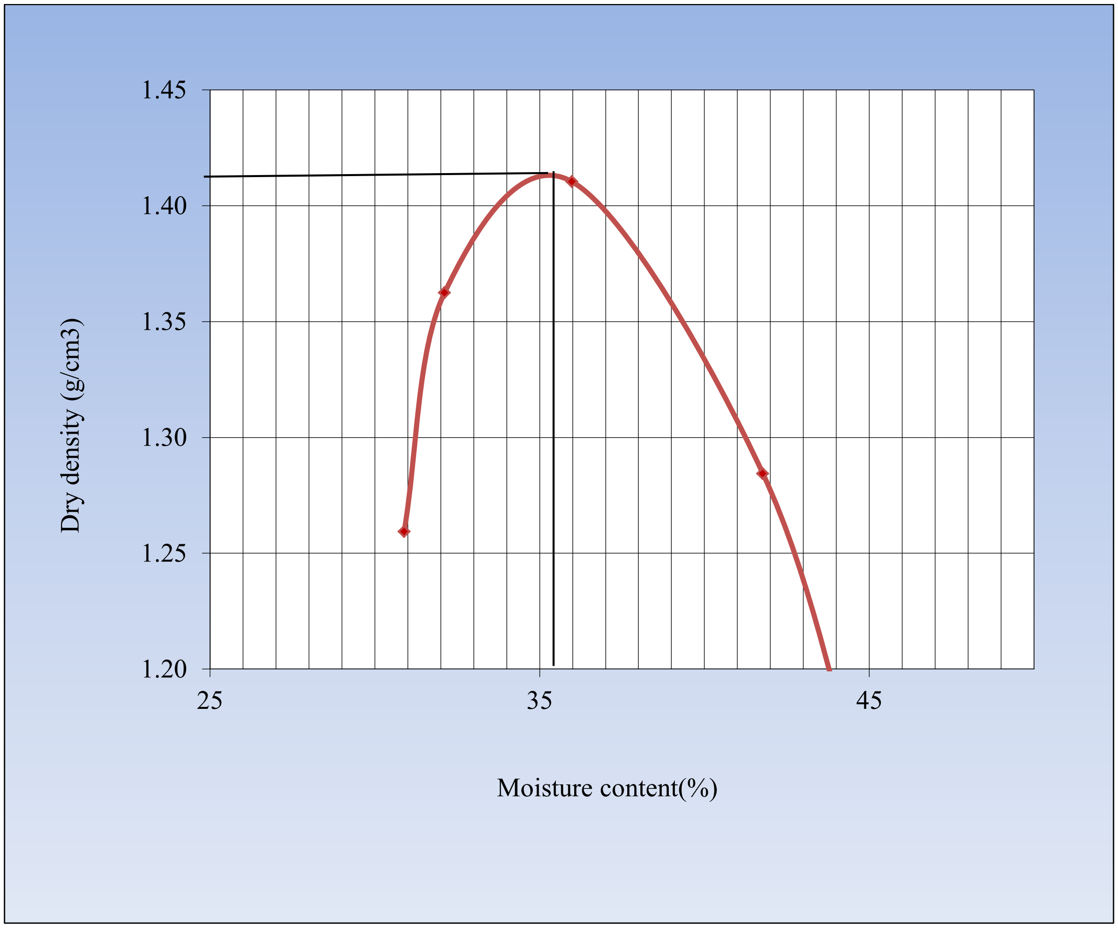

Figure 33: Dry density vs. moisture content graph

4.5 Characteristics of the soil-bamboo specimen in comparison with pure soil sample

4.5.1 Dry Densities

As shown in Figure 33, the maximum dry density (MDD) and optimum moisture content (OMC) of the soil compacted with standard compaction test is 1.42 g/cm^3 and 35.5% respectively. The variation of the molded dry densities for UCS specimens is shown in figure 34. The value of the molded dry densities decreased from 1.41 g/cm^3 at 0 bamboo specimens to 1.35g/cm^3 at 3 bamboo specimens. This is due to low specific gravity of the bamboo material that substitutes a high specific gravity soil sample. For easy referencing, ASTM testing analysis is attached in APPENDIX-D.

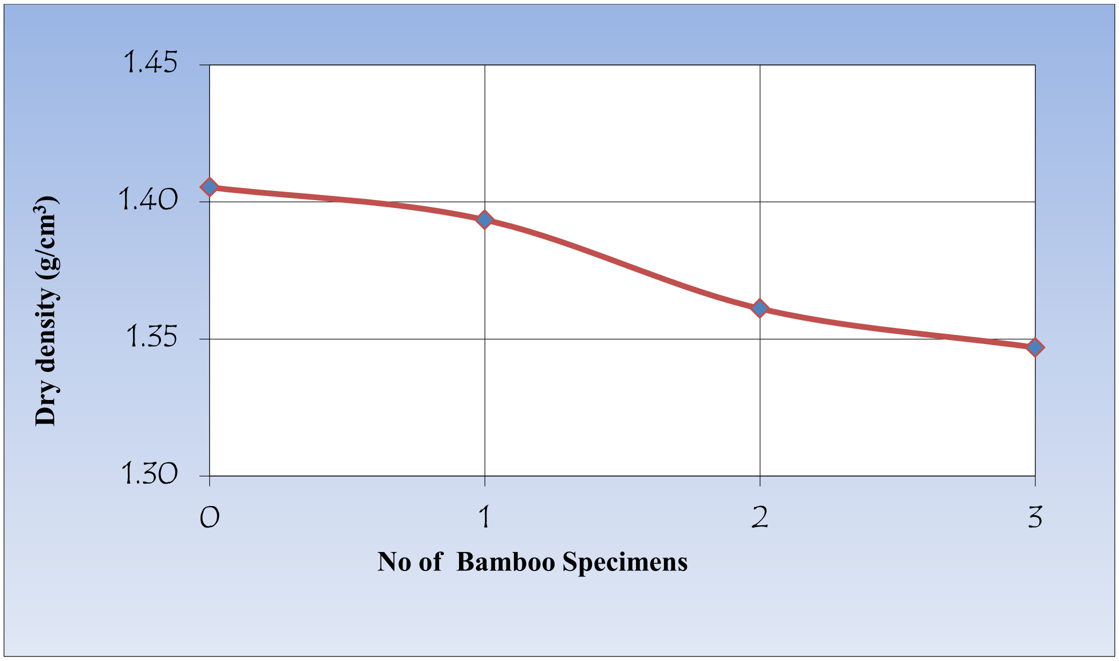

Figure 34: Change in dry density with number of bamboo specimen

4.5.2 Unconfined compressive strength (UCS)

The unconfined compression test is a special case of a triaxial compression test in which the all-round pressure is equal to zero. The tests are carried out only on cohesive samples which can stand without any lateral support. The test is an un-drained test and is based on the assumption that there is no moisture loss during the test. The unconfined compression test is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils. These tests can also be performed in the field by making use of simple loading equipment. The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated un-drained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (**q_u**) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. Specimens of height to diameter ratio of 2 are normally used for the tests. The sample fails either by shearing on an inclined plane (if the soil is of brittle type) or by bulging.

It has been observed that the UCS increased with increase in the number of bamboo specimens as shown in Figure 35. The value increased from 278.961kPa at 0 bamboos to 381.71kPa at 3 bamboo specimens. This is due to the adhesion between the soil sample and the rough surface of the bamboo specimen. For easy referencing, ASTM testing analysis is attached in APPENDIX-E.

Figure 35: Variation of UCS with the number of bamboo specimens

4.5.3 Modulus of Rigidity

Modulus of elasticity in shear or the modulus of rigidity or shear modulus, G, is the ratio of unit shear stress to unit shear strain within the proportional limit of a material in shear.

$$G = \frac{\tau}{\gamma} \quad (4.1)$$

Where

γ: Shear strain

τ : Shear stress

Under this research direct shear test data was not necessary to measure modulus of elasticity in shear. But from the data of unconfined compressive strength test result we can measure G by using the following Parry‟s STP correlation.

$$G = \frac{E}{2(1 - \nu)} \quad (4.2)$$

Where

E: Modulus of elasticity (also called Young's modulus)

ν: Poisson's ratio

The modulus of rigidity was calculated at specific strain, that is, at 0.01, 0.02, 0.03 and 0.04% strain from USC test result. Similarly modulus of elasticity and Poisson‟s ratio were measured at those strain.

The stress - strain relationship for each of the molded specimens and variation of the modulus of rigidity at 0.01, 0.02, 0.03, and 0.04% with the number of bamboo specimens are shown on Figures 36 and 37 respectively. The trend of modulus of rigidity with percentage strain is erratic in nature. While modulus of rigidity of some soil-bamboo specimen decreases with increase in percentage strain, others increase in like order. At 0 bamboo specimens, the value decreased from 140.24MPa at 0.01% to 109.3MPa at 0.04% while at 1 bamboo specimen, the value decreased from 154.4MPa at 0.01% to 148.1MPa at 0.04%. However, the trend for 2 and 3 bamboo specimens are different. At 2 bamboo specimen, the modulus of rigidity increased from 227.9MPa at 0.01% to 257.0MPa at 0.04% while the value increased from 270.4MPa at 0.01% strain to 308.7MPa at 0.04% for 3 bamboo specimens. Generally, the modulus of rigidity values increased with increase in the number of bamboo specimens. For easy referencing, ASTM testing analysis is attached in APPENDIX-F and APPENDIX-G.

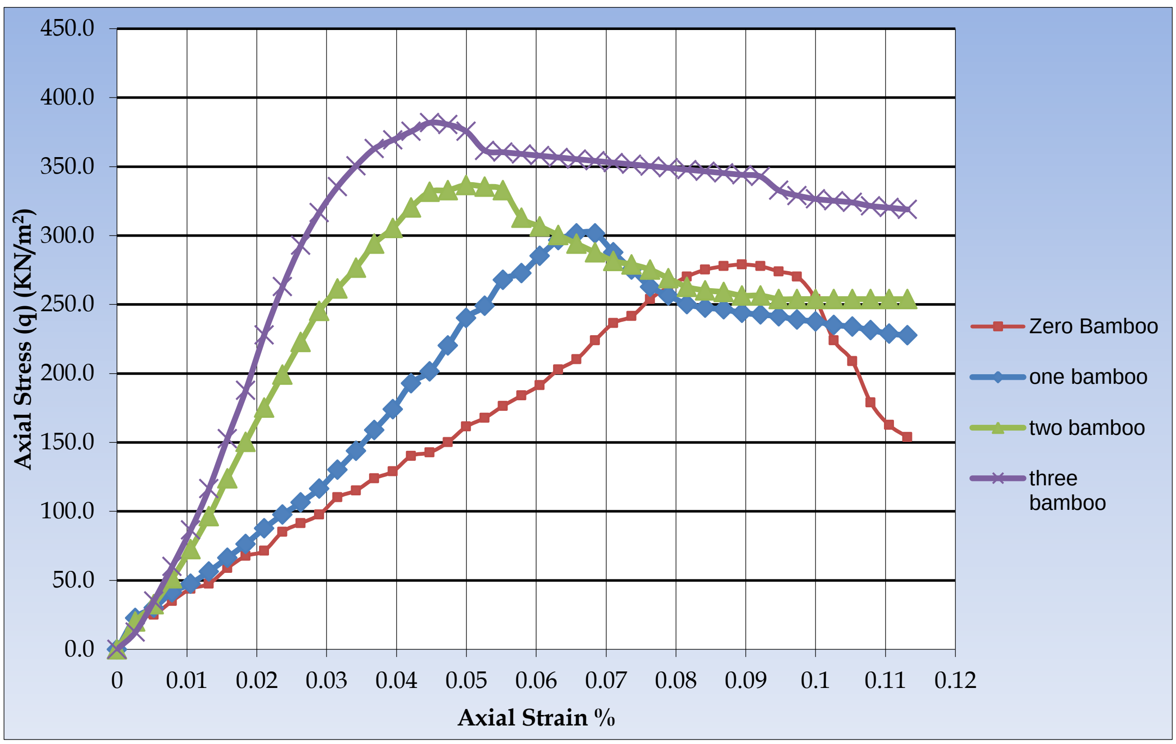

Figure 36: Stress relationship for specimens at 0, 1, 2, and 3 bamboo specimens

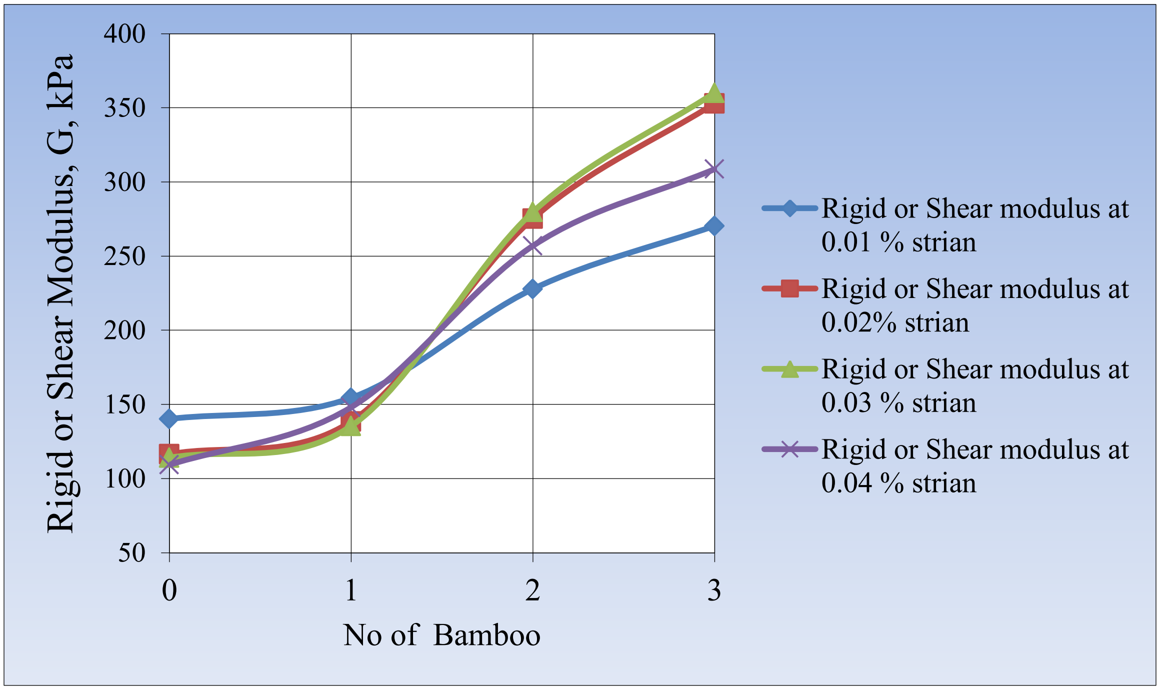

Figure 37: Variation of modulus of rigidity with No. of Bamboo specimen

This trend is in agreement with [41] and is due to friction between the soil and the rough surface of bamboo specimen.

5 CONCLUSIONS AND RECOMMENDED AREA OF FURTHER STUDY

5.1 Conclusion

Generally, the expensiveness and shortage of reinforcing steel in many parts of the world has led to increasing interest in the possible use of alternative locally available materials for construction purposes. As a result this research undertakes the use of Shimal bamboo as temporary soil reinforcement which is low-cost and abundantly available local material in Ethiopia.

Different tests were carried out to find the use of bamboo as temporary soil reinforcement material. It was observed from laboratory test results that;

1. While the dry density of the molded specimens decreased from 1.41g/cm^3 at zero bamboo to 1.35 g/cm^3 at three bamboo specimens, the UCS increased from 278.96kPa at 0 bamboos to 381.71kPa at three bamboo specimens.
2. Similarly, the modules of rigidity also increased with increase in the number of bamboo specimens for each of the percentage strains considered. At 0.01 %, the modulus of rigidity increased from 140.2MPa at zero bamboo to 270.4MPa at three bamboo specimens. At 0.02%, the modulus of rigidity increased from 116.4MPa at zero bamboo to 353.0MPa at three bamboo specimens. At 0.02 %, the modulus of rigidity increased from 114.0MPa at zero bamboo to 360.2MPa at three bamboo specimens. At 0.04 %, the modulus of rigidity increased from 109.3MPa at zero bamboo to 308.7MPa at three bamboo specimens.
3. Generally concluded as while the dry density of the molded specimens decreased with the number of bamboo specimens, the UCS and the modulus of rigidity increased with increase in the number of bamboo specimens. As a result bamboo can be used as temporary soil reinforcement instead of steel.

5.2 Recommended area of further study

1. Employing statistical analysis to determine an empirical relation between bamboo specimens, the spacing of the bamboo specimens and UCS values
2. The use of bituminous material on the smooth surface of bamboo specimen to mobilize shear strength.
3. A one to one scale model shall be performed to avoid scale problem.
4. A prototype study of the potentials of bamboo as soil reinforcement depending on bamboo‟s age.

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APPENDIX-A

Index properties test results

[A] Natural moisture content

Existing Water Content	Oven dry		Air dry	
Container No	175	73	175	125
Mass of container, g	32.7	33	32.8	33.5
Mass of container + wet soil, g	41.2	43.56	41.3	43.4
Mass of container + Dry soil, g	39.2	41	39.3	41.4
Mass of Water, g	2	2.56	2	2
Mass of Dry soil, g	6.5	8	6.5	7.9
Water content, %	30.77	32	30.77	25.32
Average Water content, %	31.4		28	
The difference b/n OD and AD, %	3.4			

[B] Specific gravity

Calibration of pycnometer

Pycnometer No.	P20	P41
Weight of dry, clean pycnometer, w_p (g)	45.3	45.8
Weight of pycnometer + water, w_{pw} (g)	144.6	145.4
Observed temperature of water, T_i (oc)	22.4	19.8

Specific gravity determination

Determination No.	1	2
Pycnometer No.	P20	P41
Weight of pycnometer + soil + water, W_{pws} (g)	161.1	160.4
Temperature, T_x(^{o}c)	24	21
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.55	145.38
Weight of dry soil , w_s (gm)	25	25
Conversion factor , K	0.9991	0.9998
Specific gravity of soil at 20°c.	2.95	2.54
Average specific gravity of soil.	2.75	

[C] Grain size analysis

Sieve Analysis (weight of dry soil= 155.18g out of total weight of sample = 1200g)

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	% Retained	Cumulative % Retained	% Passing
3"	75.0	1800.0	1800.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1217.0	1217.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.5	1178.5	0.0	0.0	0.0	100.0
1/2"	12.5	459.2	459.2	0.0	0.0	0.0	100.0
3.8"	9.5	1165.0	1180.2	15.2	1.3	1.3	98.7
No 4	4.75	1263.0	1275.6	12.6	1.0	2.3	97.7
No 8	2.36	990.0	997.5	7.5	0.6	2.9	97.1

No 10	2	955.8	958.7	2.9	0.2	3.2	96.8
No 16	1.18	894.5	906.5	12.0	1.0	4.2	95.8
No 30	0.6	831.1	870.9	39.8	3.3	7.5	92.5
No 30	0.425	786.1	791.0	4.9	0.4	7.9	92.1
No 50	0.3	750.1	840.5	90.4	7.5	15.0	85.0
No 100	0.15	777.9	847.9	70.0	5.8	20.9	79.1
No 200	0.075	765.3	813.2	47.9	4.0	24.9	75.1
Pan	----	734.8	1568.8	834.0	69.5	94.4	5.6

Hydrometer analyses

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	% Finer	% Finer Combined
0.5	1.0263	-0.0021	1.0242	9.34	0.01279	0.0553	76.06	69.35
1	1.0265	-0.0021	1.0244	9.29	0.01279	0.0390	76.69	69.92
2	1.0263	-0.0021	1.0242	9.36	0.01279	0.0277	75.90	69.21
4	1.0260	-0.0021	1.0239	9.42	0.01279	0.0196	75.11	68.49
8	1.0260	-0.0021	1.0239	9.42	0.01279	0.0139	75.11	68.49
15	1.0258	-0.0021	1.0237	9.49	0.01279	0.0102	74.33	67.77
30	1.0253	-0.0021	1.0232	9.62	0.01279	0.0072	72.76	66.34
60	1.0250	-0.0021	1.0229	9.69	0.01279	0.0051	71.97	65.63
120	1.0245	-0.0021	1.0224	9.82	0.01279	0.0037	70.40	64.19
240	1.0240	-0.0021	1.0219	9.95	0.01279	0.0026	68.83	62.76
480	1.0230	-0.0021	1.0209	10.22	0.01279	0.0019	65.69	59.89
1440	1.0230	-0.0021	1.0209	10.22	0.01279	0.0011	65.69	59.89

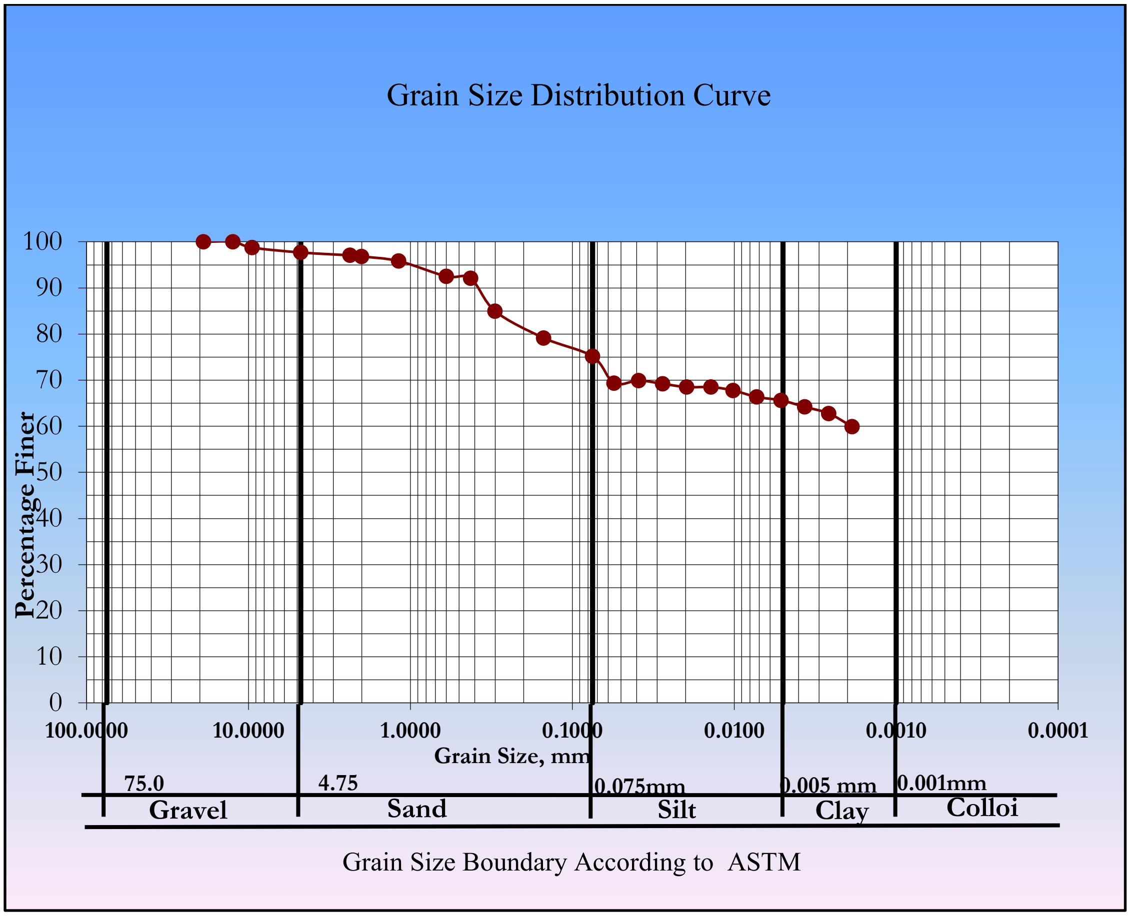

Figure 38:Grain size distribution curve

[D] Atterberg Limits

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A1	A2	A3	F1	A114	J2
Mass of container, g	15.80	15.60	15.90	15.80	15.90	15.50
Mass of container + Wet soil, g	51.00	46.40	57.80	50.70	22.80	23.10
Mass of container + Dry soil, g	38.00	34.70	42.20	37.20	20.90	20.90
Mass of water, g	13.00	11.70	15.60	13.50	1.90	2.20
Mass of dry soil, g	22.20	19.10	26.30	21.40	5.00	5.40
Water content, %	58.56	61.26	59.32	63.08	38.00	40.74
No of blows	36	29	25	13	39	

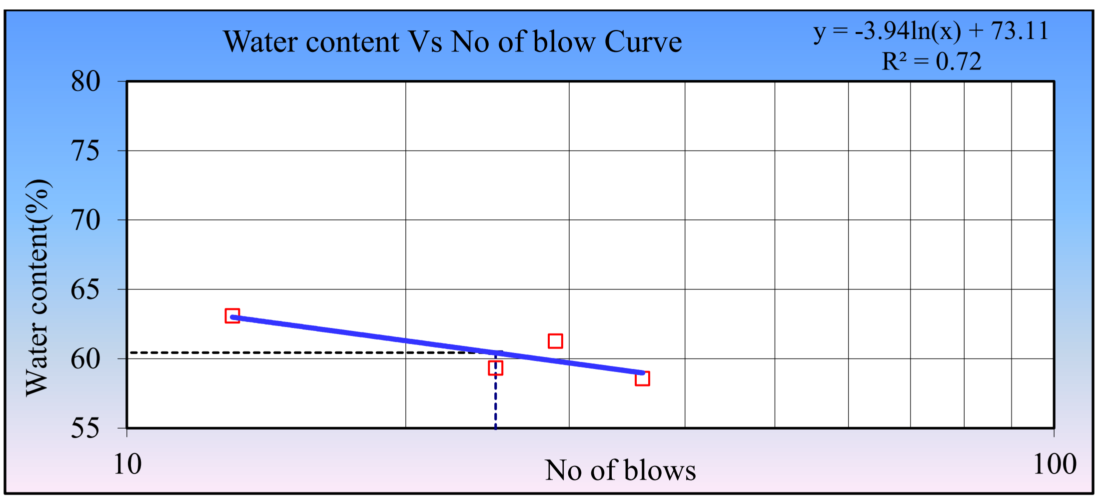

Figure 39:Water content Vs. No of blow curve

APPENDIX – B

Standard Compaction Test results

Determination No.	1	2	3	4	5
Mass of Mold, g	3128.6	3128.6	3128.6	3128.6	3128.6
Mass of mold+ Compacted Soil, g	4656.2	4772	4839.8	4810.8	4772.3
Mass of Compacted soil, g	1527.6	1643.4	1711.2	1682.2	1643.7
Volume of Mold,cm^3	944	944	944	944	944
Bulk density, g/cm^3	1.62	1.74	1.81	1.78	1.74
Water Content, %	28.49	27.77	28.53	38.74	53.95
Dry density, g/cm^3	1.26	1.36	1.41	1.28	1.13

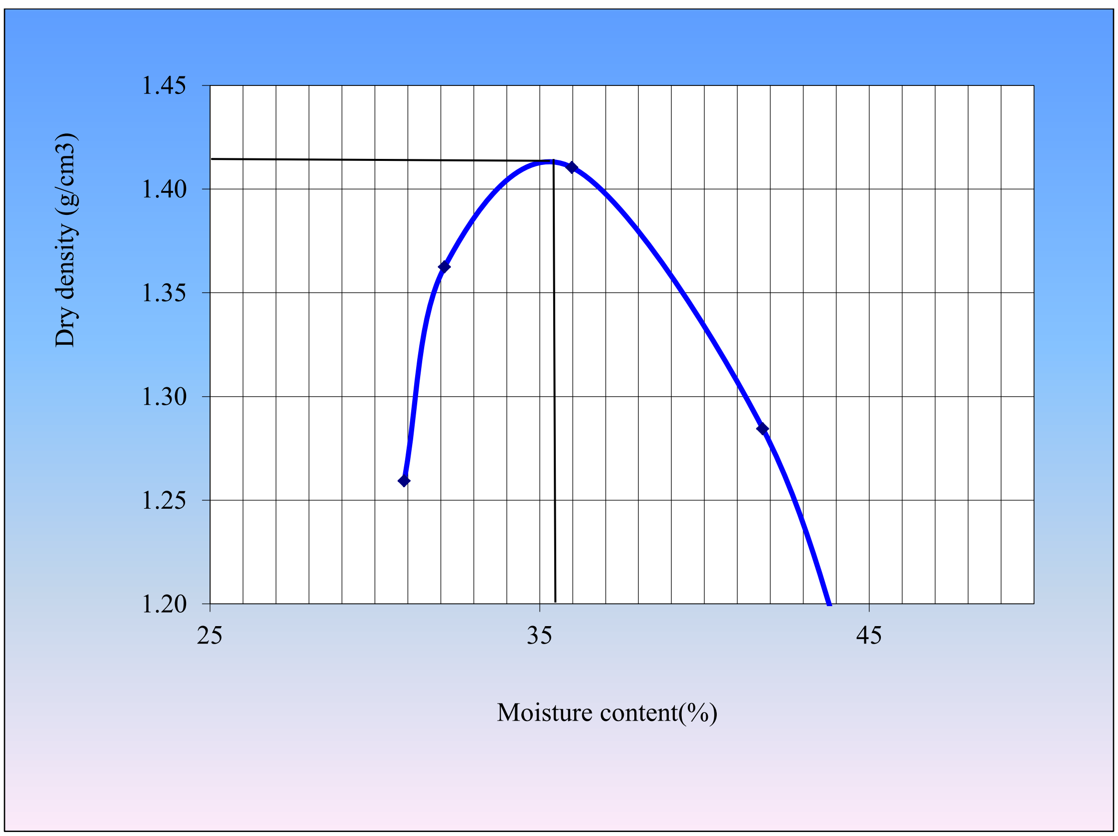

Figure 40:dry density vs. moisture content graph

APPENDIX –C

The amount of water added and mass of soil compacted

To determine the amount of water added and the amount of soil to be compacted (standard compaction test) in a cylindrical mold the following calculation should be carried out.

Let us consider,

M_1= Mass of air dry soil at initial moisture content

M_2= Mass of soil at optimum moisture content

Ms= Mass of soil to be compacted or remolded

Ms.d= Mass of dry soil

Mw= Mass of water to be added

Wo= Optimum moisture content

Wn= Existing or natural moisture content of dry soil

Vw= Volume of water to be added

V_{mold} = Volume of a triaxial compressive strength mold of diameter 38mm and height of 76mm.

=86.19cm^3

γ_w= density of water

γ_{max}= Maximum dry density of soil

- ❖ Mass of the soil needed for remolding purpose or the mass of the soil to be compacted

$$\gamma_{max} = \frac{\text{Total mass(mass of soil needed)}}{\text{Vmold}} \qquad (1.1)$$

Total mass (mass of soil needed)

$$Ms = \{\gamma \max * Vmol\} \qquad (1.2)$$

$$Ms = 1.42 \frac{g}{cm^3} * 86.19 cm^3 = 122.4 \text{ g (mass of the soil needed for remolding)}$$

- Volume of water needed for remolding purpose

$$\gamma_w = \frac{Mw}{Vw} \qquad (1.3)$$

The mass of the water, Mw

$$W1 = Ws.d * \{1 + Wn\} \quad (4.4) \quad , \quad W2 = Ws.d * \{1 + Wo\} \quad (1.4)$$

$$Mw = W2 - W1 = Ms.d * (Wo - Wn) \qquad (1.5)$$

$$Ms.d = \frac{Ms}{(1 + Wn)} \qquad (1.6)$$

$$Ms.d = \frac{122.4 \text{ g}}{(1 + 0.0901)} = 112.3 \text{ g (mass of dry soil)}$$

$$Mw = 112.3 \text{ g} * (0.335 - 0.0901) = 30\text{g (mass of water to be added)}$$

$$Vw = \frac{Ww}{\gamma w} \qquad (1.7)$$

$$Vw = \frac{30 \text{ g}}{1 \text{ g/cm}^3} = 30 \text{ cm}^3 = 30 \text{ ml (volume of water needed)}$$

APPENDIX –D

MD Vs. No of bamboo test result

No of Bamboo	0	1	2	3
Mass of Mold, g	146.20	146.20	146.20	146.20
Mass of mold+ Compacted Soil, g	302.50	300.40	298.40	296.20
Mass of Compacted soil, g	156.30	154.20	152.20	150.00
Volume of Mold, cm^3	86.19	86.19	86.19	86.19
Bulk density, g/cm^3	1.81	1.79	1.77	1.74
Water Content, %	29.03	28.38	29.73	29.21
Dry density, g/cm^3	1.41	1.39	1.36	1.35

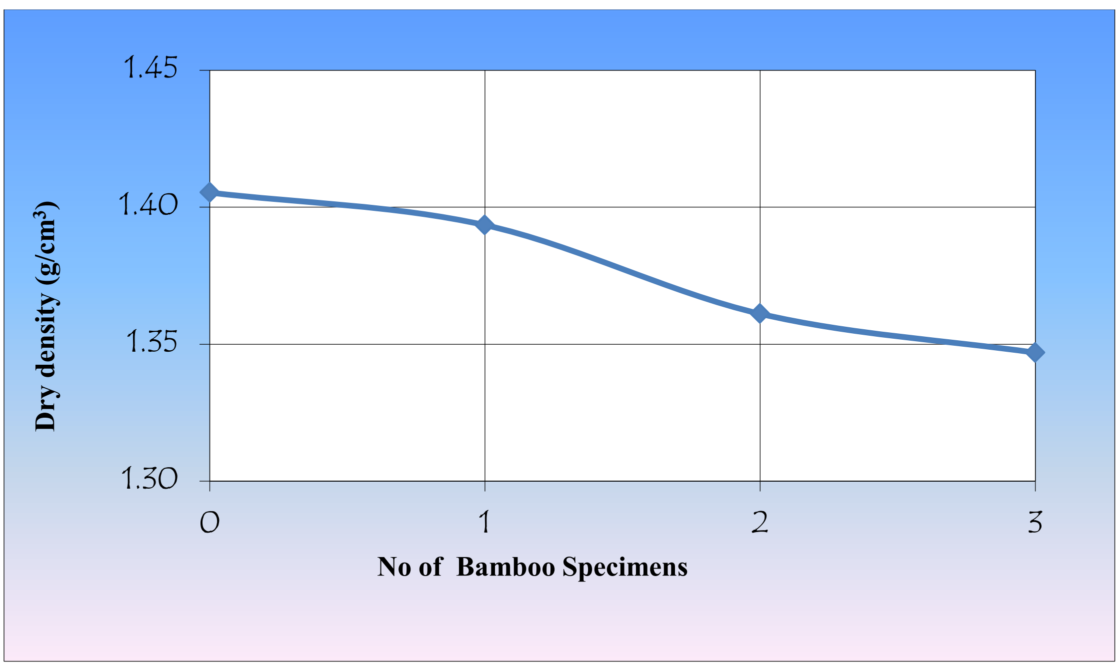

Figure 41:Change in dry density with number of bamboo specimen

APPENDIX –E

UCS Vs. No of bamboo test result

No of Bamboo	0	1	2	3
Max UCS kPa	278.96	301.55	336.64	381.71

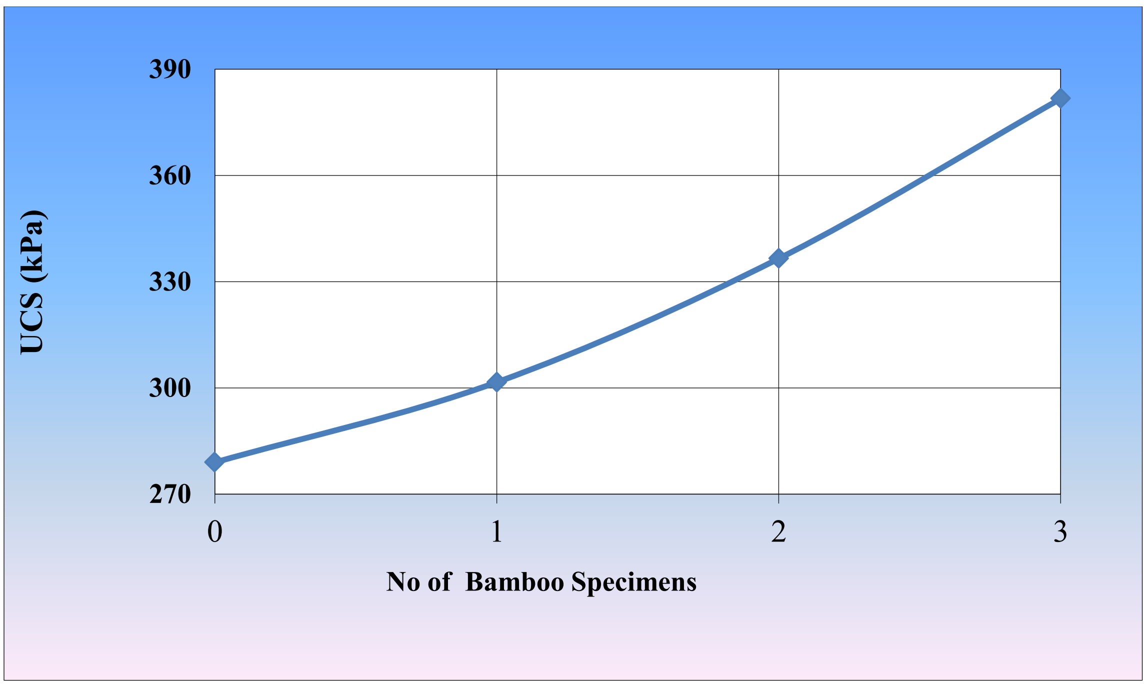

Figure 42:Variation of UCS with the number of bamboo specimens

APPENDIX – F

Unconfined Compression Strength Test Results

[A] UCS with zero bamboo reinforcement test results

Deformation Dial Reading (division)	Sample Deformation (mm)	Strain (e) (ΔL/Lo)	% Strain	Corrected Area Ac=Ao/(1-ε)	Proving Ring Reading (division)	Load (kN)	Stress (kPa)
0	0.000	0.00000	0.00000	0.00113	0	0.00000	0.00
10	0.002	0.00003	0.00263	0.00113	17	0.02414	21.28
20	0.004	0.00005	0.00526	0.00113	20	0.02840	25.04
30	0.006	0.00008	0.00789	0.00113	28	0.03976	35.06
40	0.008	0.00011	0.01053	0.00113	35	0.04970	43.82
50	0.010	0.00013	0.01316	0.00113	38	0.05396	47.57
60	0.012	0.00016	0.01579	0.00113	47	0.06674	58.84
70	0.014	0.00018	0.01842	0.00113	54	0.07668	67.60
80	0.016	0.00021	0.02105	0.00113	57	0.08094	71.35
90	0.018	0.00024	0.02368	0.00113	68	0.09656	85.12
100	0.020	0.00026	0.02632	0.00113	73	0.10366	91.38
110	0.022	0.00029	0.02895	0.00113	78	0.11076	97.63
120	0.024	0.00032	0.03158	0.00113	88	0.12496	110.15
130	0.026	0.00034	0.03421	0.00113	92	0.13064	115.15
140	0.028	0.00037	0.03684	0.00113	99	0.14058	123.91
150	0.030	0.00039	0.03947	0.00113	103	0.14626	128.91
160	0.032	0.00042	0.04211	0.00113	112	0.15904	140.17
170	0.034	0.00045	0.04474	0.00113	114	0.16188	142.67

180	0.036	0.00047	0.04737	0.00113	120	0.17040	150.18
190	0.038	0.00050	0.05000	0.00113	129	0.18318	161.44
200	0.040	0.00053	0.05263	0.00113	134	0.19028	167.69
210	0.042	0.00055	0.05526	0.00113	141	0.20022	176.45
220	0.044	0.00058	0.05789	0.00113	147	0.20874	183.95
230	0.046	0.00061	0.06053	0.00113	153	0.21726	191.45
240	0.048	0.00063	0.06316	0.00113	162	0.23004	202.71
250	0.050	0.00066	0.06579	0.00113	168	0.23856	210.21
260	0.052	0.00068	0.06842	0.00113	179	0.25418	223.97
270	0.054	0.00071	0.07105	0.00113	189	0.26838	236.47
280	0.056	0.00074	0.07368	0.00113	193	0.27406	241.47
290	0.058	0.00076	0.07632	0.00113	203	0.28826	253.98
300	0.060	0.00079	0.07895	0.00114	210	0.29820	262.73
310	0.062	0.00082	0.08158	0.00114	216	0.30672	270.23
320	0.064	0.00084	0.08421	0.00114	220	0.31240	275.23
330	0.066	0.00087	0.08684	0.00114	222	0.31524	277.72
340	0.068	0.00089	0.08947	0.00114	223	0.31666	278.96
350	0.070	0.00092	0.09211	0.00114	222	0.31524	277.71
360	0.072	0.00095	0.09474	0.00114	219	0.31098	273.95
370	0.074	0.00097	0.09737	0.00114	216	0.30672	270.19
380	0.076	0.00100	0.10000	0.00114	203	0.28826	253.92
390	0.078	0.00103	0.10263	0.00114	179	0.25418	223.89
400	0.080	0.00105	0.10526	0.00114	167	0.23714	208.88
410	0.082	0.00108	0.10789	0.00114	143	0.20306	178.85
420	0.084	0.00111	0.11053	0.00114	130	0.18460	162.59
430	0.086	0.00113	0.11316	0.00114	123	0.17466	153.83

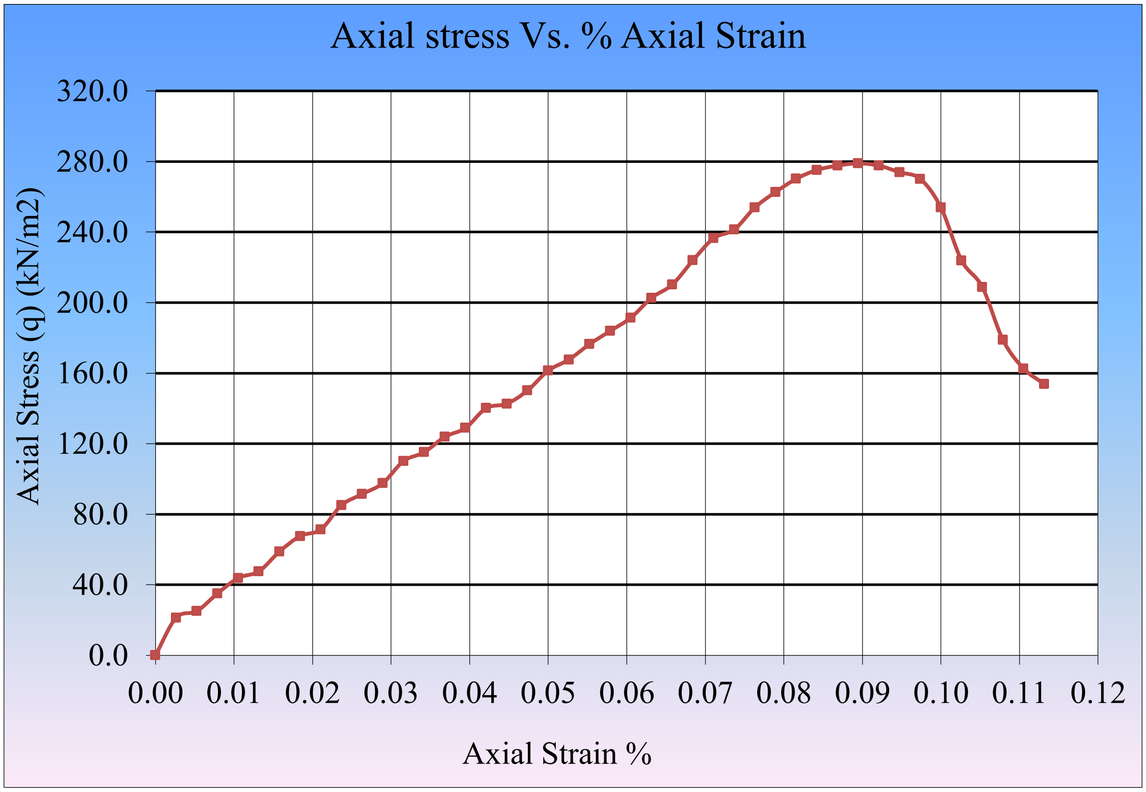

Figure 43:Axial stress Vs. % Axial Strain with zero bamboo enforcement

[B] UCS with one bamboo reinforcement test results

Deformation Dial Reading (division)	Sample Deformation (mm)	Strain (e) (ΔL/Lo)	% Strain	Corrected Area Ac=Ao/(1-ε)	Proving Ring Reading (division)	Load (KN)	Stress (Kpa)
0	0	0.00000	0.00000	0.00113	0	0	0.00
10	0.002	0.00003	0.00263	0.00113	18	0.02556	22.54
20	0.004	0.00005	0.00526	0.00113	24	0.03408	30.05
30	0.006	0.00008	0.00789	0.00113	33	0.04686	41.32
40	0.008	0.00011	0.01053	0.00113	38	0.05396	47.57
50	0.01	0.00013	0.01316	0.00113	45	0.0639	56.34
60	0.012	0.00016	0.01579	0.00113	53	0.07526	66.35

70	0.014	0.00018	0.01842	0.00113	61	0.08662	76.36
80	0.016	0.00021	0.02105	0.00113	70	0.0994	87.63
90	0.018	0.00024	0.02368	0.00113	78	0.11076	97.64
100	0.02	0.00026	0.02632	0.00113	85	0.1207	106.40
110	0.022	0.00029	0.02895	0.00113	93	0.13206	116.41
120	0.024	0.00032	0.03158	0.00113	104	0.14768	130.17
130	0.026	0.00034	0.03421	0.00113	115	0.1633	143.94
140	0.028	0.00037	0.03684	0.00113	127	0.18034	158.96
150	0.03	0.00039	0.03947	0.00113	139	0.19738	173.97
160	0.032	0.00042	0.04211	0.00113	154	0.21868	192.74
170	0.034	0.00045	0.04474	0.00113	161	0.22862	201.49
180	0.036	0.00047	0.04737	0.00113	176	0.24992	220.26
190	0.038	0.00050	0.05000	0.00113	192	0.27264	240.28
200	0.04	0.00053	0.05263	0.00113	199	0.28258	249.03
210	0.042	0.00055	0.05526	0.00113	214	0.30388	267.80
220	0.044	0.00058	0.05789	0.00113	218	0.30956	272.79
230	0.046	0.00061	0.06053	0.00113	228	0.32376	285.30
240	0.048	0.00063	0.06316	0.00113	237	0.33654	296.55
250	0.05	0.00066	0.06579	0.00113	241	0.34222	301.55
260	0.052	0.00068	0.06842	0.00113	241	0.34222	301.54
270	0.054	0.00071	0.07105	0.00113	230	0.3266	287.77
280	0.056	0.00074	0.07368	0.00113	220	0.3124	275.25
290	0.058	0.00076	0.07632	0.00113	210	0.2982	262.74
300	0.06	0.00079	0.07895	0.00114	205	0.2911	256.47
310	0.062	0.00082	0.08158	0.00114	200	0.284	250.21
320	0.064	0.00084	0.08421	0.00114	198	0.28116	247.70
330	0.066	0.00087	0.08684	0.00114	197	0.27974	246.45
340	0.068	0.00089	0.08947	0.00114	195	0.2769	243.94
350	0.07	0.00092	0.09211	0.00114	194	0.27548	242.68
360	0.072	0.00095	0.09474	0.00114	193	0.27406	241.42
370	0.074	0.00097	0.09737	0.00114	191	0.27122	238.91
380	0.076	0.00100	0.10000	0.00114	190	0.2698	237.66
390	0.078	0.00103	0.10263	0.00114	188	0.26696	235.15
400	0.08	0.00105	0.10526	0.00114	187	0.26554	233.89
410	0.082	0.00108	0.10789	0.00114	185	0.2627	231.38
420	0.084	0.00111	0.11053	0.00114	183	0.25986	228.88
430	0.086	0.00113	0.11316	0.00114	182	0.25844	227.62

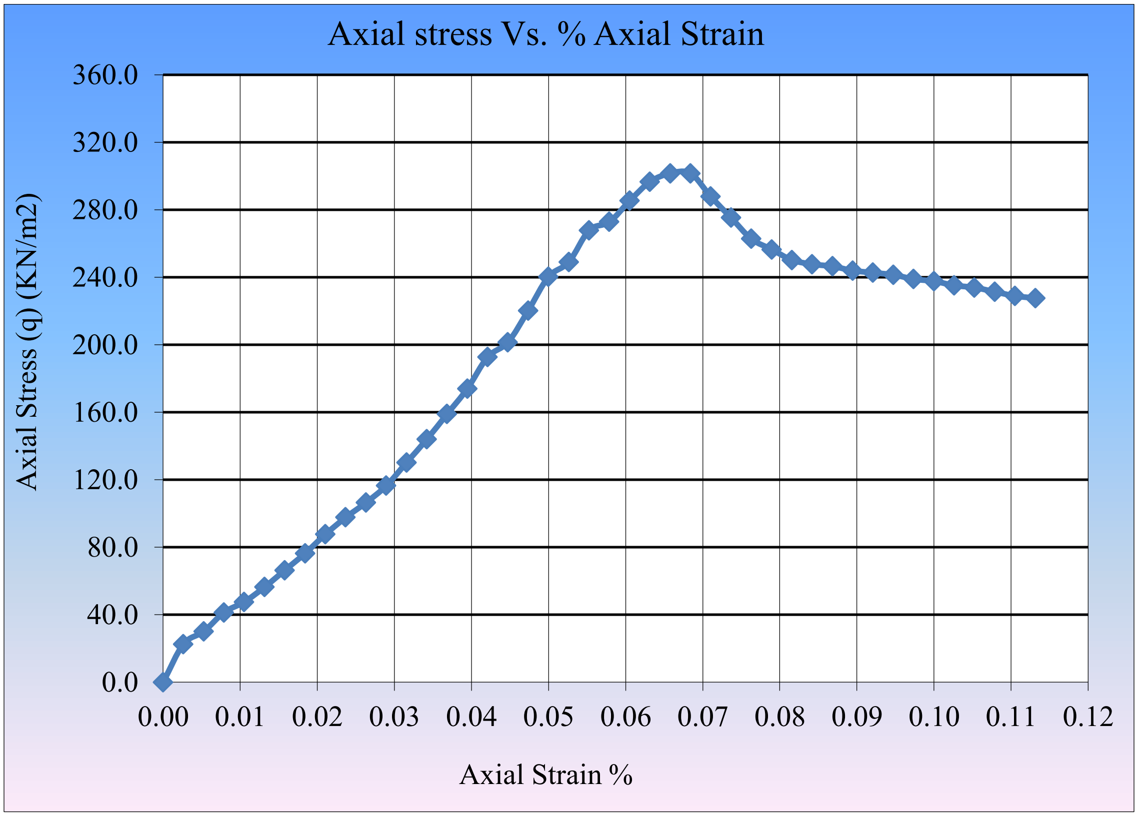

Figure 44:Axial stress Vs. % Axial Strain with one bamboo enforcement

[C] UCS with two bamboo reinforcement test results

Deformation Dial Reading (division)	Sample Deformation (mm)	Strain (e) (ΔL/Lo)	% Strain	Corrected Area Ac=Ao/(1-ε)	Proving Ring Reading (division)	Load (KN)	Stress (Kpa)
0	0	0	0.00000	0.00113	0	0	0
10	0.002	2.6E-05	0.00263	0.00113	16	0.02272	20.033
20	0.004	5.3E-05	0.00526	0.00113	26	0.03692	32.552
30	0.006	7.9E-05	0.00789	0.00113	41	0.05822	51.331
40	0.008	0.00011	0.01053	0.00113	58	0.08236	72.613
50	0.01	0.00013	0.01316	0.00113	77	0.10934	96.397

60	0.012	0.00016	0.01579	0.00113	99	0.14058	123.94
70	0.014	0.00018	0.01842	0.00113	120	0.1704	150.22
80	0.016	0.00021	0.02105	0.00113	140	0.1988	175.25
90	0.018	0.00024	0.02368	0.00113	159	0.22578	199.03
100	0.02	0.00026	0.02632	0.00113	178	0.25276	222.81
110	0.022	0.00029	0.02895	0.00113	196	0.27832	245.34
120	0.024	0.00032	0.03158	0.00113	209	0.29678	261.6
130	0.026	0.00034	0.03421	0.00113	221	0.31382	276.61
140	0.028	0.00037	0.03684	0.00113	235	0.3337	294.13
150	0.03	0.00039	0.03947	0.00113	244	0.34648	305.39
160	0.032	0.00042	0.04211	0.00113	256	0.36352	320.4
170	0.034	0.00045	0.04474	0.00113	265	0.3763	331.65
180	0.036	0.00047	0.04737	0.00113	266	0.37772	332.89
190	0.038	0.0005	0.05000	0.00113	269	0.38198	336.64
200	0.04	0.00053	0.05263	0.00113	268	0.38056	335.38
210	0.042	0.00055	0.05526	0.00113	266	0.37772	332.87
220	0.044	0.00058	0.05789	0.00113	250	0.355	312.84
230	0.046	0.00061	0.06053	0.00113	245	0.3479	306.57
240	0.048	0.00063	0.06316	0.00113	240	0.3408	300.31
250	0.05	0.00066	0.06579	0.00113	235	0.3337	294.04
260	0.052	0.00068	0.06842	0.00113	230	0.3266	287.78
270	0.054	0.00071	0.07105	0.00113	225	0.3195	281.52
280	0.056	0.00074	0.07368	0.00113	223	0.31666	279.01
290	0.058	0.00076	0.07632	0.00113	220	0.3124	275.25
300	0.06	0.00079	0.07895	0.00114	215	0.3053	268.98
310	0.062	0.00082	0.08158	0.00114	210	0.2982	262.72
320	0.064	0.00084	0.08421	0.00114	208	0.29536	260.21
330	0.066	0.00087	0.08684	0.00114	207	0.29394	258.95
340	0.068	0.00089	0.08947	0.00114	205	0.2911	256.45
350	0.07	0.00092	0.09211	0.00114	205	0.2911	256.44
360	0.072	0.00095	0.09474	0.00114	203	0.28826	253.93
370	0.074	0.00097	0.09737	0.00114	203	0.28826	253.92
380	0.076	0.001	0.10000	0.00114	203	0.28826	253.92
390	0.078	0.00103	0.10263	0.00114	203	0.28826	253.91
400	0.08	0.00105	0.10526	0.00114	203	0.28826	253.9
410	0.082	0.00108	0.10789	0.00114	203	0.28826	253.9
420	0.084	0.00111	0.11053	0.00114	203	0.28826	253.89
430	0.086	0.00113	0.11316	0.00114	203	0.28826	253.88

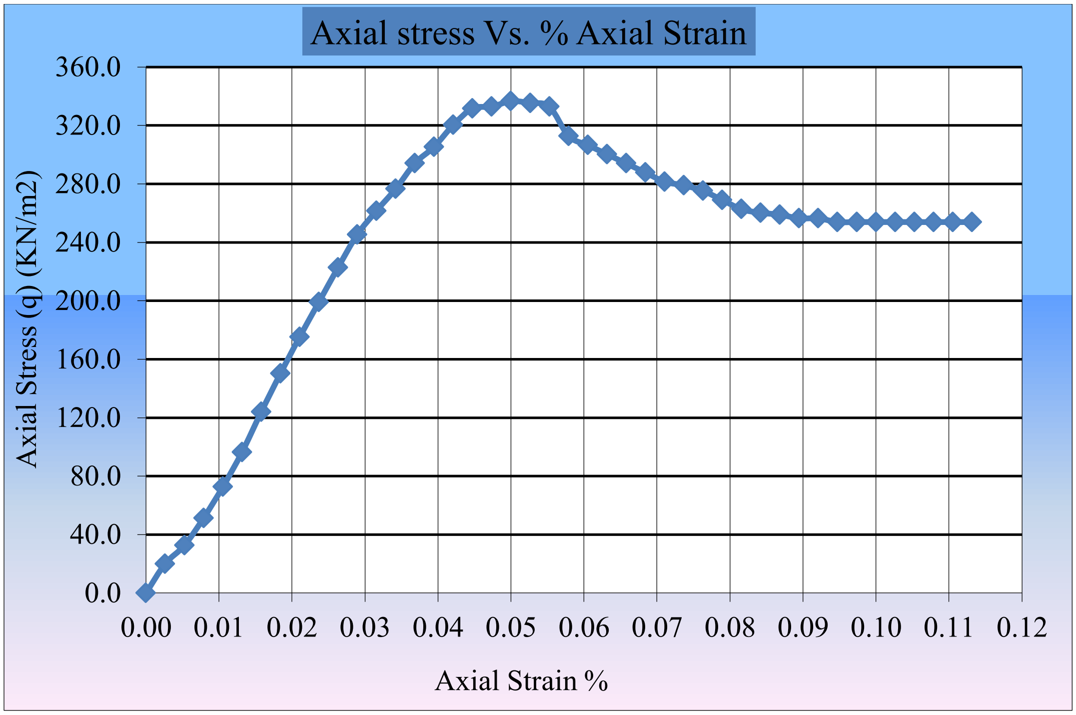

Figure 45:Axial stress Vs. % Axial Strain with two bamboo enforcement

[D] UCS with three bamboo reinforcement test results

Deformation Dial Reading (division)	Sample Deformation (mm)	Strain (e) (ΔL/Lo)	% Strain	Corrected Area Ac=Ao/(1-ε)	Proving Ring Reading (division)	Load (kN)	Stress (kPa)
0	0.000	0.00000	0.00000	0.00113	0	0.00000	0.00
10	0.002	0.00003	0.00263	0.00113	10	0.01420	12.52
20	0.004	0.00005	0.00526	0.00113	28	0.03976	35.06
30	0.006	0.00008	0.00789	0.00113	48	0.06816	60.09
40	0.008	0.00011	0.01053	0.00113	69	0.09798	86.38
50	0.010	0.00013	0.01316	0.00113	93	0.13206	116.43
60	0.012	0.00016	0.01579	0.00113	122	0.17324	152.73

70	0.014	0.00018	0.01842	0.00113	150	0.21300	187.78
80	0.016	0.00021	0.02105	0.00113	182	0.25844	227.83
90	0.018	0.00024	0.02368	0.00113	210	0.29820	262.87
100	0.020	0.00026	0.02632	0.00113	234	0.33228	292.91
110	0.022	0.00029	0.02895	0.00113	253	0.35926	316.68
120	0.024	0.00032	0.03158	0.00113	268	0.38056	335.45
130	0.026	0.00034	0.03421	0.00113	280	0.39760	350.46
140	0.028	0.00037	0.03684	0.00113	290	0.41180	362.97
150	0.030	0.00039	0.03947	0.00113	295	0.41890	369.22
160	0.032	0.00042	0.04211	0.00113	300	0.42600	375.47
170	0.034	0.00045	0.04474	0.00113	305	0.43310	381.71
180	0.036	0.00047	0.04737	0.00113	304	0.43168	380.45
190	0.038	0.00050	0.05000	0.00113	300	0.42600	375.44
200	0.040	0.00053	0.05263	0.00113	289	0.41038	361.66
210	0.042	0.00055	0.05526	0.00113	288	0.40896	360.40
220	0.044	0.00058	0.05789	0.00113	287	0.40754	359.14
230	0.046	0.00061	0.06053	0.00113	286	0.40612	357.88
240	0.048	0.00063	0.06316	0.00113	285	0.40470	356.62
250	0.050	0.00066	0.06579	0.00113	284	0.40328	355.36
260	0.052	0.00068	0.06842	0.00113	283	0.40186	354.10
270	0.054	0.00071	0.07105	0.00113	282	0.40044	352.84
280	0.056	0.00074	0.07368	0.00113	281	0.39902	351.57
290	0.058	0.00076	0.07632	0.00113	280	0.39760	350.31
300	0.060	0.00079	0.07895	0.00114	279	0.39618	349.05
310	0.062	0.00082	0.08158	0.00114	278	0.39476	347.79
320	0.064	0.00084	0.08421	0.00114	277	0.39334	346.53
330	0.066	0.00087	0.08684	0.00114	276	0.39192	345.27
340	0.068	0.00089	0.08947	0.00114	275	0.39050	344.01
350	0.070	0.00092	0.09211	0.00114	274	0.38908	342.75
360	0.072	0.00095	0.09474	0.00114	266	0.37772	332.74

370	0.074	0.00097	0.09737	0.00114	263	0.37346	328.98
380	0.076	0.00100	0.10000	0.00114	261	0.37062	326.47
390	0.078	0.00103	0.10263	0.00114	260	0.36920	325.21
400	0.080	0.00105	0.10526	0.00114	259	0.36778	323.95
410	0.082	0.00108	0.10789	0.00114	257	0.36494	321.44
420	0.084	0.00111	0.11053	0.00114	256	0.36352	320.18
430	0.086	0.00113	0.11316	0.00114	255	0.36210	318.92

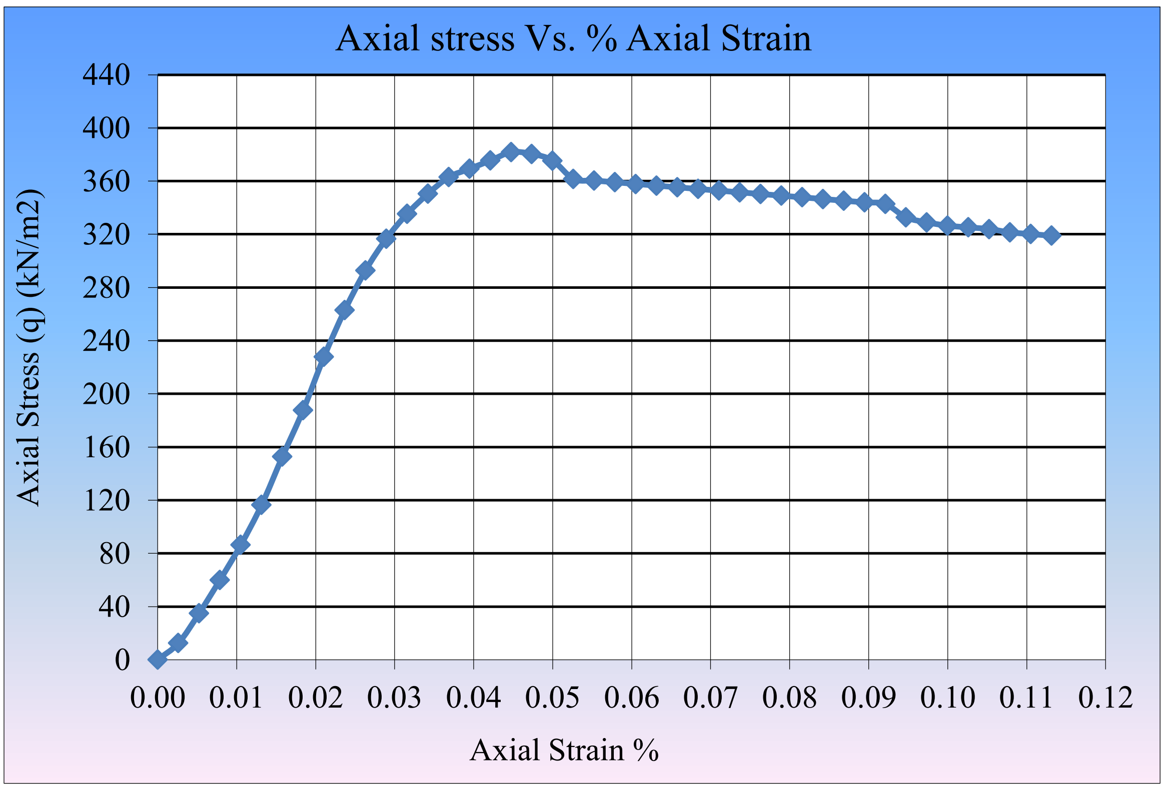

Figure 46:Axial stress Vs. % Axial Strain with three bamboo enforcement

APPENDIX-G

MR Vs. No of bamboo test result

Determination of modulus of rigidity at different % strain

E: Modulus of elasticity (also called Young's modulus) is the ratio of unit stress to unit strain within the proportional limit of a material in tension or compression.

$$E = \frac{\sigma}{\varepsilon} \tag{4.3}$$

	No of bamboo			
range of strain % at 0.01	0	1	2	3
modules of elasticity (E) kPa at % strain	420.66	463.22	683.57	811.26
Poisson‟s ratio	0.50004	0.50004	0.50004	0.50004
rigid or shear module‟s GkPa	140.22	154.40	227.85	270.41
	No of bamboo			
range of strain % at 0.02	0	1	2	3
modules of elasticity (E) kPa at % strain	349.26	415.61	826.21	1059.04
Poisson‟s ratio	0.50008	0.50008	0.50008	0.50008
rigid or shear module‟s GkPa	116.41	138.53	275.39	353.00
	No of bamboo			
range of strain % at 0.03	0	1	2	3
modules of elasticity (E) kPa at % strain	342.13	406.39	839.47	1080.64
Poisson‟s ratio	0.50011	0.50011	0.50011	0.50011
rigid or shear module‟s GkPa	114.04	135.45	279.80	360.18

range of strain % at 0.04	No of bamboo 0	1	2	3
modules of elasticity (E) kPa at % strain	327.91	444.31	770.97	926.17
Poisson"s ratio	0.50015	0.50015	0.50015	0.50015
rigid or shear module"s GkPa	109.29	148.09	256.96	308.69

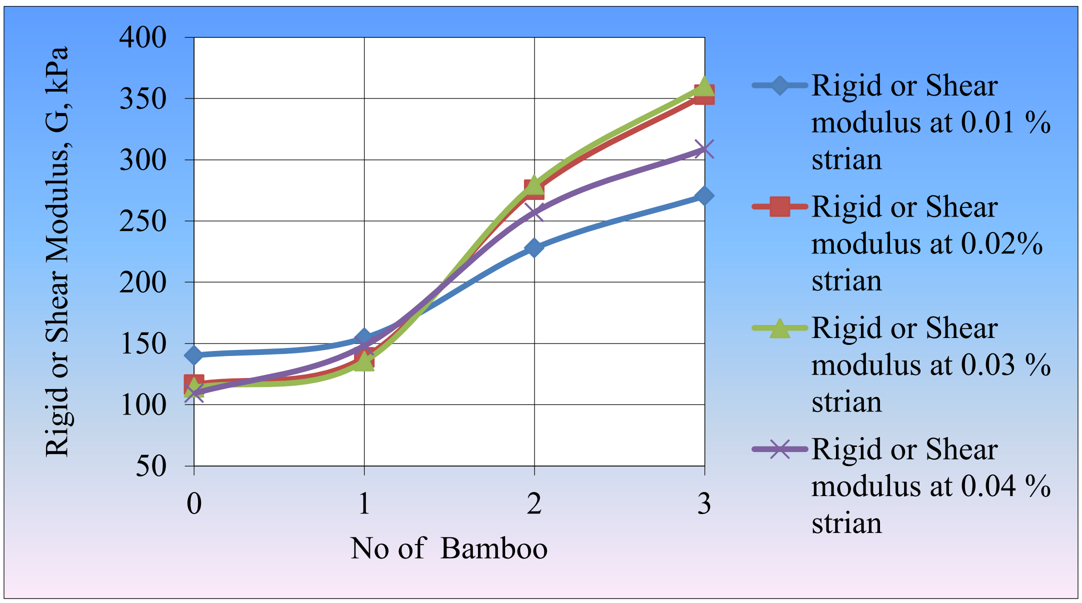

Figure 47: Variation of modulus of rigidity with No. of Bamboo specimen

Determination of Poisson"s ratio at different % strain

ν: Poisson's ratio is the ratio of lateral or radial , ε_r ,and longitudinal or axial ,ε_a,

$$\nu = \frac{\varepsilon r}{\varepsilon a} \tag{4.4}$$

poisson's ratio at % strain	0 bmboo	1 bamboo	2 bamboo	3 bamboo
0.01	0.50004	0.50004	0.50004	0.50004
0.02	0.50008	0.50008	0.50008	0.50008
0.03	0.50011	0.50011	0.50011	0.50011
0.04	0.50015	0.50015	0.50015	0.50015

Determination of axial or longitudinal strain at different % strain

axial or longitudinal straain at % strain	0 bmboo	1 bamboo	2 bamboo	3 bamboo
0.01	0.00010	0.00010	0.00010	0.00010
0.02	0.00020	0.00020	0.00020	0.00020
0.03	0.00030	0.00030	0.00030	0.00030
0.04	0.00040	0.00040	0.00040	0.00040

Determination of radial or lateral strain at different % strain

radial or lateral straain at % strain	0 bmboo	1 bamboo	2 bamboo	3 bamboo
0.01	0.00005	0.00005	0.00005	0.00005
0.02	0.00010	0.00010	0.00010	0.00010
0.03	0.00015	0.00015	0.00015	0.00015
0.04	0.00020	0.00020	0.00020	0.00020