ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

APPLICATIONS OF BAMBOO AS A SUB GRADE SOIL REINFORCEMENTS (ZIWAY-HAWASSA ROAD), ETHIOPIA

BY: GOSAYE ZERIHUN MELESSE

“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 Science in Civil and Environmental Engineering” (Major in Geotechnical Engineering)

ADVISOR:

DR.-ING. SAMUEL TADESSE

MARCH, 2017

ADDIS ABABA, ETHIOPIA

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr.ing Samuel Taddese and has not been presented as a thesis for a degree in any other university, and that all sources of materials used for this thesis have also been duly acknowledged.

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TABLE OF CONTENTS

ACKNOWLEDGMENTS..i

TABLE OF CONTENTS...ii

LIST OF TABLES...v

LIST OF FIGUREURES...viii

SYMBOLS AND ABBREVIATIONS.. xii

ABSTRACT..xiii

CHAPTER1: INTRODUCTION 1

1.1. Back ground of the problem 1

1.2. Natural fibber and soil reinforcements..3

1.3. Objectives of the study 5

1.3.1. General objectives……………………………………………………….5

1.3.2. Specific objectives………………………………………………….........5

1.4. Scope of the Study...6

1.5. Structure of the Thesis...6

CHAPTER 2: LITERATURE REVIEW……………………..7

2.1. General types of soil ……………………………………………………...……7

2.2. Index properties of soil…………………………………………………………7

2.2.1. Particle-size distribution…………………………………………..7

2.2.2. Atterberg Limits ………………………………………………….…7

2.2.3. Specific gravity……………………………………………………....9

2.3. Compaction of soil ……………………………………………………………10

2.4. Shear Strength of soil……………………………………….……………...…10

2.5. California Bearing Ratio (CBR)……………………………………………......11

2.6. Soil reinforcements and its applications……………………………………...11

2.7. Bamboo……………………………………………………………………...…13

2.7.1. Bamboo Morphology and Growth……………………………………13

2.7.2. Physical Properties of bamboo……………………………………..15

2.7.3. Mechanical Properties of bamboo……………………………………16

2.7.4. Occurrence and Distribution of Bamboo Resources in Ethiopia ……………..16

2.7.5. Bamboo and its engineering applications……………………………..19

2.7.6. Bamboo as soil reinforcements...20

CHAPTER 3: DESCRIPTION OF THE STUDY AREAS……………………………22

3.1. Identification of Soil in the Study Area…………………………………………22

CHAPTER 4: METHODOLOGY……………………………………………….…...24

4.1. Soil Sampling and Testing…...24

4.2. Index properties…………………………………………………………..24

4.2.1. Grain size analysis ……………………………………………………24

4.2.2. Atterberg limits……………………………………………………..24

4.2.3. Specific gravity……………………………………………………..25

4.3. Compaction tests……………………………………………………………26

4.4. Direct shear tests………………………………………………………....28

4.5. California bearing ratio (CBR)……………………………………….…...29

4.6. Bamboo sample preparations……………………………………………..30

4.7. Tests on bamboo samples…………..……………………………………35

4.7.1. Water Absorption Test on Bamboo ……………………………….…...35

CHAPTER 5: TEST RESULTS AND ANALYSIS……………………………………...36

5.1 Index test results and analysis…………………………………………..…36

5.1.1. Specific gravity………………………………………………….………36

5.1.2. Grain size analysis……………………………………………….……36

5.1.3. Atterberg´s limit test results and analysis……………………………......39

5.2. Compaction test results on natural soil……………………………………………40

5.3. Compaction test results on reinforced soil samples…………………………………41

5.4. Direct shear test results on natural soil samples……………………………………...46

5.5. Direct shear test results on reinforced soil samples…………………………………48

5.6. California bearing ratio (CBR) test results for natural soil sample…………………..52

5.7. California bearing ratio (CBR) test results on reinforced soil sample………………..54

CHAPTER 6: TEST RESULTS AND DISCUSSIONS………………………………...60

6.1 Index properties and soil classifications……………………………….…………...60

6.1.1. Unified soil classification system (USCS) …………………………….…....60

6.1.2. Classifications of soils based on AASHTO Classification system …….………63

6.1.3. Determination of group index (GI)………………………..…………….….64

6.2. Compaction test results and discussions……………………………………….….65

6.3. Direct shear test results and discussions…………………………………….……72

6.4. California Bearing Ratio (CBR Test) results and discussions………………………79

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS......................................82

7.1. Conclusions…………………………………..………………………………82

7.2. Recommendation..83

REFERNCES...84

Appendixes………………………………………………………………………..86

Appendix A- descriptions of the study area…………………………………………………..86

Appendix B -Specific gravity test result………………………………………………………88

Appendix C -Grain size and hydrometer analysis results……………………………………..89

Appendix D-LL and PL test results…………………………………………………………...95

Appendix E -Compaction test results…………………………………………………………...97

Appendix F- Direct shear test results..……..……111

Appendix G - California Bearing Ratio (1 point -CBR) test results.......................................123

LIST OF TABLES

Table 2.1. Specific gravities of the test pits……………………………………………………9

Table 2.2. Index property Test Results in different parts of the country………………………9

Table 2.3. Typical values of drained angle of friction for sands and silts................................10

Table 2.4. Major Highland Bamboo Areas in Ethiopia...18

Table 3.1. The location of test pits in global position system……………………….……..23

Table 5.1 .Specific Gravity of the Soil of the Study Area ……………….……………………36

Table 5.2. Summary of grain size analysis result…….……………….…………………….36

Table 5.3. Summary of Atterberg limits results of the soil samples………………………...40

Table 5.4. Summary of maximum dry density and optimum moisture content…....…………41

Table 5.5. Summary of compaction results for 15mm, 1% of bamboo………………………..41

Table 5.6. Summary of compaction results for 15mm, 0.5% of bamboo……….……………..42

Table 5.7. Summary of compaction results for 15mm, 0.25% of bamboo……………………43

Table 5.8. Summary of compaction results for 45mm, 1% of bamboo………….……………44

Table 5.9. Summary of compaction results for 45mm, 0.5% of bamboo……….……….…45

Table 5.10. Summary of direct shear test results……………….……………………………47

Table 5.11. Un-soaked (1-point) CBR………………………………………………………..52

Table 5.12. Soaked (1-point) CBR………………...…………………………………………53

Table 5.13. CBR (0.5%, 15mm)…………………...…………………………………………54

Table 5.14. CBR (0.5%, 30mm)…………………...…………………………………………55

Table 5.15. CBR (0.5%, 45mm)……………………………………………………………...56

Table 5.16. CBR (1%, 15mm)………………………………………………………………..57

Table 5.17. CBR (1%, 45mm)………………………………………………………………..58

Table 5.18. CBR (1%, 30mm)………………………………………………………………..59

Table 6.1. Classification of soil sample according to USCS classification……………………60

Table 6.2. Comparison of index property Test Results in different parts of the country...…….61

Table 6.3. Classifications of soils based on AASHTO Classification system……………..…64

Table 6.4. Maximum dry density and OMC of both samples………………….…………...……65

Table 6.5. Compaction test results for different bamboo percentages (15mm)……….........66

Table 6.6. Comparisons of compaction test results for different bamboo lengths (1%)…...….68

Table 6.7. Comparisons of compaction test results for different length of bamboo (0.5%)…...69

Table 6.8. Direct shear test results for different percentages of bamboo (45mm)……………..72

Table 6.9. Direct shear test results for different percentages of bamboo (15mm)…...............…73

Table 6.10. Direct shear test results for different lengths of bamboo (1%)…………................74
Table 6.11. Maximum shear stress for different bamboo percentages of 45mm………..……76
Table 6.12. Maximum shear stress for different bamboo percentages of 15mm………..……77
Table 6.13. Maximum shear stress for different lengths of bamboo (1%)…………………....78

Table 6.14. CBR value at different bamboo percentages………………………………..79

Table 6.15. CBR value at different bamboo lengths…………..…….. ……..………………80

Table A-1. Descriptions of the study area (TP-1)…………..………………………………86

Table A-2. Descriptions of the study area (TP-2)…………….……………………………87

Table B-1. Specific gravity test result (TP-1)…………………..…………………………88

Table B-2. Specific gravity test result (TP-2)…………………...……………………..……88

Table C-1. Grain size analysis test result (TP-1)…………………….…………………89

Table C-2. Hydrometer Analysis (TP-1)……………………………………………….…..90

Table C-3. Grain size analysis test result (TP-2)…………..……………………………92

Table C-4. Hydrometer Analysis (TP-2)……………………………………………….…...93

Table D-1. Liquid limit and plastic limit on TP-1……………………………….…….…95

Table D-2. Liquid limit and plastic limit on TP-2……………………………………….96

Table E-1. Compaction data sheet (TP-1)…………………..……………..………….97

Table E-2. Determination of moisture content (TP-1)…………………..……………….97

Table E-3. Compaction data sheet (TP-2)…………………………………………………99

Table E-4. Determination of moisture content (TP-2)…………………………..…………99

Table E-5. Compaction test results (15mm, 1% bamboo)…………………………......101

Table E-6. Moisture contents (15mm, 1%)………………………………………………101

Table E-7. Compaction test results (15mm, 0.5% bamboo)………...……………………103

Table E-8. Moisture contents (15mm, 0.5%)……………………..…………………….103

Table E-9. Compaction test results (15mm, 0.25% bamboo)……………………………105

Table E-10. Moisture contents (15mm, 0.25%)…………………….…………….……..105

Table E-11. Compaction test results (45mm, 1% Bamboo)……………………………………107

Table E-12. Moisture contents (45mm, 1% Bamboo)…………………………………………107

Table E-13. Compaction test results (45mm, 0.5 % Bamboo)…………………………………109

Table E-14. Moisture contents (45mm, 0.5 % Bamboo)………………………………………109

Table F-1. Direct shear test results on TP-1………………….……...………………………111

Table F-2. Direct shear test results on TP-2………………….……...………………………113

Table F-3. Direct shear test results on Reinforced soil (45mm, 1%, TP-1)…………………115

Table F-4. Direct shear test results on Reinforced soil (45mm, 0.5 %, TP-1)……….………117

Table F-5. Direct shear test results on Reinforced soil (15mm, 1%, TP-1)…………………119

Table F-6. Direct shear test results on Reinforced soil (15mm, 0.5%, TP-1)……………..…121

Table G-1. Un -soaked CBR test result ………………………………………..……………123

Table G-2.Soaked CBR test result ……………………………………...…………………124

Table G-3.CBR test result (0.5%, 15mm)………………………………...…………………125

Table G-4.CBR test result (0.5%, 30mm)………………………………..………………….126

Table G-5.CBR test result (0.5%, 45mm)……………………………...……………………127

Table G-6.CBR test result (1%, 15mm)……………………………….…………………….128

Table G-7.CBR test result (1%, 30mm)……………………………..………………………129

Table G-8.CBR test result (1%, 45mm)……………………………..………………………130

LIST OF FIGUREURES

Figure 1.1: Different procedures of soil reinforcement……………………….……………4
Figure 2.1: Casegrande´s plasticity chart……………………………………………….....8
Figure 2.2: Bamboo plant, parts and types 15
Figure 2.3: Bamboo resources of the world…………………...17
Figure 24: Study localities in bamboo-growing and processing regions of Ethiopia……….....18
Figure 2.5: Green Bamboo…………………………………………………………………21
Figure 2.6: Bamboo Housing in Ethiopia……………………………………………..21
Figure 3.1: Location of the thesis area on the map of Ethiopia…….………………………22
Figure 3.2: Location of sampling areas shown on map of Ziway town………………………23
Figure 4.1: Casagrande´s Plasticity chart……………………………………………..25
Figure 4.2: Preparation of sample for compaction (reinforced soil)…………………………27
Figure 4.3: Reinforced soil after compaction (high ductility)…………...…………………27
Figure 4.4: Bamboo forest……………………………………………………………………31
Figure 4.5: Nodes, internodes, inner and outer culm parts of green bamboo…………………31
Figure 4.6: Bamboo sample preparation and air drying at Lideta Campus …………….…..32
Figure 4.7: Bamboo sample preparation and store at EiABC soil testing centre…….….……32
Figure 4.8: Bamboo sample prepared at specified lengths…………………………….…...33
Figure 4.9: Bamboo fiber……..……………………………………………………………33
Figure 4.10: Mixture of soil and kerosene treated bamboo…………………………….….34
Figure 4.11: Water absorption test on bamboo (removing of excess water)……………….…35
Figure 5.1: Combined sieve analysis curve for test pit-1……….…………………………….37
Figure 5.2: Combined sieve analysis curve for test pit-2…………………………….……..38
Figure 5.3: Flow curve for samples from test pit-1…..39
Figure 4: Flow curve for samples from test pit-2…..39
Figure 5.5: Compaction curve for TP-1……………………………………………………40
Figure 5.6: Compaction curve for TP-2……………………………………………………40
Figure 5.7: Compaction curves (15mm, 1%)…………………………...…………………41
Figure 5.8: Compaction curves (15mm, 0.5%)…………………………….……………....42
Figure 5.9: Compaction curves (15mm, 0.25%)……………………………………….....43
Figure 5.10: Compaction curve (45mm, 1%)………………………………………………44
Figure 5.11: Compaction curve (45mm, 0.5%)……………………………………….……45
Figure 5.12: Shear stress vs displacement for different normal stress (TP-1)…………………46

Figure 5.13: Maximum shear stress vs normal vertical stress (TP-1)…………………………....46
Figure 5.14: Shear stress vs displacement for different normal stress (TP-2)………………...47
Figure 5.15: Maximum shear stress vs normal vertical stress (TP-2)……………………….…...47
Figure 5.16: Shear stress vs displacement (45mm, 1%)………………………………………48
Figure 5.17: Maximum shear stress vs normal applied stress (TP-1, 45mm, 1%)…………….48
Figure 5.18: Shear stress vs displacement for different normal stress (45mm, 1%)…………...49
Figure 5.19: Maximum shear stress vs normal applied stress (TP-1, 45mm, and 0.5%)……...49
Figure 5.20: Shear stress vs displacement for different normal stress (15mm, 1%)………..…50
Figure 5.21: Maximum shear stress vs normal applied stress (TP-1, 15mm, 1%)…………….50
Figure 5.22: Shear stress vs displacement (15mm, 0.5%)…………………………………….51
Figure 5.23: Shear stress versus normal applied stress (15mm, and 0.5%)…………………..…51
Figure 5.24: Stress-strain curve (un-soaked CBR)..52
Figure 5.25: Stress-strain curve (socked CBR)……………………………………………….53
Figure 5.26: Stress-strain curve (0.5%, 15mm)……………………………………………….54
Figure 5.27: Stress-strain curve (0.5%, 30mm)……………………………………………….55
Figure 5.28: Stress-strain curve (0.5%, 45mm)………………………………….………..……56
Figure 5.29: Stress-strain curve (1%, 15mm)…………………………….....…………….……57
Figure 5.30: Stress-strain curve (1%, 30mm)……………………………………………….…….58
Figure 5.31: Stress-strain curve (1%, 45mm)……………………………...……………59
Figure 6.1: Combined grain size distribution curve for TP-1 and TP-2………………………62
Figure 6.2: AASHTO classification for soil…………………….…………………….………63
Figure 6.3: Combined compaction curves for both samples………………………….........65
Figure 6.4: Combined curve for different bamboo percentages and 15mm length…………....66
Figure 6.5: Effects of bamboo percentages on MDD for 15mm length……………………….…67
Figure 6.6: Effects of bamboo percentages on OMC for 15mm length ……………………….67
Figure 6.7: Combined curve for different lengths of bamboo (1%)……………………..…....68
Figure 6.8: Combined curve for different length of bamboo (0.5%)….………………………69
Figure 6.9: Effects of bamboo length on MDD for 0.5%...70
Figure 6.10: Effects of bamboo length on OMC for 0.5%…………………….……………....70
Figure 6.11: Effects of bamboo percentages on cohesion for 45mm lengths………………….72
Figure 6.12: Effects of bamboo percentages on angle of internal friction for 45mm lengths….72

Figure 6.13: Effects of bamboo percentages on cohesion for 15mm lengths ………………...73

Figure 6.14: Effects of bamboo percentages on angle of internal friction for 15mm lengths….74

Figure 6.15: Effects of bamboo lengths on cohesion for 1%…………………………………75

Figure 6.16: Effects of bamboo lengths on angle of internal frictions for 1%..........................75

Figure 6.17: Effects of bamboo percentages on shear strengths for 45mm……………..………76

Figure 6.18: Effects of bamboo percentages on shear strengths for 15mm …………….……77

Figure 6.19: Effects of bamboo length on shear strengths for 1%..78

Figure 6.20: Effects of bamboo percentages on CBR value for different lengths ………...….80

Figure C-1: Combined grain size distribution curve for TP-1……………………...……91

Figure C-2: Combined grain size distribution curve for TP-2…………………….……..……94

Figure E-1: Compaction curve for TP-1……………………………………….…………..….98

Figure E-2: Compaction curve for TP-2……………………………………………………..…100

Figure E-3: Compaction curve (15mm, 1%)……………………………………………..…102

Figure E-4: Compaction curve (15mm, 0.5%)………………………………………………104

Figure E-5: Compaction curve (15mm, 0.25%)………………………………….…………106

Figure E-6: Compaction curve (45mm, 1%)..108

Figure E-7: Compaction curve (45mm, 0.5%)……….……………………..……………110

Figure F-: Shear stress versus displacement (TP-1)…………………………...…….………112

Figure F-2: Shear stress versus applied load (TP-1)…………..……………….……………112

Figure F-3: Shear stress versus displacement (TP-2)…………………………………..………114

Figure F-4: Shear stress versus applied load (TP-2)…………………………………………114

Figure F-5: Shear stress versus displacement (45mm, 1%)…………………………………..116

Figure F-6: Shear stress versus applied load (45mm, 1%)………..……….………………116

Figure F-7: Shear stress versus displacements (45mm, 0.5%)………………………………118

Figure F-8: Shear stress versus applied loads (45mm, 0.5%)……………….……………118

Figure F-9: Shear stress versus displacements (15mm, 1%)……………………...………120

Figure F-10: Shear stress versus applied load (15mm, 1%)……….…….…….………..120

Figure F-11: Shear stress versus displacements (15mm, 0.5%)…………………………..122

Figure F-12: Shear stress versus applied load (15mm, 0.5%)……………..………………122

Figure G-1: Stress-strain curve (Un-soaked)..123

Figure G-2: Stress-strain curve (soaked)……………………………………………….124

Figure G-3: Stress-strain curve (0.5%, 15mm)…………………………………..….125

Figure G-4: Stress-strain curve (0.5%, 30mm)…………………………………...……126

Figure G-5: Stress-strain curve (0.5%, 45mm)……………………….…………...……127

Figure G-6: Stress-strain curve (1%, 15mm)………………………………………...………128

Figure G-7: Stress-strain curve (1%, 30mm)…………………………………………...129

Figure G-8: Stress-strain curve (1%, 45mm)……………...………………………………130

SYMBOLS AND ABBREVIATIONS

AAiT-Addis Ababa Institute of Technology

AASHTO - American Association of Highway and Transportation Officials

AAU-Addis Ababa University

ASCE-American Society of Civil Engineering

ASTM - American Society for Testing Materials standard

CBR-California Bearing Ratio

c-Cohesion

Central Board of Irrigation and Power (CBIP).

EiABC-Ethiopian Institute of Architecture and Building Construction

GI-Group Index

GIZ-German International cooperation

IRC (international research committee)

LL - Liquid limit

MDD- Maximum dry density

ML- Inorganic Silt

NBCC-National Bamboo construction centre

Ø-Angle of internal frictions

OL-organic silts of low plasticity

OMC -Optimum moisture content

PI - Plastic Index

PL-Plastic limit

SM-Silty sand

TP-Test pit

USCS-Unified Soil Classification System

ABSTRACT

Road construction on fine grained soils are challenges to geotechnical engineers and designers because of its low bearing capacity which results in cracks in the pavement structure as well as increase in the thickness of the pavement. Use of natural fiber in geotechnical engineering for improving soil properties is advantageous because they are cheap, locally available, biodegradable and eco-friendly and causes significant improvement in tensile strength, shear strength, and other engineering properties of the soil.

This thesis work is aimed to evaluate the applications of bamboo as a subgrade soil reinforcements. The soil samples was collected from Ziway town and Bamboo sample was collected from Hagere selam. Two test pits of soil samples were collected for the investigation purposes but tests on reinforced soil were conducted on only one selected test pit. The preliminary investigation of the soil on index properties shows that it belongs to A-4 class of soil in the AASHTO soil classification system and ML under USCS system. Compaction, direct shear and CBR tests were used to evaluate properties of bamboo reinforced soil.

The soil was reinforced with bamboo in percentages of 0.25%, 0.5% and 1% by dry weight of the soil and length of 15mm, 30mm and 45mm with a maximum thickness of 3mm to 5mm.Certain percentages of bamboo with varying lengths are used for the experimental investigations. All bamboo samples were treated by a certain amounts of kerosene by mixing it with kerosene to avoid the absorption of moisture. Water absorption test shows that the water absorption of bamboo coated by kerosene was decreased by about 20%.Soil samples were prepared at its MDD corresponding to its OMC to conduct direct shear and CBR tests with and without reinforcements.

Analysis of test results shows that bamboo reinforcements of soil reduces MDD very slightly while OMC remains more or less the same. Bamboo reinforcements of sandy silt soil has no significant effects on shear strength parameters (C and Ø) but significantly increases CBR (i.e.CBR increases by about more than 200% of that unreinforced soil) at 1% of 45mm.

Generally the CBR value of sub-grade soil increases significantly with the inclusion of bamboo but different factors such as removal of bamboo (environmental cost), transporting of bamboo (transportation cost), preparation of bamboo (technical cost), decomposition of bamboo makes the design un-economical and as the sub-grade soil is sandy silt it is better to improve its engineering properties by compaction only.

CHAPTER 1: INTRODUCTION

1.1. Back ground of the problem

Construction of roads and other civil engineering structures on soft fine grained soil is highly risky on geotechnical grounds because such soil is susceptible to differential settlements, poor shear strength and high compressibility. Improvement of load bearing capacity of the soil may be undertaken by a variety of ground improvement techniques like stabilisation of soil, adoption of reinforced earth technique etc. Reinforced earth technique is considered as an effective ground improvement method because of its cost effectiveness, easy adaptability and reproducibility.

During last 40 years, much work has been done on strength deformation behaviour of natural fiber reinforced soil and it has been established beyond doubt that addition of fiber in soil improves the engineering performances of soil. Among the notable properties that improved are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness. Use of natural fibers such as cotton, bamboo, jute, coir, etc. as soil reinforcing materials has been prevalent for a long time. Natural fiber reinforced soil has been used in many countries in the recent, past and further research is in progress for many hidden aspects of it. They are abundantly used in many countries like India, Philippines, and Bangladesh etc.

Fiber reinforced soil is effective in all types of soils (i.e. sand, silt and clay). The main advantages of these materials are they are locally available and are very cheap. They are biodegradable and hence do not create disposal problem in environment. If these materials are used effectively, the rural economy can get uplift and also the cost of construction can be reduced, if the material use leads to beneficial effects in engineering construction. Studies have also shown that durability of natural fibber can be improved using coating of fiber with kerosene and Bitumen, (Siva Kumar Babu and Vasudevan 2008).

Many studies have been conducted relating to the behaviour of soil reinforced with randomly distributed fiber. Gray and Ohashi (1983), conducted a series of direct shear tests on soil reinforced with different synthetic, natural and metallic fiber to evaluate the effects of parameters such as fiber orientation, fiber content and fiber area ratios on contribution to shear strength. Based on the test results they concluded that an increase in shear strength is directly proportional to the fiber area ratios.

The fiber -reinforced soil behaves as a composite material. When loaded, it mobilize tensile resistance, which in turn provides greater strength to the soil. Natural fibers in geotechnical engineering has been used in the construction of pavement layers, road and railway embankments, and retaining walls as well as in the protection of slopes. The primary purposes of reinforcing a soil mass is to improve its stability by increasing its bearing capacity, and by reducing settlement and lateral deformation. Randomly distributed fiber-reinforced soils have recently attracted increasing attention in geotechnical engineering. A number of published works are available which deal with different types of geo-synthetics being used for separation, filtration, reinforcement, etc. But the data related to natural fibers is only very limited and resources of it is not still studied well for its importance as a soil reinforcements for a road construction. Hence there is a need for conducting studies to exploit the potential use of natural fibbers as construction materials.

In this thesis bamboo fiber is used as soil reinforcing material, in subgrade of road system. Silty soil samples from Ziway town was collected and investigated for their various engineering and strength properties. The properties of unreinforced soil such as specific gravity, grain size distribution, optimum moisture content, maximum dry density ,shear strength and CBR are determined and as well as strength properties of reinforced and unreinforced soils such as maximum dry density, optimum moisture contents, shear strength and CBR at different bamboo lengths and percentages were investigated and compared. Bamboo is purchased from the local area and cut in to small pieces, air dried and finally oven dried to remove all the moistures. Then it is treated by kerosene by immersing in it and mixed with soil by percent from 0.25% to 1% by dry mass. The lengths of bamboo used for laboratory case was taken as 15 mm, 30 mm and 45mm. The experimental study of this work involves standard proctor's compaction tests, direct shear test, and California Bearing Ratio tests on unreinforced and reinforced soil with varying percentage of bamboo (0.25%, 0.5% and 1%) and the strength and engineering properties of reinforced soil are compared with that of unreinforced soil.

1.2. Natural fibers as a soil reinforcements

Blending of two or more than two materials is quite common, in order to obtain better engineering properties such as reinforced concrete. In the same context reinforced earth is not an unusual phenomenon. Reinforcing the earth with randomly mixing of discrete fibres attracted considerable attention.

The concept of earth reinforcement is an ancient technique and demonstrated abundantly in nature by animals, birds and the action of tree roots. Since the invention by Hennery Vidal in 1966, nearly 4000 structures have been built in more than 37 countries so far using the concept of earth reinforcement. Conventional methods of reinforcement consists of continuous inclusions of strips, fabrics, and grids into an earth mass. But as a modification of the same technique, random inclusion of various types of fibres is also considered as a soil reinforcement material. These fibres act to interlock particles and group of particles in a unitary coherent matrix.

We have several examples of reinforcing the soil like Great Wall of China (earliest example of reinforced earth using branches of trees as tensile materials), ziggurats of Babylon (woven mats of read were used) etc. In United States of America and Europe, the erosion & stability of slopes for highway and railway embankment is controlled using reinforced soil.

The first national workshop on reinforced soil was held in 1985, under an aegis of Central Board of Irrigation and Power (CBIP). Since then the subject began to be commonly discussed at various Indian Geotechnical Conferences organized by CBIP, Geotechnical society institute of engineers, Textile association etc. The CBIP also organized an international workshop on reinforcing soil with textile in 1989 at Bangalore. The efforts are being made to make the concept popular but still it requires much to be done in this regard.

Economy in road network can be achieved through economical pavement design. Weak subgrade results in greater thickness of pavement layer, so that the stresses on the subgrade are inconsonant with their load carrying capacity and resulting in increased construction cost. Empirically flexible pavements are designed on the basis of CBR value of the subgrade and traffic on the proposed road. As per IRC (International Research Committee) recommendation increase in CBR value from 2.0% to 5.0% reduces the thickness requirement by 35%. Therefore improvement in subgrade has always been an area of concern to highway and geotechnical engineers. With the aim of reducing pavement thickness on weak subgrade new techniques of construction and soil stabilization have been continuously explored.

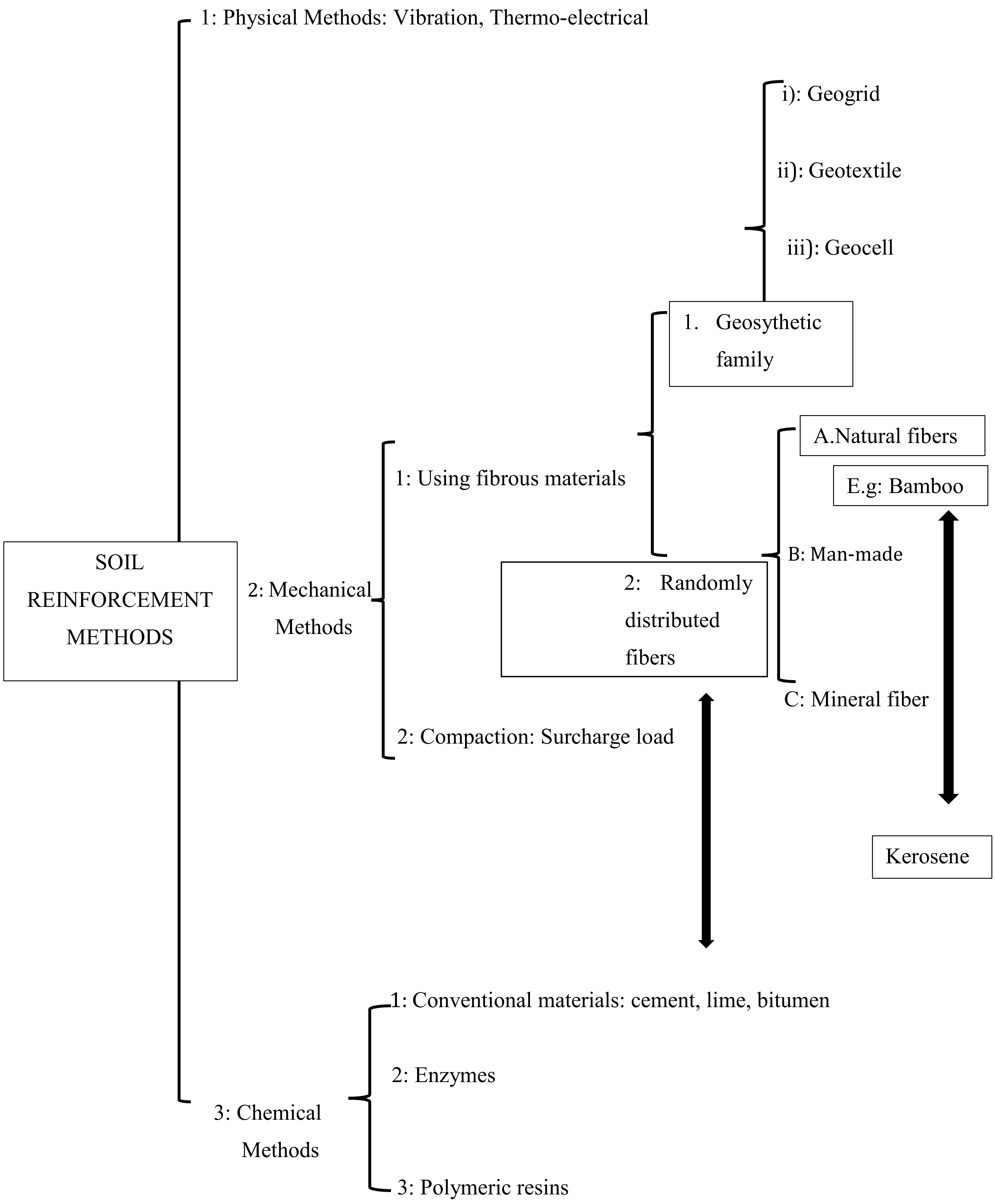


Figure 1.1: Different procedures of soil reinforcements

1.3. Objectives of the Study

Now a days the construction of roads in Ethiopia is increasing at a faster rate. In the construction of roads the most important parameter are the engineering properties of a subgrade materials. This study is mainly designed to use locally available, cheap, nonabrasive and environmentally degradable natural Bamboo as a subgrade soil reinforcements.

1.3.1. General objectives

- Using of locally available bamboo as subgrade soil reinforcements on road constructions.
- To explore the effective utilization of Ethiopian bamboo as a geotechnical construction materials.
- Investigating the engineering properties of kerosene coated bamboo reinforced subgrade soil.

1.3.2. Specific objectives

The specific objective of this study is mainly focused on the investigation of engineering properties of bamboo reinforced subgrade soil which includes:

- To investigate the effects of bamboo reinforcements on the CBR of subgrade soils.
- To study the effects of bamboo reinforcements on the shear strength parameters (cohesion and angle of internal friction) of subgrade soil.
- To investigate effects of bamboo reinforcements on the compaction characteristics (MDD and OMC) of subgrade soil.

1.4. Scope of the Study

The scope of this study is limited to engineering classification of the soil samples from the two test pits of Ziway town for a depth of about 0.6m using AASHTO and USCS by conducting sieve analysis, hydrometer, atterberg's limit (liquid limit and plastic limit), and specific gravity. Conducting water absorption tests on bamboo samples, investigation of strength characteristics such as compaction, CBR and shear strength of unreinforced and bamboo reinforced soil sample by varying the lengths and contents of bamboo. Finally analysing, comparing, discussions, concluding and recommending on test results and observations.

1.5. Structure of the Thesis

This thesis work is divided in to seven Chapters, each covering a specific topic of the thesis work. In the introductory Chapter the background of the problem, objective, scope of the thesis work and structure of the thesis are presented. Chapter two deals with a brief literature review. Chapter three deals with the description of area (Ziway town) in which this research is done. The fourth Chapter deals with methodology and sample preparations. Analysis of test results are covered in chapter five. The discussion and comparison on the laboratory test results obtained from this work is covered in Chapter six. Chapter seven is the conclusions and recommendations drawn from the research. Detailed soil profiles for test pits, calculation of specific gravity test result, grain size and hydrometer analysis test results, liquid limit results, compaction test results, CBR and direct shear test results of reinforced as well as natural soil samples are all included in the appendix.

CHAPTER 2: LITERATURE REVIEW

2.1. General types of soil

According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75mm to 76.2mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eyes is about 0.075mm. Soil grains ranging from 0.075mm to 0.002mm are termed as silt and those that are finer than 0.002mm as clay USCS (Budhu,2000).

2.2. Index properties

The behaviour of soil samples are understood by conducting tests on physical attributes of the soil particle and soil aggregate constituents. 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.

2.2.1. Particle-size distribution

Grain size analysis is used to determine the effective diameter of the soil particles that constitute and strongly affect the uniformity characteristics of the soil mass. Mechanical analysis is used for the coarse sized soils by using nest of sieve and hydrometer analysis is used for fine grained soils. For a soil-containing fine to coarse sized particles the combined analysis is employed. Silt soils of Ziway town has clay content ranging from 6.7 to 10.9%, silt fraction 51.5 to 73.0%, sand fraction 15.1 to 40.4%, and gravel content from 0.84 to 1.9% and for silty sand soils clay content ranging from 0.6 to 4.4%, silt fraction 17.1 to 42.2%, sand fraction 52.1 to 81.3%, and gravel content from 0.9 to 1.6%, (Beza Tesfaye, 2015).

2.2.2. Atterberg´s Limits

Atterberg Limits tests are used to confirm visual descriptions. They are performed on fine-grained soils (clays, silts) to determine the amount of water necessary to achieve a range of behavioural states. These test results have been correlated with other soil properties. The liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) are Atterberg limits. However, for classification purposes, the term Atterberg limits generally refers to the more common liquid and plastic limits only.

The shrinkage limit test is less often included in common laboratory programs. The shrinkage limit test is performed when swelling behaviour in soils are suspected that could influence design and construction.

Liquid Limit (LL): the moisture content of a soil at the boundary between the liquid and plastic states.

Plastic Limit (PL): is the moisture content at the boundary between the plastic and semisolid states. The plastic limit is determined by ascertaining the lowest moisture content at which the material can be rolled into threads 3mm in diameter before crumbling.

Plasticity Index (PI): is simply the numerical difference between the liquid limit and the plastic limit and indicates the magnitude of the range of moisture content over which the soil remains plastic. It is the measure of the cohesion qualities of the binder resulting from the clay content. Also it gives some indication of the amount of swelling and shrinkage that will result in the wetting and drying of that fraction tested.

$$PI = LL - PL \qquad \ldots\ldots 2.1$$

The Atterberg limits and related indices have proved to be very useful for soil identification and classification. Soils are classified by AASHTO and USCS based on their Atterberg limits and on particle size as determined by sieving, (ASTM).

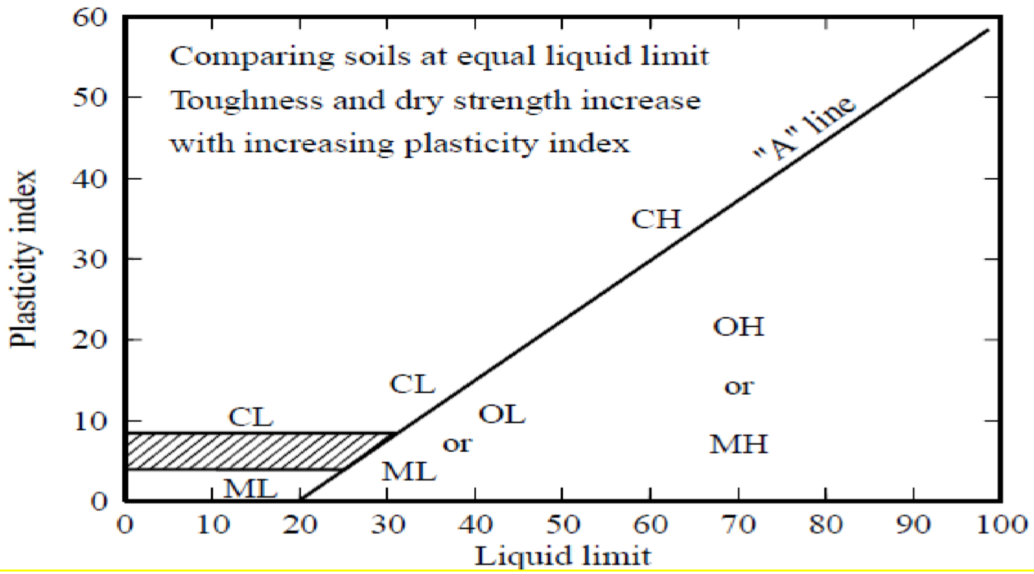


Figure 2.1: Casagrande's Plasticity chart

The Atterberg Limits for silt soils in Ziway town are summarized below. Liquid limit ranges from 27– 37%, plastic limit ranges from 23–29% and plastic index from 4 to 8%, (Beza Tesfaye, 2015).

2.2.3. Specific gravity

Specific gravity of the soil solids is useful in the determination of void-ratio and degree of saturation. It is also useful in computing the unit weight of the soil under different conditions and also in the determination of particle size by hydrometer analysis.

Table 2.1 Specific gravities of some soil types (Arora, 2003)

S.NO	Soil types	Specific gravities
1	Gravel	2.65-2.68
2	Sand	2.65-2.68
3	Silty sand	2.66-2.7
4	Silt	2.66-2.7
5	Inorganic clay	2.68-2.8
6	Organic soil	Variable may be fall below 2.00

Table 2.1 shows the specific gravities of some soil types by (Arora, 2003). Studies shows that the specific gravity of Ziway soils ranges from 2.40 to 2.62.

Table 2.2 Index property Test Results in different parts of the country (Beza Tesfaye, 2015)

Descriptions	Abu Gemechu, 2007	Dagnachew Debebe ,2011	Beza Tesfaye, 2015
Soil type	Silt & silty sand	Silt & silt sand	Silt, silty sand, sand-silt mixtures
Location	Adama	Adama	Ziway
Clay Content (%)	14-58	5.4 – 40.5	0.66-10.93
Silt fraction (%)	14-61	17.6-60.7	17.15-73.03
Sand fraction (%)	25-56	14.5-54.6	15.16-81.3
Liquid Limit (%)	39-49.4	29-73	27-37
Plastic limit (%)	26-37.4	24-39	23-29
Plasticity Index (%)	10-15	5-34	4-8
Moisture content (%)	25-30.5	17.5-36.5	22.6-35.83
Specific Gravity	2.61-2.7	2.4-2.7	2.4-2.62
Compaction (g/cm3)	1.33-1.53	1.2-1.62	1.22-1.55
From plasticity chart	ML&SM	SM, ML, MH	SM & ML

Table 2.2 shows the average values of various tests done at different parts of countries (i.e., Sieve analysis, Liquid Limit, Plastic Index and specific gravities showing different properties). As indicated in Table 2.2 above soil of Ziway is classified under SM, ML and MH and shows lower plasticity (low clay content) as compared to Adama soil.

2.3. Compaction of soil: Compaction is rapid process of reduction of volume of soil by mechanical methods. Air during compaction is expelled from the void space in the soil mass and, therefore the mass density is increased. Compaction of soil mass is done to improve its engineering properties. Compaction generally increases the shear strength of soil, and hence the stability and bearing capacity. It is also useful in reducing the compressibility and permeability of the soil. Design specifications usually state the required density (as a percentage of the "maximum density'' measured in a standard laboratory test), and the water content. The MDD of Ziway soil ranges from 1.22-1.55 (g/cm3) and OMC ranges from 22.5% to 36%, (Beza Tesfaye, 2015).

2.4. Shear Strength: The shear strength of a soil is the maximum shearing stress the soil structure can resist before failure. Soils generally derive their strength from friction between particles (expressed as the angle of internal friction, Ø) or cohesion between particles (expressed as the cohesion **C** in units of force/unit area), or both.

Table 2.3. Typical values of drained angle of friction for sands and silts (Arora, 2003)

Soil type	Ø (deg.)
Sand :Rounded grains	
Loose	27-30
Medium	30-35
Dense	35-80
Sand: Angular grains	
Loose	30-35
Medium	35-40
Dense	40-45
Gravel with some sands	34-48
Silts	26-35

Studies shows that for Ziway soil direct shear test results i.e. Cohesion (C) in kPa ranges from 2 to 20.5 and angle of internal friction (Ø) in degrees ranges from 18.5 to 28.5 respectively.

2.5. California bearing ratio (CBR)

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of classifying and evaluating soil subgrade and base course materials for flexible pavements. CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. CBR test may be conducted in remoulded or undisturbed sample. Test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.27mm/min. The loads for 2.54mm and 5.08mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value, (Chegenizadeh and Nikraz, 2011).

CBR tests are carried out on natural or compacted soils in water soaked or un-soaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the subgrade soil. For applications where the effect of compaction water content on CBR is small or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort, (ASTM).

2.6. Soil reinforcements and its applications

Reinforced soil structure may be cost effective alternative for conventional sloped embankment, gravity walls or cantilever walls when right of way is restricted, foundation conditions are weak, weak subgrade soil (low bearing capacity and high compressibility).

Gosavi (2004), reported that soil can be reinforced with low-cost materials like natural fibers obtained from jute, bamboo, coir etc. For well graded sandy silty soil, the authors suggested that inclusion of randomly oriented discrete fibers increases the California bearing ratio (CBR) value of remoulded soil. By mixing nylon fiber and jute fiber, the CBR value is enhanced by about 50% of that of unreinforced soil, whereas coconut fiber increase the value by as high as 96 %. The optimum quantity of fiber to be mixed with soil is found to be 0.75% and any addition of fiber beyond this quantity does not have any significant increase in the CBR value. The authors in their study showed that the value of optimum moisture content (OMC) increases and the value of maximum dry density (MDD) decreases with increases in quantity of woven fabrics and fibre glass, and the maximum value of reinforcement quantity may be limited to 1% only.

The rate of increase in the CBR value with 1% addition of fibers is small and the absolute value of CBR decreases further with more addition. Ranjan (1996), reported that the shear strength of short, randomly distributed fiber-reinforced soil is a function of fiber weight fraction, aspect ratio and surface friction, soil characteristics (i.e. angle of internal friction) and its density and confining stress on shear strength of reinforced soils. The internal friction angle is used to quantify the strength of the granular matrix and the fiber characterized by volumetric concentration, aspect ratio, and the fiber soil interface friction angle.

The results of a study by Islam, Mohammad S. and Kazuyoshi Iwashita (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 and it control the behaviour of the specimen. There was a direct relationship between the fiber length and content and the bearing capacity of the soil.

A similar study, performed by Sassa, Kyoji and Canuti which evaluated the load penetration behaviour of a reinforced soil, established the same relationship between the fiber content of the reinforcement and the bearing capacity of the soil. Soil mass reinforced with randomly distributed discrete fibers resembles the conventional earth reinforcement in many of its properties. The preparation is quite similar to that of admixture stabilisation. Mostly the discrete fibers are simply added and mixed with the soil, much the same as cement, lime or any other additives.

One of the main advantages of randomly distributed fibers is the maintenance of strength isotropy and absence of potential failure plane that can develop parallel to the oriented reinforcement. Very limited information has been reported on the use of randomly distributed discrete fibers for soil reinforcement, e.g. some limited information available of the use of bamboo. Only recently, the natural fibers have tried in the field of soil reinforcement due to their affordable cost, strength, friendly environmental nature and bulk availability. In addition to these stated advantages it has some practical drawbacks, such as reproducibility and biodegradability. The problem of biodegradability can be effectively overcome by applying chemical coatings using water repellent compounds such as kerosene and bitumen. This is a proven solution for biodegradability of natural fibers.

2.7. Bamboo

Bamboo is one of the oldest building materials used by mankind. The bamboo has been made into an extended diversity of products ranging from domestic household products to industrial applications. In Asia and Ethiopia bamboo is quite common for bridges, scaffolding and housing, but it is usually a temporary exterior structural material. In many overly populated regions of the tropics, certain bamboos supply the one suitable material that is sufficiently cheap and plentiful to meet the extensive need for economical housing. Indeed, bamboo has many applications beyond imagination. Its uses are broad and plentiful. With the advancement of science and technology and the tight supply of timber, new methods are needed for the processing of bamboo to make it more durable and more usable in terms of building materials. Studies have been done on the basic properties, and processing bamboo into various kinds of composite products. More studies are needed to aid and promote its application in the modern world. Some information on the basic properties of bamboo were documented, however its properties particularly in relation to their applications as the raw material for composite products is very limited. Bamboos grow particularly well in the tropics and subtropics. Lee, stated that the smaller bamboo species are mostly found in high elevations or temperate latitudes, and the larger ones are abundant in the tropic and subtropics areas. Bamboos are also adaptable to various types of habitat. They grow in plains, hilly and high-altitude mountainous regions, and in most kinds of soils. Abd.Latif and Abd.Razak mention that bamboo could grow from sea level to as high as 3000 meter.

2.7.1. Bamboo Morphology and Growth

Bamboo is divided into 2 major portions, the rhizomes and the culms. The rhizome is the underground part of the stem .The upper ground portion of the stem, called the culm. It is the portion of the bamboo tree that contains most of the woody material. Most of bamboo culms are cylindrical and hollow, with diameters ranging from 0.25 inch to 12 inches, and height ranging from 1 foot to 120 feet. It is without any bark and has a hard smooth outer skin due to the presence of silica. The culm is complimented by a branching system, leaves, flowering, fruits and seedlings.

Bamboo is a fast growing species and a high yield renewable resource. Bamboo growth depends on species, but generally all bamboo matures quickly. The bamboo culm is divided into segments by diaphragms or nodes. The nodes separate the culm into several sections termed internodes. The culms outermost layer, the bark, consists of epidermal cells that contain a waxy layer called cutin. It was found that the presence of nodes, moisture content and culm location had a significant effect on strength. The presence of nodes reduced the compression, tension strength .The top location of the culm exhibited higher compression strength, tension strength. Bamboo, according to Lee is similar to wood in regard to an isotropic shrinkage.

Abd.Latif stated that bamboo might have 40 to 50 stems in one clump, which adds 10 to 20 culms yearly. Bamboo can reach its maximum height in 4 to 6 months with a daily increment of 15 to 18 cm (5 to 7 inches). Wong stated that culms take 2 to 6 years to mature, which depends on the species. It is suggested that with a good management of the bamboo resource, the cutting cycle is normally 3 years. According to Lee, bamboo mature in about 3 to 5 years, which means its growth is more rapid than any other plant on the planet. The fast growth characteristic of bamboo is an important incentive for its utilization. Due to the fact that it is abundant and cheap, bamboo should be used to its fullest extent as a geotechnical engineering material.

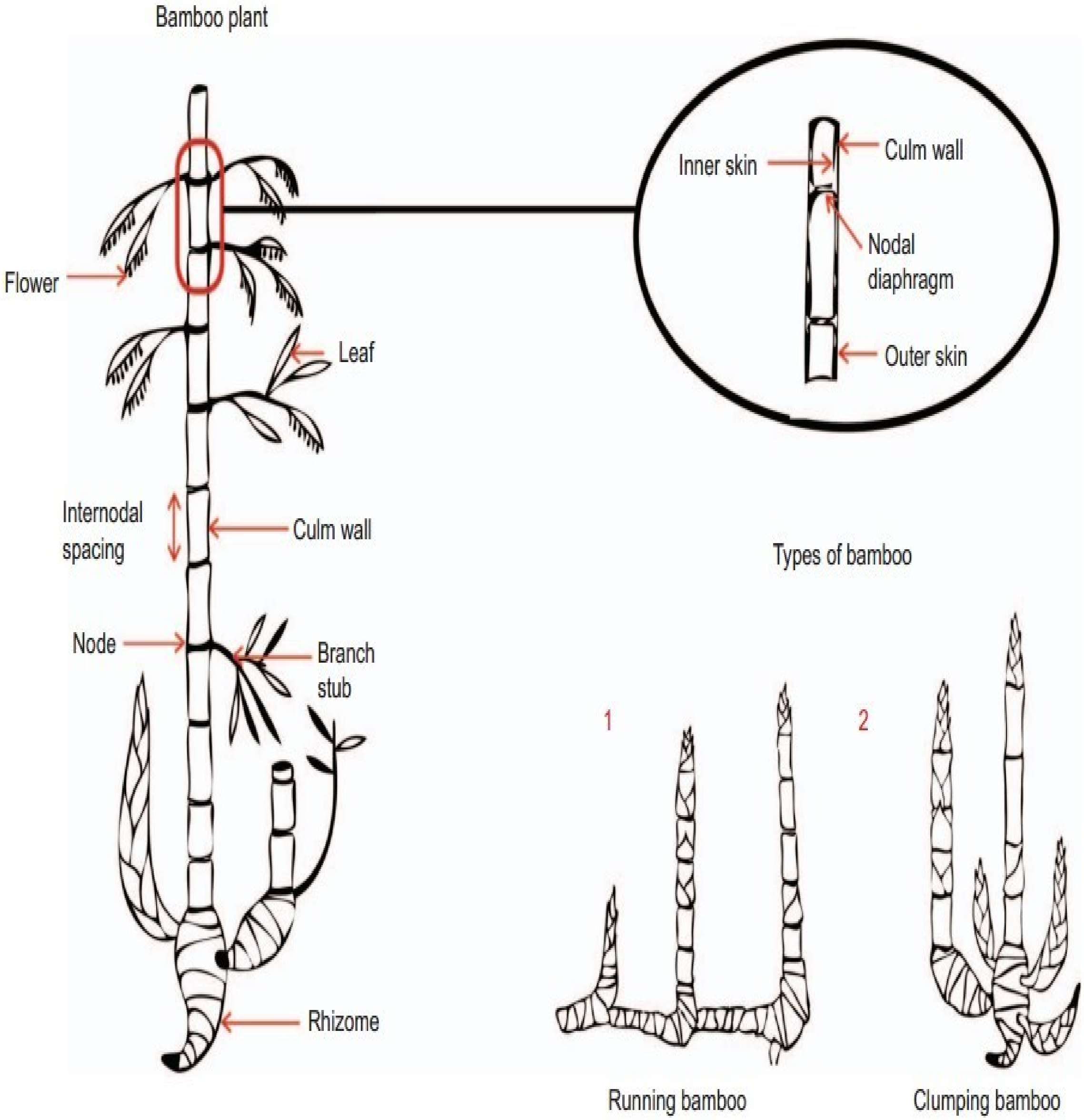


Figure 2.2: Bamboo plant, parts and types

2.7.2. 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 the dry condition the strength is higher than in the green condition. For some bamboos, moisture content is about 30% to 130%. However the density of bamboo varies from about 0.5g/cm3 to 0.9g/cm3 with the outer culm having a far higher density than the inner part. Internodes contain 2% to 7% more moisture than the nodes.

2.7.3. Mechanical Properties of bamboo

The strength of bamboo depends on the species, its age, moisture content, density and culm height. However, higher moisture content will decrease the strength of bamboo. The strength of this material also related to its density. The density of bamboo varies approximately from 0.5 to 0.9 g/cm3 but can differ considerably within the culm (increase with the height of the culm) and between species, (Abdi. Latif 1992). As the 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 reached its maximum strength. Young bamboo with higher moisture content shows greater increase in strength on drying than the older culms. 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. The bending stress at proportional limit was ranged from 21MPa to 49MPa and it shows the differences in static bending strengths of specimens. According to Ghavami (2005), the tensile strength of bamboo is relatively high and can reach 370MPa. This makes bamboo an attractive alternative to steel in tensile loading applications.

2.7.4. Occurrence and Distribution of Bamboo Resources in Ethiopia

Africa has a wealth of bamboo resources, comprising an estimated 7% of the world stock, Kigomo (1988). Approximately 2/3 of this stock is located in Ethiopia, home to 1.5 million hectare of bamboo, (LUSO CONSULT, 1997). Until recently, there has been very little investment in the bamboo sector. Ethiopia had no formal bamboo economy until 2012. Two species of bamboo occur naturally in Ethiopia: “lowland bamboo’’, (Oxytenanthera abyssinica) and “highland bamboo”, (Yushania alpine). Lowland bamboo, known locally as “Shimel”, makes up approximately 70% of the country’s bamboo resources. This species grows in western Ethiopia between altitudes of 700 and 1,800 m. Highland bamboo, or “Kerekeha”, grows in the rainy highlands of North-western and Southern Ethiopia at an altitude of 2,200 – 3,500 m. Bamboo makes up 6.5% of total forest cover in Ethiopia. The coverage of lowland bamboo is estimated to be 1,000,000 hectares, while the highland bamboo is estimated to be 400,000 hectares, (LUSO CONSULT, 1997).

This means that 86% of the African bamboo resource is found in Ethiopia, Habtemariam Kassa (2014). In Ethiopia, bamboo is used mainly for house construction and as a fuel source. Many farmers harvest and sell young green bamboo culms for this purpose, though these are immature and lack the strength and durability of mature culms. Ethiopia’s important natural bamboo resources is endangered by poor management and by negligence. A recent LUSO CONSULT, ‘’Study on the bamboo management and utilization in Ethiopia’’ has elaborated the present situation with recommendations for the improvement of management and utilization of bamboo to benefit the farmers as well as the handicraft business. Bamboo can contribute considerably to the sustainable development of the rural areas in Ethiopia. The existence of the only two bamboo species in Ethiopia, their importance for the rural people and the need for further promotion was presented based on a ‘’Study on suitable bamboo management ‘’ by LUSO CONSULT on behalf of the German Technical cooperation (GTZ), Eschborn in (1997). Out of the total area covered by highland bamboo, 130,000 hectares have already been mapped, (LUSO CONSULT, 1997). Highland bamboo is medium sized bamboo with straight culms of 12-20 m height and a base diameter of 8-12 (20) cm.

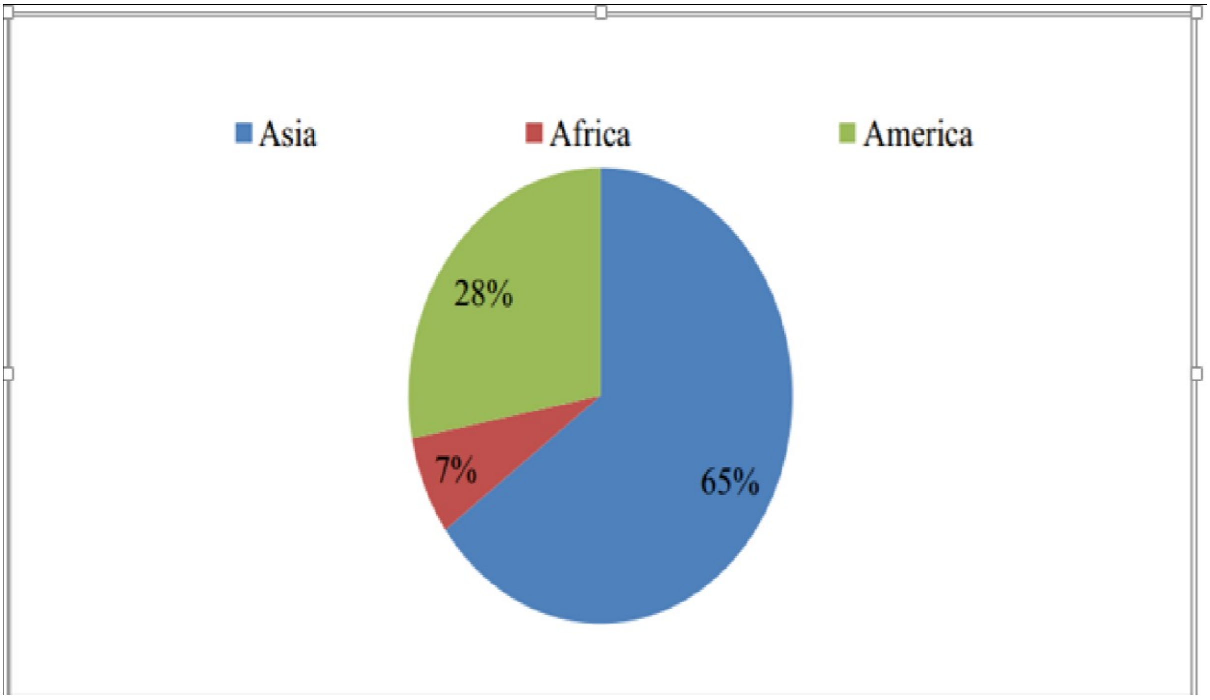


Figure 2.3: Bamboo Resources of the World

Table.2.4. Major Highland Bamboo Areas in Ethiopia (LUSO CONSULT, 1997)

No	Bamboo Area	Region	Natural Stand(Ha)	Plantation (Ha)	Total (Ha)
1	Injibara	Amhara	30	2350	2,380
2	Agaro	Oromiya	-	1500	1,500
3	Bale Mountains	Oromiya	56,851	-	56,851
4	Shenen/Jibat	Oromiya	1,774	2561	4,335
5	Gera	Oromiya	36,000	1250	37,250
6	Bore/Hagereselam/Hula	Oromiya/South	-	2460	2,460
7	Chencha/Arbaminch	South	2,460	3250	5,710
8	Indibir/Jembero	South	-	1850	1,850
9	Jima/Ameya	Oromiya/South	-	900	900
10	Mizan Teferi/Kulish	South	-	1850	1850
11	Bonga/Ameya	South	7,997	-	7997
13	Masha	South	18,652	-	18,652

Figure 2.4: Localities in bamboo-growing and processing regions of Ethiopia. Addis Ababa(A) ,Asosa (B) ,Bahir dar(C),Bambasi(D),Banja(E),Chencha(F).Hawassa(G),Hula(H),Masha(I),Tikur -Enchini(J). Source: Habtemariam Kassa, (2014).

2.7.5. Bamboo and its engineering applications

To increase the amount of information concerning bamboo several successful research programs have been carried out since 1979. The present energy crisis provoked by indiscriminate industrial growth has caused increasing concerns about managing the energy resources still available and about environmental degradation. There is an intense ongoing search for non-polluting materials and manufacturing processes, which require less energy.

In consequence of the consumers choosing industrialized products, among other effects, activities are suppressed in rural areas or even in small towns, and renewable materials are wasted and causing permanent pollution. In this sense, it becomes obvious that ecological materials satisfy such fundamental requirements, making use of agricultural by-products such as rice, husk, coconut fibres, sisal and bamboo, therefore minimizing energy consumption, conserving non-renewable natural resources, reducing pollution and maintaining a healthy environment. The structural advantage of bamboo over other engineering materials is studied in terms of modulus of elasticity and density using the material selection method developed at Cambridge University. The greater part has been dedicated to the development of a methodology for bamboos application in space structures and as reinforcement in concrete, (Alito, M. 2005)

In developing countries like Ethiopia due to the educational system, which is mainly based on programs from industrialised nations, there are to date no formal education or research programs concerning the traditional and locally available materials and technologies. Lack of reliable technical information about the local materials makes the consumers use mainly industrialised materials for which the information is freely available. Sound development of bamboo resources and businesses, however, requires a good understanding of its contribution to: (i) local, regional, and national economies, (ii) production and marketing systems, and (iii) factors affecting decisions to engage, develop, and benefit from the bamboo resources across the major bamboo-growing regions in Ethiopia. Such understanding could facilitate improved utilization and sustainable management of the ever-declining bamboo forests (Habtemariam Kassa, 2014).

2.7.6. Bamboo as soil reinforcements

Bamboo is used as reinforcement in soil mainly to stabilize slopes and subgrades to support roads. Now a days treated and untreated bamboo is used along with other materials such as bitumen, kerosene, geotextile etc. in soft soil reinforcement. Case studies in Malaysia reveal that the bamboo mattresses along with nonwoven needle punched geotextiles increases the bearing capacity of soft sub grade and also serves as a good separator. Studies have shown that bamboo possess high tensile and compressive strength and have been used as reinforcement in concrete and soil especially when it is properly seasoned and have lasted more than 3 years.

Just like timber, bamboo is vulnerable to environmental degradation and attacks by insects and moulds. Its durability varies with the type of species, age, conservation condition, treatment and curing. Curing should be initiated when bamboo is being cut in the bamboo grove. Tiwari explained that bamboo start to shrink both in the wall thickness and diameter as soon as it starts to loose moisture. There is a strong relation between insect attacks and the levels of starch plus humidity content of bamboo culm. In order to reduce the starch content, bamboo receives a variety of treatments including curing on the spot, immersion in bitumen or kerosene, heating or smoke. Drying bamboo is fundamental to its conservation for various reasons. Physical and mechanical properties of bamboo increase with a decrease in its humidity content. Bamboo to be treated with a preservative needs to be dry to facilitate penetration and obtain a better result and reducing transport costs. Bamboo can be dried in air, green house, and oven or by fire. The durability of bamboo depends strongly on the preservative treatment methods in accordance with basic requirements: its chemical composition should not have any effect on the bamboo and once injected it must not be washed out by rain or humidity.

In Ethiopia there are to date no formal education or research programs concerning the traditional and locally available materials like bamboo as a soil reinforcing materials.

Figure 2.5: Green Bamboo

Figure 2.6: Bamboo Housing in Ethiopia

CHAPTER 3: DESCRIPTION OF THE STUDY AREAS

Ziway is a town and separate woreda in central Ethiopia. It is located on the road connecting Addis Ababa - Hawassa –Moyale-Nairob Kenya in the Misraq Shewa Zone of the Oromia Region of Ethiopia. Ziway is located at latitude and longitude of 7°00´56‟N 38°00´43‟E and with an elevation of 1643 meters above mean sea level. It is about 163 kilometres away from Addis Ababa in southeast direction. Hager Selam (Hula) is the very cold woreda in Sidama zone, South Nations, Nationalities and Peoples Region (SNNPR) of Ethiopia which located at an elevation of about 2200m above mean sea level and it is about 365 km away from Addis Ababa it has a enough amount of highland Bamboo with poor managements by local users for local uses only.

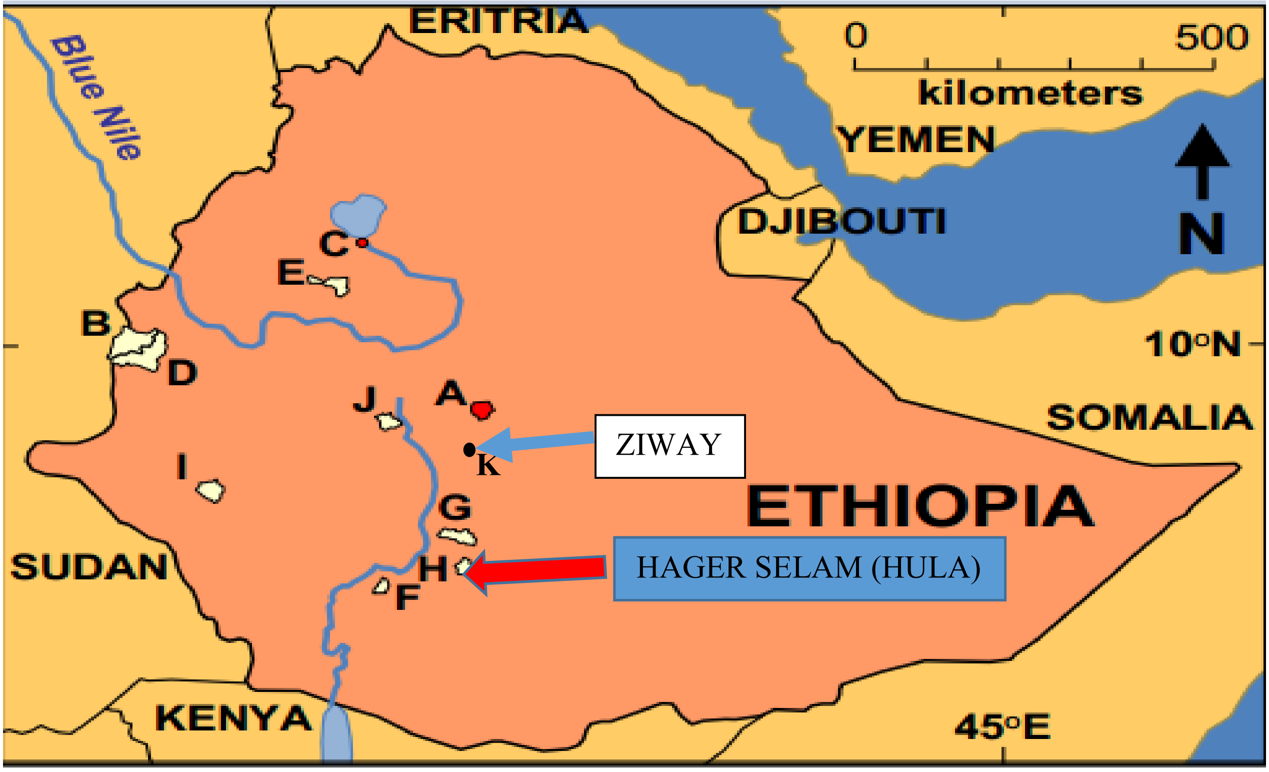


Figure 3.1: Location of the research area on the map of Ethiopia (K-Ziway, H-Hagere selam)

3.1. Identification of Soil in the Study Area

The soil samples for this thesis work were collected from Ziway town. Accordingly, two representative sampling areas were selected from different locations of the town. In the field visual soil description was made and sample for laboratory testing were collected. The global coordinates of sampling location is determined and presented in Table 3.1.

Table 3.1. The location of test pits in Global Position System

Test Pit No	Location at the town	Longitude (in degrees)	Latitude(in degrees)	Elevation(m)
TP1	Around market near old Butajira road	7^{0}51´06”	38^{0}42´30“	1650
TP2	Near Bekele Molla Hotel	7^{0}55´00”	38^{0}00´43¨	1649

Figure 3.2: Soil Test Pit locations on map of Ziway

CHAPTER 4: METHODOLOGY

4.1. Soil Sampling and Testing

The disturbed soil sample used in this study was collected from Ziway town. The soil sample was collected to a maximum depth of 0.6m after removing the top surface soil 0.2m from natural ground surface (TP-1 and TP-2).The sample then transported to AAiT geotechnical laboratory safely. The various index properties (specific gravity, liquid limit, plastic limit, and particle size distribution) for classification and checking of the engineering properties of the soil were done in the geotechnical laboratory. Also compaction properties (MDD and OMC), shear strength tests and California bearing ratio (CBR) test of the test pits are determined in the laboratory without reinforcements for the investigation purposes by using AASHTO and ASTM standards. But soil reinforcement tests are conducted on selected test pit (i.e. TP-1).

4.2. Index properties

The physical properties of soils, which serve mainly for identification and classification, are commonly known as index properties. The various properties of soils, which could be considered as index properties are: Grain size analysis, Atterberg limits and Specific gravity.

4.2.1. Grain-size distribution of soil

Grain size analysis is used to determine the effective diameter of the soil particles that constitute and strongly affect the uniformity characteristics of the soil mass. The procedure followed to run this test is according to ASTM standard. According to ASTM D422-63 the distribution of particles, finer than 75µm can be done by hydrometer test and courser than 75µm by mechanical sieve. After complete grain size analysis, the relative proportion of different size groups in each soil sample can be determined. Soil samples that pass 4.75mm sieve size have been taken for analysis, after air drying and pulverizing. The analysis was done by wet sieving for composite analysis of both sieve and hydrometer.

4.2.2. Atterberg Limits

Atterberg limits were determined for air-dried samples. It was done based on the Standard Reference: ASTM D 4318-98 –Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. Figure 4.1: shows Casagrande´s Plasticity chart for classification of soil by Atterberg limits.

Liquid Limit: is the moisture content of a soil at the boundary between the liquid and plastic states. The liquid limit is determined by ascertaining the moisture content at which two halves of a soil cake will flow together for a distance of 0.5 inch along the bottom of the groove separating the halves, when the blows they are in is dropped between 15 to 35 times from a distance of 0.4 inches at the rate of 2 drops/second. A plot of the relationship between the water content and the number of drops is made using the results of the tests. The water content corresponding to the intersection of the line with the 25-drop abscissa is the liquid limit of the soil.

Plastic Limit: The plastic limit is determined by ascertaining the lowest moisture content at which the material can be rolled into threads 3mm in diameter before crumbling.

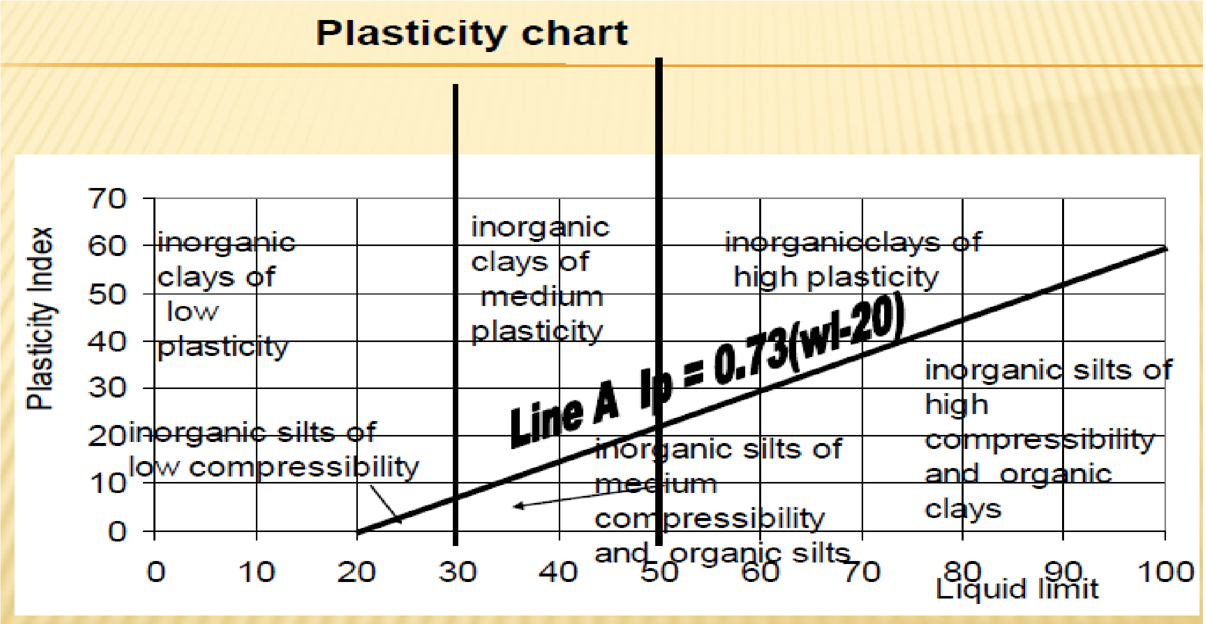


Figure 4.1: Casagrande´s Plasticity chart

4.2.3. Specific gravity

The specific gravity of the soil minerals affects the specific gravity of soils derived from them. Soil sample passing 4.25mm sieve were used for the preparation of the sample for this test. According to ASTM D 854-98, two procedures for performing specific gravity are provided. These are Method-A, procedures for oven dried specimen and Method-B, procedure for moist specimen. For specimens of organic soils and highly plastic, fine-grained soils, Procedure B shall be the preferred method. But in this thesis the specific gravities are determined using method A. Method-A give more reasonable value than that of Method-B, for this soil type and Method-A are used in other calculations like hydrometer analysis.

4.3. Compaction test

For any soil, optimal water content exists at which it will achieve its maximum density. In-situ density is the weight of soil to the total soil volume (i.e. soil + water + air) but maximum dry density (compacted soil density) is the weight of soil to the volume of soil plus volume of water. Design specifications usually state the required density (as a percentage of the "maximum density'' measured in a standard laboratory test), and the water content. The optimum water content is the water content that results in the greatest density for a specified compactive effort. Two types of compaction tests are: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. But in this thesis compaction was done by The Standard Proctor test (i.e. three layers and 25 number of blows for each layers).For reinforced soil the tests were designed systematically so that the effect of each fiber parameters (i.e. lengths and contents) with a maximum thicknesses of 3mm to 5mm can be obtained. Bamboo samples are distributed in dry soil samples uniformly. Special care was taken for achieving uniformity of mixture (bamboo and soil) while compaction procedure. Each soil sample was prepared by initial dry mixing of raw soil and corresponding quantity of fibre according to percentage (by weight of dry soil) of fibre content. Then water was added and mixed again until the water spreads all over the soil. The dry and wet mixing of soil–fiber–water was carried out in anon-porous metal tray in order to avoid water loss. All the test samples were subjected to this test and respective optimum moisture content and maximum dry density of all combinations were determined. Determination of water content was carried out by the oven drying method. First series of the test was related to effect of bamboo percentages. In these test bamboo contents changed while the length was constant. The bamboo percentages were 0.25%, 0.5% and 1% with constant length. The second round was related to effect of length. Therefore, different length (i.e. 15mm, 30 mm and 45mm) with constant bamboo contents were evaluated as per ASTM Standard procedures. Compaction tests are conducted on a certain percentages of a variety of lengths of bamboo because the increase in percentages of bamboo to a higher degree decreases the interactions between bamboo and soil samples. The mixing of soil–fibre was felt very difficult as the fibers are sticking together to form lumps. This also caused pockets of low density. So it has decided to stop with 1% fibre content. From the plot of dry density versus moisture content, OMC corresponding to MDD can be obtained for a specific compaction test.

Figure 4.2: Preparation of sample for compaction (Reinforced soil)

Figure 4.3: Reinforced soil with bamboo after compaction (High ductility)

4.4. Direct shear test

The shear strength of soil mass is its property against sliding along internal planes within itself. In a situations which needs the shearing strength of a soil direct shear test is applied. The test can be performed on an undisturbed sample or remoulded samples. This test has the disadvantage that lateral pressure and stress on other than the plane of shear are not known during test. The test used to determine the angle of internal friction and cohesion of the soil with the shear stress-strain characteristics of soil sample. This test is performed on a disturbed sample remoulded to its maximum dry density.

- A direct shear device is used to determine the shear strength parameters (i.e. angle of internal friction (∅) and cohesion (C) of soil.
- From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific vertical confining stress.
- After the experiment is run several times for various vertical-confining stresses, a plot of the maximum shear stresses versus the vertical (normal) confining stresses for each of the tests is produced.
- From the plot, a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn. Angle of internal friction (∅) and cohesion (C) may be determined the graph (i.e. Ø is slope of the straight line and C is the intercept of the vertical axis).

The experimental study of the thesis involved performing a series of direct shear tests. The tests were conducted inside a shear box of 60mmx60mm in plane and 25 mm in depth. The tests were performed at the vertical normal stresses of 100kPa, 200kPa and 300 kPa in order to completely define the shear strength parameters [i.e., the angle of shear strength (∅) and cohesion (C)] for both the unreinforced and reinforced soil.

The designated bamboo were weighed according to the prescribed reinforcement content and mixed into the soil in small increments until all of the bamboo were effectively distributed within the soil. The added fibers were mixed thoroughly by hand to achieve a fairly uniform mixture. Fibers are randomly mixed in soil to form a homogeneous mixture before adding water. Once bamboo were mixed into the soil, a segregation or floating tendency of fibers was noted. Much care was required to obtain reasonably uniform distribution of the bamboo. The mixing of fibres into the soil increased in difficulty as the reinforcement content increased. However, the fiber-soil mixtures appeared acceptably uniform for the reinforcement contents evaluated. Direct shear tests were conducted on samples which were prepared by kerosene coated bamboo by percent, 0.5% and 1% (by dry weight of soil) and according to the proposed length with a maximum thicknesses of 3mm to 5mm and soil samples remoulded at optimum moisture content by using direct shear test machine as per ASTM standards. The length of fibre corresponding to each percentages of fiber was taken as 15mm and 45mm.

It is to be noted that the choice of a small direct shear apparatus as the testing platform brings some inherent problems into the experimental study. This limits the amount of fiber inclusion. Other problems such as the imposed plane of shear failure and end effect in such a small sample size make it more difficult to model fiber-reinforced soil behaviour realistically. Despite these limitations, direct shear device has been widely used for different theoretical and practical research projects in most laboratories all over the world due to its simplicity.

4.5. California bearing ratio (CBR)

California bearing ratio (CBR) test consists of causing a cylindrical plunger of 50mm diameter to penetrate a soil sample at 1.27mm/min. The loads for 2.54mm and 5.08mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value. CBR tests are carried out on compacted soils in water soaked and un-soaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the subgrade soil. CBR test was conducted on remoulded samples at its MDD. The tests were conducted as per ASTM standards on the selected soils with and without reinforcement to investigate the influence of length and content of bamboo on CBR values. For the preparation of soil samples of reinforced soil the desired amount of kerosene coated bamboo was mixed in dry state before the addition of water and then compacted to same dry density. The length of bamboo to be used are 15mm, 30mm and 45mm and the percentages of bamboo to be used are 0.5% and 1% and with a maximum thicknesses of 3mm to 5mm. For different length and bamboo contents, the dry weight required to fill the CBR mould was calculated based up on the volume of the mould. The water corresponding to optimum moisture content (OMC) was added and mixed thoroughly, compacted and in case of soaked CBR test the mould along with compacted soil was then transferred to a tank containing water for soaking of the sample socked for 4 days. After 4 days (i.e. 96 hours) of soaking, the mould assembly was taken out from water. The CBR mould along with soaked soil sample was brought to a loading frame for testing. Then using CBR test machine record the load readings at penetrations of 0.64 mm, 1.27 mm, 1.91 mm, 2.54 mm, 3.81 mm, 5.08 mm, 7.62 mm, 10.16 mm and 12.70 mm.

Calculations

Load-Penetration Curve:-Calculate the penetration stress and plot the stress-penetration curve.

Bearing Ratio:-Using stress values taken from the stress penetration curve for 2.54 mm and 5.08 mm penetrations, calculate the bearing ratios for each by dividing the corrected stresses by the standard stresses of (6.9 MPa) and (10.3 MPa) respectively, and multiplying by 100. The CBR values of the test samples of reinforced soil were determined corresponding to plunger penetrations of 2.54 mm and 5.08 mm as per the standard procedures. But the bearing ratio reported for the soil is normally the one at 2.54 mm penetration. When the ratio at 5.08 mm penetration is greater, rerun the test. If the check test gives a similar result, use the bearing ratio at 5.08 mm penetration.

$$\boxed{\mathbf{CBR}= \frac{\textbf{Stress}}{\textbf{Standard stress}}\mathbf{x100}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{4.1}$$

4.6. Bamboo sample preparations

Mature Highland bamboo, or “Kerekeha ‘’with different diameter and length is purchased from the local area of Southern part of Ethiopia (SNNP, Hager Salam). The parts of bamboo used for the reinforcement purposes are the culms. Certain amounts of mature dry bamboo culms approximately one (1) meter in length are collected from the areas and transported to the laboratory safely. The bamboo culm is cut in to a shorter lengths and it is disintegrated in to a small finer fibre of the proposed thicknesses and lengths by using cutting machines in wood workshops at Addis Ababa University, Lideta campus (EiABC). The air dried bamboo culm samples are cut in to finer fiber manually and then it is allowed to dry in oven at low temperature of 50^0C for 24 hours to remove all the moistures because existence of moisture affects the durability and strength of bamboo and at higher temperature the bamboo fiber might exposed to burning. The oven dried sample are mixed with certain amounts of kerosene by soaking the prepared bamboo sample in the tray containing kerosene for 24 hours to protect the fibre from moisture effect, degradation and microbial effects prior to mixing it with soil.

The amount of kerosene used was small (i.e. around 2 litres of kerosene) was used for the treatment purposes of all bamboo samples because kerosene once filled in the dish is used repeatedly. After 24 the samples soaked in kerosene was removed and dried to protect water absorption and measured according to the percentages. The amount of kerosene coated bamboo are 0.25%, 0.5%, and 1% by dry weight of oven dried sample. The lengths of bamboo used for different tests was taken as 15 mm, 30 mm and 45 mm with a maximum thicknesses of 3mm to 5mm with an average thickness of 4mm.

Figure 4.4: Bamboo forest

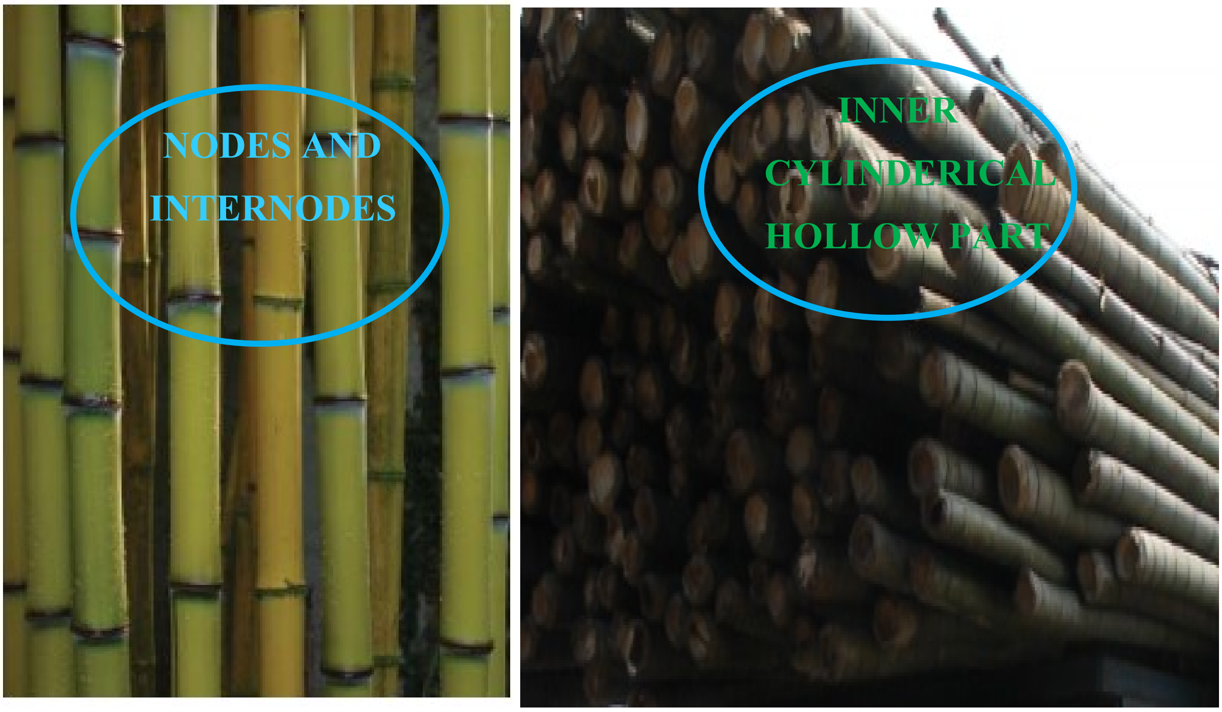


Figure 4.5: Nodes, internodes, inner and outer culm parts of green bamboo

Figure 4.6: Bamboo sample preparation and air drying at Lideta campus

Figure 4.7: Bamboo sample preparation and store at EiABC soil testing centre

Figure 4.8: Bamboo sample prepared at specified lengths

Figure 4.9: Bamboo sample prepared to fiber

Some difficulties encountered during preparation of bamboo samples and experimentations are:

- ✓ Inner and outer culm body have different strengths (i.e. outer culm body has higher strengths than inner culm body).
- ✓ Nodes and internodes has different strengths (internodes has higher strength than nodes).
- ✓ Lower and upper culm parts has different strength properties.
- ✓ Outer culm has higher densities.

Tests on reinforced soil were conducted by distributing inner and outer culm, nodes and internodes, and upper and lower parts of culm randomly and uniformly.

Lengths of bamboo are fixed to a certain dimensions because as the length of bamboo increases to a large extent as a reinforcement for soil:

- The interactions in between bamboo and soil samples decreases,
- Difficult for the preparations of test samples due to limited sizes of test machines in the laboratory.

Figure 4.10: Mixture of soil and kerosene treated bamboo

4.7. Tests on bamboo

The sample of kerosene coated bamboo is prepared according to the proposed lengths and contents to suit it for the laboratory test. The lengths and contents of bamboo fibers are taken by considering the sizes of test machines.

4.7.1. Water Absorption Test on bamboo fiber

Water absorption is used to determine the amount of water absorbed by bamboo. Uncoated bamboo and kerosene coated bamboo are used to investigate the effects of kerosene on the moisture effects of bamboo. Before the measurement, the sample was dried in an air and oven at 50°C for 24 hours, cooled in a desiccator, and immediately weighed which is then taken as the dry initial weight of the sample. Then the specimen was immersed in distilled water maintained at a temperature of 23°C for 24 hours. After 24 hours, the specimen was removed from water and placed on blotting paper to remove excess water before weighing which is taken as final wet mass of the sample. For kerosene coated bamboo the oven dried and cooled bamboo is immersed in kerosene for 24 hours, dried and initial mass was measured and then it is immersed in water again for 24 hours and final wet mass of the sample is determined to see the effects of kerosene on the water absorption of bamboo. The water absorption of the sample was calculated as percent weight change. Test results indicates that the water absorption of kerosene coated bamboo was reduced from 37.24% to 17%.

Figure 4.11: Water absorption test on bamboo (Removing of excess water)

CHAPTER 5: TEST RESULTS AND ANALYSIS

5.1 Index test results and analysis

5.1.1. Specific gravity

Table 5.1 .Specific Gravity of the Soil of the Study Area

Serial no	Designation	Depth in meter	Specific Gravity	Water used for testing
1	TP1	@ 0.6m	2.48	Tap water
2	TP2	@ 0.6m	2.48	Tap water

As shown in Table 5.1 the specific gravities of the test pits are very small due to the light weight of the soil which is derived from the mineral contents of the soil (i.e. test pits was collected from shallow depth from the farm land soil which may contain a certain amount of organic matter). But according to different investigations the specific gravity of the ziway town soil ranges from 2.4-2.62.

5.1.2. Grain size analysis

Table 5.2. Summary of grain size analysis result

Serial no	Designation	Depth(meter)	Percent amount of particle size (%)			
			Gravel	Sand	Silt	Clay
1	TP-1	@ 0.6m	5.1	36.7	50.1	8.1
2	TP-2	@0.6m	0	44.1	48	7.8

TP-1(Total mass=500g)

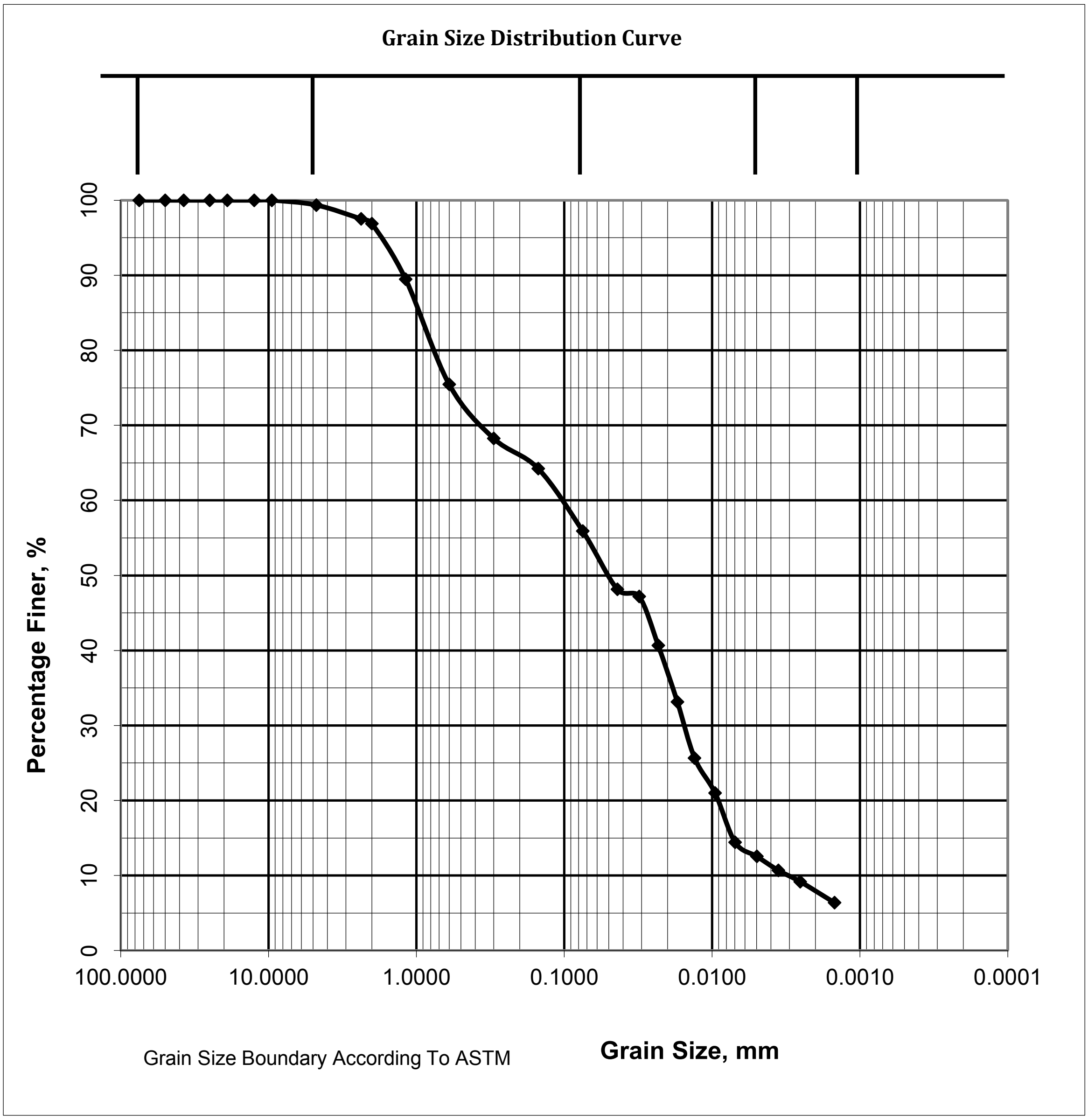


Figure 5.1: Combined sieve analysis curve for TP-1

TP-2(Total mass=500g)

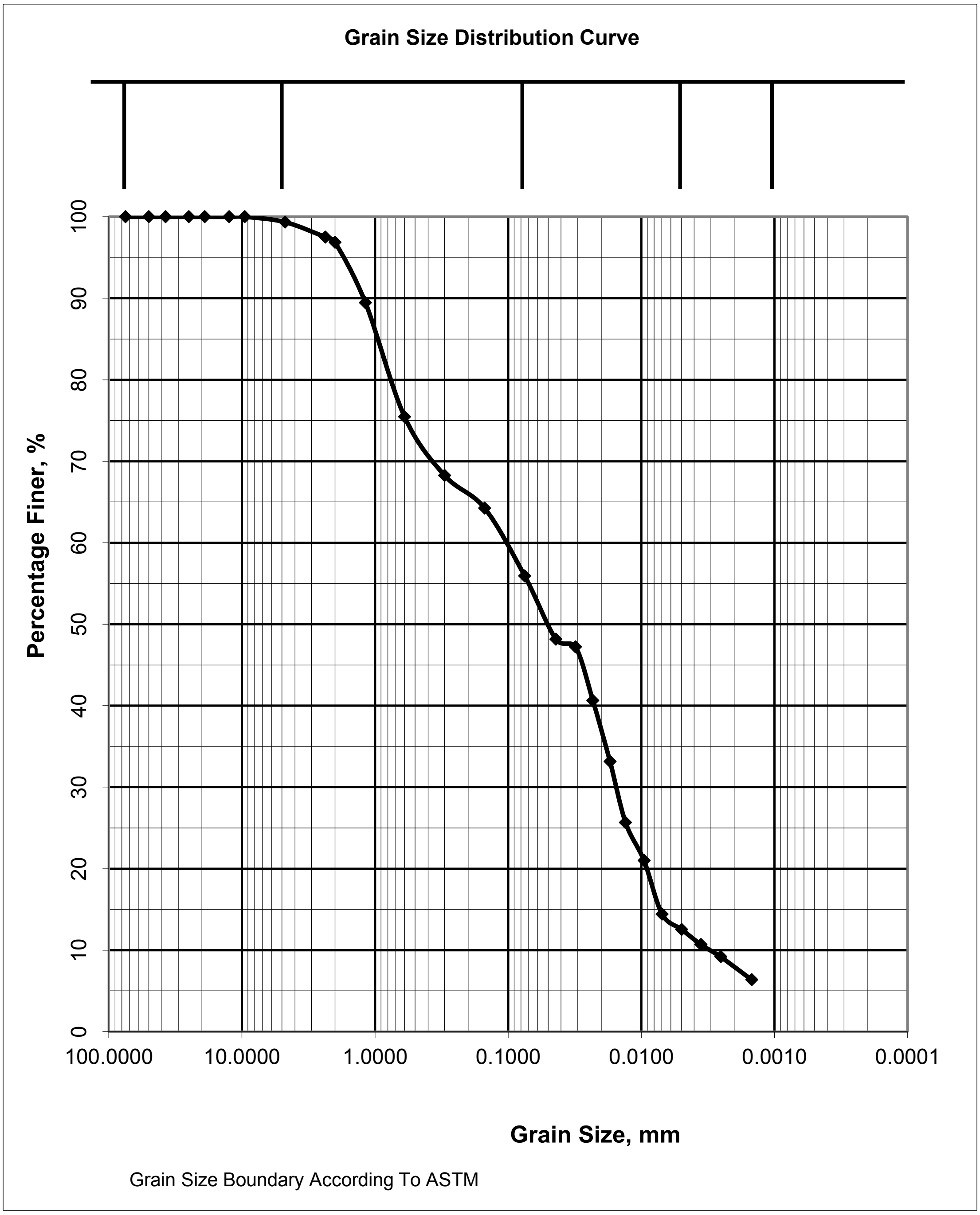


Figure 5.2: Combined sieve analysis curve for TP-2

5.1.3. Atterberg´s limit test results and analysis

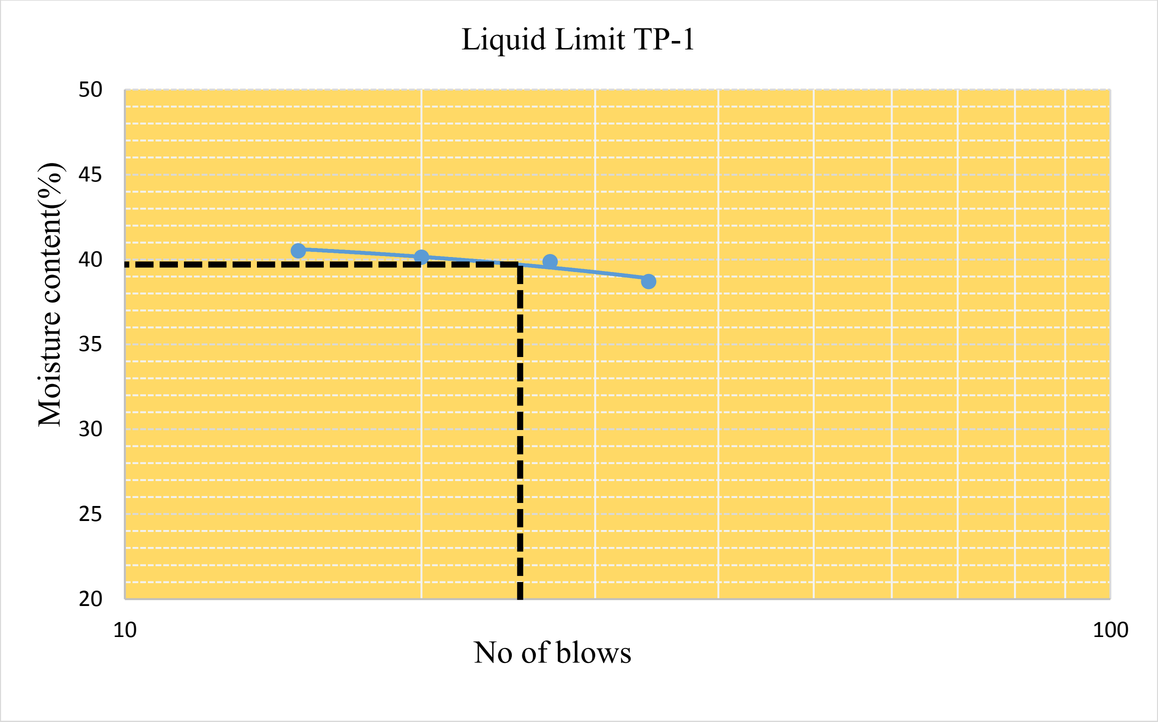


Figure 5.3: Flow curve for samples from TP-1

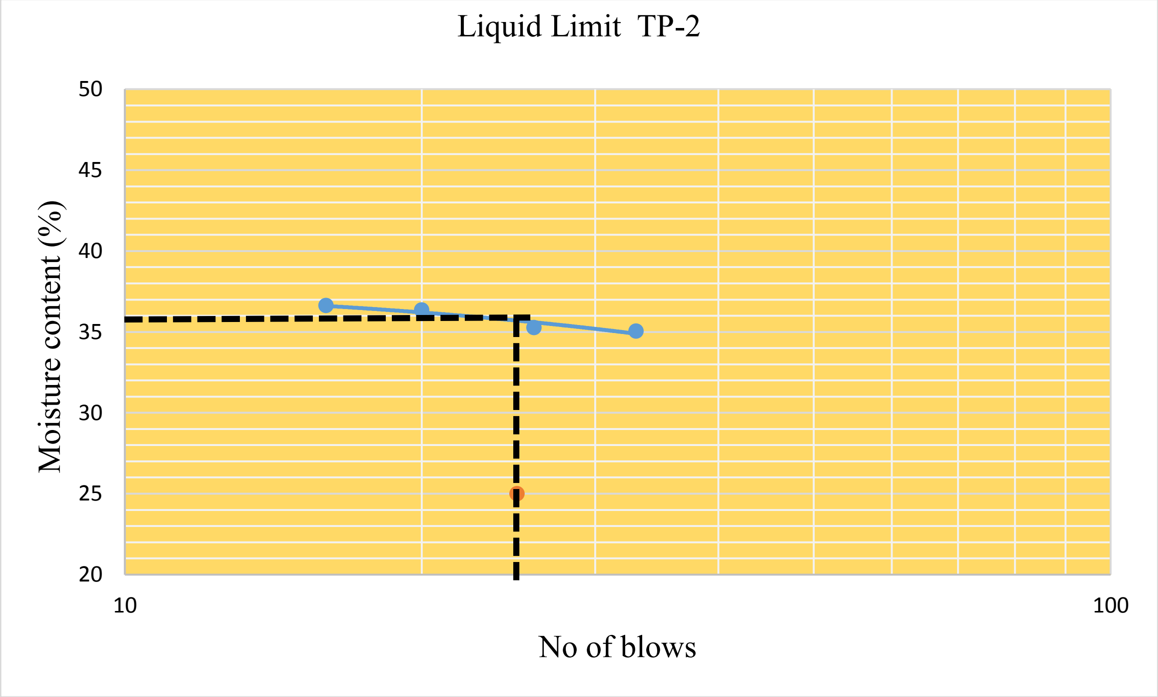


Figure 5.4: Flow curve for samples from TP-2

Table .5.3 Atterberg limits of the study area

Serial No	Designation number	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	TP-1	40	32	8
2	TP-2	36	27	9

5.2. Compaction test results of natural soil

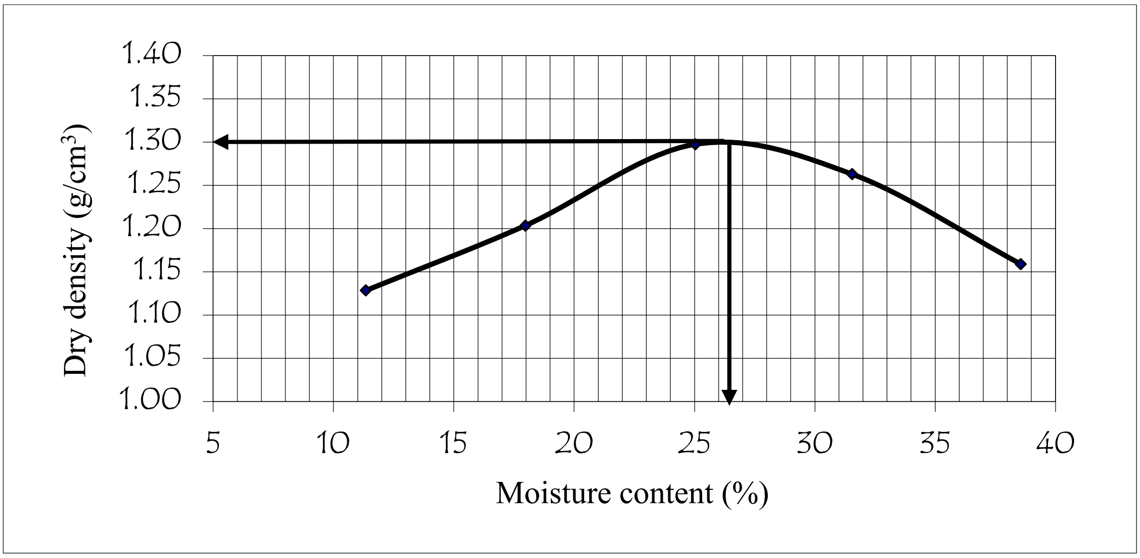


Figure 5.5: Compaction curve for TP-1(MDD=1.3 g/cm3 and OMC=26.5%)

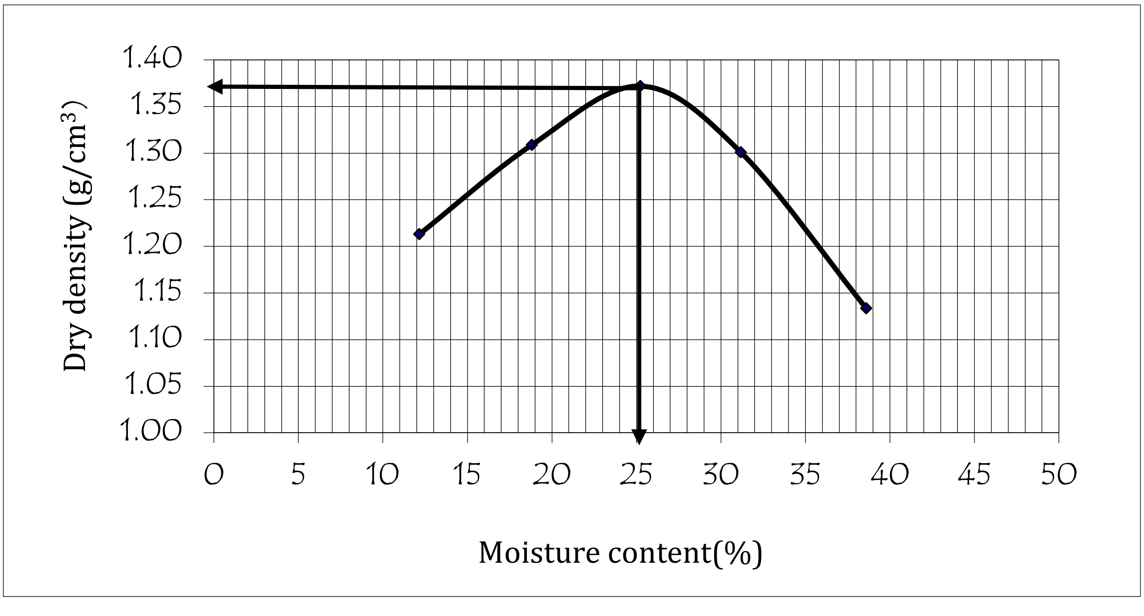


Figure 5.6: Compaction curve for TP-2 (MDD=1.37 g/cm3 and OMC=25%)

Table 5.4 Summary of maximum dry density and optimum moisture content

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.3	26.5
TP-2	1.37	25

5.3. Compaction test results on reinforced soil samples

Compaction tests on reinforced soil samples was done by varying a certain lengths and percentages of bamboo. Figures below shows the laboratory test results on MDD and OMC of the reinforced soil at different length and percentages.

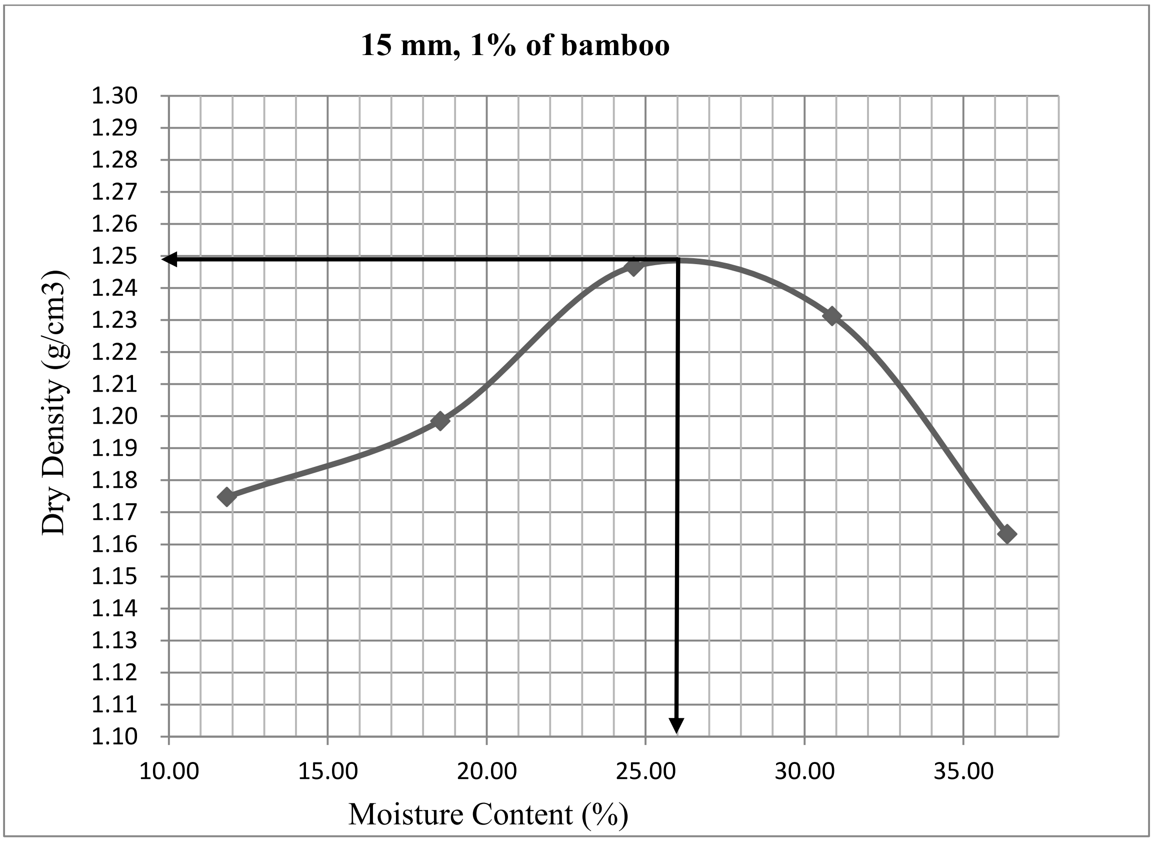


Figure 5.7: Compaction curve for length 15mm and 1% of bamboo

Table 5.5 Summary of compaction results for 15mm, 1% of bamboo

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.249	26

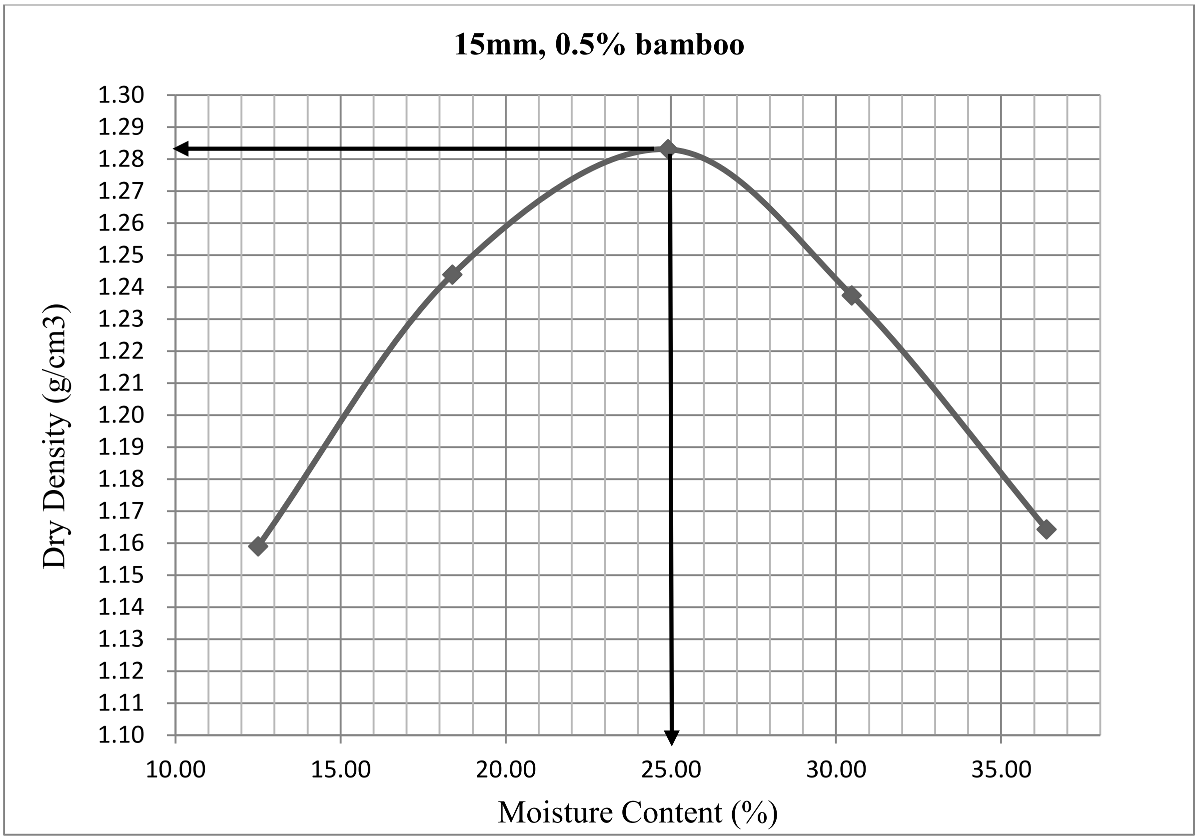


Figure 5.8: Compaction curve for length 15mm and 0.5% of bamboo

Table 5.6 Summary of compaction results for 15mm, 0.5% of bamboo

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.283	25

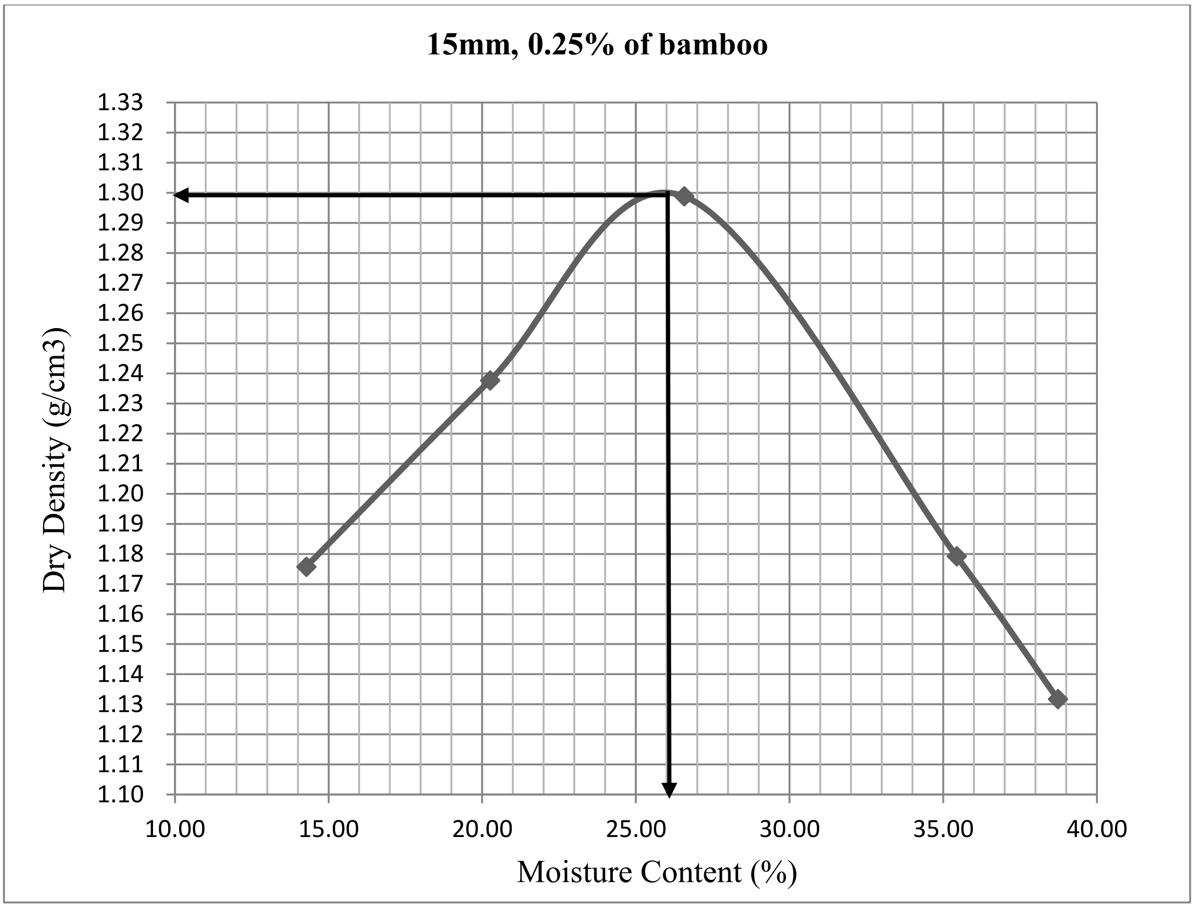


Figure 5.9: Compaction curve for length 15mm and 0.25% of bamboo

Table 5.7 Summary of compaction results for 15mm, 0.25% of bamboo

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.299	26

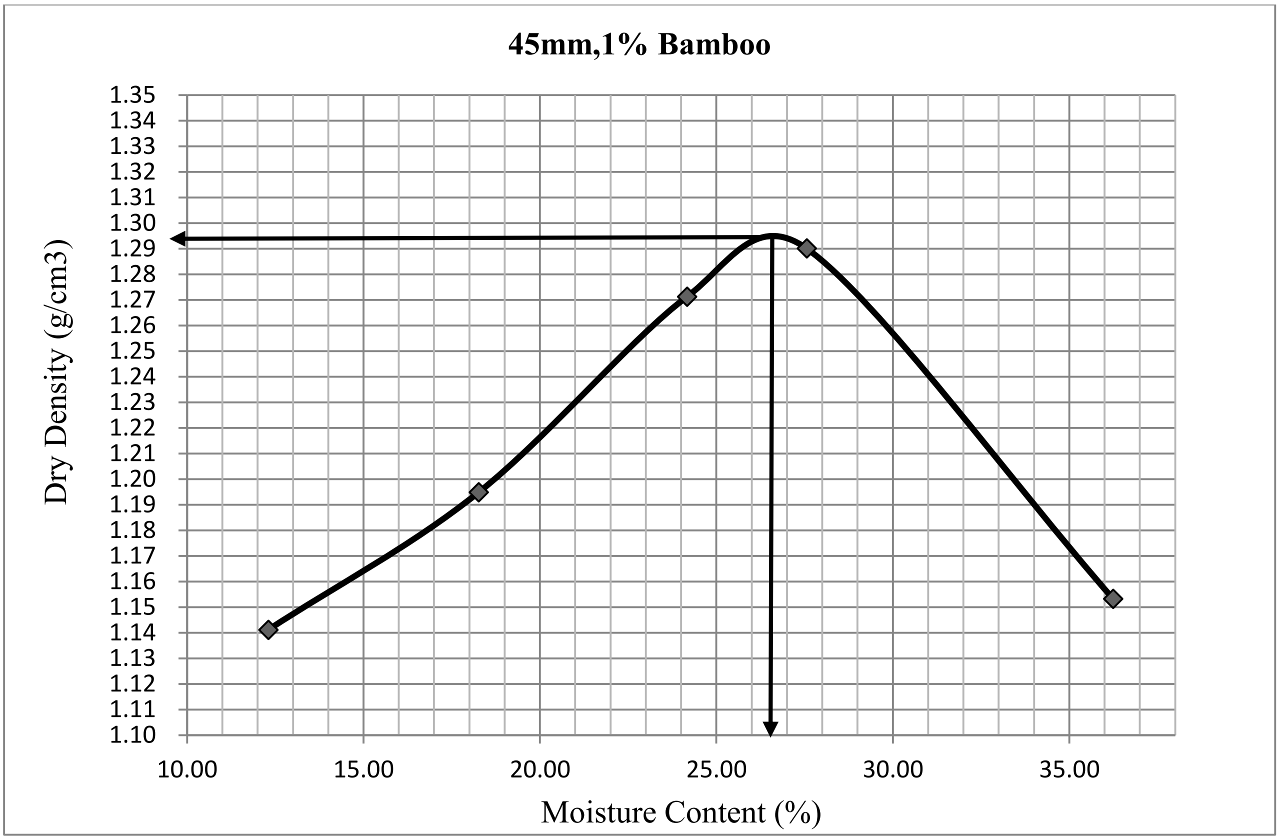


Figure 5.10: Compaction curve for length 45mm, 1% Bamboo

Table 5.8 Summary of compaction results for 45mm, 1% of bamboo

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.294	26.6

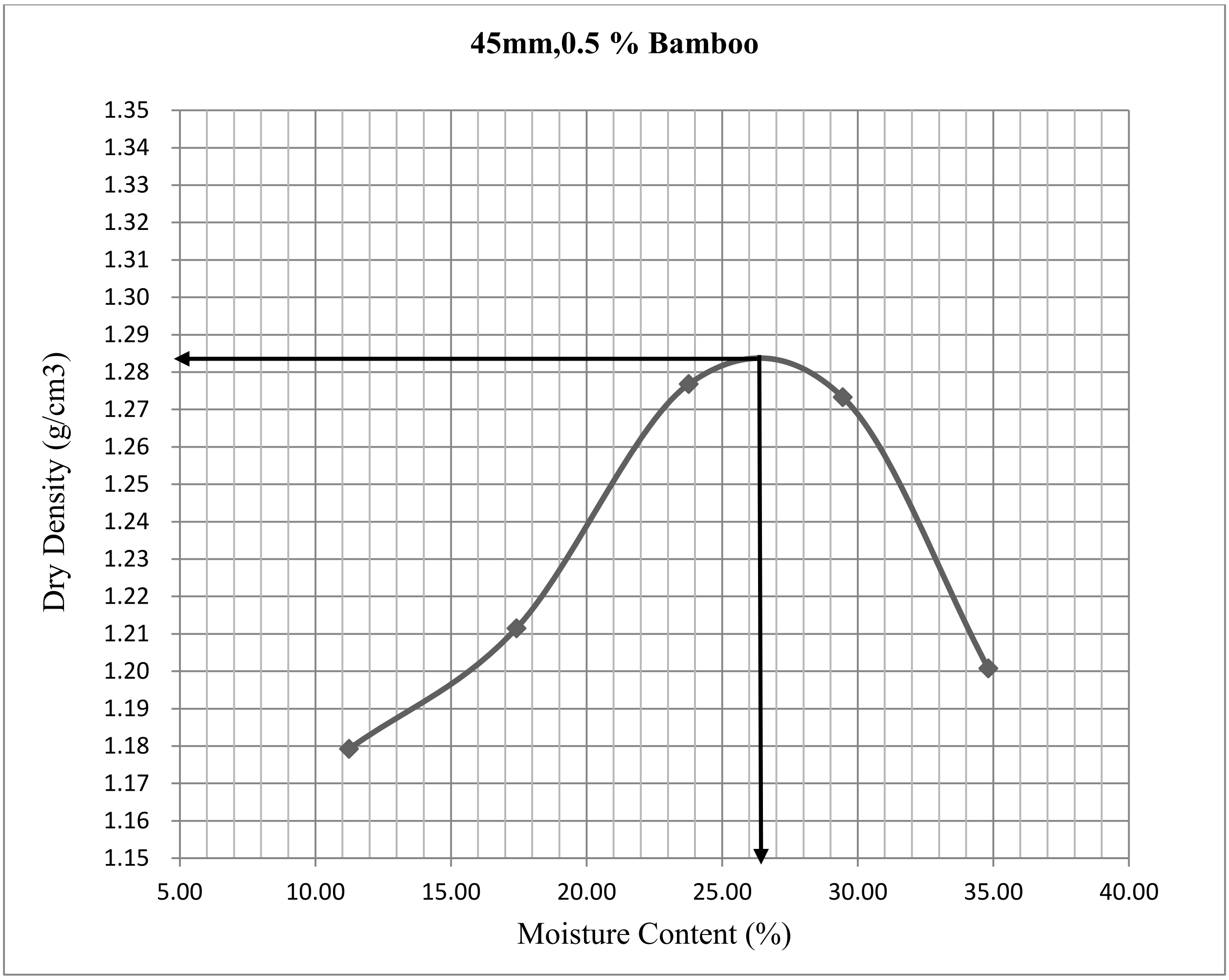


Figure 5.11: Compaction curve for length 45mm, 0.5 % Bamboo

Table 5.9 Summary of compaction results for 45mm, 0.5% of bamboo

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.282	26.4

5.4. Direct shear test results on natural soil samples

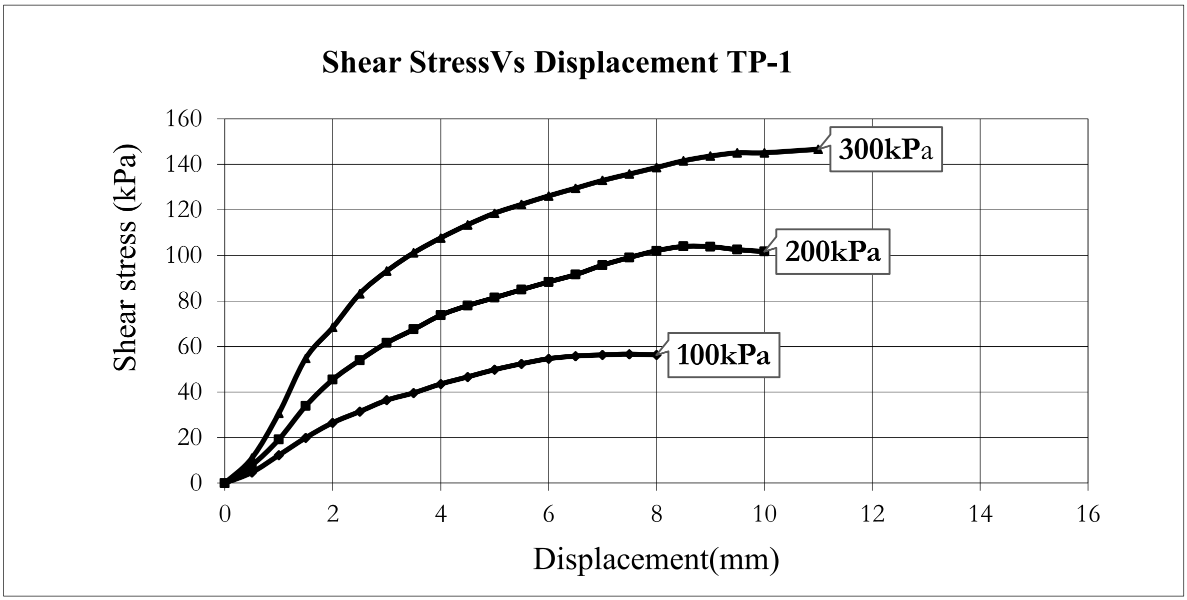


Figure 5.12: Shear stress versus displacement for different normal stress (TP-1)

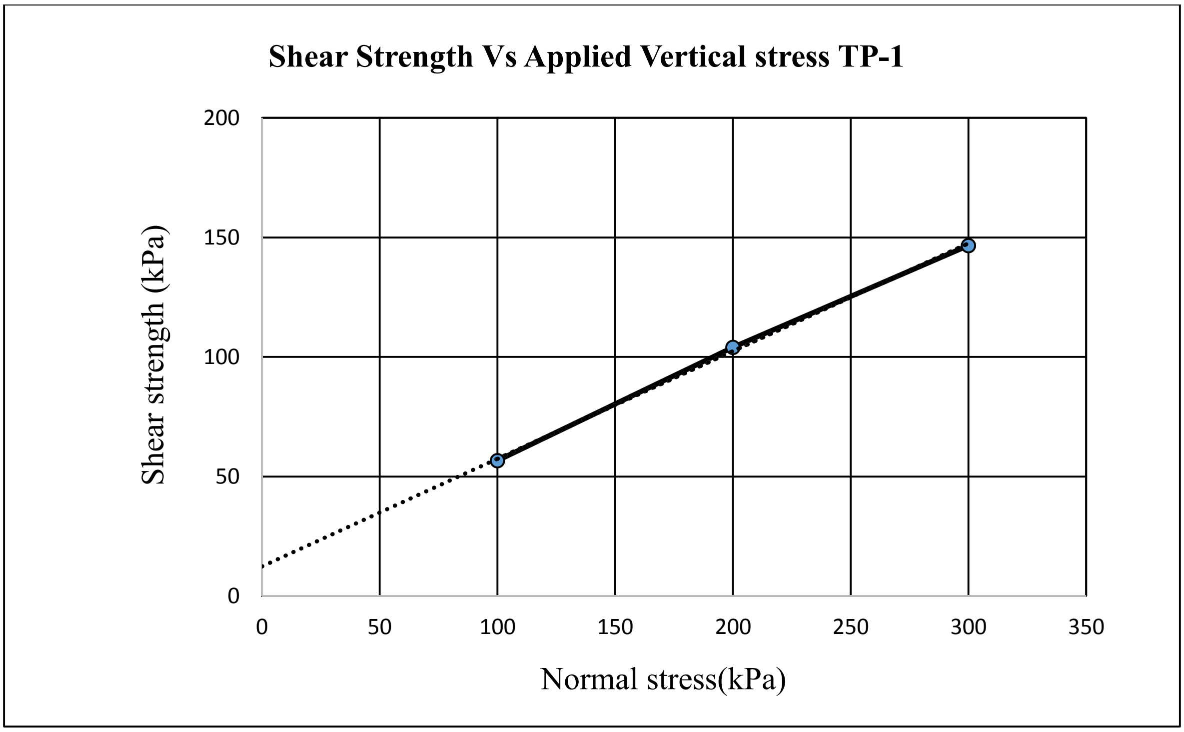


Figure 5.13: Shear strength versus applied vertical stress (TP-1)

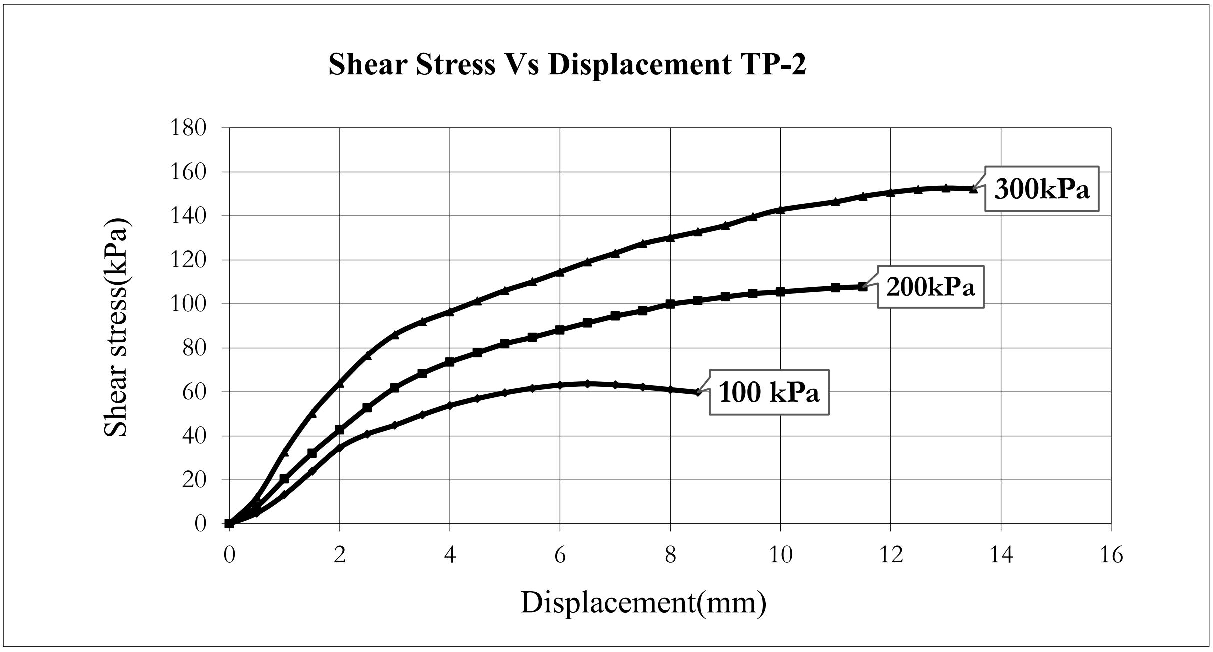


Figure 5.14: Shear stress versus displacement for different normal stress (TP-2)

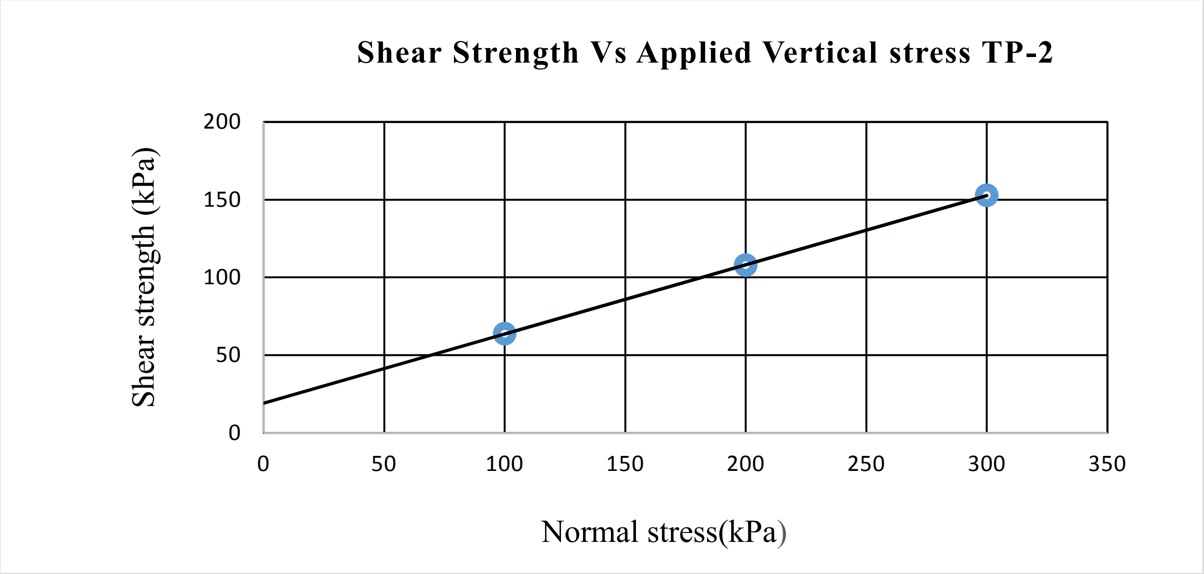


Figure 5.15: Shear strength versus applied vertical stress (TP-2)

Table 5.10 Summary of direct shear results

Serial no	designation	Depth (m)	Cohesion (C) in (kPa)	Angle of internal friction (Ø)in deg.
1	TP-1	@0.6m	12.4	24.2
2	TP-2	@0.6m	19	24

5.5. Direct shear test results and analysis on reinforced soil sample

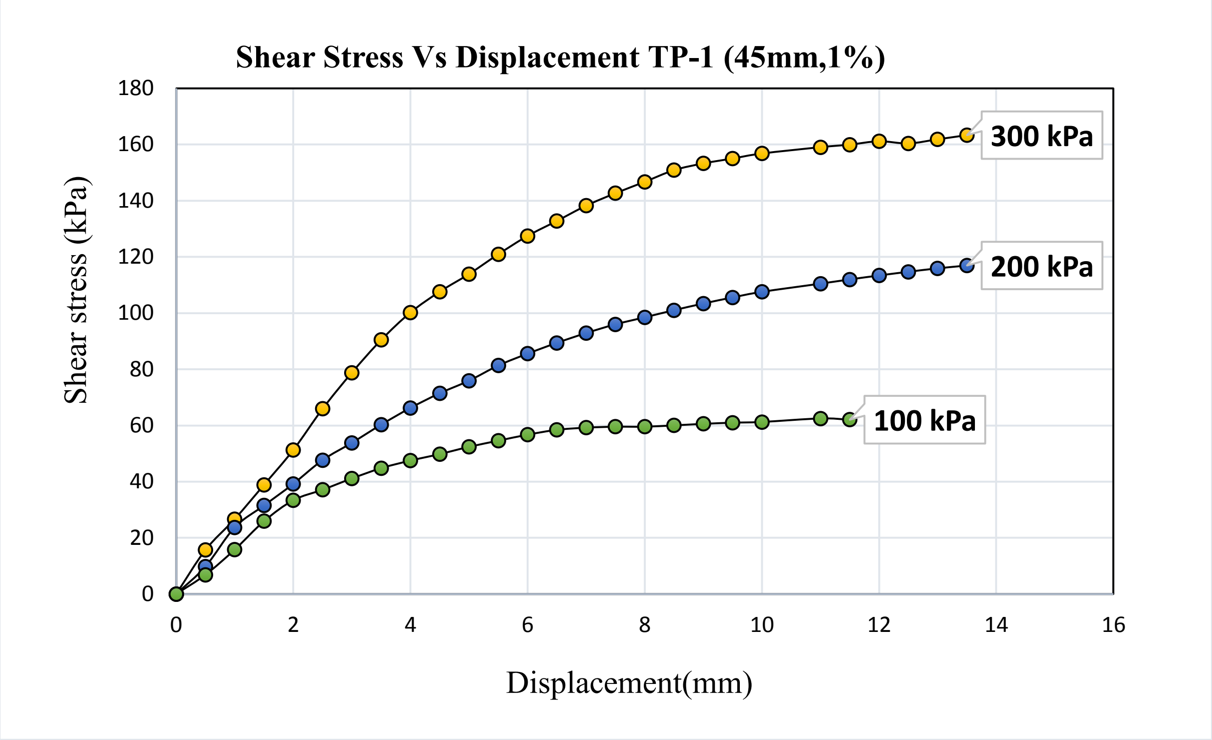


Figure 5.16: Shear stress versus displacement for different normal stresss

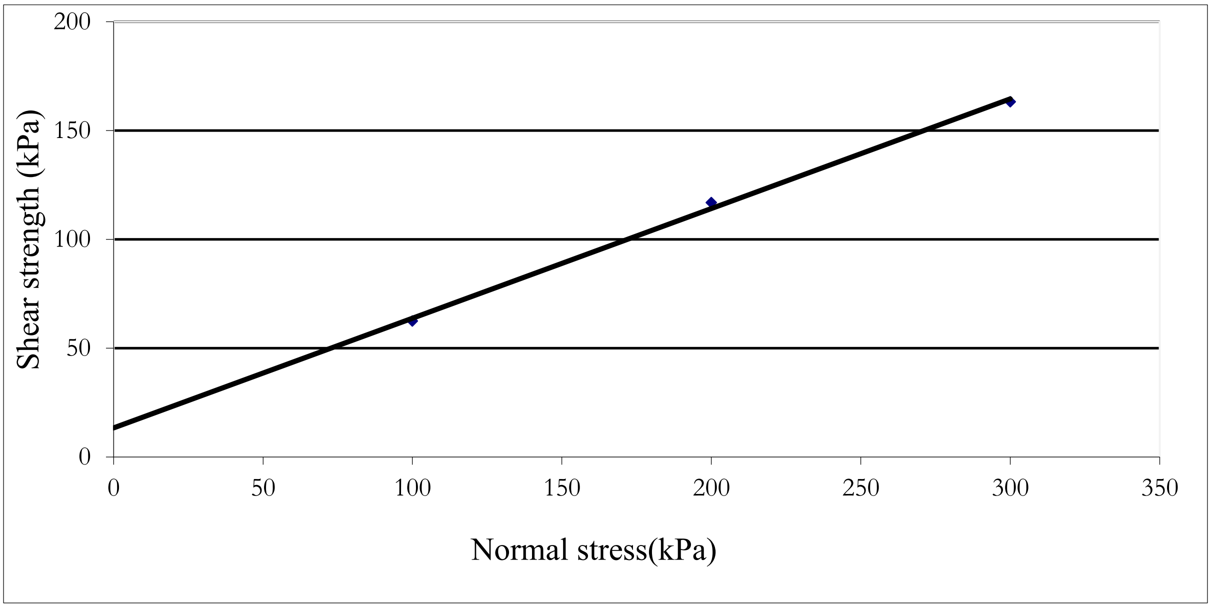


Figure 5.17: Shear strength versus applied vertical stress (45mm, 1%)

Angle of internal friction, Ø=	26.65^0	Cohesion , C (kN/m^2) =	13.4

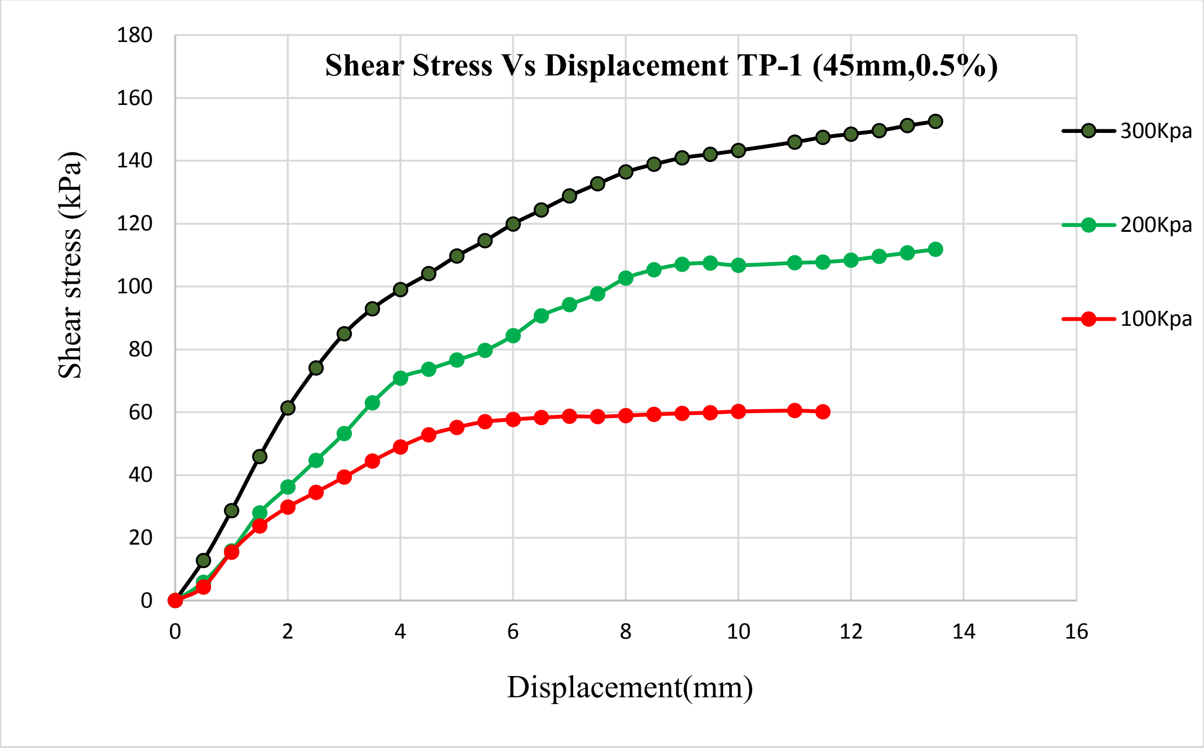


Figure 5.18: Shear stress versus displacement for different normal stress

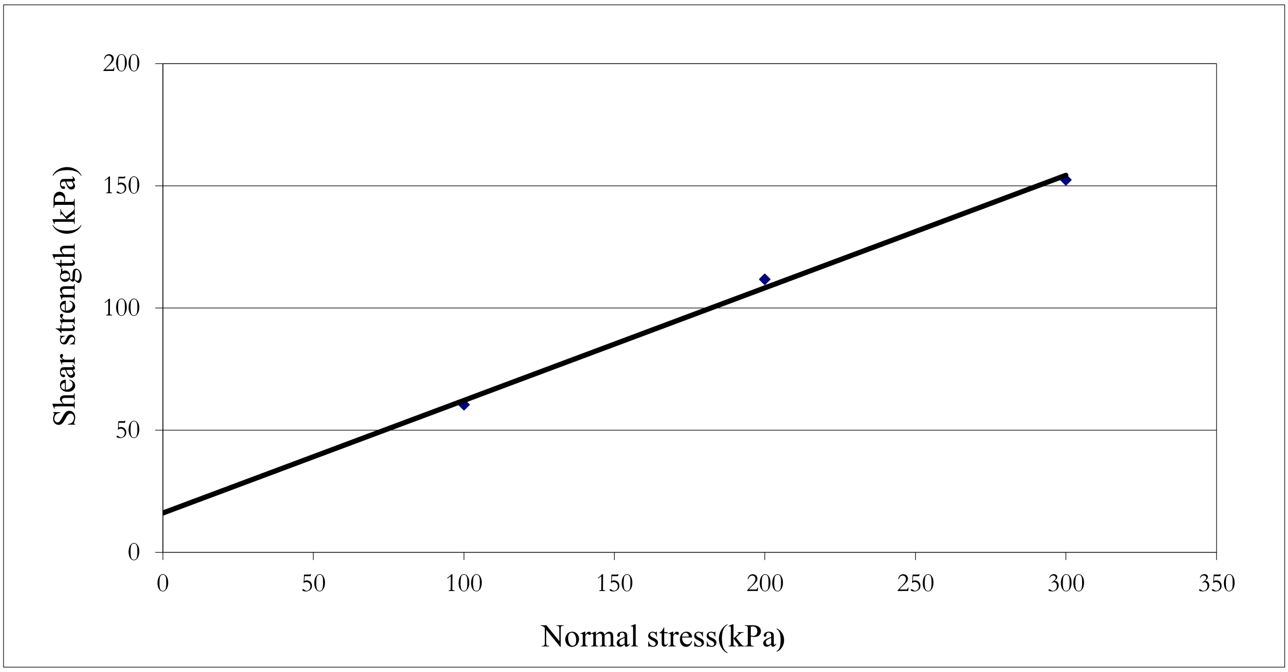


Table 5.19: Shear strength versus applied vertical stress (45mm, 0.5%)

Angle of internal friction, Ø=	24.46^0	Cohesion , C (kN/m^2) =	16

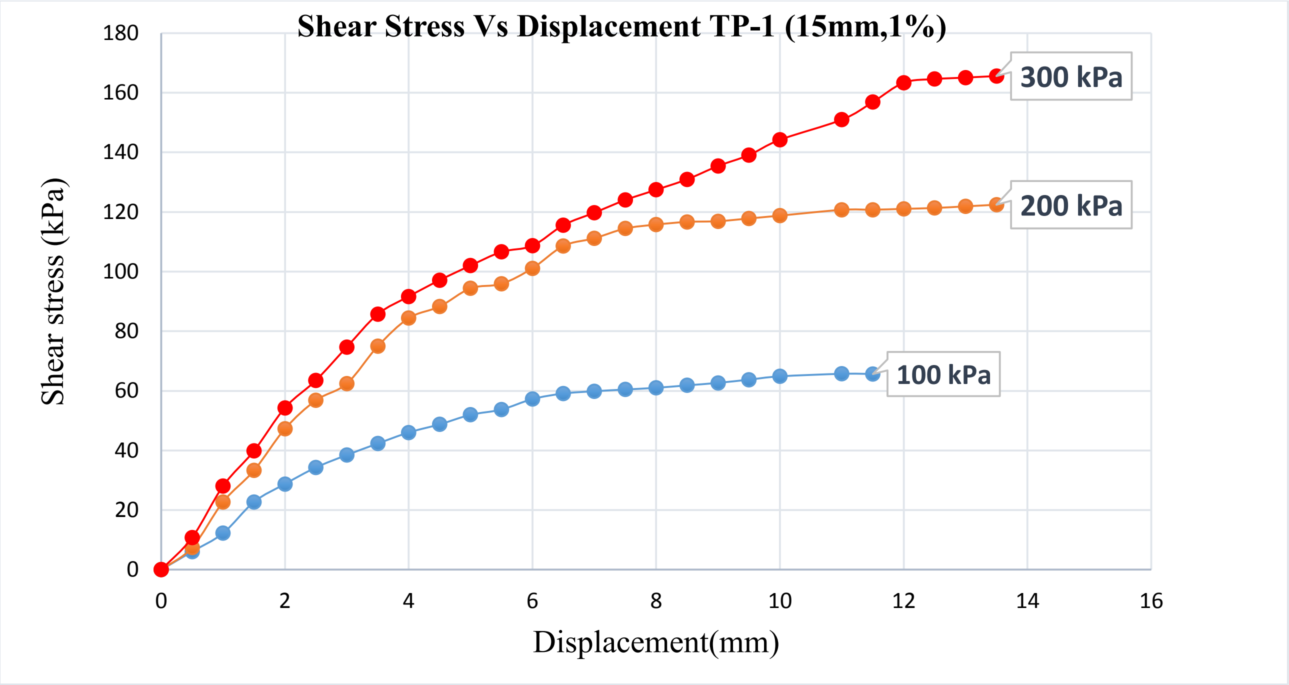


Figure 5.20: Shear stress versus displacement for different normal stress

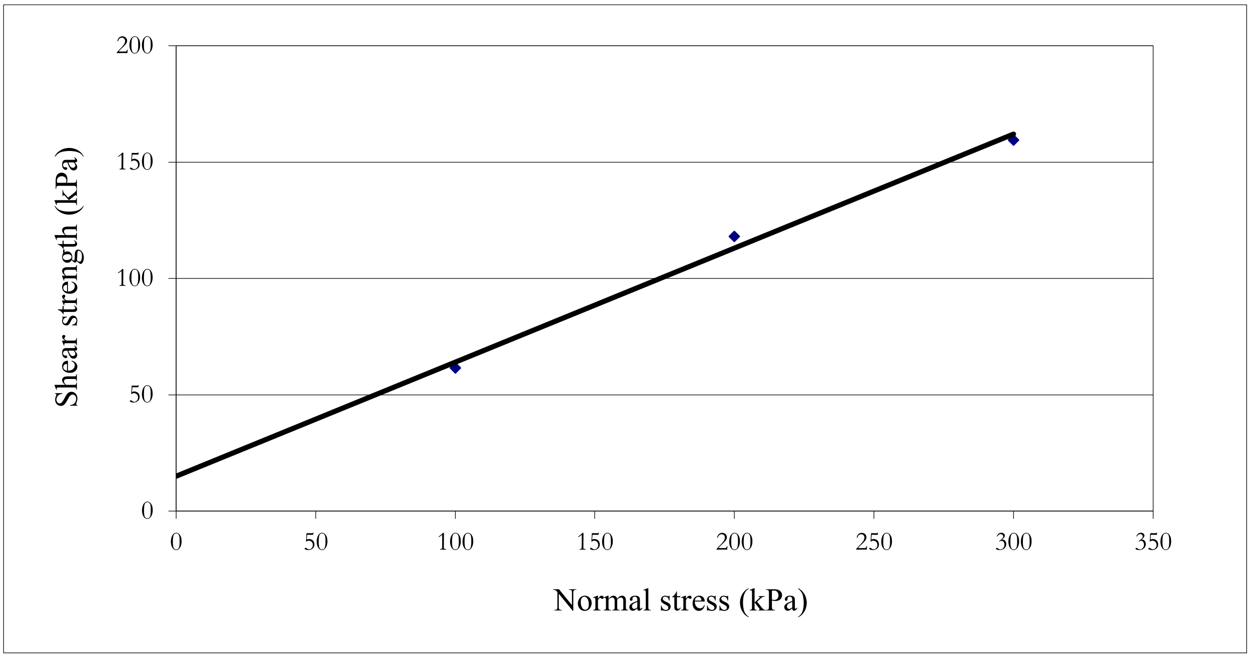


Figure 5.21: Shear strength versus applied vertical stress (15mm, and 1%)

Angle of internal friction, Ø=	26.3^0		Cohesion , C (kN/m^2) =	18

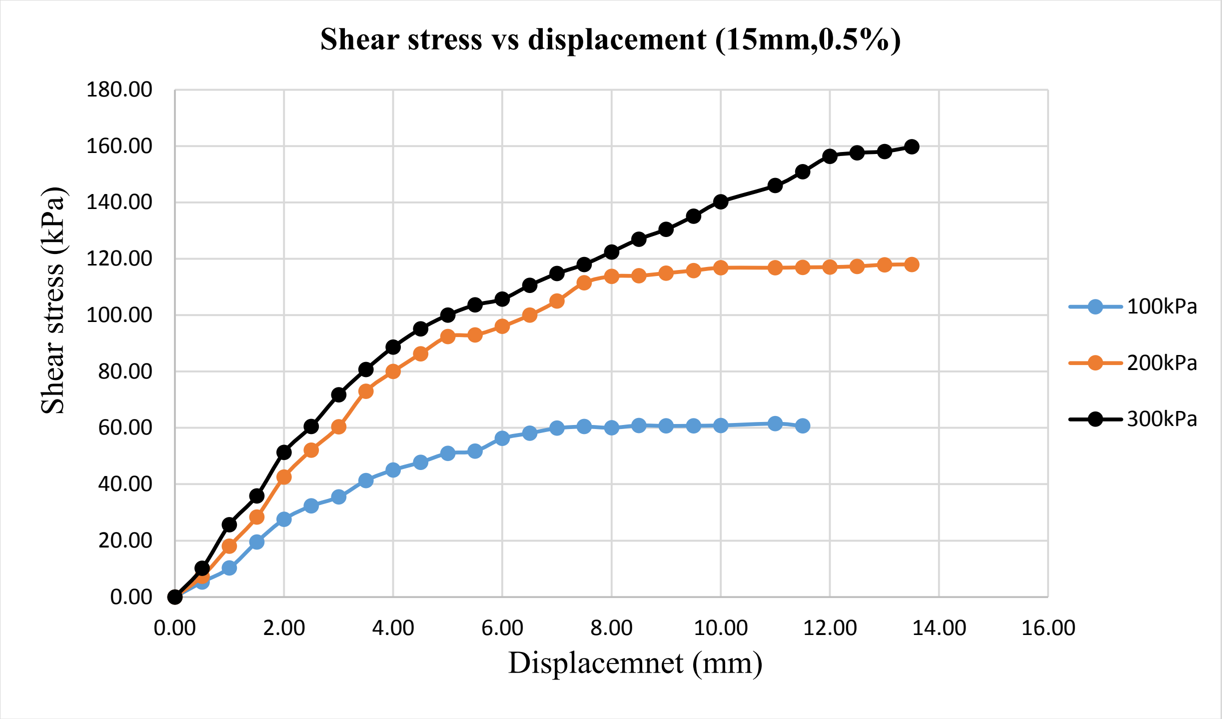


Figure 5.22: Shear stress versus displacement for different normal stress (15mm, 0.5%)

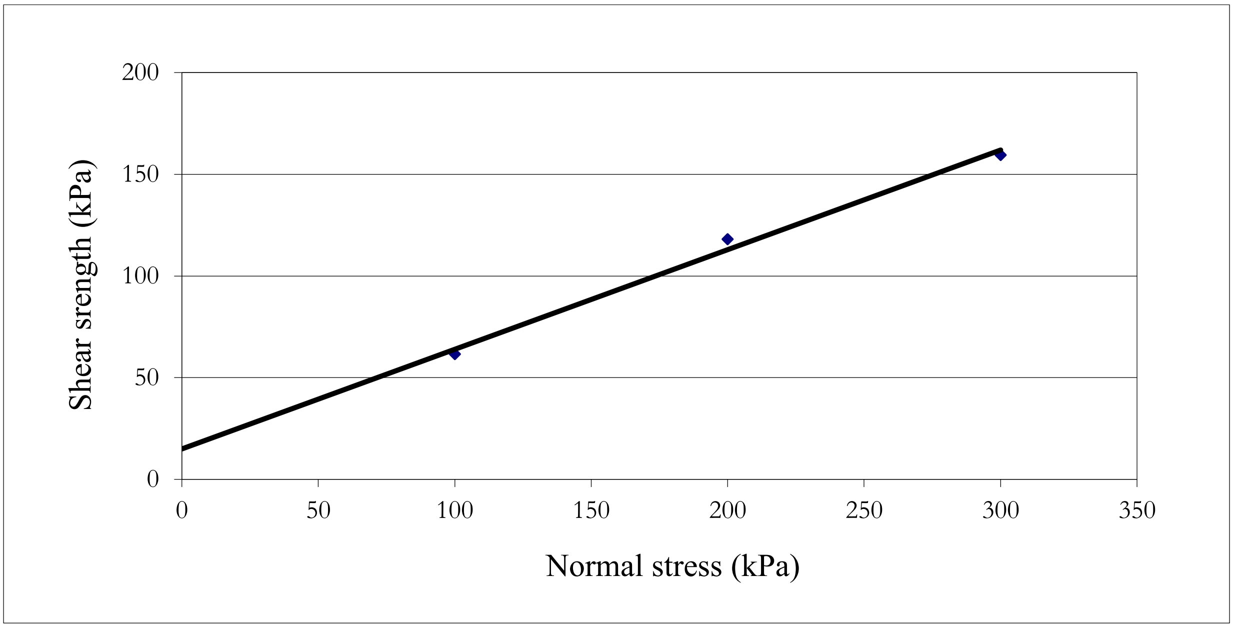


Figure 5.23: Shear strength versus applied vertical stress (15mm, and 0.5%)

Angle of internal friction, Ø=	26.1^0		Cohesion , C (kN/m^2) =	15

5.6. California bearing ratio (1-point CBR) test results for natural soil sample

Table 5.11 Un-soaked CBR

Blow/ Layer:	=56/5	OMC:	26.5
CBR Value, %	**=7.97**	Max. Dry Density:	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	6.0	153	0.08		
1.27	17.9	456	0.24		
1.91	28.0	713	0.37		
2.54	41.8	1064	0.55	6.9	7.97
3.81	53.7	1367	0.71		
5.08	59.7	1519	0.79	10.3	7.66
7.62	83.6	2127	1.10		
10.16	119.4	3039	1.57		
12.70	155.2	3950	2.04		

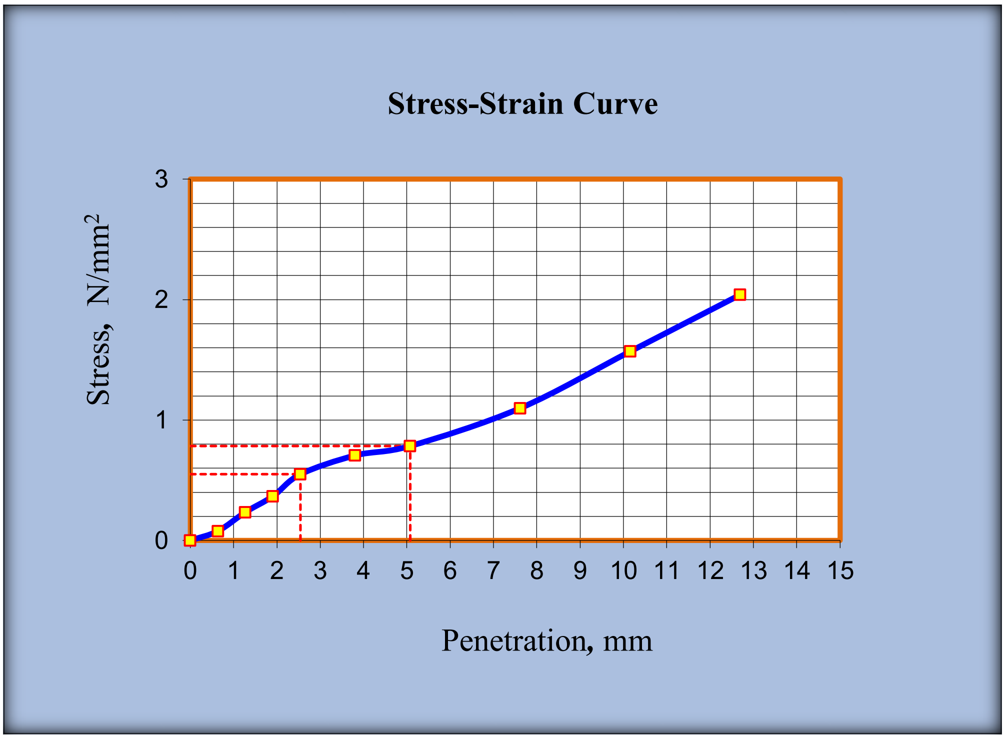


Figure 5.24: Stress-strain curve (un-soaked CBR)

Table 5.12 Soaked CBR

Blow/ Layer:	56/5	OMC:	26.5
CBR Value, % =	**5.52**	Max. Dry Density:	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	6.0	153	0.08		
1.27	11.9	304	0.16		
1.91	17.9	456	0.24		
2.54	26.9	684	0.36	6.9	5.52
3.81	29.9	760	0.39		
5.08	38.8	987	0.51	10.3	5.0
7.62	47.8	1215	0.63		
10.16	65.7	1671	0.86		
12.70	83.6	2127	1.10		

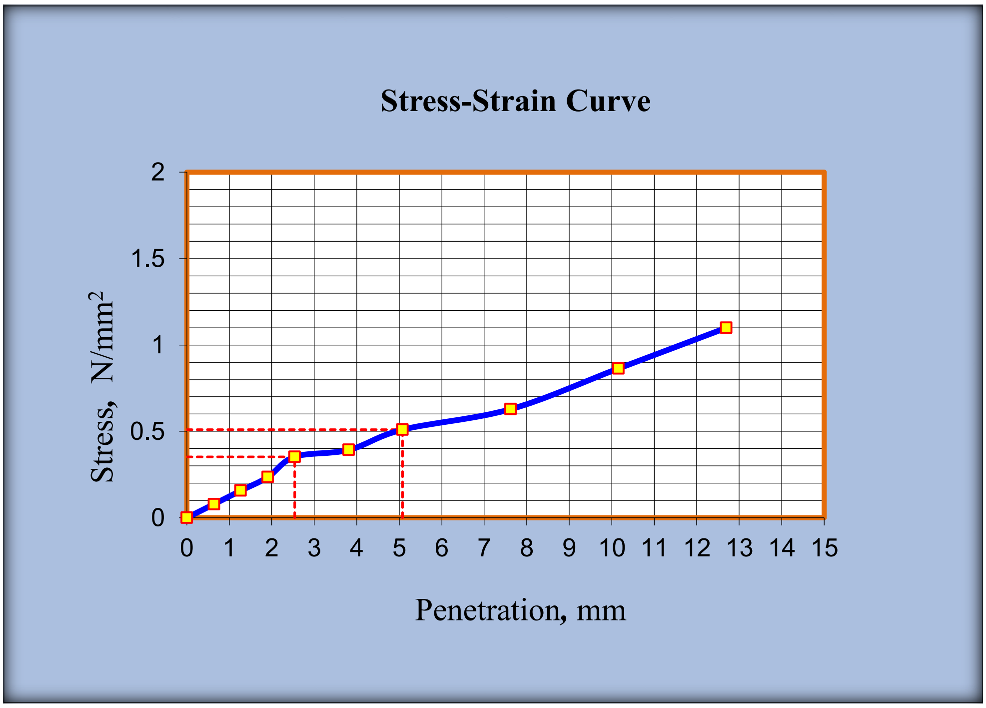


Figure 5.25: Stress-strain curve (soaked CBR)

5.5.3 California bearing ratio (CBR) test results on reinforced soil sample (soaked)

Table 5.13 CBR (0.5%,15mm)

Blow/ Layer:	56/5		OMC:	26.5	
CBR Value, % =	**7.68**		Max. Dry Density:	1.3	

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	11.2	284	0.15		
1.27	22.4	571	0.29		
1.91	33.6	855	0.44		
2.54	40.3	1025	0.53	6.9	7.68
3.81	51.5	1311	0.68		
5.08	56.0	1424	0.74	10.3	7.14
7.62	71.6	1823	0.94		
10.16	100.7	2563	1.32		
12.70	123.2	3134	1.62		

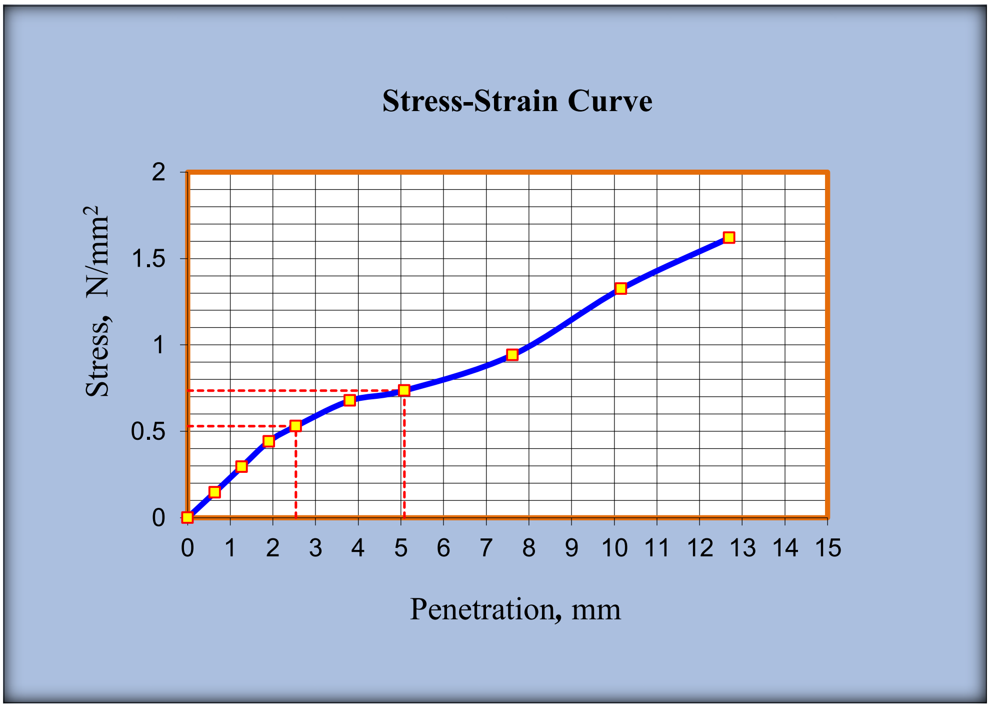


Figure 5.26: Stress-strain curve (0.5%, 15mm)

Table 5.14 CBR (0.5%,30mm)

Blow/ Layer:	56/5	OMC:	26.5
CBR Value, % =	**9.47**	Max. Dry Density:	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	11.8	300	0.16		
1.27	27.9	710	0.37		
1.91	34.6	881	0.46		
2.54	49.7	1265	0.65	6.9	9.47
3.81	66.3	1687	0.87		
5.08	73.5	1871	0.97	10.3	9.39
7.62	80.0	2036	1.05		
10.16	114.9	2924	1.51		
12.70	142.5	3627	1.87		

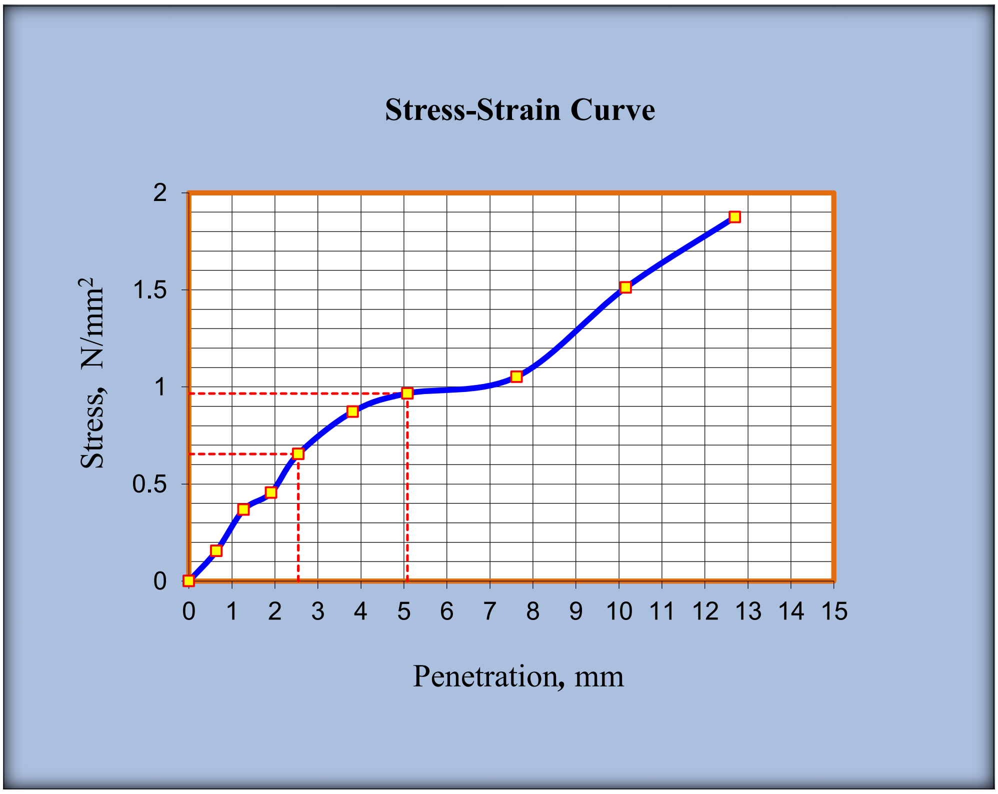


Figure 5.27: Stress-strain curve (0.5%, 30mm)

Table 5.15 CBR (0.5%,45mm)

Blow/ Layer:	56/5	OMC:	26.5
CBR Value, % =	**11.76**	Max. Dry Density:	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	12.4	316	0.16		
1.27	31.8	809	0.42		
1.91	40.8	1038	0.54		
2.54	61.7	1570	0.81	6.9	11.76
3.81	70.6	1797	0.93		
5.08	84.0	2138	1.10	10.3	10.73
7.62	96.0	2443	1.26		
10.16	121.4	3090	1.60		
12.70	160.2	4077	2.11		

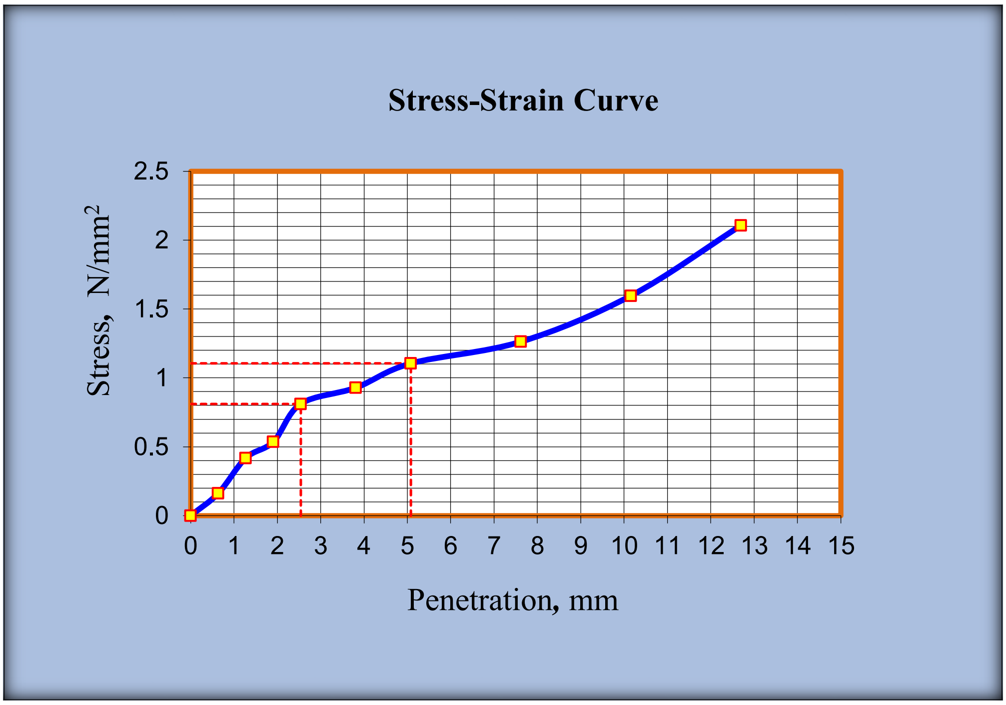


Figure 5.28: Stress-strain curve (0.5%, 45mm)

Table 5.16 CBR(1%,15mm)

Blow/ Layer:	56/5	OMC:	26.5
CBR Value, % =	**14.12**	Max. Dry Density:	1.3

Penetration. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	23.7	603	0.31		
1.27	45.4	1154	0.60		
1.91	60.9	1549	0.80		
2.54	74.1	1885	0.97	6.9	14.12
3.81	95.5	2431	1.26		
5.08	108.6	2765	1.43	10.3	13.87
7.62	139.7	3555	1.84		
10.16	187.4	4770	2.47		
12.70	234.0	5956	3.08		

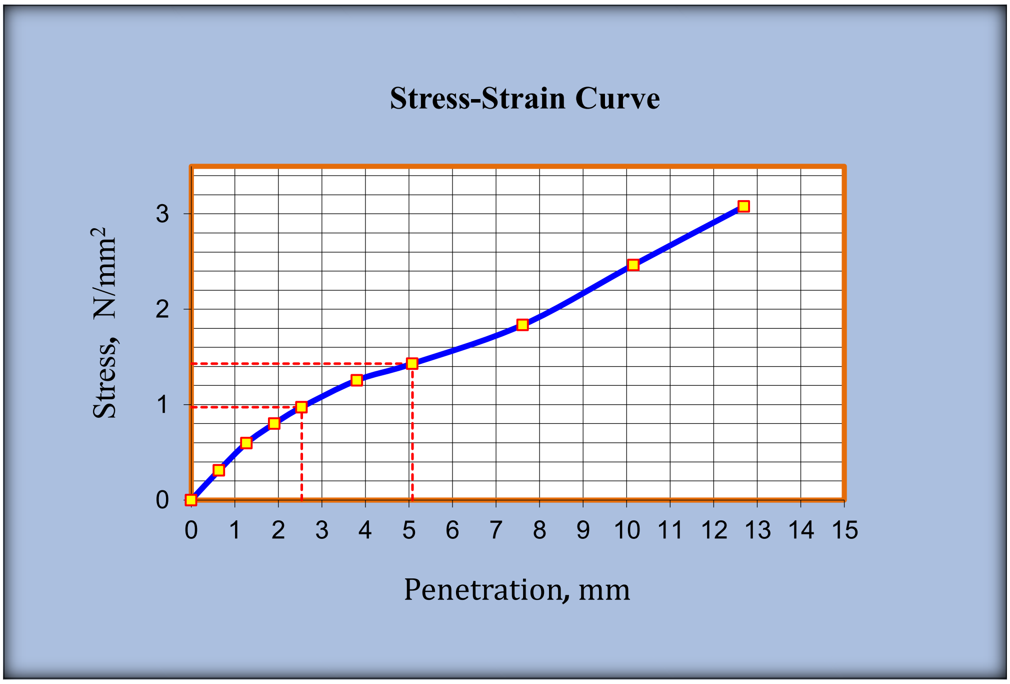


Figure 5.29: Stress-strain curve (1%, 15mm)

Table 5.17 CBR (1%,30mm)

Blow/ Layer	56/5	OMC:	26.5
CBR Value, % =	**14.69**	Max. Dry Density	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	21.5	547	0.28		
1.27	48.4	1231	0.64		
1.91	68.0	1732	0.89		
2.54	77.0	1961	1.01	6.9	14.69
3.81	93.1	2370	1.22		
5.08	112.8	2871	1.48	10.3	14.40
7.62	139.7	3555	1.84		
10.16	179.1	4558	2.36		
12.70	225.7	5743	2.97		

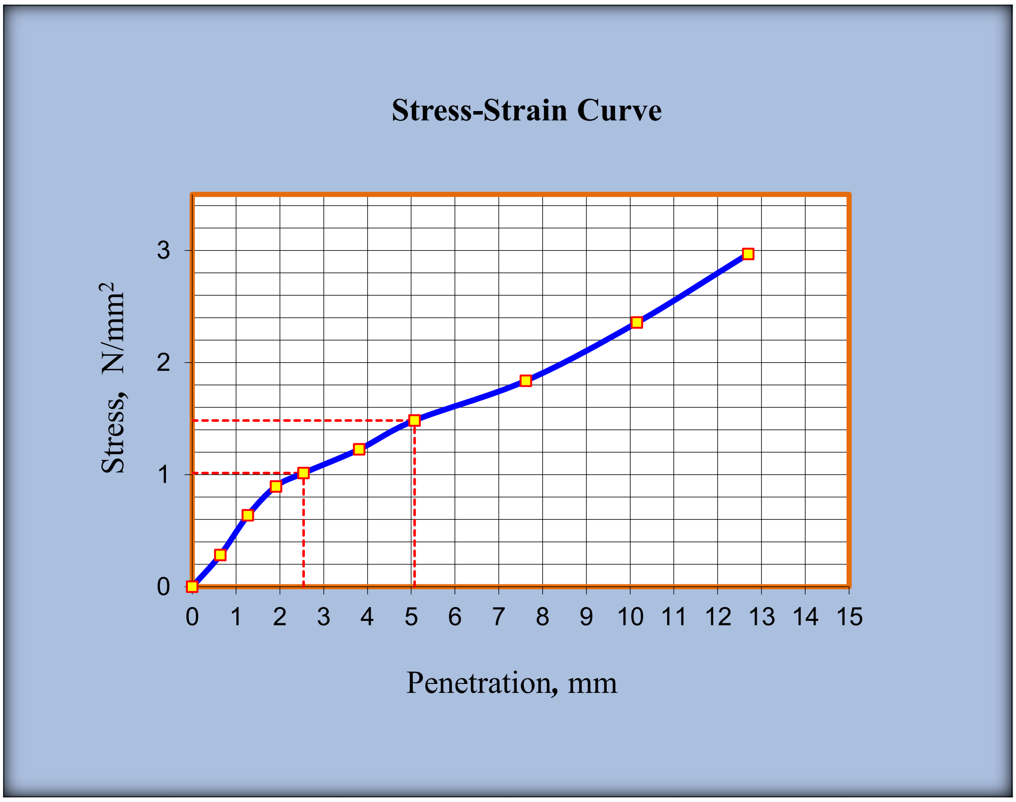


Figure 5.30: Stress-strain curve (1%, 30mm)

Table 5.18 CBR(1%,45mm)

Blow/ Layer:	56/5	OMC:	26.5
CBR Value, % =	**17.75**	Max. Dry Density:	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	28.6	729	0.38		
1.27	53.7	1367	0.71		
1.91	76.4	1944	1.00		
2.54	93.1	2370	1.22	6.9	17.75
3.81	109.8	2795	1.44		
5.08	136.1	3464	1.79	10.3	17.38
7.62	152.8	3889	2.01		
10.16	199.4	5075	2.62		
12.70	244.8	6229	3.22		

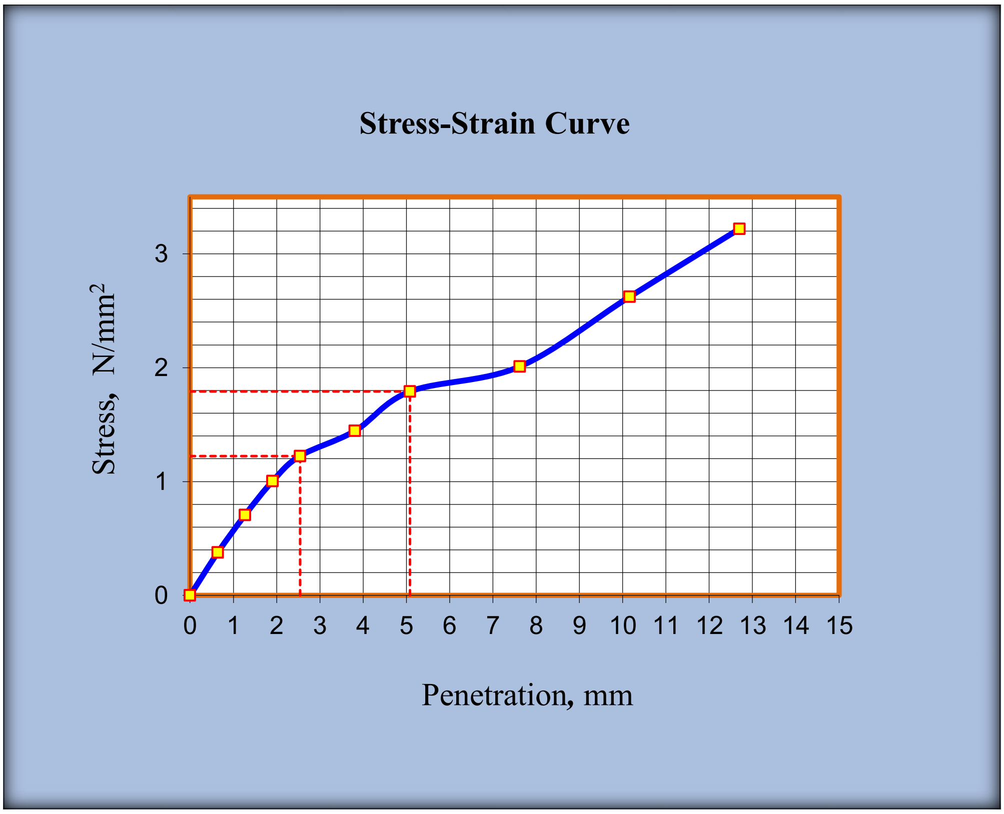


Figure 5.31: Stress-strain curve (1%, 45mm)

CHAPTER 6: TEST RESULTS AND DISCUSSIONS

6.1 Index properties and soil classifications

The soils under investigation have been classified according to USCS and AASHTO. These methods are among the widely used classification systems in our country.

6.1.1. Unified soil classification system (USCS)

Grain size analysis of the two samples revealed that more than 50% from each samples pass the No 200 sieve. They are classified as fine-grained soils and are sub divided based on their Atterberg limit values. By making use of laboratory determined liquid limit and plasticity indexes for a soil sample the proper group of the soil for the as received condition has been made by use of the plasticity chart, or A- line diagram, as illustrated by Figure: 4.1. Within the depth of exploration, the specific gravity of the soil was 2.48 for both samples. These values are low because the soils are light weighted. Grain size analysis tests on samples revealed that the soil is silt. In which for TP1 and TP2 clay content 8.1 and 7.8%, silt fraction 50.1 and 48%, sand fraction 36.7 and 44.1% and gravel content from 5.80 and 0% respectively. From the consistency limit test results, liquid limit are about 40% and 36 %for TP1 and TP2 respectively, plastic limit are about 32 and 27 % respectively and plastic index are 8% and 9% for TP1 and TP-2.

Table 6.1 Classification of soil sample according to USCS classification

Serial no	Designation	Depth (m)	Percent amount of particle size (%)				LL (%)	PL (%)	PI (%)	Classification According to USC
			Gravel	Sand	Silt	Clay				
1	TP-1	@0.6m	5.1	36.7	50.1	8.1	40	32	8	ML
2	TP-2	@0.6m	0	44.1	48	7.8	36	27	9	ML

Table 6.2 Comparison of index property Test Results in different parts of the country

Description	Thesis by Abu Gemechu, 2007	Thesis by Dagnachew,2011	Thesis by Beza Tesfaye 2015	Current thesis ,2017
Soil type	Silt & silty sand	Silt & silt sand	Silt, silty sand, sand-silt mixtures	TP-1 and TP-2 Silts
Location	Adama	Adama	Ziway	Ziway
Clay Content (%)	14-58	5.4 – 40.5	0.66-10.93	8.1 and 7.8
Silt fraction (%)	14-61	17.6-60.7	17.15-73.03	50.1 and 48
Sand fraction (%)	25-56	14.5-54.6	15.16-81.3	36.7 and 44.1
Liquid Limit (%)	39-49.4	29-73	27-37	40 and 36
Plastic limit (%)	26-37.4	24-39	23-29	32 and 27
Plasticity Index (%)	10-15	5-34	4-8	8 and 9
OMC (%)	25-30.5	17.5-36.5	22.6-35.83	26.5 and 25
Specific Gravity	2.61-2.7	2.4-2.7	2.4-2.62	2.48
MDD(g/cm3)	1.33-1.53	1.2-1.62	1.22-1.55	1.3 and 1.37
From plasticity chart	ML&SM	SM, ML, MH	SM & ML	ML

According to USC classification scheme the soil of the study area falls under silty soil. From the plot of plasticity chart in Figure 4.1 and the classification of soils of the two test pits fall under inorganic silts of medium compressibility (ML) and Figure 6.1.below shows that the two test pits are more or less similar in their classifications .Table 6.2 also shows that there is a considerable similarity in the physical properties of Adama and Ziway town soils. But Ziway soils show lower plasticity (clay content) as compared to Adama soil.

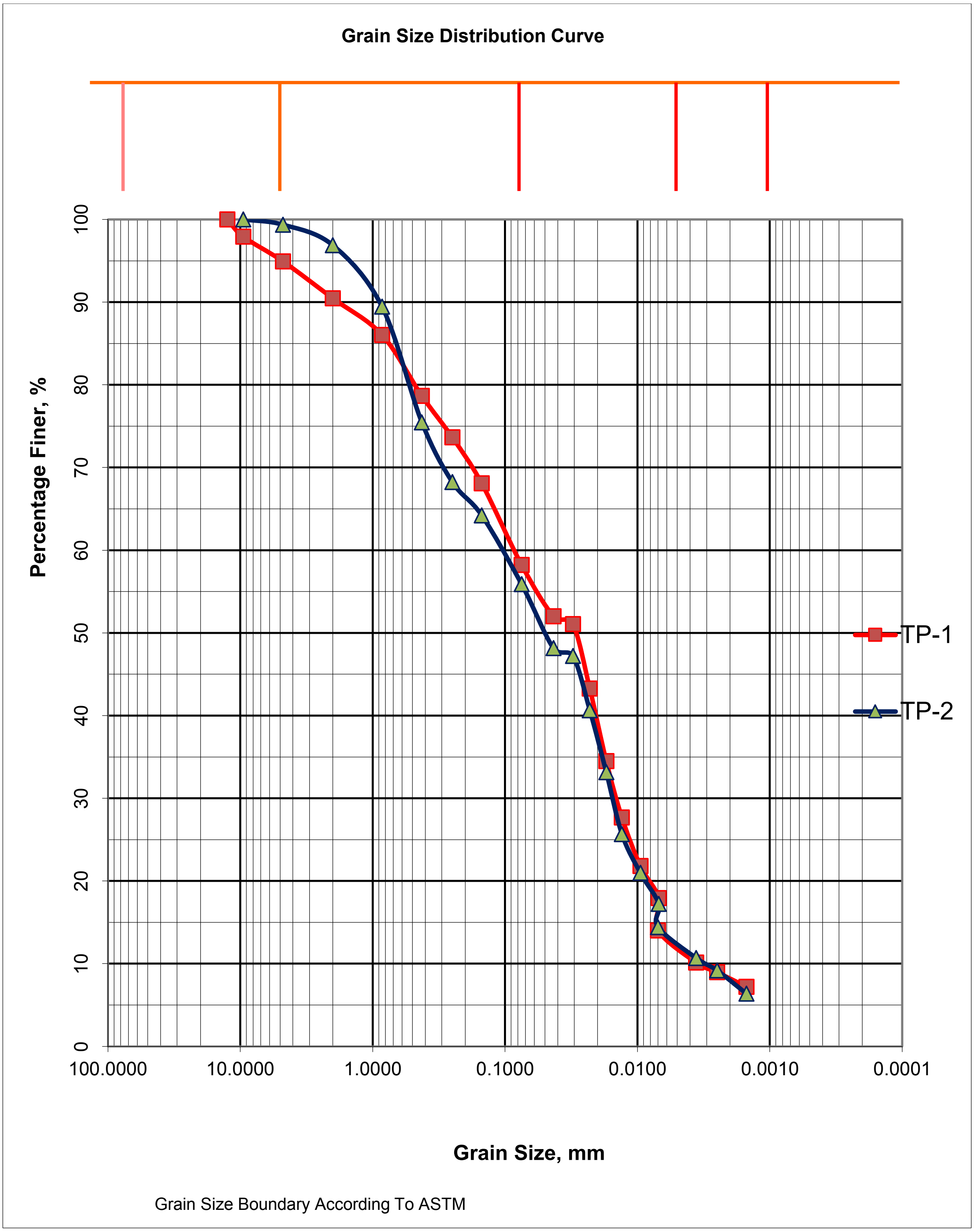
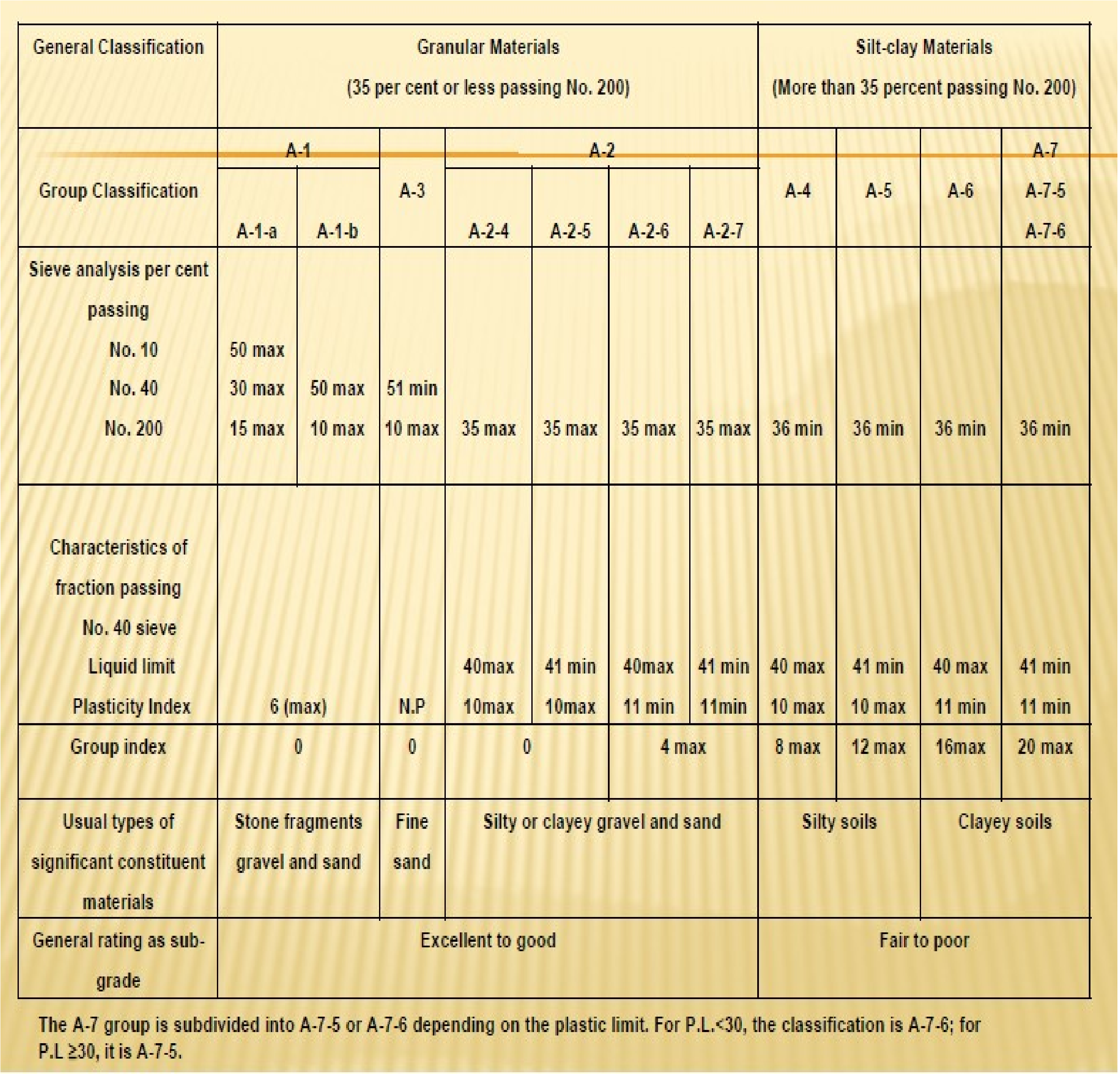


Figure 6.1: Combined grain size distribution curve for TP-1 and TP-2

6.1.2 Classifications of soils based on AASHTO Classification system

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 USCS.



General Classification	Granular Materials (35 per cent or less passing No. 200)							Silt-clay Materials (More than 35 percent passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7 A-7-5 A-7-6
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				
Sieve analysis per cent passing											
No. 10	50 max										
No. 40	30 max	50 max	51 min								
No. 200	15 max	10 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40 sieve											
Liquid limit				40max	41 min	40max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 (max)		N.P	10max	10max	11 min	11min	10 max	10 max	11 min	11 min
Group index	0		0	0		4 max		8 max	12 max	16max	20 max
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 sub-grade	Excellent to good							Fair to poor			

The A-7 group is subdivided into A-7-5 or A-7-6 depending on the plastic limit. For P.L.<30, the classification is A-7-6; for P.L ≥30, it is A-7-5.

Figure 6.2: AASHTO Classification for soil

6.1.3 Determination of Group Index (GI)

Group index (G.I):- is used to describe the performance of a soil when used as a highway subgrade material. It is not used to place the soil in a particular group, but is actually a means of rating the value of a soil as a subgrade material, within its own group.
For obtaining the GI of fine-grained soils, the following equation are used:

GI = (F200 - 35) [0.2 + 0.005(LL - 40)] + 0.01(F2oo - l5) (PI - 10).

If the GI comes out negative, round it off to zero. However, if it is positive, round it off to the nearest whole number.

For TP-1, GI= (58.12-35) [0.2+0.005(40-40)] +0.01(58.12-15) (8-10) =3.761=3%

For TP-2, GI= (55.7-35) [0.2+0.005(36-40)] + (0.01(55.7-15) (9-10) =3.319=3 % Where F200=percentage of soil finer than 200mm sieve.

LL=liquid limit and PI= plastic index.

The AASHTO system classifies soils into seven groups, A-1 through A-7-6. As per this system of soil classification, soils of Ziway town fall under A-4 with group index of

(GI=3%) with maximum of 8%

Table 6.3 Classifications of soils based on AASHTO Classification system

Serial No	Designation	Percent passing on sieve			LL (%)	PL (%)	PI (%)	Group index (%)	Group Classification tion	Usual type of significant constitute materials	General rating as subgrade materials
		No. 10	No. 40	No. 200							
1	TP-1	90.5	78.7	58.2	40	32	8	3	A-4	Silty soils	fair
2	TP-2	96.9	75.5	60	36	27	9	3	A-4	Silty soils	fair

According to AASHTO classification (Table 6.3 and Figure 6.2) the soil samples of the study areas falls under group classification A-4 which is silty soil and fair quality as a subgrade materials with a group index of 3.

6.2 Compaction test results and discussions

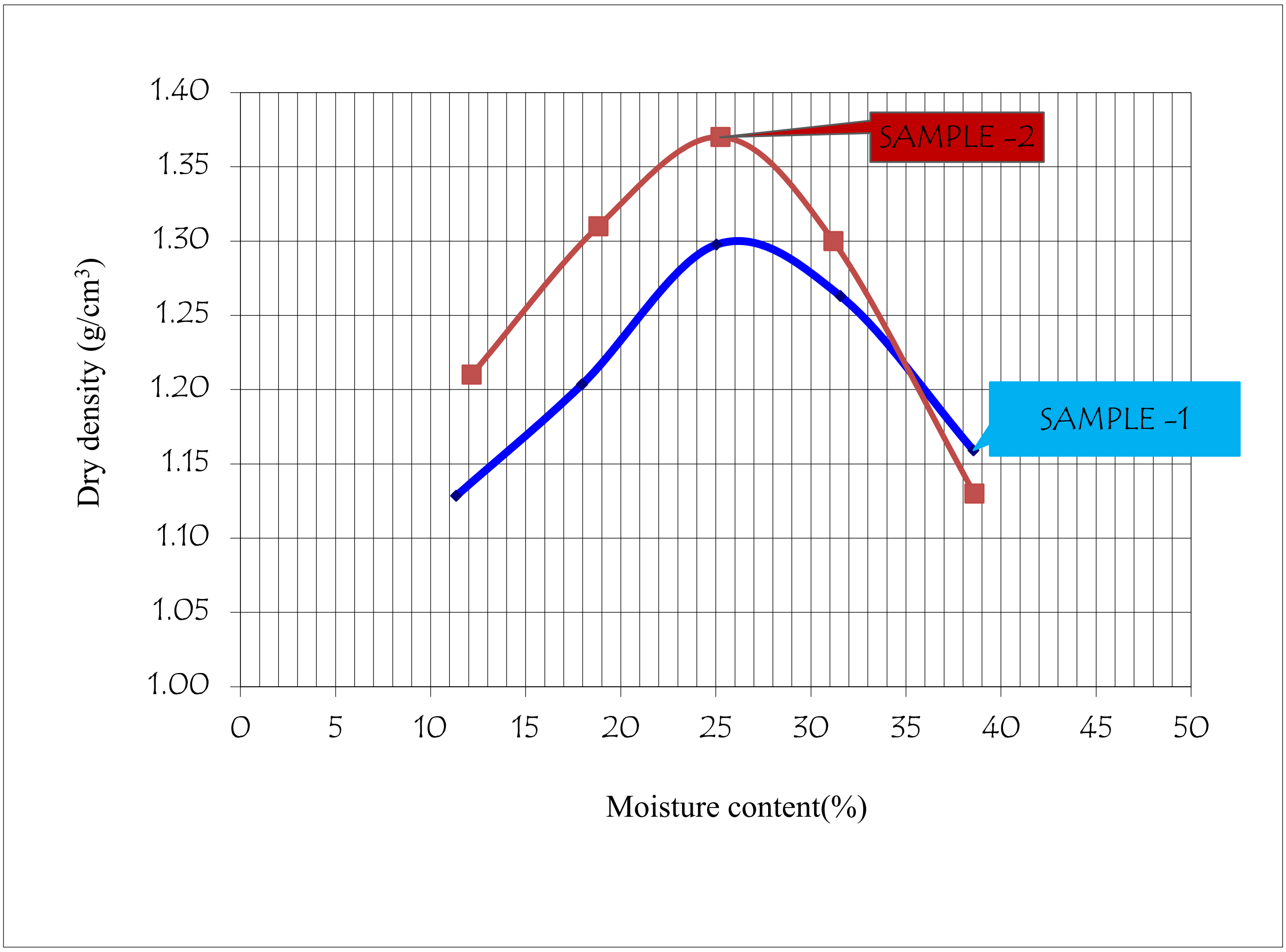


Figure 6.3: Combined compaction curves of both samples

Table 6.4 Comparison of maximum dry density and optimum moisture content

No of test pits	MDD(kN/m3)	OMC (%)
TP-1	1.3	26.5
TP-2	1.37	25

Natural soil compaction test results (Figure 6.3) shows that TP-2 has higher density and low optimum moisture content than TP-1 which shows test pit-2 are denser than test pit-1.

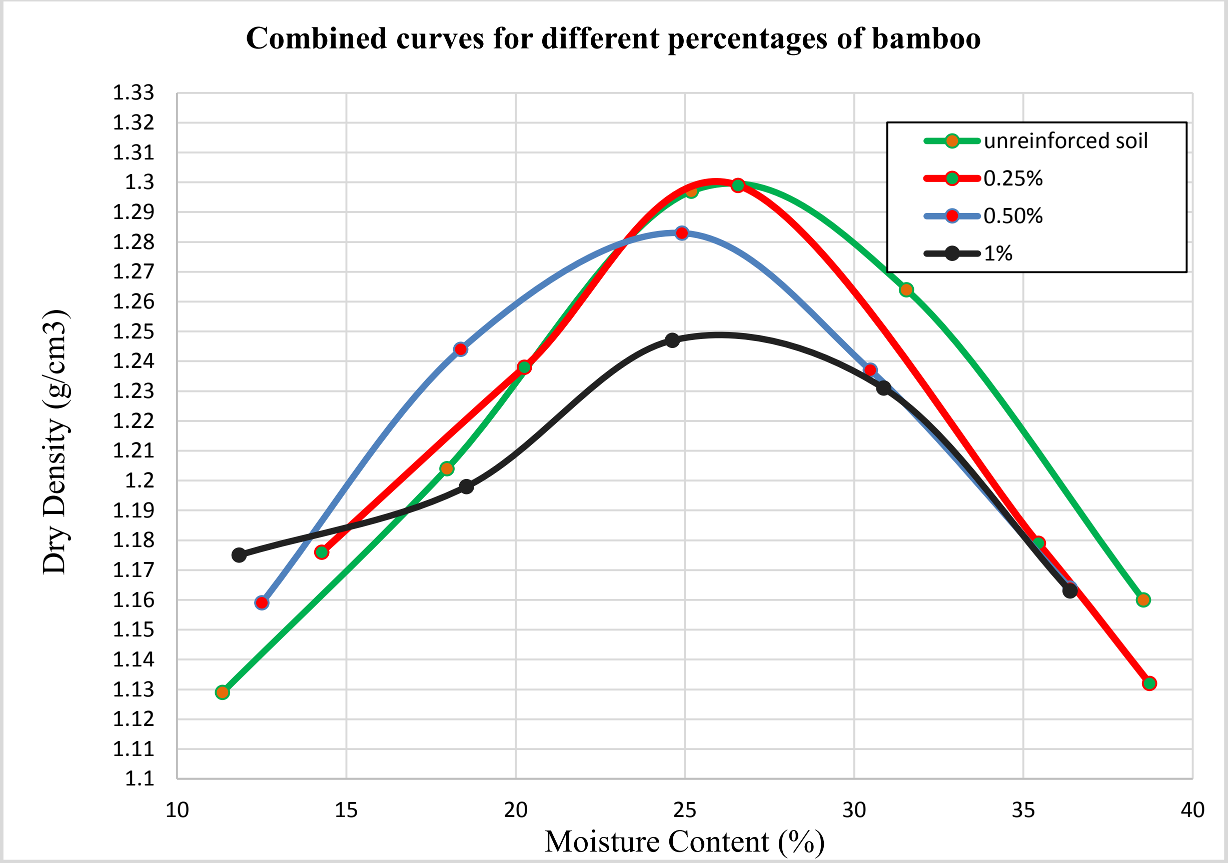


Figure 6.4: Combined curve for different bamboo percentages and length (15mm)

Table 6.5 Comparisons of compaction test results for different bamboo percentages

Percentage of bamboo added (15mm length)	MDD(kN/m3)	OMC (%)
0%	1.3	26.5
0.25%	1.299	26.57
0.5%	1.283	25
1%	1.249	26

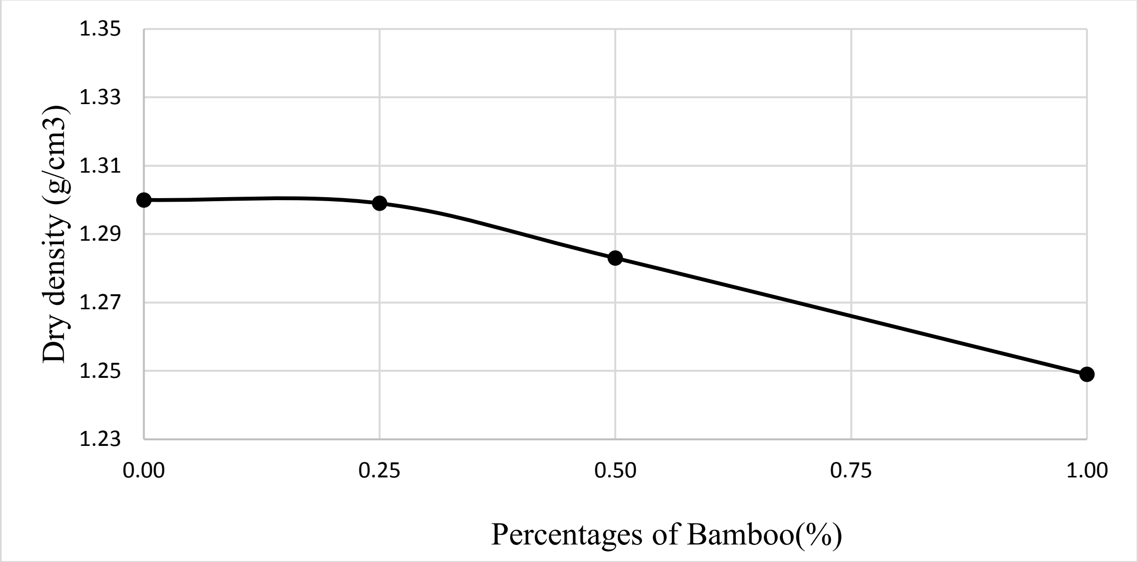


Figure 6.5: Effects of bamboo percentages on MDD for 15mm bamboo

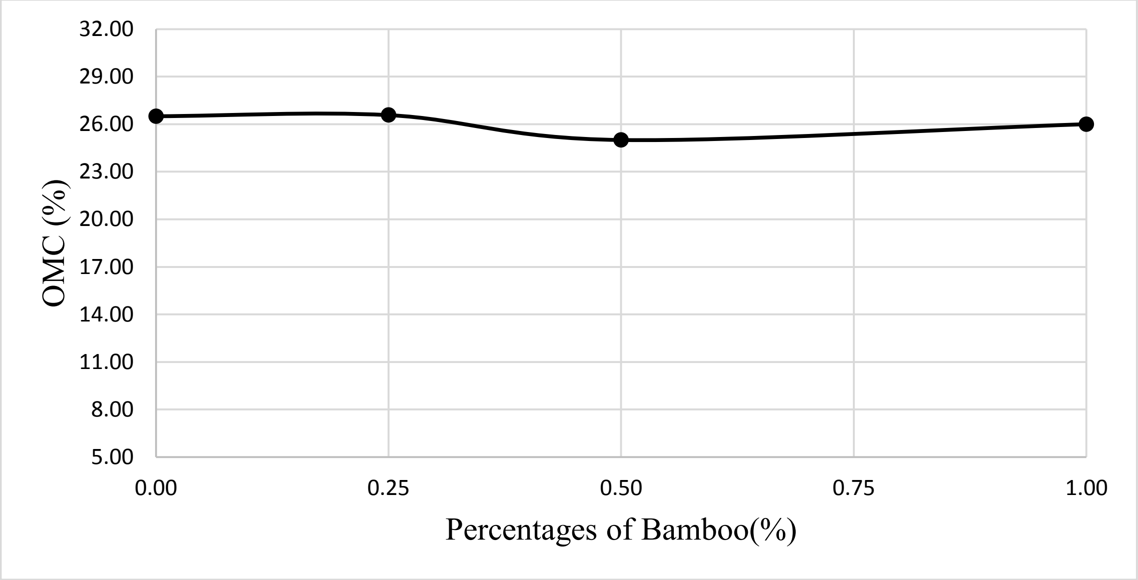


Figure 6.6: Effects of bamboo percentages on OMC for 15mm bamboo

As indicated above (Figure 6.5 and Figure 6.6) combined compaction curve shows that for the same length of bamboo (i.e. 15mm) when the percentages of bamboo increases MDD decreases very slightly and this indicates that when bamboo is added to the soil the high density of soil were replaced by low density of bamboo. OMC more or less remains the same because kerosene coated bamboo doesn't absorb water. Generally the variations in MDD as the percentages of bamboo increased is not significant and as there is no variations in MDD of soil reinforced by bamboo it is economical to improve the soil by field compaction only.

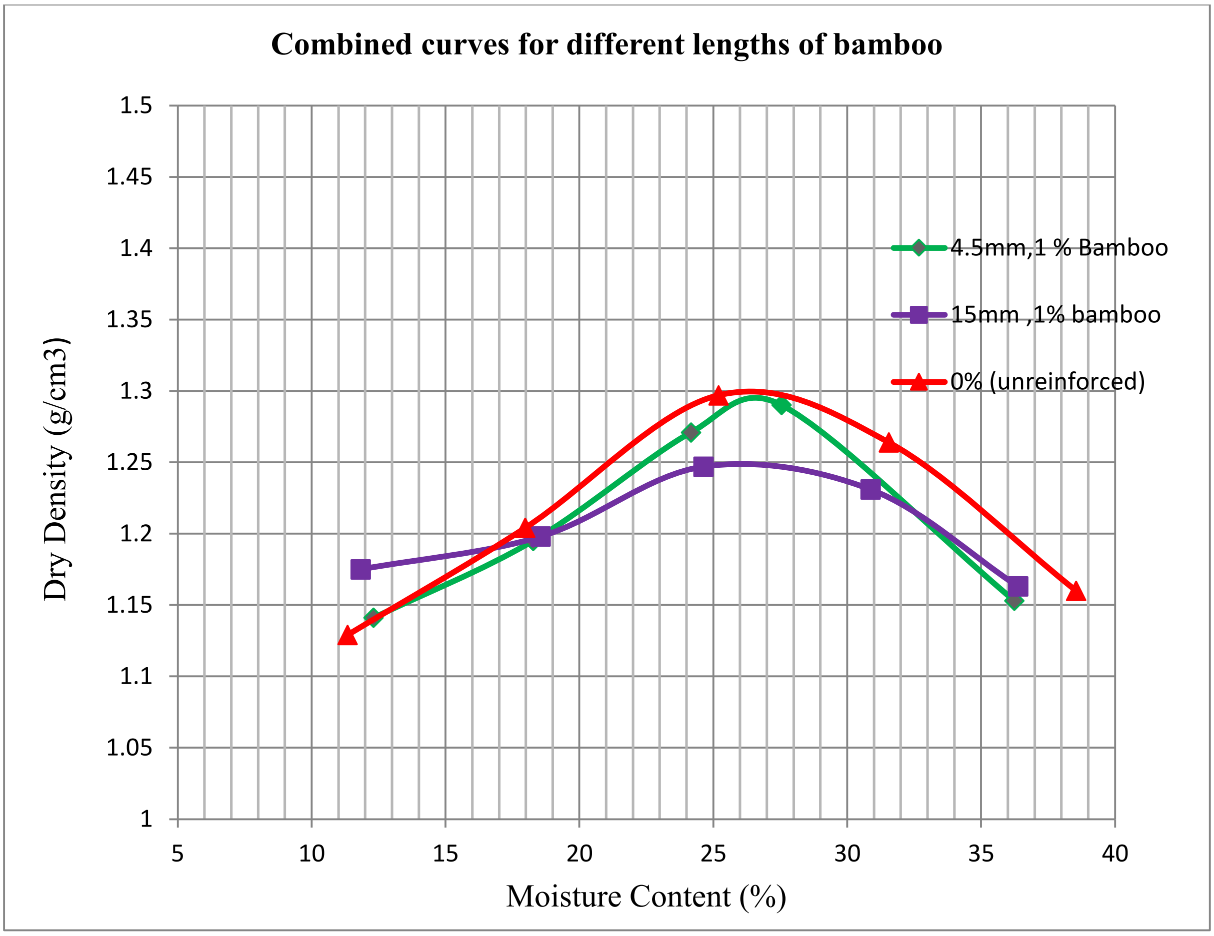


Figure 6.7: Combined curves for different lengths of bamboo and percentage (1%)

Table 6.6 Comparisons of compaction test results for different bamboo lengths (1%)

Length of bamboo added (1%)	MDD(kN/m3)	OMC (%)
45(mm)	1.294	26.6
15(mm)	1.249	26
0(mm)	1.3	26.5

Combined compaction curve (Figure 6.7) shows that for the same percentage of bamboo (i.e. 1%) when the length of bamboo increases MDD decreases slightly initially and tends to increases very slightly as the length of bamboo increases .These may be due to concentration of outer denser inter-nodal fiber as the lengths of bamboo increases, lack uniform mixing of bamboo with soil and methods of compactions. But for all lengths MDD are slightly less than that of the natural soil and OMC remains more or less the same as the length of bamboo increases. Generally the variation in MDD as length of bamboo increases is not significant.

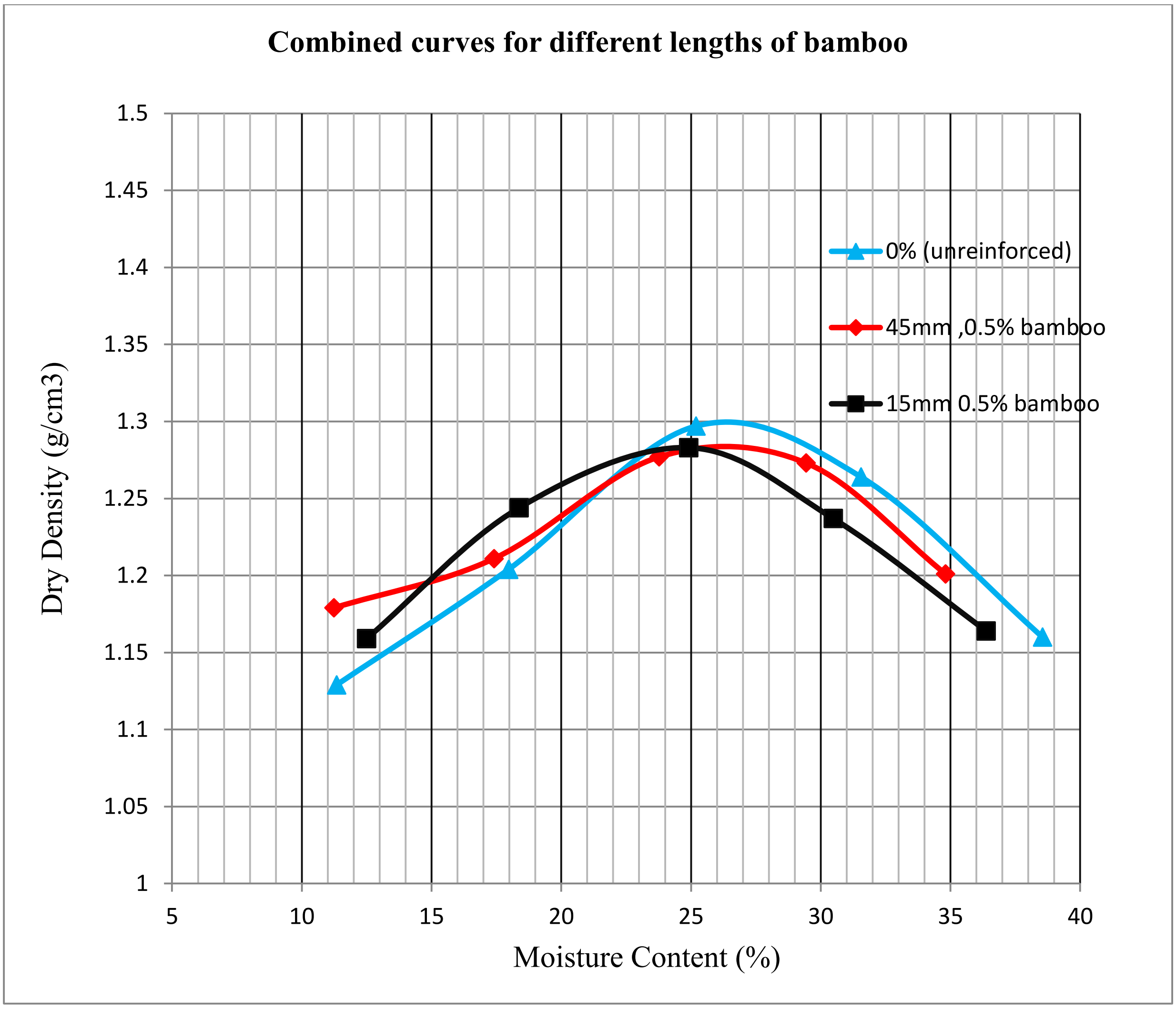


Figure 6.8: Combined curves for different lengths of bamboo and constant percentage (0.5%)

Table 6.7 Comparisons of compaction test results for different length of bamboo (0.5%)

Length of bamboo added (0.5%)	MDD(kN/m3)	OMC (%)
45 (mm)	1.282	26.4
15 (mm)	1.283	25
0(mm)	1.3	26.5

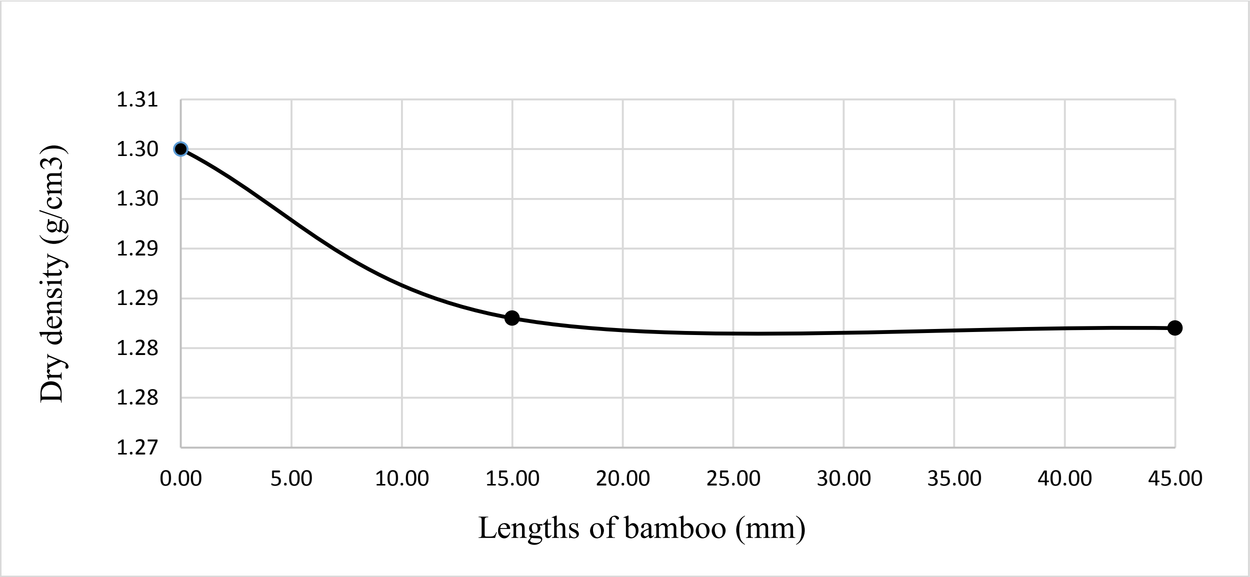


Figure 6.9: Effects of bamboo lengths on MDD for 0.5% of bamboo

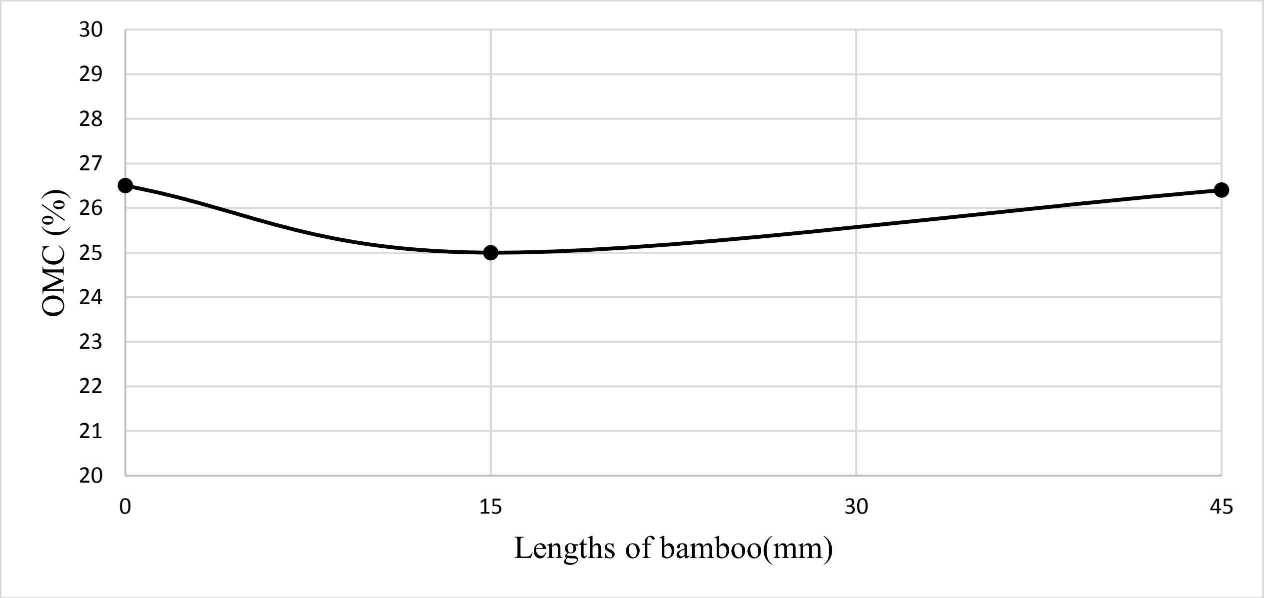


Figure 6.10: Effects of bamboo lengths on OMC for 0.5% of bamboo

Combined compaction curve (Figure 6.8) shows that for the same percentage of bamboo (i.e. 0.5%) when the length of bamboo increases MDD decreases in-significantly and OMC remains non-linearly the same as stated above in Figure: 6.10.

Generally the effect of fiber addition in soil on compaction characteristics shows that the shape of the compaction curves are similar to that of unreinforced sample. For all samples, the dry density increases with increase in water content up to the point of optimum moisture content beyond which increase in water content reduces the dry density. For any particular percentage of fibre content, dry density decreased slightly with increase in fibre length. Therefore, it implies that the maximum dry density of the soil is decreased slightly with increase in fibre length. OMC remains more or less the same but very slight fluctuations on optimum moisture content shows the existence of certain amounts of moisture in the bamboo fiber.

The effect of bamboo content on maximum dry density is presented in Figure 6.5. For any particular fibre length, an increase in fibre content causes insignificant reduction in maximum dry density. As already explained this is due to reduction of average unit weight of the solids in the soil fibre mixture. If there was a decreases in MDD the field compaction energy and costs of bamboo reinforced soil will be decreased but according to the investigations done in this thesis the variations of MDD is not significant as compared to the raw soil. Generally the variations in MDD as the length and percentages of bamboo increases is not significant and as the preparations of bamboo are difficult and the classification of soil is sandy silt it is better to improve the properties of soil by compaction only.

6.3 Direct shear test results and discussions

Table 6.8 Direct shear test results for different percentages of bamboo (45mm)

Percentage of bamboo added (45mm)	Cohesion, C (kN/m2)	Angle of internal friction , Ø(in degree)
0%	12.4	24.2
0.5%	16	24.46
1%	13.4	26.65

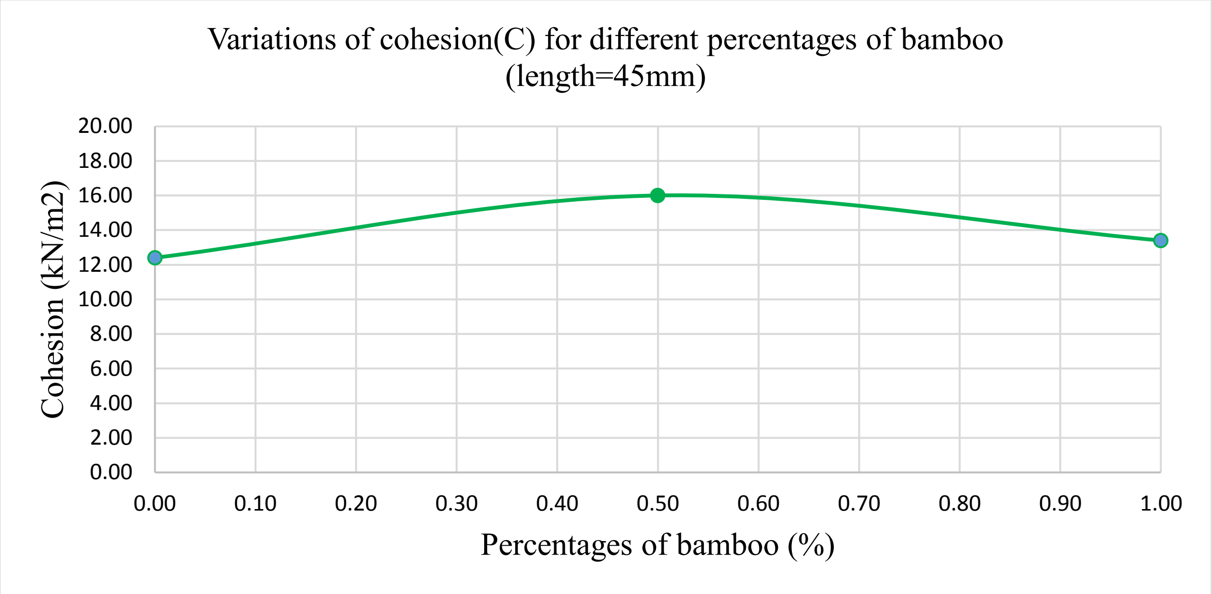


Figure 6.11: Effects of bamboo percentages on cohesion (C) for 45mm length

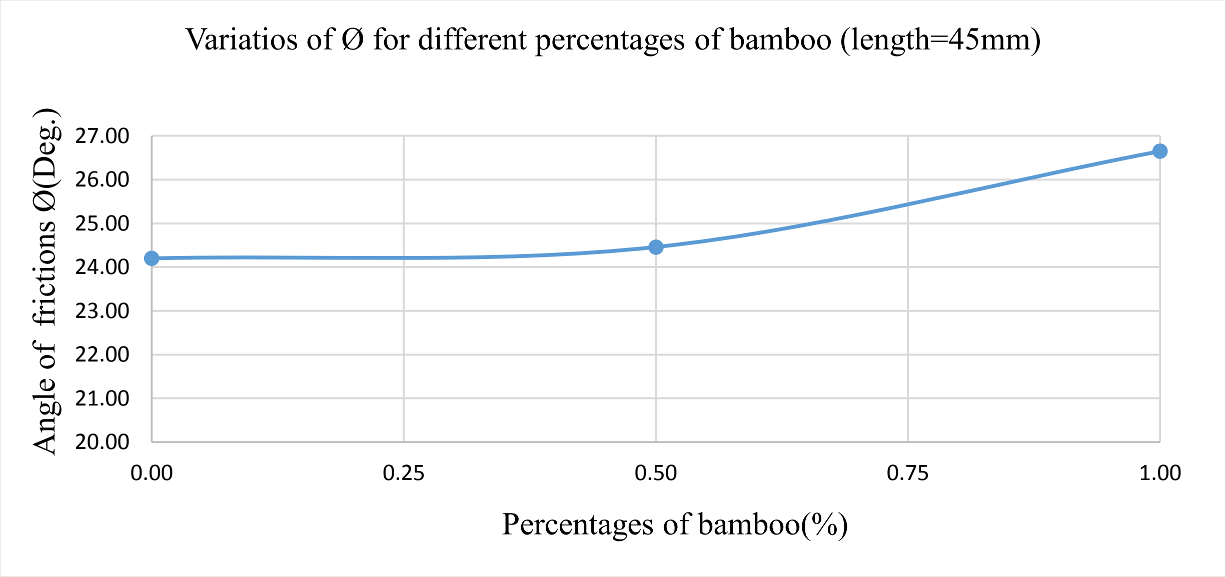


Figure 6.12: Effects of bamboo percentages on angle of internal friction (Ø)

Figure 6.11: shows that for a certain length of bamboo (45mm) as the percentages of bamboo increases the cohesion will be increases slightly and then decreases to the some extents due to the interactions between soil and bamboo decreases. But Figure 6.12: shows that as the percentages of bamboo increases angle of internal frictions (Ø) increases slightly.

Table 6.9 Direct shear test results for different percentages of bamboo (15mm)

Percentage of bamboo added (15mm)	Cohesion, C (kN/m2)	Angle of internal friction , Ø(in degree)
0%	12.4	24.2
0.5%	15	26.1
1%	18	26.3

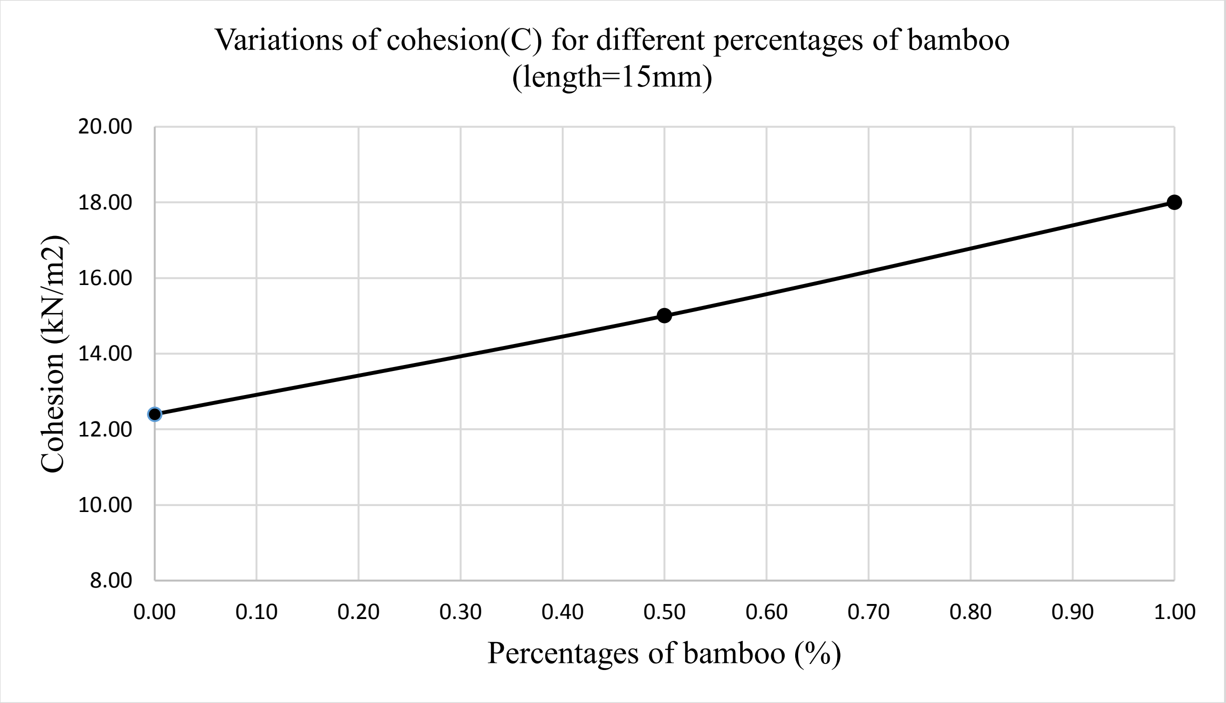


Figure 6.13: Effects of bamboo percentages on cohesion (C) for 15mm length

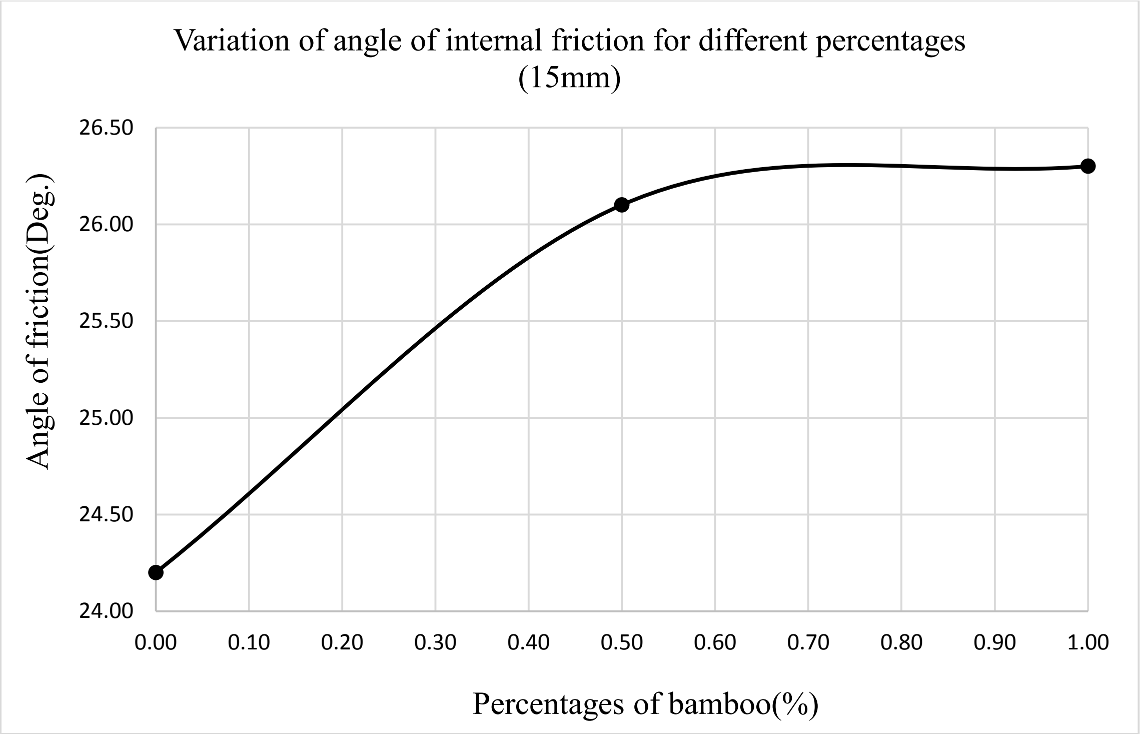


Figure 6.14: Effects of bamboo percentages on angle of internal friction (Ø)

Figure 6.13 and Figure 6.134 shows that for 15mm length bamboo fiber as the percentages of bamboo increases both cohesion and angle of internal frictions (Ø) increases slightly. The increasing characteristics of cohesion(C) at 15mm are linear and different from 45mm length bamboo due to the shorter lengths of 15mm which results in increasing the interactions between bamboo and soil samples.

Table 6.10 Comparisons of direct shear test results for different lengths of bamboo

Length of bamboo added(mm) for 1%	Cohesion ,C (kN/m2)	Angle of internal friction , Ø(in degree)
0 mm	12.4	24.2
15 mm	18	26.3
45 mm	13.4	26.65

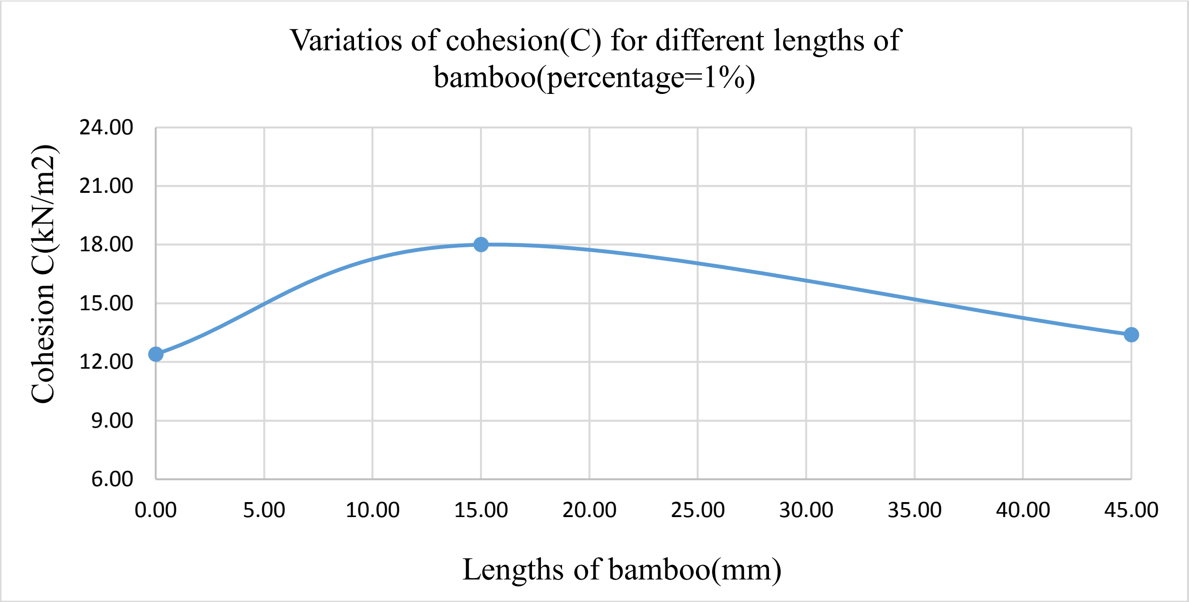


Figure 6.15: Effects of bamboo lengths on cohesion (C) for 1% of bamboo

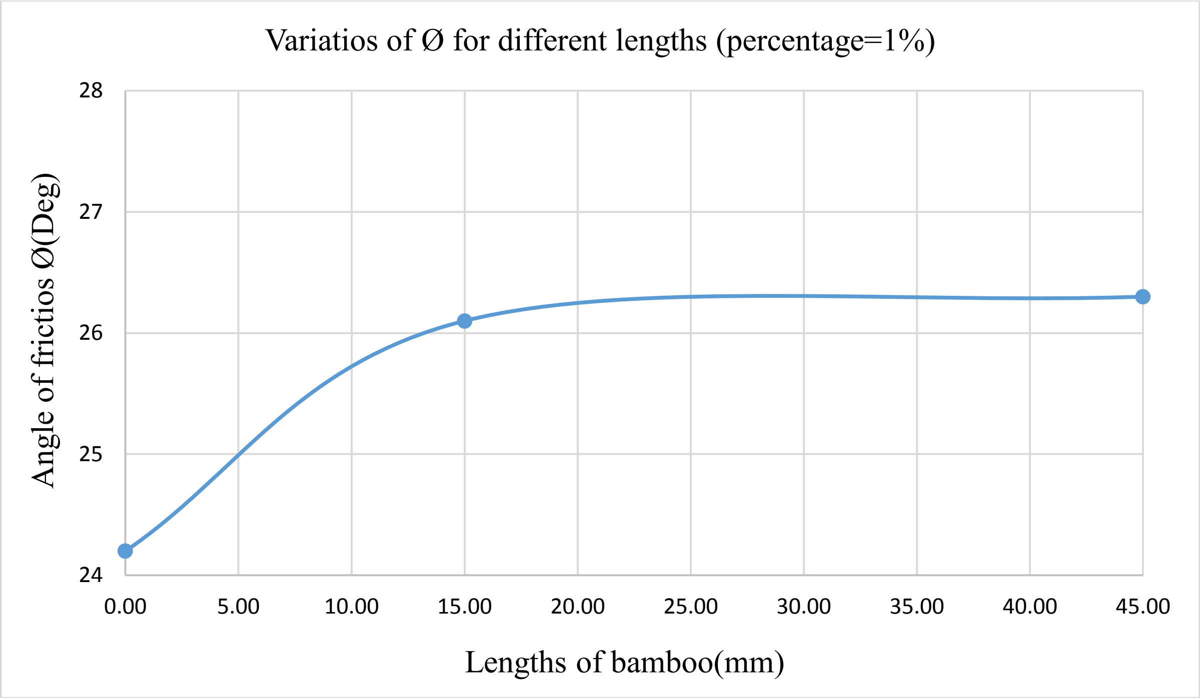


Figure 6.16: Effects of bamboo lengths on angle of internal friction (Ø) for 1%

Figure 6.15 shows that for a certain percentages of bamboo as the lengths of bamboo increases the cohesion will be increases initially slightly and then decreases to the some extents due to the interactions between soil and bamboo decreases. But Figure 6.16 shows that as the lengths of bamboo increases angle of internal frictions (Ø) increases insignificantly.

Table 6.11 Shear strength (in kPa) for different bamboo percentages of (length=45mm)

Percentage of bamboo added(45mm)	Vertical applied stress		
	100kPa	200kPa	300kPa
0%	57	104	147
0.5%	60	113	153
1%	62.5	117	164

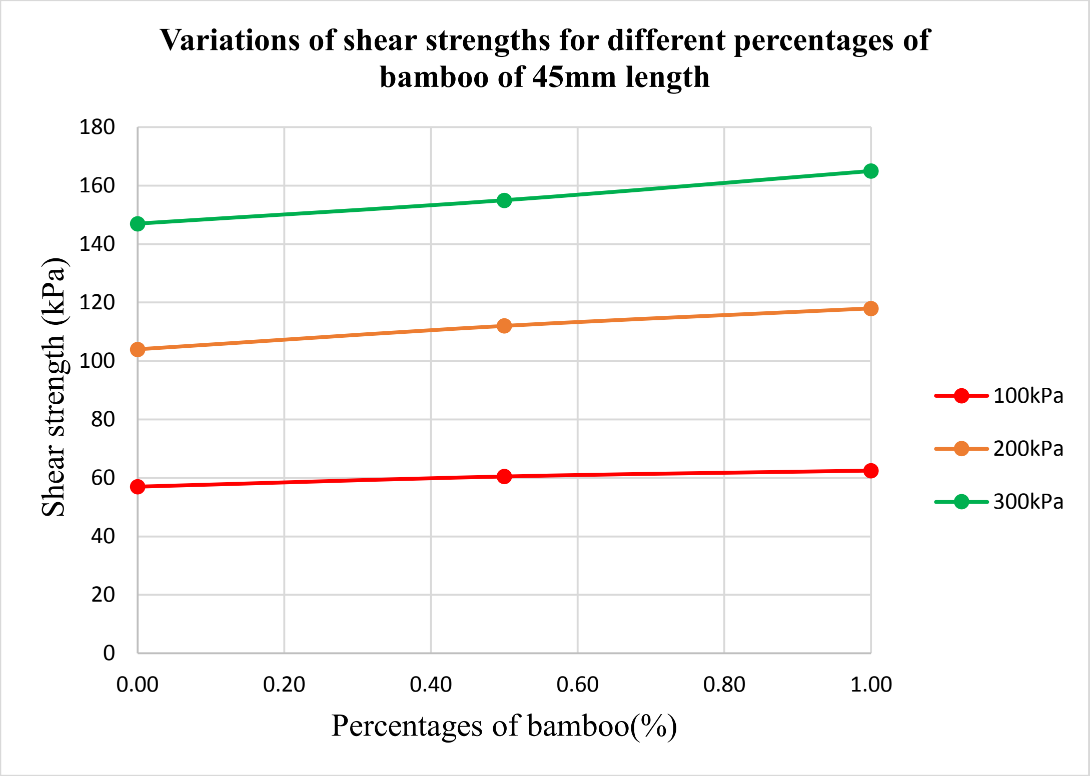


Figure 6.17: Effects of bamboo percentages on shear strengths (45mm)

Figure 6.17 shows that the increase in bamboo percentages from 0% to 1% has no significant effects on shear strengths of reinforced soil but the increase in applied normal pressure from 100kPa to 300kPa increases shear strengths significantly. Therefore it is better to increase the shear strength of the ziway silty soil by increasing the applied normal pressure (by increasing compaction energy only).

Table 6.12 Shear stress (in kPa) for different bamboo percentages of (length=15mm)

Percentage of bamboo added(15mm)	Vertical applied stress		
	100kPa	200kPa	300kPa
0%	57	104	147
0.5%	61.5	118	159.5
1%	65.7	123	167

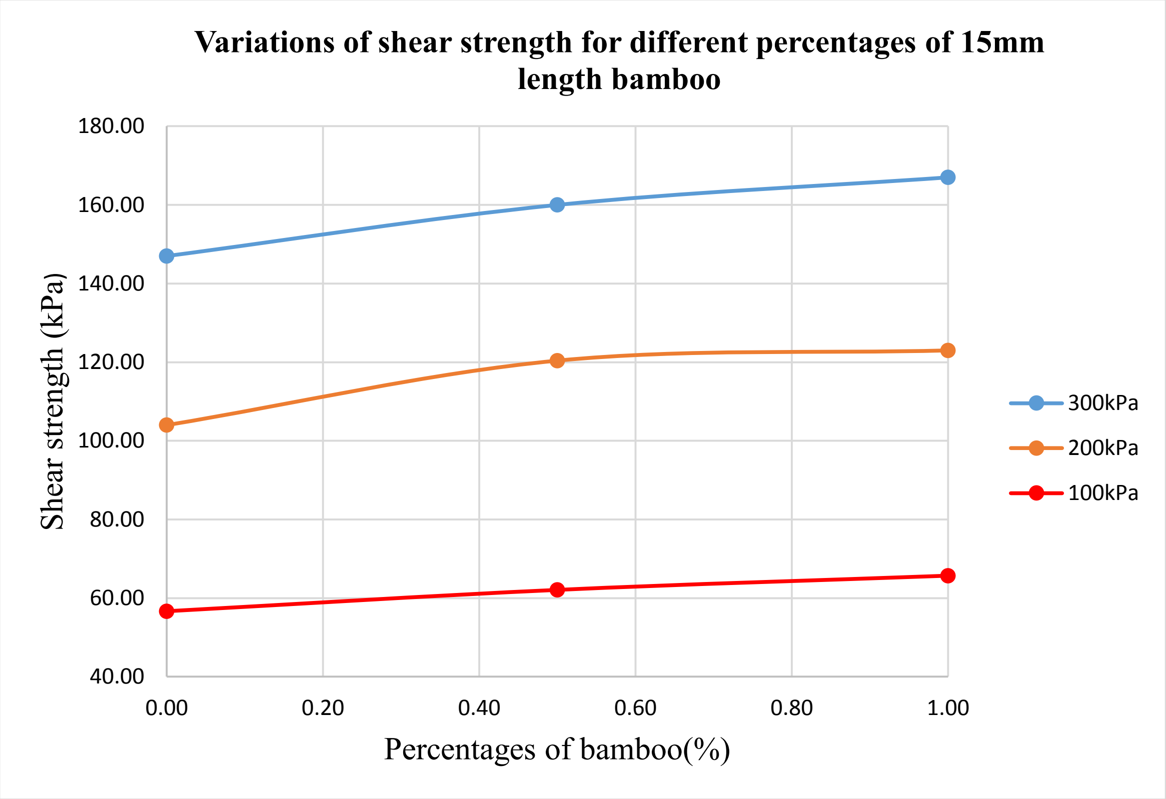


Figure 6.18: Effects of bamboo percentages on shear strengths (15mm)

From the test results (Figure 6.17 and Figure 6.18) for a certain length of bamboo as the percentages of bamboo increases shear strength increases linearly and insignificantly, and tends to remain constant for a higher percentages. But the increase in applied normal pressure from 100kPa to 300kPa increases shear strengths to a large extent. Therefore it is better to increase the shear strength of the soil by increasing the applied normal pressure (by compaction).

Table 6.13 Shear strength (in kPa) for different lengths of bamboo (1%)

Lengths of bamboo added for 1%(mm)	Vertical applied stress		
	100kPa	200kPa	300kPa
0	57	104	147
15	65.7	123	167
45	62.5	117	164

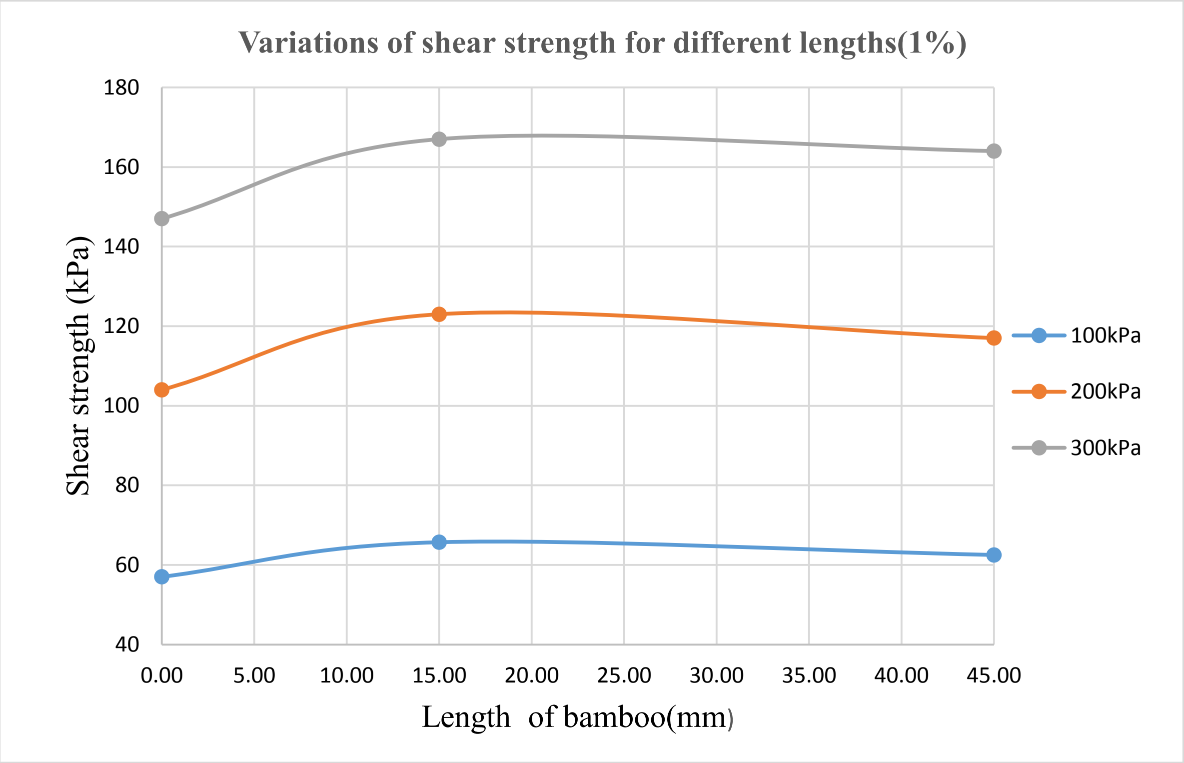


Figure 6.19: Effects of bamboo lengths on shear strengths (1%)

Figure 6.19 above shows the variations of shear strength for a different lengths of bamboo and a constant percentages of 1% of bamboo. As the length of bamboo increases shear strength slightly increases and decreases for a longer lengths because the interactions between bamboo and soil decreases. Test results shows that the optimum percentages of bamboo which gives the maximum increase in shear strengths are 1% of bamboo.

Generally both the length of fiber and percentage of fiber played an insignificant role in the development of shear strength parameters C and Ø of the fiber reinforced soil. It is observed that by increase in fiber content, the value of cohesion increases, but beyond 1% of 15mm reinforcement the cohesion value drastically reduced. The influence of fiber length on the cohesion value also insignificant as the length increases. The cohesion mobilised by the fiber is maximum when the length of the fibre is 15mm. Of course there is no much variation in the angle of friction.

It is finally agreed that bamboo reinforcement does not have a significant influence on the improvement of angle of shearing resistance. The increase in the cohesion of soil-fibre matrix may due to the increase in the confining pressure due to the development of tension in the fiber which enables the reinforced soil to act as single coherent matrix of soil fibre mass. The variation of cohesion with percentage of fibre content and length is non-linear.

The shear strength of fibre reinforced soil is improved insignificantly due to the addition of the bamboo fibre. The shear strength is increased slightly with increase in length and percentages of fiber up a certain percentages and beyond, where an increase in length reduces the shear strength. The increase in the length of fiber fails to interlock the soil particles and therefore, soil-fibre particles do not act as a single coherent matrix. Bamboo reinforcement of silt soil has no significant effects on shear strength parameters (i.e. cohesion and angle of internal frictions). Generally as shown above in figures the increase in bamboo percentages and lengths has no significant effects on shear strengths of the ziway town soil but the increase in applied normal pressure significantly increases shear strength therefore it is better to increase the strength of soil by increasing the normal pressure by high compactive effort.

6.4 .California Bearing Ratio (CBR Test) results and discussions on soaked soil samples

Table 6.14 Comparisons of CBR value at different bamboo percentages

Percentage of bamboo by dry Weight of Soil (%)	Length of bamboo(mm)	CBR Value (%)	increase in CBR value (%)
0%	15	5.52	0
	30		
	45		
0.5%	15	7.68	39.13
	30	9.47	71.55
	45	11.76	113.0
1%	15	14.12	155.79
	30	14.69	166.12
	45	17.75	221.60.

Table 6.15 Comparisons of CBR value at different bamboo lengths

Length of bamboo (mm)	Percentage of bamboo by Dry Weight of Soil (%)	CBR Value (%)	increase in CBR value (%)
15	0	5.52	0
	0.5	7.68	39.13
	1	14.12	155.79
30	0	5.52	0
	0.5	9.47	71.55
	1	14.69	166.12
45	0	5.52	0
	0.5	11.76	113.0
	1	17.75	221.60

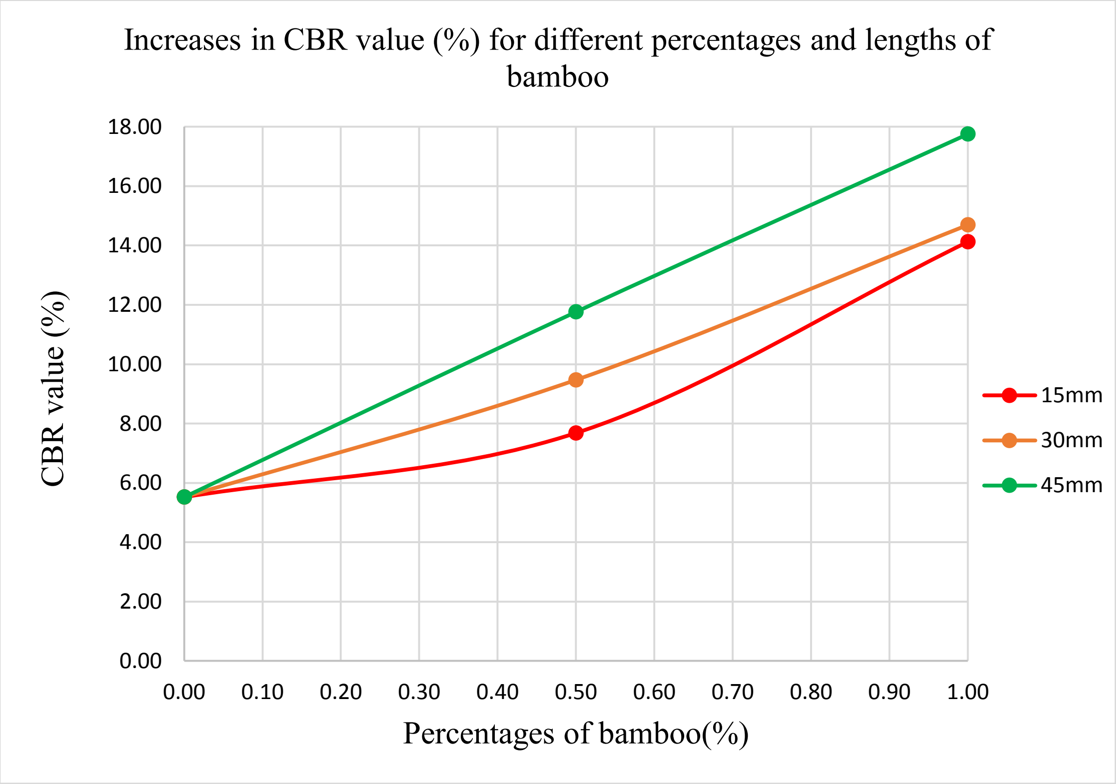


Figure 6.20: Effects of bamboo percentages on CBR value for different lengths

One-point socked CBR test results (Figure 6.20) shows that for the same lengths of bamboo as the percentages of bamboo increases CBR values increases significantly. Addition of bamboo to silt soil increases CBR value at a better performances. This is due to reason that randomly oriented discrete inclusions incorporated into soil mass improves its load-deformation behaviour by interacting with the soil particles mechanically through surface friction and also by interlocking. The function of bond or interlock is to transfer the stress from soil to the discrete inclusion by mobilizing the tensile strength of discrete inclusion. Thus, fiber reinforcement works as frictional and tension resistance element.

From the test results the amounts of bamboo which leads to maximum increases to CBR value (i.e. 221.6%) is 1% of 45mm. With the increase in CBR value the thickness of layer formed for pavement will be decreased and so is the number of layers but different considerations related to bamboo and soil properties makes the use of bamboo as a sandy silt soil reinforcement un-economical.

The factors that makes using of bamboo as a sub-grade soil reinforcements un-economical are:

1. Cutting of bamboo has environmental problems (environmental cost)
2. Transportation of bamboo to long distance (transportation cost)
3. Preparations and treatments of bamboo is difficult (technical cost)
4. Soil of ziway town is sandy silt (can improved by compaction)
5. Bamboo reinforcement has no significant effects on MDD and shear strengths.
6. Applicability in the field (decomposition of bamboo).

Generally using of bamboo as a sub-grade soil reinforcements of sandy silty soil of ziway soil is not economical. As the properties of the sandy silt soil are fair as subgrade materials and inclusion of bamboo has no significant effects on engineering properties of soil it is better to improve the soil by using compaction only.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The following conclusions can be drawn from the present study:

- Water Absorption Capacity (WAC) of kerosene treated bamboo reduced by 20% as that of uncoated.
- The compaction characteristics namely MDD and OMC are changed insignificantly with addition of bamboo in silty soil. The addition of bamboo fiber slightly decreased MDD. The reason may be the addition of lesser weight material to silt soil.
- OMC more or less remains the same as the percentages and lengths of bamboo increases. The reason may be kerosene coated bamboo fiber doesn't absorb water
- Shear strength parameters (angle of internal friction and cohesion) of bamboo reinforced soil slightly increases with increase in bamboo contents and lengths. The shear strength is increased insignificantly with increase in length and percentages of fibre up a certain percentages and beyond, where an increase in length reduces the shear strength. It is generally concluded that bamboo reinforcement does not have a significant influence on the improvement of cohesion and angle of internal frictions.
- Based on the present investigation it is concluded that CBR value of soil increases significantly with the inclusion of bamboo. But different factors such as removal of bamboo (environmental cost), transporting of bamboo (transportation cost), preparation of bamboo (technical cost), decomposition of bamboo makes the design un-economical and as the soil is sandy silt it is better to improve its engineering properties by compaction only.

7.2. Recommendations

- ✓ In this thesis samples of soil for the reinforcement purpose were only from one test pits and bamboo of a certain lengths and percentages, by increasing the number of sampling area in-depth and varying the percentages and lengths of bamboo investigation should be done in future.
- ✓ In this thesis the bamboo sample used was highland bamboo, applications of lowland bamboo as a subgrade reinforcement's should be studied in the future.
- ✓ The dynamic characteristics of bamboo reinforced soils with relation to respond of soil to earthquake should be studied in future.
- ✓ In this thesis preparations of bamboo sample in to small fibber and mixing with soil was done manually and it is time consuming, therefore designing of machine for the preparation of samples for the desired thickness and uniform mixing should be done in the future.

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APPENDIXES

Appendix –A descriptions of the study area

Table A-1 Descriptions of the study area (TP-1)

<table>
<tr><td colspan="3">PROJECT: MSC Thesis</td><td rowspan="3">DATE: March 11,2016</td></tr>
<tr><td colspan="3">LOCATION: Near market -old Butajira Road</td></tr>
<tr><td colspan="3">TEST PIT No.: TP-1</td></tr>
<tr><td>Depth, m</td><td>Visual soil description</td><td>Field test type</td><td>Sampled for</td></tr>
<tr><td>-0.6m</td><td>Silty soil</td><td></td><td>• Grain size analysis,
• Consistency limit test,
• Compaction test,
• specific gravity test,
• direct shear test and
• CBR tests</td></tr>
<tr><td colspan="3">TEST PIT SIZE=1.5x 1.50 x0.6m</td><td rowspan="4"></td></tr>
<tr><td colspan="3">LOCATION: Near market</td></tr>
<tr><td colspan="3">LOGGED BY:Gosaye Zerihun</td></tr>
<tr><td colspan="3">TEST PIT NO : TP-1</td></tr>
</table>

Table A-2 Descriptions of the study area (TP-2)

PROJECT: MSC Thesis LOCATION: Near Bekele Molla Hotel (Ziway) TEST PIT No.: TP-2			DATE: March 11,2016
Depth, m	Visual soil description	Field test type	Sampled for
-0.6m	Silty soil		• Grain size analysis • Consistency limit test, • Compaction test, • specific gravity test, • direct shear test and • CBR tests
TEST PIT SIZE=1.5x 1.50 x0.6m LOCATION: Near Bekele Molla Hotel LOGGED BY: Gosaye Zerihun TEST PIT NO : TP-2			

Appendix – B (Specific gravity test result)

Table B-1 Specific gravity test result (TP-1)

Determination No.	1	2
Pycnometer No.	A5	9A
Weight of pycnometer + soil + water, W_{pws} (g)	159.6	158
Temperature, T_x(°c)	23.8	23.9
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.6	143
Weight of dry soil , w_s (gm)	25	25
Mass of equal volume of water as the soil solids, Ww (g) = (W_{pw} + Ws)- W_{pws}	10.0	10.0
Specific gravity of soil at T_x(°C)=Ws/Ww	2.48	2.48
Conversion factor , K	0.9992	0.9992
Specific gravity of soil at 20°c.	2.48	2.48
Average specific gravity of soil.	2.48	

Table B-2 Specific gravity test result (TP-2)

Determination No.	1	2
Pycnometer No.	A6	B7
Weight of pycnometer + soil + water, W_{pws} (g)	161.7	158.9
Temperature, T_x(°C)	24.4	24.7
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	146.8	144.0
Weight of dry soil , Ws (gm)	25	25
Mass of equal volume of water as the soil solids, Ww (g) = (W $_{pw}$ + Ws)- W_{pws}	10.1	10.1
Specific gravity of soil at T_x(°C)=Ws/Ww	2.48	2.48
Conversion factor , K	0.9990	0.9987
Specific gravity of soil at 20°c.	2.48	2.48
Average specific gravity of soil.	2.48	

Appendix – C

(Grain size and hydrometer analysis results)

Table C-1 Grain size analysis test result (TP-1)

Sieve number	Sieve opening (mm)	Mass of retained soil(g)	Percentage retained (%)	Cumulate percent retained (%)	Cumulate percent passing (%)	Total amount of sample-1 washed=500g According to USCS , Gravel=5.0 % Sand=36.7% Fine =58.1%
¾ in	9.5	10.4	2.08	2.08	97.92	
4	4.75	15	3.0	5.08	94.92	
10	2	22.3	4.46	9.54	90.46	
20	.85	22.1	4.42	13.96	86.04	
40	.425	36.9	7.38	21.34	78.66	
60	.25	25.1	5.02	26.36	73.64	
100	.15	27.8	5.56	31.92	68.08	
200	0.075	49.3	9.86	41.78	58.22	
	pan	290.6	58.12	99.90	0.100	
Total		499.5	99.90			

Hydrometer Analysis for TP-1

Specific Gravity of soil =2.48 Test Temperature=19.7^{0}c

Table C-2 Hydrometer Analysis (TP-1)

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0285	-0.0018	1.0267	8.76	0.01455	0.043	89.48	52.02
1	1.0280	-0.0018	1.0262	8.89	0.01455	0.030	87.81	51.05
2	1.0240	-0.0018	1.0222	9.95	0.01455	0.022	74.40	43.26
4	1.0195	-0.0018	1.0177	11.14	0.01455	0.017	59.32	34.49
8	1.0160	-0.0018	1.0142	12.07	0.01455	0.013	47.59	27.67
15	1.0130	-0.0018	1.0112	12.86	0.01455	0.009	37.54	21.82
30	1.0110	-0.0018	1.0092	13.39	0.01455	0.006	30.83	17.93
60	1.0090	-0.0018	1.0072	13.92	0.01455	0.007	24.13	14.03
120	1.0080	-0.0018	1.0062	14.18	0.01455	0.005	20.78	12.08
240	1.0070	-0.0018	1.0052	14.45	0.01455	0.003	17.43	10.13
480	1.0064	-0.0018	1.0046	14.61	0.01455	0.002	15.42	8.96
1440	1.0055	-0.0018	1.0037	14.85	0.01455	0.001	12.40	7.21

Figure C-1: Combined grain size distribution curve for TP-1

Table C-3 Grain size analysis result (TP-2)

Sieve number	Sieve opening (mm)	Mass of retained soil(g)	Percentage retained (%)	Cumulate percent retained (%)	Cumulate percent passing (%)	Total amount of sample-2 washed=500g According to USCS , Gravel=0.0% Sand=44.1% Fine =55.7%
3.8’’	9.5	0.00	0.00	0.00	100	
4	4.75	3.2	0.64	0.64	99.36	
10	2	12.4	2.48	3.12	96.88	
20	.85	37.1	7.42	10.54	89.46	
40	.425	70	14	24.54	75.46	
60	.25	36.1	7.22	31.76	68.24	
100	.15	20.1	4.02	35.78	64.22	
200	0.075	41.6	8.32	44.1	55.9	
	pan	278.7	55.74	99.84	0.16	
Total		499.20	99.84			

Hydrometer analysis for TP-2

Specific Gravity of soil =2.48 Test Temperature=19.70^{0}C

Table C-4 Hydrometer Analysis (TP-2)

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0275	-0.0018	1.0257	9.03	0.01455	0.0437	86.13	48.15
1	1.0270	-0.0018	1.0252	9.16	0.01455	0.0311	84.45	47.21
2	1.0235	-0.0018	1.0217	10.08	0.01455	0.0231	72.72	40.65
4	1.0195	-0.0018	1.0177	11.14	0.01455	0.0172	59.32	33.16
8	1.0155	-0.0018	1.0137	12.20	0.01455	0.0131	45.91	25.67
15	1.0130	-0.0018	1.0112	12.86	0.01455	0.0095	37.54	20.98
30	1.0110	-0.0018	1.0092	13.39	0.01455	0.0069	30.83	17.24
60	1.0095	-0.0018	1.0077	13.79	0.01455	0.0070	25.81	14.43
120	1.0085	-0.0018	1.0067	14.05	0.01455	0.0050	22.45	12.55
240	1.0075	-0.0018	1.0057	14.32	0.01455	0.0036	19.10	10.68
480	1.0067	-0.0018	1.0049	14.53	0.01455	0.0025	16.42	9.18
1440	1.0052	-0.0018	1.0034	14.92	0.01455	0.0015	11.39	6.37

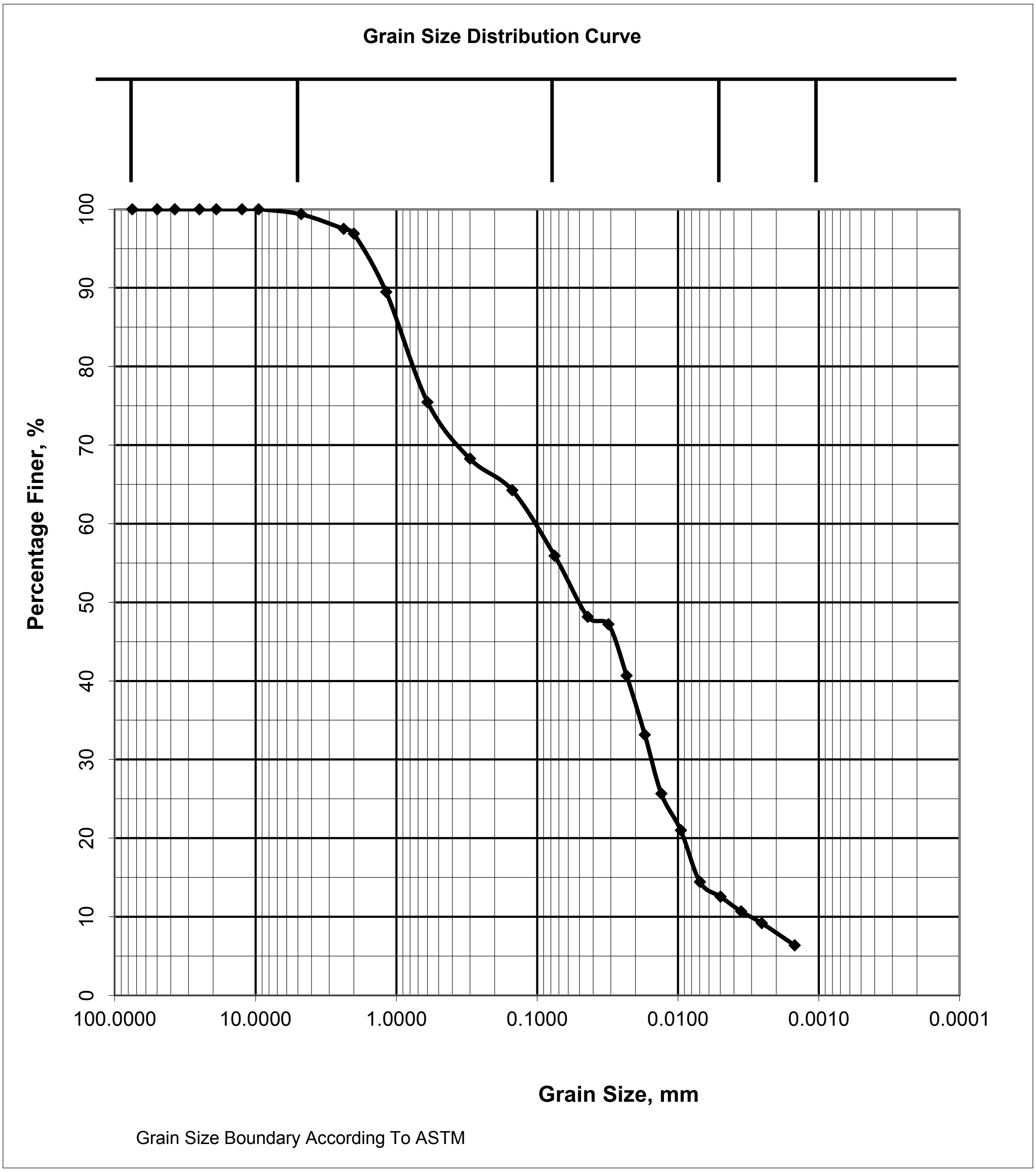

Figure C-2: Combined grain size distribution curve for TP-2

Appendix –D (Liquid limit and plastic limit test result)

Table D-1. Liquid limit and plastic limit on TP-1

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	26	A36	C31	C18	C34	71
Mass of container, g	33.10	33.00	33.10	32.90	33.10	33.00
Mass of container + Wet soil, g	52.10	53.70	55.10	55.10	42.90	43.40
Mass of container + Dry soil, g	46.80	47.80	48.80	48.70	40.50	40.90
Mass of water, g	5.30	5.90	6.30	6.40	2.40	2.50
Mass of dry soil, g	13.70	14.80	15.70	15.80	7.40	7.90
Water content, %	38.69	39.86	40.13	40.51	32.43	31.65
No of blows	34	27	20	15	------	------

Liquid Limit, % = 40 Plastic Limit, % = 32 PI, %= 8

Table D-2. Liquid limit and plastic limit on TP-2

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	**2**
Container No	115	101	132	179	106	799
Mass of container, g	33.60	32.90	33.00	33.60	33.20	32.90
Mass of container + Wet soil, g	59.80	58.60	63.0	61.20	45.00	41.90
Mass of container + Dry soil, g	53.00	51.90	55.0	53.80	42.40	40.10
Mass of water, g	6.80	6.70	8.0	7.40	2.60	1.80
Mass of dry soil, g	19.40	19.00	22.0	20.20	9.20	7.20
Water content, %	35.05	35.26	36.36	36.63	28.26	25.00
No of blows	33	26	20	16	-	**-**

Liquid limit=36 and Plastic limit=27 , Plastic index=9

Appendix – E: **Compaction test result**

Table E-1 Compaction data sheet (TP-1)

Sample -1 Determination No.	1	2	3	4	5
Mass of Mold, g	4572.4	4572.4	4572.4	4572.4	4572.4
Mass of mold+ Compacted Soil, g	5834.4	5998.5	6201.9	6241.3	6185.5
Mass of Compacted soil, g	1262	1426.1	1629.5	1668.9	1613.1
Volume of Mold,cm3	1004.44	1004.44	1004.44	1004.44	1004.44
Bulk density, g/cm3	1.26	1.42	1.62	1.66	1.61
Water Content, %	11.34	17.97	25.03	31.55	38.55
Dry density, g/cm3	1.13	1.20	1.27	1.26	1.16

Table E-2 Determination of moisture content (TP-1)

Test Number	**1**	2	3	4	5
Container Number	11	22	33	44	55
Wt.of Wet soil + container	141	154.2	151.9	171.6	210
Wt.of Dry soil + container	130.1	135.8	128.1	138.5	160.5
Wt.of Water	10.9	18.4	23.8	33.1	49.5
Weight of container	34	33.4	33	33.6	32.1
Wt.of Dry soil	96.1	102.4	95.1	104.9	128.4
Moisture content	11.34	17.97	25.03	31.55	38.55
Dry density (g/cm^3)	1.13	1.20	1.27	1.26	1.16

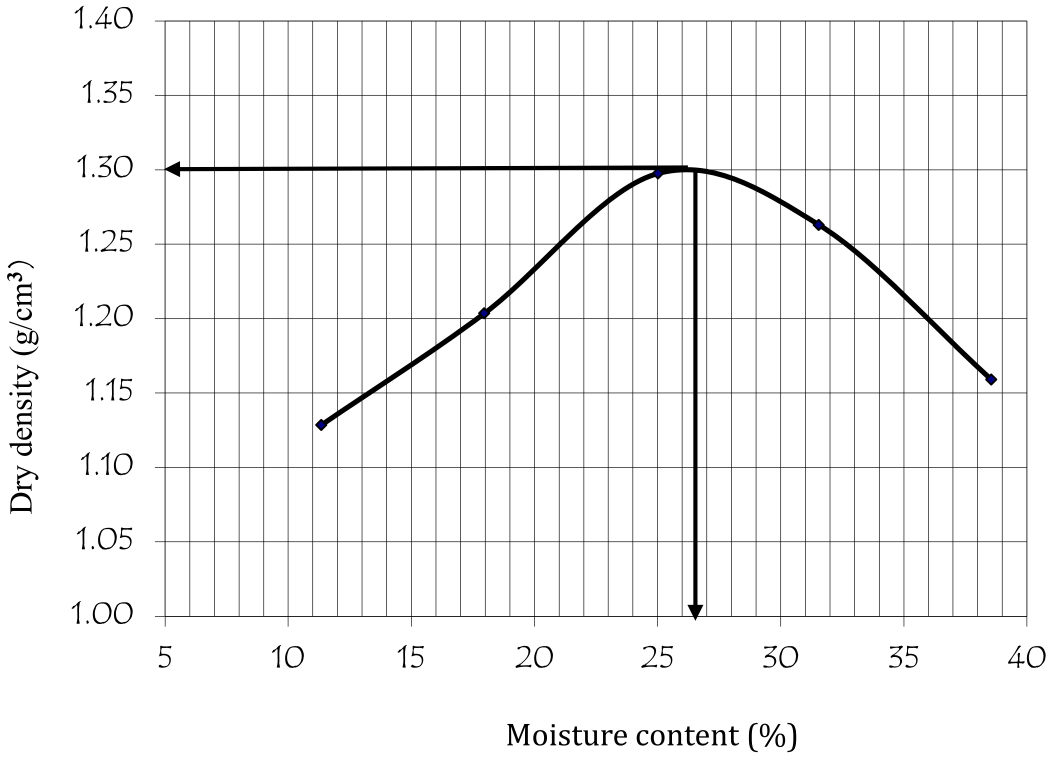

Figure E-1: Compaction curve for TP-1 (MDD=1.3 g/cm3and OMC=26.5%)

Table E-3 Compaction data sheet (TP-2)

Determination No.	1	2	3	4	5
Mass of Mold, g	4572.4	4572.4	4572.4	4572.4	4572.4
Mass of mold+ Compacted Soil, g	5938.9	6134.5	6298.1	6286.5	6150.5
Mass of Compacted soil, g	1366.5	1562.1	1725.7	1714.1	1578.1
Volume of Mold,cm3	1004.44	1004.44	1004.44	1004.44	1004.44
Bulk density, g/cm3	1.36	1.56	1.72	1.71	1.57
Water Contenet, %	12.16	18.82	25.24	31.18	38.60
Dry density, g/cm3	1.21	1.31	1.36	1.30	1.13

Table E-4 Determination of moisture content (TP-2)

Test Number	**1**	2	3	4	5
Container Number	77	40	49	B2	42
Wt.of Wet soil + container	172.1	162.2	164.8	226.4	230.5
Wt.of Dry soil + container	157.1	141.8	138.2	180.6	175.5
Wt.of Water	15	20.4	26.6	45.8	55
Weight of container	33.7	33.4	32.8	33.7	33
Wt.of Dry soil	123.4	108.4	105.4	146.9	142.5
Moisture content	12.16	18.82	25.24	31.18	38.60
Dry density (g/cm^3)	1.21	1.31	1.36	1.30	1.13

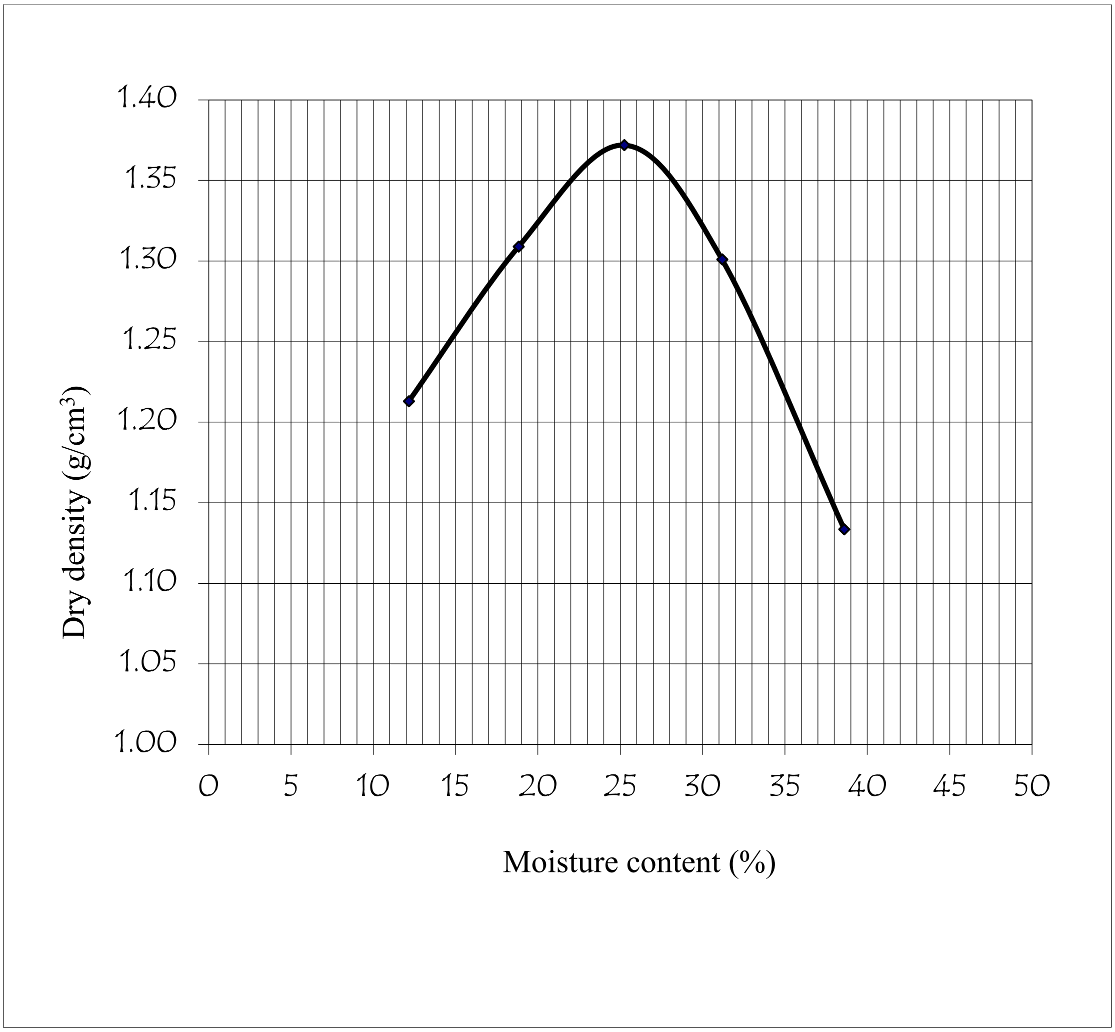

Figure E-2: Compaction curve for TP-2 (MDD=1.37 g/cm3 and OMC=25%)

Compaction Data Sheet for reinforced soil

Table E-5 Compaction test results (15mm, 1% bamboo)

Wt.of Soil + Mould **(gm)**	5892.60	6000.00	6133.60	6191.40	6166.30
Wt.of Mould **(gm)**	4573.7	4573.7	4573.7	4573.7	4573.7
Diam. of mould **(cm)**	10.5	10.5	10.5	10.5	10.5
Height of mould **(cm)**	11.6	11.6	11.6	11.6	11.6
Volume of Mould **(cm^3)**	1003.93	1003.9365	1003.9365	1003.9365	1003.9365
Bulk Unit wt.	1.314	1.421	1.554	1.611	1.586

Table E-6 Moisture contents (15mm, 1%)

Container Number	11	22	33	44	55
Wt.of Wet soil + container	141.2	155	159	154.1	238.4
Wt.of Dry soil + container	129.8	136	134.1	125.7	183.8
Wt.of Water	11.4	19	24.9	28.4	54.6
Weight of container	33.4	33.6	33	33.7	33.7
Wt.of Dry soil	96.4	102.4	101.1	92	150.1
Moisture content	11.83	18.55	24.63	30.87	36.38
Dry density (g/cm^3)	1.175	1.198	1.247	1.231	1.163

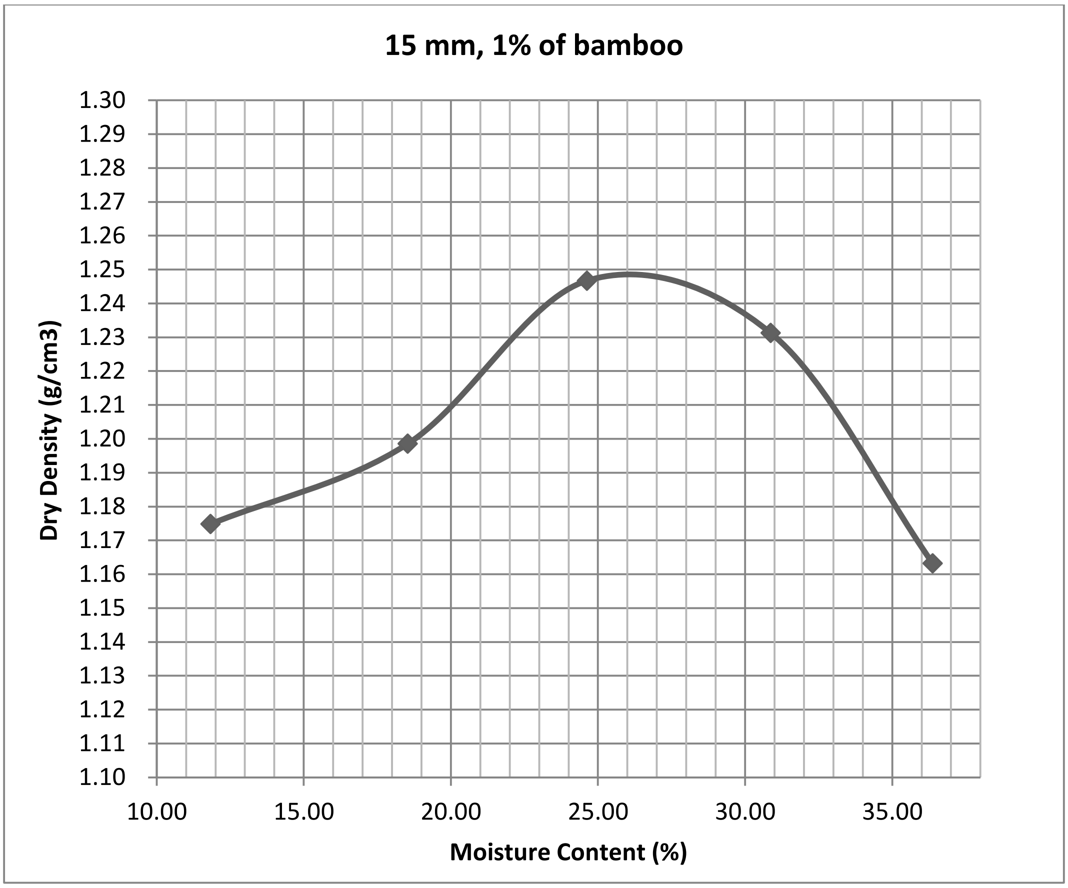

Figure E-3: Compaction curve (15mm, 1%)

Standard Proctor Compaction Test Result		
Maximum dry density (g/cm^3)	=	1.249
Optimum moisture content (%)	=	26
Sample No.	=	Sample-1

Table E-7 Compaction test results (15mm, 0.5% bamboo)

Wt.of Soil + Mould **(gm)**	5881.20	6050.50	6181.20	6193.10	6166
Wt.of Mould **(gm)**	4572.2	4572.2	4572.2	4572.2	4572.2
Diam. of mould **(cm)**	10.5	10.5	10.5	10.5	10.5
Height of mould **(cm)**	11.6	11.6	11.6	11.6	11.6
Volume of Mould **(cm^3)**	1003.937	1003.93	1003.9365	1003.93	1003.9365
Bulk Unit wt.	1.304	1.473	1.603	1.615	1.588

Table E-8 Moisture contents (15mm, 0.5%)

Test Number	**1**	2	3	4	5
Container Number	21	22	23	24	25
Wt.of Wet soil + container	151.5	168.1	138.6	146.1	235
Wt.of Dry soil + container	138.4	147.2	117.6	119.8	183.8
Wt.of Water	13.1	20.9	21	26.3	54.6
Weight of container	33.6	33.5	33.3	33.5	33.7
Wt.of Dry soil	104.8	113.7	84.3	86.3	150.1
Moisture content	12.50	18.38	24.91	30.48	36.38
Dry density (g/cm^3)	1.159	1.244	1.280	1.237	1.164

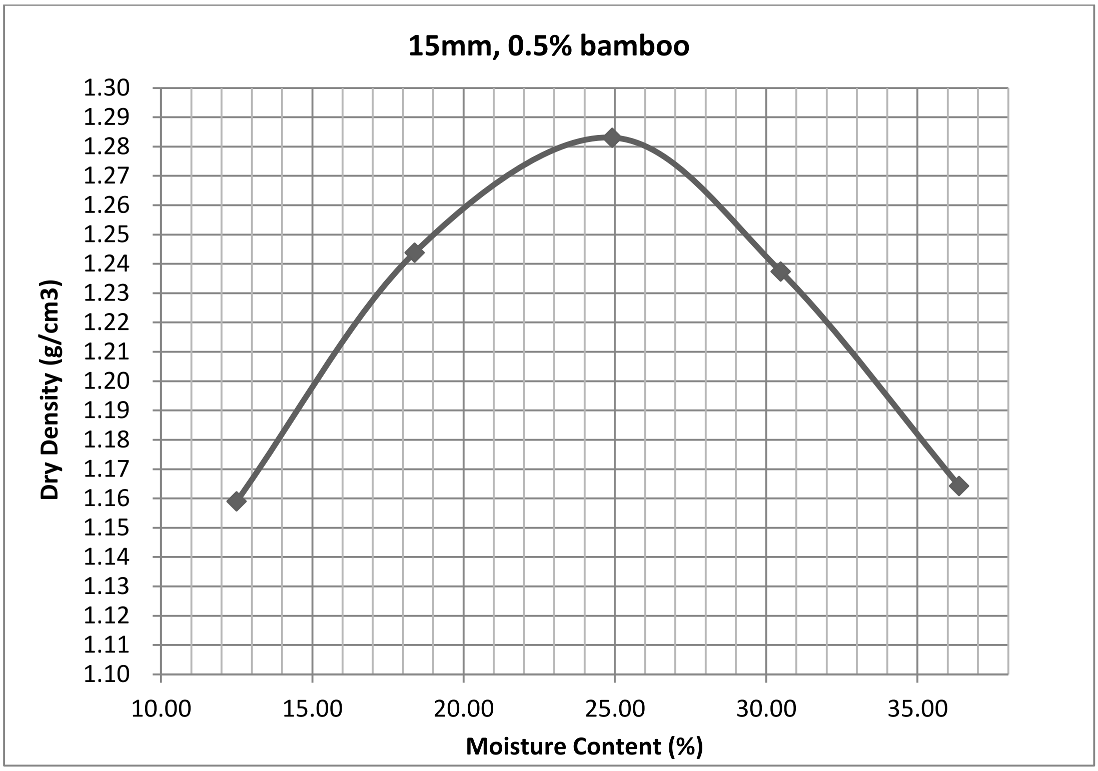

Figure E-4: Compaction curve (15mm, 0.5%)

Standard Proctor Compaction Test Result		
Maximum dry density (g/cm^3)	=	1.283
Optimum moisture content (%)	=	25.00
Sample No.	:	Sample-1

Table E-9 Compaction test results (15mm, 0.25% bamboo)

Wt.of Soil + Mould (**gm**)	5922.50	6067.90	6224.10	6177.10	6150.00
Wt.of Mould (**gm**)	4573.7	4573.7	4573.7	4573.7	4573.7
Diam. of mould (**cm**)	10.5	10.5	10.5	10.5	10.5
Height of mould (**cm**)	11.6	11.6	11.6	11.6	11.6
Volume of Mould (**cm^3**)	1003.937	1003.9365	1003.936	1003.93	1003.9365
Bulk Unit wt.	1.344	1.488	1.644	1.597	1.570

Table E-10 Moisture contents (15mm, 0.25%)

Test Number	**1**	2	3	4	5
Container Number	A1	B2	C3	D4	E5
Wt.of Wet soil + container	149.7	145.1	172	196.7	230
Wt.of Dry soil + container	135.2	126.2	142.8	154	175
Wt.of Water	14.5	18.9	29.2	42.7	55
Weight of container	33.6	32.9	32.9	33.5	33
Wt.of Dry soil	101.6	93.3	109.9	120.5	142
Moisture content	14.27	20.26	26.57	35.44	38.73
Dry density (g/cm^3)	1.176	1.238	1.299	1.179	1.132

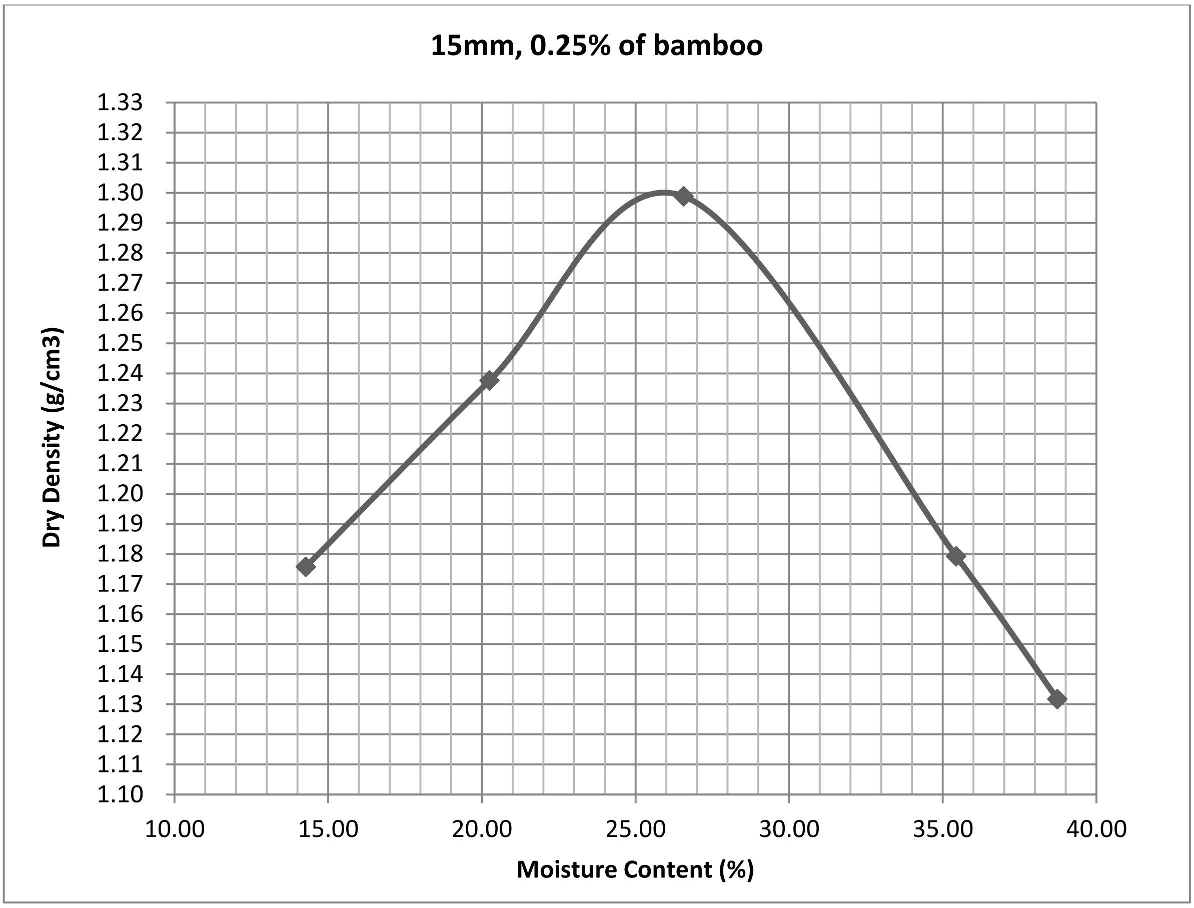

Figure E-5: Compaction curve (15mm, 0.25%)

Standard Proctor Compaction Test Result		
Maximum dry density (g/cm^3)	=	1.299
Optimum moisture content (%)	=	26.57
Sample No.	=	Sample -1

Table E-11 Compaction test results (45mm, 1% Bamboo)

Wt.of Soil + Mould **(gm)**	5859.60	5990.50	6157.50	6225.80	6151.30
Wt.of Mould **(gm)**	4573	4571.9	4572.9	4573.7	4573.9
Diam. of mould **(cm)**	10.5	10.5	10.5	10.5	10.5
Height of mould **(cm)**	11.6	11.6	11.6	11.6	11.6
Volume of Mould **(cm^3)**	1003.9365	1003.9365	1003.9365	1003.9365	1003.9365
Bulk Unit wt.	1.282	1.413	1.578	1.646	1.571

Table E-12 Moisture contents (45mm, 1% Bamboo)

Test Number	1	2	3	4	5
Container Number	A	B	C	D	E
Wt.of Wet soil + container	176.9	175.2	166.9	166.2	216.3
Wt.of Dry soil + container	161.1	153.3	140.8	137.4	167.7
Wt.of Water	15.8	21.9	26.1	28.8	48.6
Weight of container	32.7	33.4	32.8	32.9	33.6
Wt.of Dry soil	128.4	119.9	108	104.5	134.1
Moisture content	12.31	18.27	24.17	27.56	36.24
Dry density (g/cm^3)	1.141	1.195	1.271	1.290	1.153

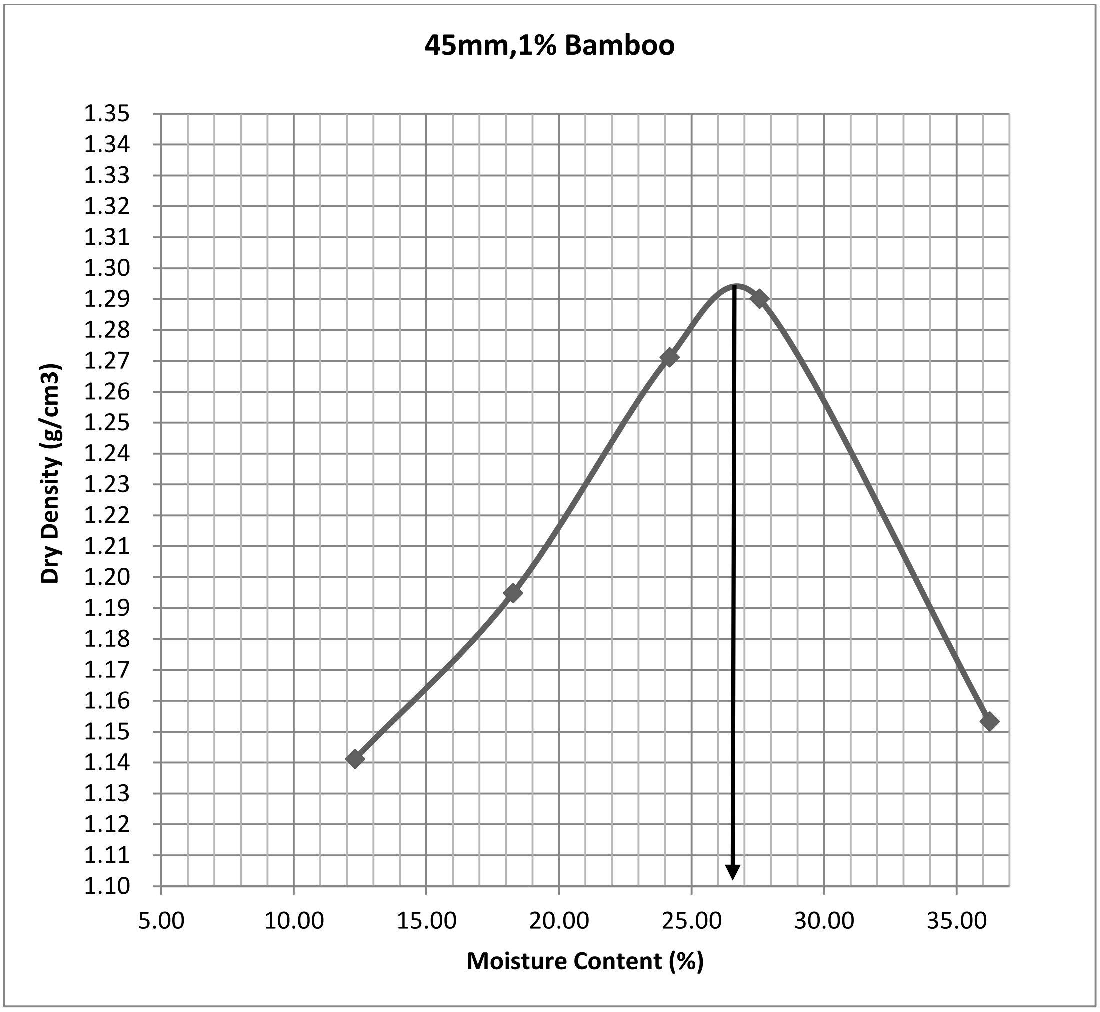

Figure E-6: Compaction curve (45mm, 1%)

Standard Proctor Compaction Test Result		
Maximum dry density (g/cm^3)	=	1.294
Optimum moisture content (%)	=	26.6
Sample No.	=	TP1

Table E-13 Compaction test results (45mm, 0.5 % Bamboo)

Wt.of Soil + Mould **(gm)**	5890.00	6000.00	6158.50	6228.40	6198.20
Wt.of Mould **(gm)**	4573	4572	4572	4573.7	4573
Diam. of mould **(cm)**	10.5	10.5	10.5	10.5	10.5
Height of mould **(cm)**	11.6	11.6	11.6	11.6	11.6
Volume of Mould (**cm^3**)	1003.9365	1003.9365	1003.9365	1003.9365	1003.9365
Bulk Unit wt.	1.312	1.422	1.580	1.648	1.619

Table E-14 Moisture contents (45mm, 0.5 % Bamboo)

Test Number	1	2	3	4	5
Container Number	11	12	13	14	15
Wt.of Wet soil + container	153.5	159.4	153.8	179.5	202.6
Wt.of Dry soil + container	141.3	140.7	130.6	146.2	158.7
Wt.of Water	12.2	18.7	23.2	33.3	43.9
Weight of container	32.8	33.3	33	33.1	32.6
Wt.of Dry soil	108.5	107.4	97.6	113.1	126.1
Moisture content	11.24	17.41	23.77	29.44	34.81
Dry density (g/cm^3)	1.179	1.211	1.261	1.273	1.201

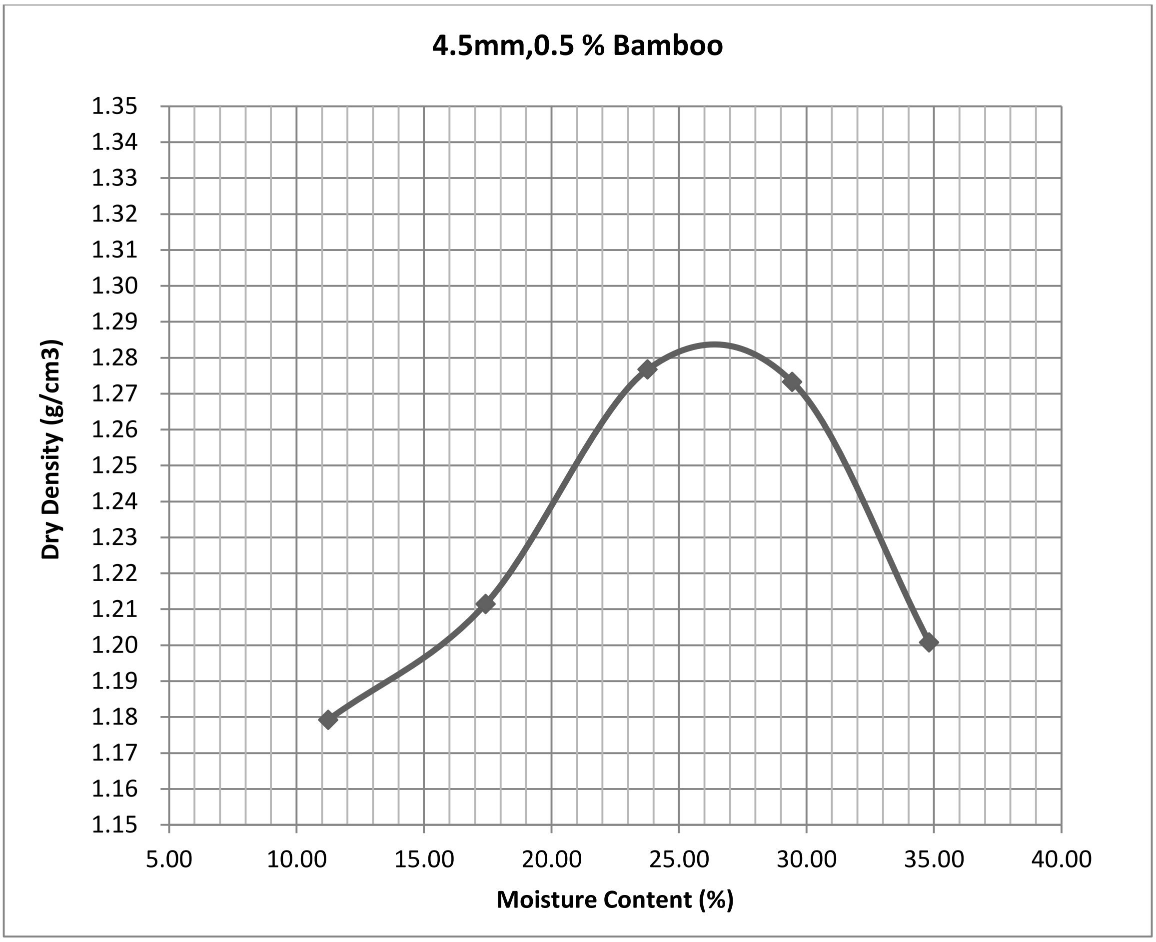

Figure E-7: Compaction curve (45mm, 0.5%)

Standard Proctor Compaction Test Result		
Maximum dry density (g/cm^3)	=	1.277
Optimum moisture content (%)	=	26.4
Sample No.	=	TP1

Appendix – F: Direct shear test results

Table F-1 Direct shear test results on TP-1

Sample No.		**TP-1**	Sample Depth, m:		0.60					
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 N/div					
Length of sample :		60 mm	Rate of strain :		1.6 mm/min					
Width of sample:		60 mm	Moisture content, %		26.5		Sample Condition:			disturbed
		Applied Vertical Stress			Applied Vertical Stress			Applied Vertical Stress		
		100 kPa			**200 kPa**			**300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	24.00	16.80	4.71	40.00	28.00	7.84	56.00	39.20	10.98
1.0	3540	62.00	43.40	12.26	97.00	67.90	19.18	155.00	108.50	30.65
1.5	3510	100.00	70.00	19.94	170.00	119.00	33.90	275.00	192.50	54.84
2.0	3480	132.00	92.40	26.55	226.00	158.20	45.46	340.00	238.00	68.39
2.5	3450	155.00	108.50	31.45	266.00	186.20	53.97	410.00	287.00	83.19
3.0	3420	178.00	124.60	36.43	301.00	210.70	61.61	455.00	318.50	93.13
3.5	3390	192.00	134.40	39.65	327.00	228.90	67.52	490.00	343.00	101.18
4.0	3360	209.00	146.30	43.54	354.00	247.80	73.75	517.00	361.90	107.71
4.5	3330	222.00	155.40	46.67	371.00	259.70	77.99	540.00	378.00	113.51
5.0	3300	235.00	164.50	49.85	384.00	268.80	81.45	559.00	391.30	118.58
5.5	3270	245.00	171.50	52.45	397.00	277.90	84.98	572.00	400.40	122.45
6.0	3240	253.00	177.10	54.66	409.00	286.30	88.36	584.00	408.80	126.17
6.5	3210	256.00	179.20	55.83	420.00	294.00	91.59	594.00	415.80	129.53
7.0	3180	256.00	179.20	56.35	435.00	304.50	95.75	604.00	422.80	132.96
7.5	3150	255.00	178.50	**56.67**	446.00	312.20	99.11	611.00	427.70	135.78
8.0	3120	251.00	175.70	56.31	455.00	318.50	102.08	618.00	432.60	138.65
8.5	3090				459.00	321.30	**103.98**	625.00	437.50	141.59
9.0	3060				454.00	317.80	103.86	628.00	439.60	143.66
9.5	3030				444.00	310.80	102.57	628.00	439.60	145.08
10.0	3000				436.00	305.20	101.73	622.00	435.40	145.13
11.0	2940							616.00	431.20	**146.67**
11.5	2910									

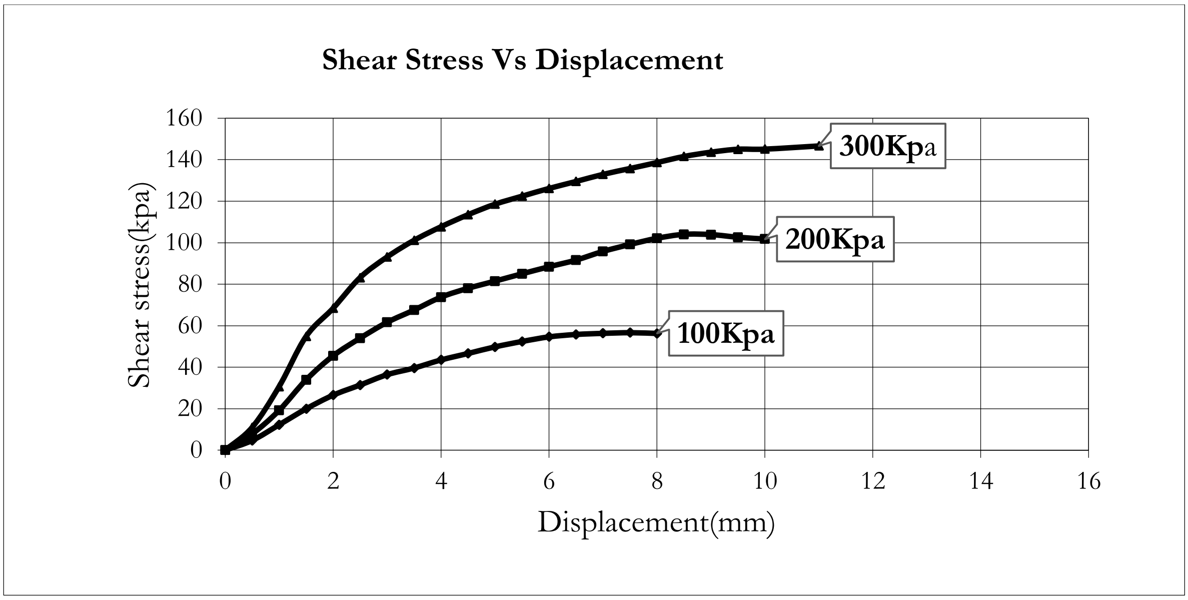

Figure F-1: Shear stress versus displacement (TP-1)

Angle of internal friction, Ø=	24.2^0		Cohesion , C (kN/m^2) =	12.4

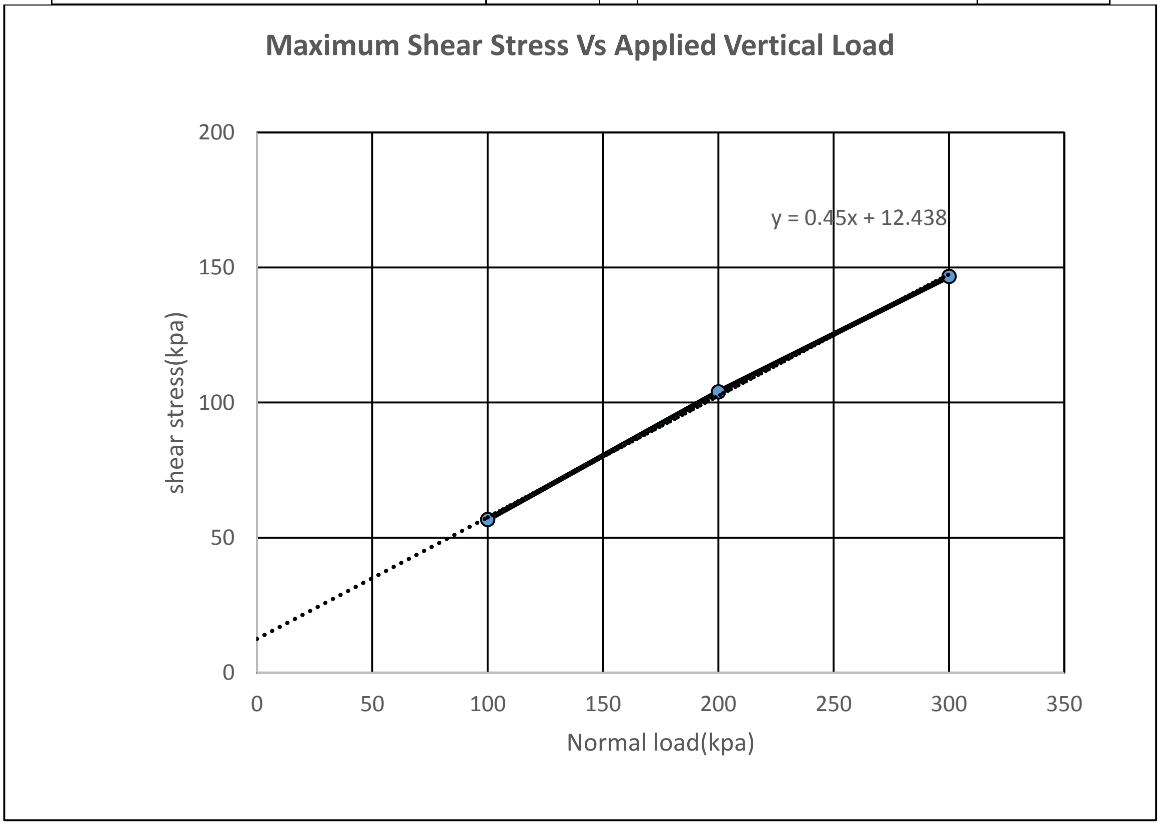

Figure F-2: Shear stress versus applied load (TP-1)

Table F-2 Direct shear test results on TP-2

Sample No.	**TP-2**	Sample Depth, m:	0.60		
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div		
Length of sample :	60 mm	Rate of strain :	1.6 mm/min		
Width of sample:	60 mm	Moisture content, %	25.0	Sample condition:	disturbed

		Applied Vertical Stress			Applied Vertical Stress			Applied Vertical Stress		
		100 kPa			**200 kPa**			**300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	36.00	25.20	7.06	40.00	28.00	7.84	57.00	37.10	10.39
1.0	3540	99.00	69.30	19.58	103.00	72.10	20.37	158.00	110.60	31.24
1.5	3510	145.00	101.50	28.92	161.00	112.70	32.11	252.00	176.40	50.26
2.0	3480	172.00	120.40	34.60	212.00	148.40	42.64	318.00	222.60	63.97
2.5	3450	201.00	140.70	40.78	260.00	182.00	52.75	377.00	263.90	76.49
3.0	3420	219.00	153.30	44.82	302.00	211.40	61.81	420.00	294.00	85.96
3.5	3390	240.00	168.00	49.56	331.00	231.70	68.35	445.00	311.50	91.89
4.0	3360	258.00	180.60	53.75	353.00	247.10	73.54	463.00	324.10	96.46
4.5	3330	271.00	189.70	56.97	370.00	259.00	77.78	482.00	337.40	101.32
5.0	3300	281.00	196.70	59.61	386.00	270.20	81.88	500.00	350.00	106.06
5.5	3270	288.00	201.60	61.65	396.00	277.20	84.77	514.00	359.80	110.03
6.0	3240	292.00	204.40	63.09	408.00	285.60	88.15	530.00	371.00	114.51
6.5	3210	292.00	204.40	**63.68**	419.00	293.30	91.37	546.00	382.20	119.07
7.0	3180	287.00	200.90	63.18	429.00	300.30	94.43	559.00	391.30	123.05
7.5	3150	280.00	196.00	62.22	436.00	305.20	96.89	573.00	401.10	127.33
8.0	3120	272.00	190.40	61.03	445.00	311.50	99.84	580.00	406.00	130.13
8.5	3090	264.00	184.80	59.81	448.00	313.60	101.49	586.00	410.20	132.75
9.0	3060				451.00	315.70	103.17	593.00	415.10	135.65
9.5	3030				453.00	317.10	104.65	604.00	422.80	139.54
10.0	3000				452.00	316.40	105.47	612.00	428.40	142.80
11.0	2940				450.50	315.35	107.26	615.00	430.50	146.43
11.5	2910				448.00	313.60	**107.77**	619.00	433.30	148.90
12.0	2880							620.00	434.00	150.69
12.5	2850							619.00	433.30	152.04
13.0	2820							615.00	430.50	**152.66**
13.5	2790							607.00	424.90	152.29

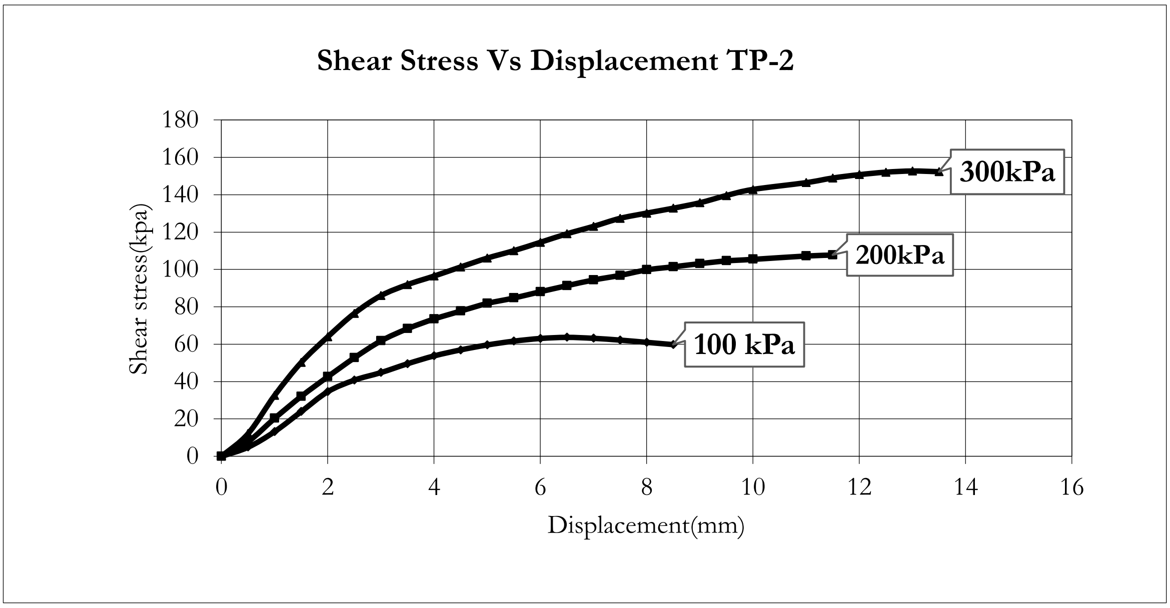

Figure F-3: Shear stress versus displacement (TP-2)

Angle of internal friction, Ø=	24^0		Cohesion , C (kN/m^2) =	19

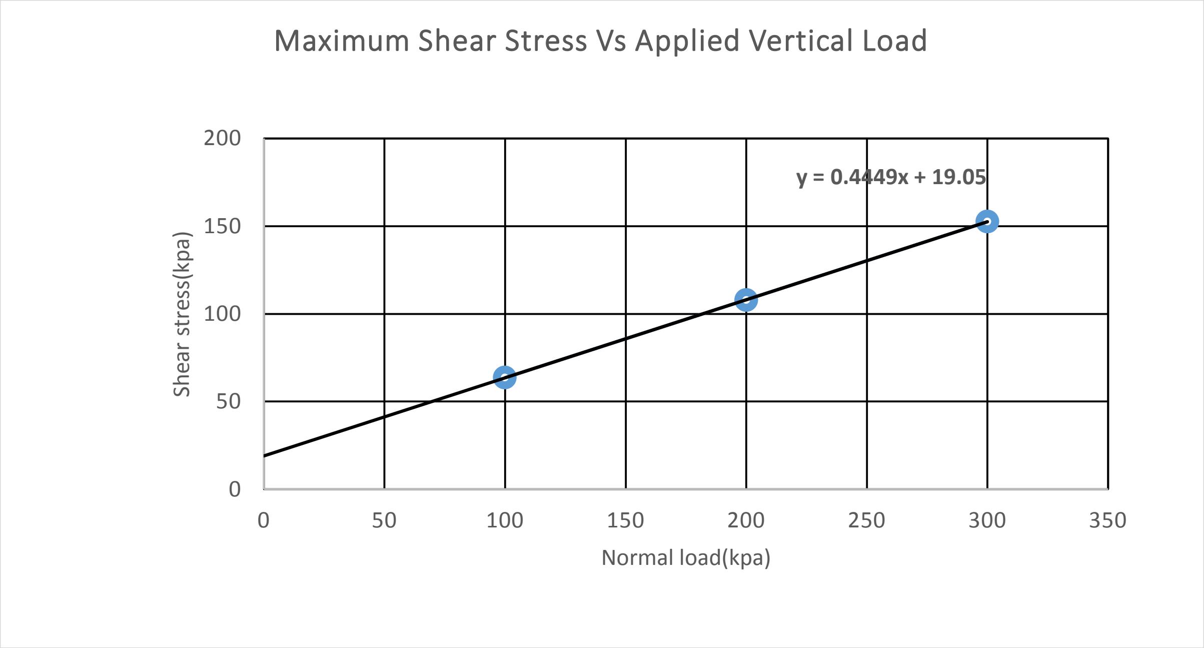

Figure F-4: Shear stress versus applied load (TP-2)

Table F-3 Direct shear test results on Reinforced soil (45mm, 1%, TP-1)

Sample No.	**TP-1**	Sample Depth, m:	=0.60		
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div		
Length of sample :	60 mm	Rate of strain :	1.6 mm/min		
Width of sample:	60 mm	Moisture content, %	26.5	Sample Condition:	disturbed

		Applied Vertical Stress			Applied Vertical Stress			Applied Vertical Stress		
		100 kPa			**200 kPa**			**300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	35.00	24.50	6.86	50.00	26.60	7.45	80.00	28.00	7.84
1.0	3540	80.00	78.40	22.15	120.00	80.50	22.74	135.00	84.00	23.73
1.5	3510	130.00	100.10	28.52	158.00	110.60	31.51	195.00	122.50	34.90
2.0	3480	166.00	116.20	33.39	195.00	136.50	39.22	255.00	178.50	51.29
2.5	3450	183.00	128.10	37.13	235.00	164.50	47.68	325.00	227.50	65.94
3.0	3420	201.00	140.70	41.14	263.00	184.10	53.83	385.00	269.50	78.80
3.5	3390	217.00	151.90	44.81	292.00	204.40	60.29	438.00	306.60	90.44
4.0	3360	228.00	159.60	47.50	318.00	222.60	66.25	481.00	336.70	100.21
4.5	3330	237.00	165.90	49.82	340.00	238.00	71.47	512.00	358.40	107.63
5.0	3300	247.00	172.90	52.39	358.00	250.60	75.94	537.00	375.90	113.91
5.5	3270	255.00	178.50	54.59	380.00	266.00	81.35	565.00	395.50	120.95
6.0	3240	262.50	183.75	56.71	396.00	277.20	85.56	590.00	413.00	127.47
6.5	3210	268.00	187.60	58.44	410.00	287.00	89.41	609.00	426.30	132.80
7.0	3180	269.00	188.30	59.21	422.00	295.40	92.89	628.00	439.60	138.24
7.5	3150	268.00	187.60	59.56	432.00	302.40	96.00	642.00	449.40	142.67
8.0	3120	265.50	185.85	59.57	439.00	307.30	98.49	654.00	457.80	146.73
8.5	3090	265.00	185.50	60.03	446.00	312.20	101.04	666.00	466.20	150.87
9.0	3060	264.80	185.36	60.58	452.00	316.40	103.40	670.00	469.00	153.27
9.5	3030	264.00	184.80	60.99	457.00	319.90	105.58	671.00	469.70	155.02
10.0	3000	262.50	183.75	61.25	461.00	322.70	107.57	672.00	470.40	156.80
11.0	2940	262.50	183.75	**62.50**	464.00	324.80	110.48	668.00	467.60	159.05
11.5	2910	258.00	180.60	62.06	465.50	325.85	111.98	665.00	465.50	159.97
12.0	2880				466.50	326.55	113.39	663.00	464.10	161.15
12.5	2850				467.00	326.90	114.70	653.00	457.10	160.39
13.0	2820				467.00	326.90	115.92	652.00	456.40	161.84
13.5	2790				466.00	326.20	**116.92**	651.00	455.70	**163.33**

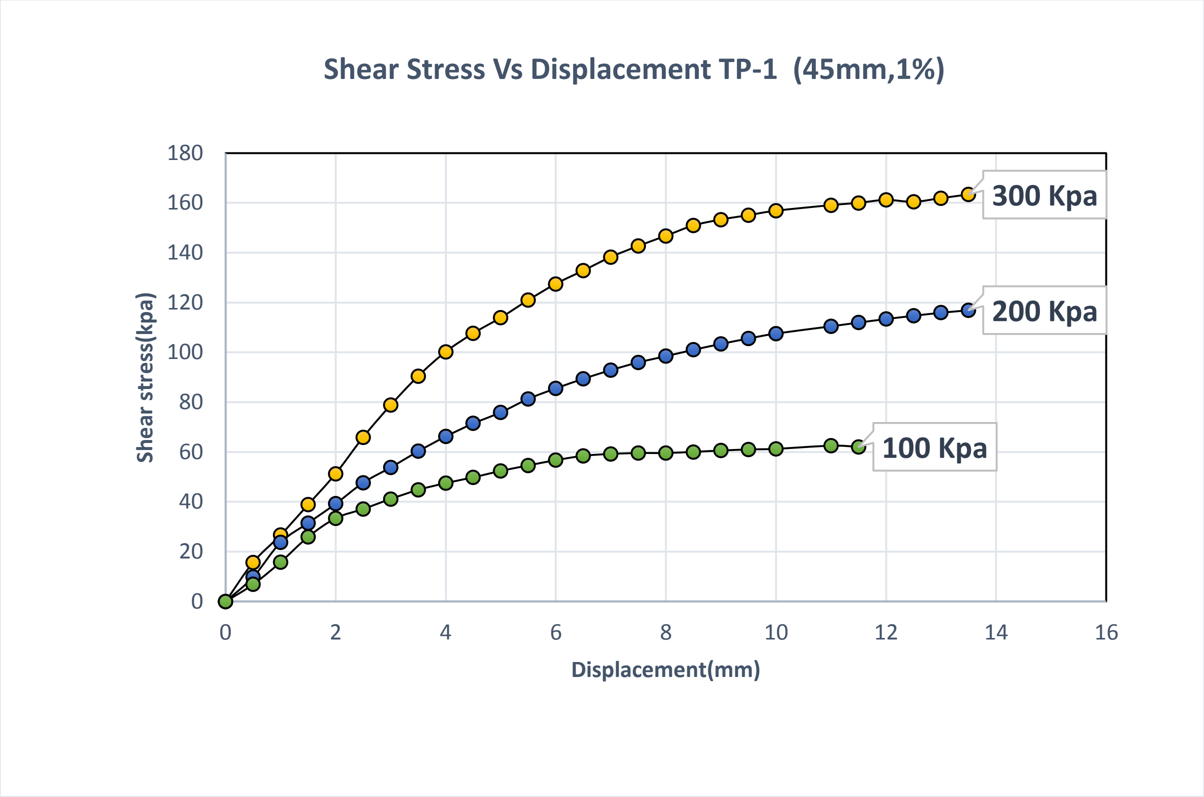

Figure F-5: Shear stress versus displacement (45mm, 1%)

Angle of internal friction, Ø=	26.65^0		Cohesion , C (kN/m^2) =	13.4

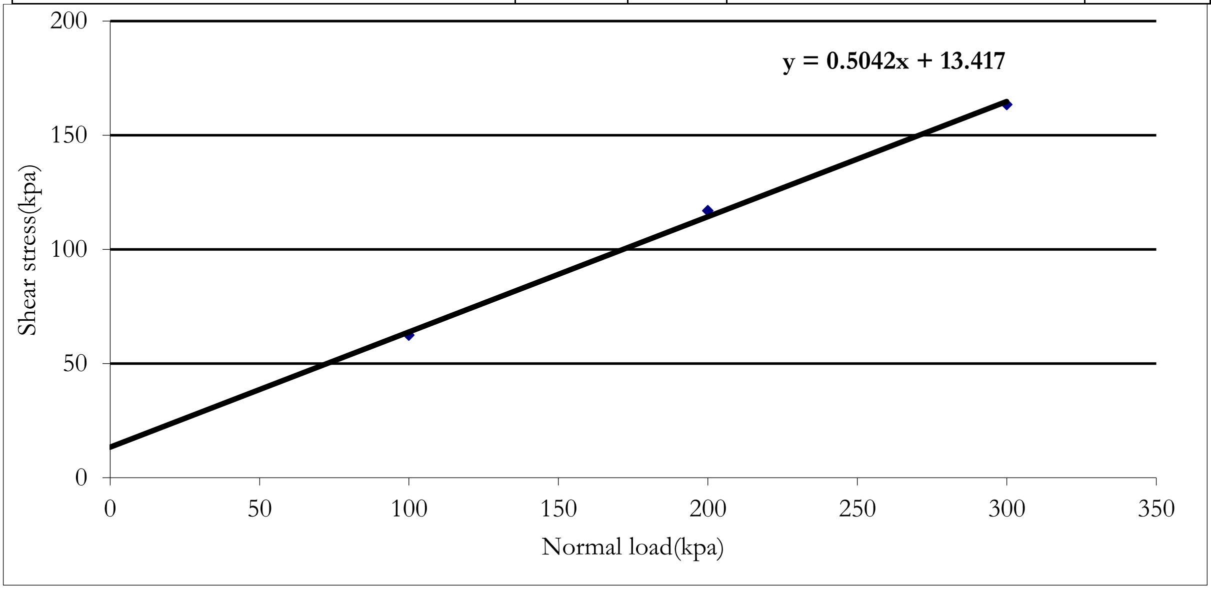

Figure F-6: Shear stress versus applied load (45mm, 1%)

Table F-4 Direct shear test results on Reinforced soil (45mm, 0.5 %, TP-1)

Sample No.	**TP-1**	Sample Depth, m:	0.60		
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div		
Length of sample :	60 mm	Rate of strain :	1.6 mm/min		
Width of sample:	60 mm	Moisture content, %	26.5	Sample Condition:	disturbed

		Applied Vertical Stress			Applied Vertical Stress			Applied Vertical Stress		
		100 kPa			**200 kPa**			**300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	22.00	15.40	4.31	30.00	21.00	5.88	65.00	45.50	12.75
1.0	3540	78.00	54.60	15.42	80.00	56.00	15.82	145.00	101.50	28.67
1.5	3510	119.00	83.30	23.73	140.00	98.00	27.92	230.00	161.00	45.87
2.0	3480	148.00	103.60	29.77	180.00	126.00	36.21	305.00	213.50	61.35
2.5	3450	170.00	119.00	34.49	220.00	154.00	44.64	365.00	255.50	74.06
3.0	3420	192.00	134.40	39.30	260.00	182.00	53.22	415.00	290.50	84.94
3.5	3390	215.00	150.50	44.40	305.00	213.50	62.98	450.00	315.00	92.92
4.0	3360	235.00	164.50	48.96	340.00	238.00	70.83	475.00	332.50	98.96
4.5	3330	251.00	175.70	52.76	350.50	245.35	73.68	495.00	346.50	104.05
5.0	3300	260.00	182.00	55.15	361.00	252.70	76.58	517.00	361.90	109.67
5.5	3270	266.00	186.20	56.94	372.00	260.40	79.63	535.00	374.50	114.53
6.0	3240	267.00	186.90	57.69	390.40	273.28	84.35	555.00	388.50	119.91
6.5	3210	267.00	186.90	58.22	415.60	290.92	90.63	570.00	399.00	124.30
7.0	3180	266.50	186.55	58.66	428.00	299.60	94.21	585.00	409.50	128.77
7.5	3150	263.50	184.45	58.56	439.50	307.65	97.67	597.00	417.90	132.67
8.0	3120	262.50	183.75	58.89	457.40	320.18	102.62	608.00	425.60	136.41
8.5	3090	261.80	183.26	59.31	465.00	325.50	105.34	613.00	429.10	138.87
9.0	3060	260.50	182.35	59.59	468.00	327.60	107.06	616.00	431.20	140.92
9.5	3030	259.00	181.30	59.83	465.00	325.50	107.43	615.00	430.50	142.08
10.0	3000	258.00	180.60	60.20	457.50	320.25	106.75	614.00	429.80	143.27
11.0	2940	254.00	177.80	**60.48**	451.50	316.05	107.50	613.00	429.10	145.95
11.5	2910	250.00	175.00	60.14	448.00	313.60	107.77	613.00	429.10	147.46
12.0	2880				446.00	312.20	108.40	611.00	427.70	148.51
12.5	2850				446.00	312.20	109.54	609.00	426.30	149.58
13.0	2820				446.00	312.20	110.71	609.00	426.30	151.17
13.5	2790				445.50	311.85	**111.77**	608.00	425.60	**152.54**

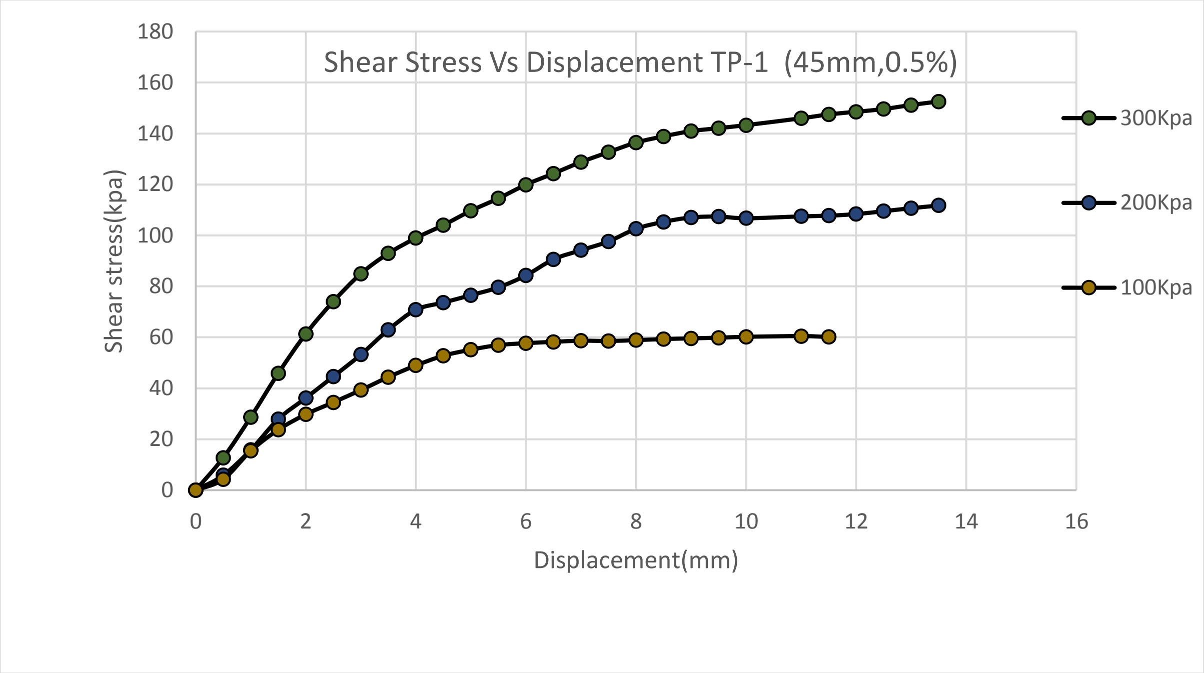

Figure F-7: Shear stress versus displacements (45mm, 0.5%)

Angle of internal friction, Ø=	24.46^0		Cohesion , C (kN/m^2) =	16

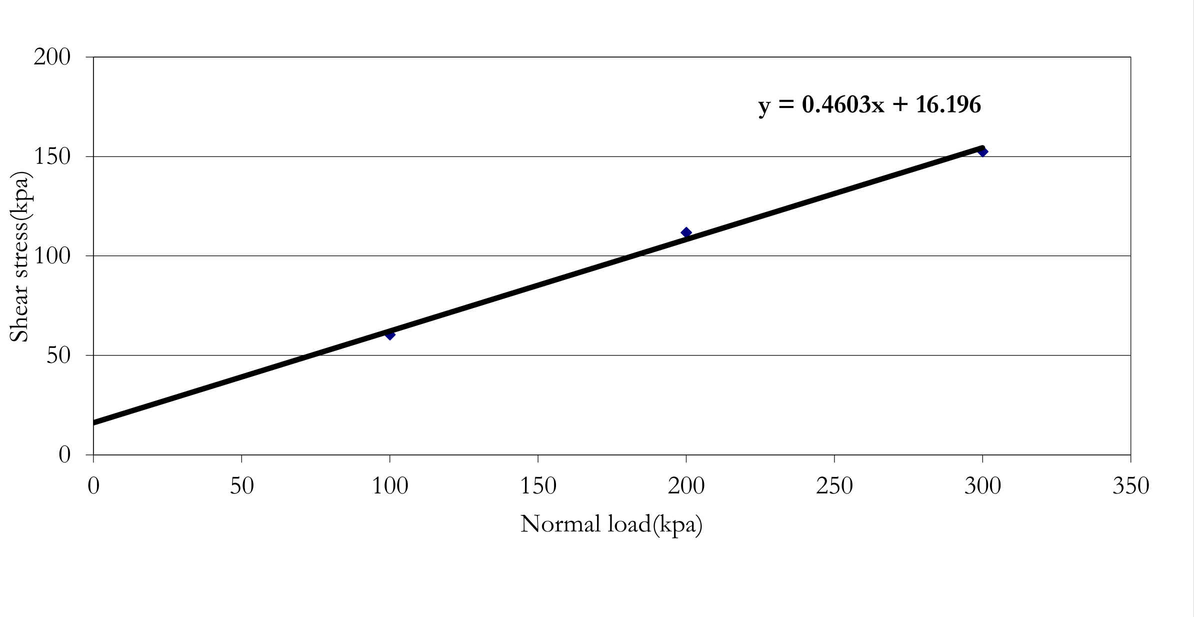

Figure F-8: Shear stress versus applied loads (45mm, 0.5%)

Table F-5 Direct shear test results on Reinforced soil (15mm, 1%, TP-1)

Sample No.	TP-1	Sample Depth, m:	0.6m		
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div		
Length of sample :	60 mm	Rate of strain :	1.6 mm/min		
Width of sample:	60 mm	Moisture content, %	26.5	Sample Condition:	disturbed

		Applied Vertical Stress			Applied Vertical Stress			Applied Vertical Stress		
		100 kPa			**200 kPa**			**300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	31.00	21.70	6.08	38.00	26.60	7.45	55.00	38.50	10.78
1.0	3540	62.00	43.40	12.26	115.00	80.50	22.74	142.00	99.40	28.08
1.5	3510	114.00	79.80	22.74	167.00	116.90	33.30	200.00	140.00	39.89
2.0	3480	143.00	100.10	28.76	235.00	164.50	47.27	270.00	189.00	54.31
2.5	3450	169.00	118.30	34.29	280.00	196.00	56.81	313.00	219.10	63.51
3.0	3420	188.00	131.60	38.48	305.00	213.50	62.43	365.00	255.50	74.71
3.5	3390	205.00	143.50	42.33	363.00	254.10	74.96	415.00	290.50	85.69
4.0	3360	221.00	154.70	46.04	405.00	283.50	84.38	440.00	308.00	91.67
4.5	3330	232.00	162.40	48.77	420.00	294.00	88.29	462.00	323.40	97.12
5.0	3300	245.00	171.50	51.97	445.00	311.50	94.39	481.00	336.70	102.03
5.5	3270	251.00	175.70	53.73	448.00	313.60	95.90	498.00	348.60	106.61
6.0	3240	265.00	185.50	57.25	468.00	327.60	101.11	503.00	352.10	108.67
6.5	3210	271.00	189.70	59.10	498.00	348.60	108.60	530.00	371.00	115.58
7.0	3180	272.00	190.40	59.87	505.00	353.50	111.16	544.00	380.80	119.75
7.5	3150	272.00	190.40	60.44	515.00	360.50	114.44	558.00	390.60	124.00
8.0	3120	272.00	190.40	61.03	516.00	361.20	115.77	568.00	397.60	127.44
8.5	3090	273.00	191.10	61.84	515.00	360.50	116.67	578.00	404.60	130.94
9.0	3060	274.00	191.80	62.68	511.00	357.70	116.90	592.00	414.40	135.42
9.5	3030	276.00	193.20	63.76	510.00	357.00	117.82	602.00	421.40	139.08
10.0	3000	278.00	194.60	64.87	509.00	356.30	118.77	618.00	432.60	144.20
11.0	2940	276.00	193.20	**65.71**	507.00	354.90	120.71	634.00	443.80	150.95
11.5	2910	273.00	191.10	65.67	502.00	351.40	120.76	652.00	456.40	156.84
12.0	2880				498.00	348.60	121.04	672.00	470.40	163.33
12.5	2850				494.00	345.80	121.33	670.00	469.00	164.56
13.0	2820				491.00	343.70	121.88	665.00	465.50	165.07
13.5	2790				488.00	341.60	**122.44**	660.00	462.00	**165.59**

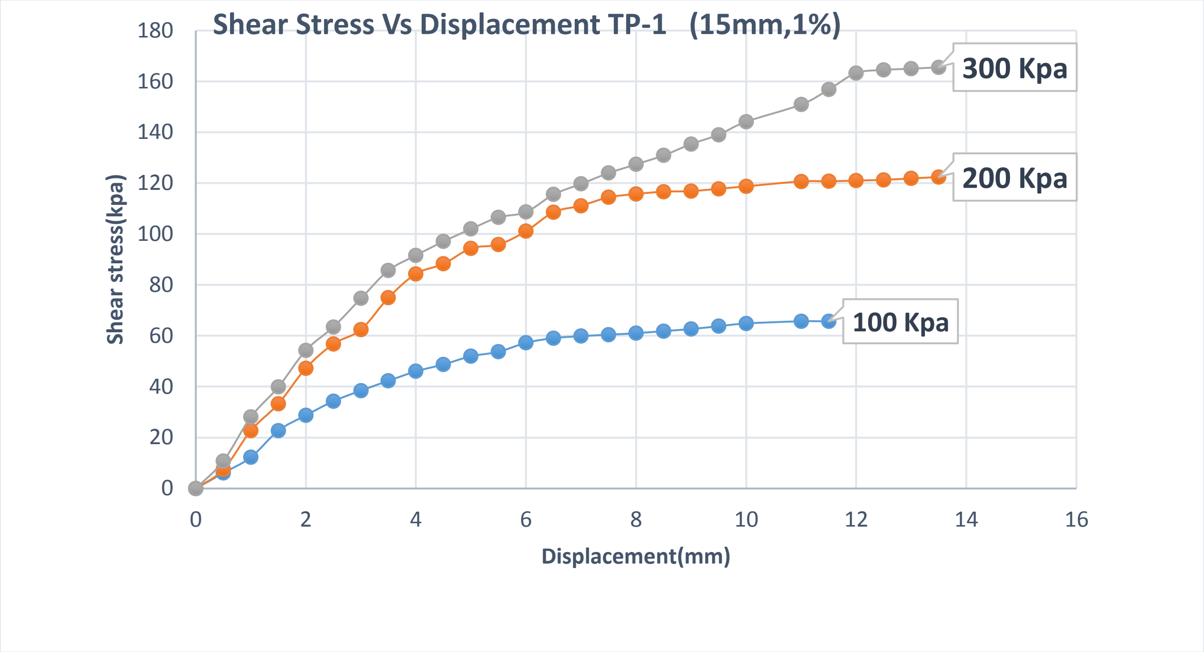

Figure F-9: Shear stress versus displacements (15mm, 1%)

Angle of internal friction, Ø=	26.3^0		Cohesion , C (kN/m^2) =	18

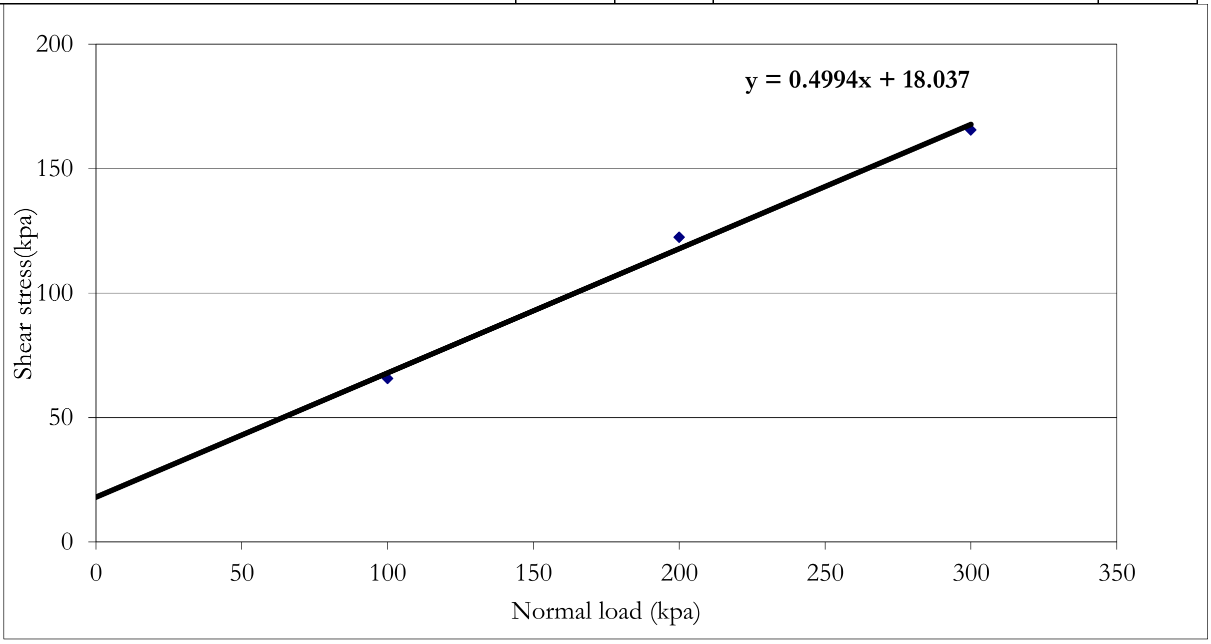

Figure F-10: Shear stress versus applied load (15mm, 1%)

Table F-6 Direct shear test results on Reinforced soil (15mm, 0.5%, TP-1)

Sample No.	TP-1	Sample Depth, m:	0.6m		
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div		
Length of sample :	60 mm	Rate of strain :	1.6 mm/min		
Width of sample:	60 mm	Moisture content, %	26.5	Sample Condition:	disturbed

		Applied Vertical Stress			Applied Vertical Stress			Applied Vertical Stress		
		100 kPa			**200 kPa**			**300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	26.90	18.850	5.28	37.23	26.60	7.30	51.76	36.20	10.15
1.0	3540	51.88	36.320	10.26	101.90	71.30	20.14	129.70	90.80	25.65
1.5	3510	97.77	68.440	19.50	152.00	106.90	30.30	180.00	126.00	35.89
2.0	3480	135.53	94.90	27.56	224.00	157.50	45.27	255.00	178.50	51.31
2.5	3450	169.00	118.30	32.29	270.00	189.00	54.81	298.20	208.80	60.51
3.0	3420	188.00	131.60	35.48	295.00	206.50	60.43	350.00	245.50	71.71
3.5	3390	205.00	143.50	41.33	353.00	244.10	72.96	410.00	280.50	80.69
4.0	3360	221.00	154.70	45.04	3955.00	233.50	82.38	435.00	305.00	88.67
4.5	3330	232.00	162.40	47.77	410.00	284.00	86.29	462.00	320.40	95.12
5.0	3300	245.00	171.50	50.97	435.00	311.50	92.39	481.00	335.70	100.03
5.5	3270	251.00	175.70	51.73	438.00	313.60	93.90	498.00	348.60	103.61
6.0	3240	265.00	185.50	56.25	458.00	327.60	99.11	503.00	352.10	105.67
6.5	3210	251.00	189.70	58.10	488.00	348.60	106.60	530.00	371.00	110.58
7.0	3180	252.00	190.40	59.87	505.00	353.50	109.16	544.00	380.80	114.75
7.5	3150	252.00	180.40	60.44	515.00	360.50	111.44	558.00	390.60	118.00
8.0	3120	252.00	180.40	60.03	516.00	361.20	113.77	568.00	397.60	122.44
8.5	3090	253.00	181.10	60.84	515.00	360.50	113.97	578.00	404.60	126.94
9.0	3060	265.20	185.68	60.68	511.00	357.70	114.90	592.00	414.40	130.42
9.5	3030	263.20	184.10	60.76	510.00	357.00	115.82	602.00	421.40	135.08
10.0	3000	260.80	182.61	60.87	500.44	350.30	116.77	608.00	432.60	140.20
11.0	2940	258.30	180.81	**61.50**	499.00	344.90	116.81	614.00	443.80	145.95
11.5	2910	252.20	176.54	60.67	486.00	340.40	116.96	626.20	439.00	150.84
12.0	2880				481.00	337.60	117.04	643.40	450.20	156.33
12.5	2850				478.00	334.80	117.33	641.50	449.00	157.56
13.0	2820				474.88	332.42	117.88	636.80	445.75	158.07
13.5	2790				470.30	329.22	**118.00**	636.50	445.50	**159.7**

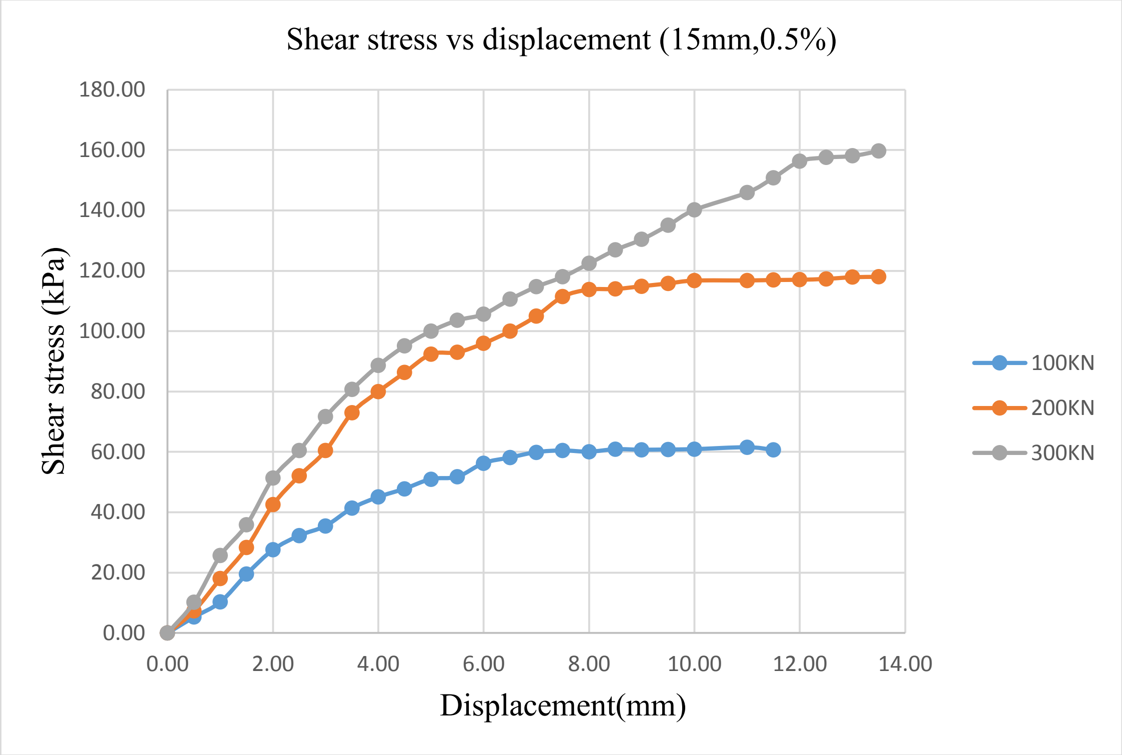

Figure F-11: Shear stress versus displacements (15mm, 0.5%)

Angle of internal friction, Ø=	26.1^0		Cohesion , C (kN/m^2) =	15

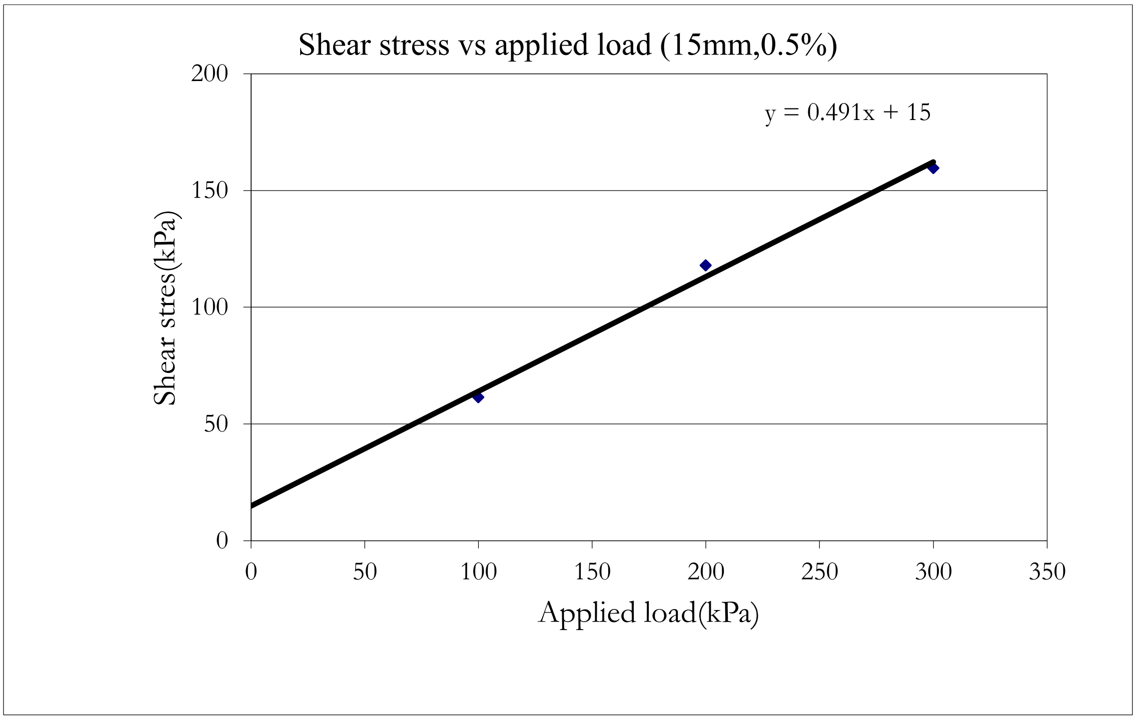

Figure F-12: Shear stress versus applied load (15mm, 0.5%)

Appendix –G: California Bearing Ratio (1 point -CBR)

G-1 CBR Test results on natural sol

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm2)	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-1. Un soaked CBR

Blow/ Layer	56/5	Optimum MC.	26.5
CBR Value, %	**7.97**	Max. Dry Density	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	6.0	153	0.08		
1.27	17.9	456	0.24		
1.91	28.0	713	0.37		
2.54	41.8	1064	0.55	6.9	7.97
3.81	53.7	1367	0.71		
5.08	59.7	1519	0.79	10.3	7.62
7.62	83.6	2127	1.10		
10.16	119.4	3039	1.57		
12.70	155.2	3950	2.04		

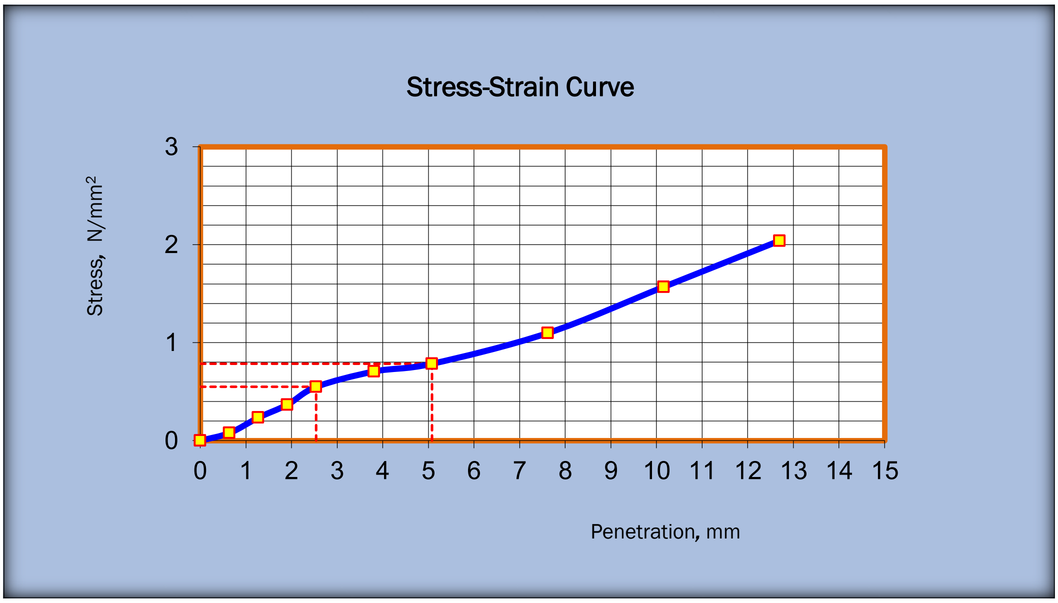

Figure G-1: Stress-strain curve (Un-soaked)

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm$^{2)}$	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-2.Soaked CBR

Blow/ Layer	56/5	Optimum MC.	26.5
CBR Value, %	**5.52**	Max. Dry Density	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	6.0	153	0.08		
1.27	11.9	304	0.16		
1.91	17.9	456	0.24		
2.54	26.9	684	0.35	6.9	5.52
3.81	29.9	760	0.39		
5.08	38.8	987	0.51	10.3	5.0
7.62	47.8	1215	0.63		
10.16	65.7	1671	0.86		
12.70	83.6	2127	1.10		

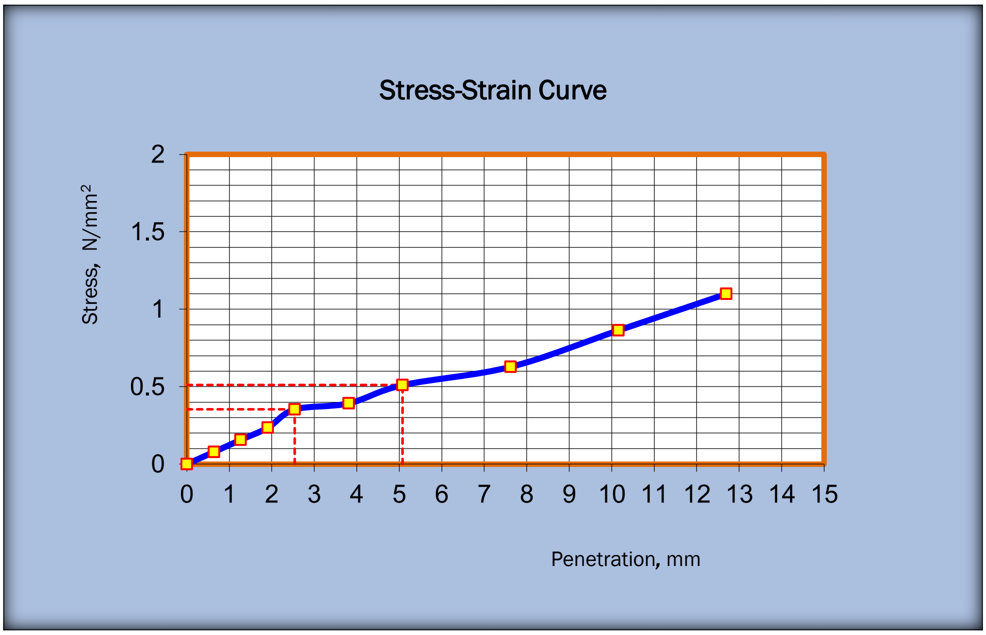

Figure G-2: Stress-strain curve (soaked)

G-2. CBR Test Results on Reinforced soil sample

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm$^{2)}$	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-3.CBR (0.5%,15mm)

Blow/ Layer	56/5		
CBR Value, %	**7.68**	Optimum MC. Max. Dry Density	26.5 1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	11.2	284	0.15		
1.27	22.4	571	0.29		
1.91	33.6	855	0.44		
2.54	40.3	1025	0.53	6.9	7.68
3.81	51.5	1311	0.68		
5.08	56.0	1424	0.74	10.3	7.14
7.62	71.6	1823	0.94		
10.16	100.7	2563	1.32		
12.70	123.2	3134	1.62		

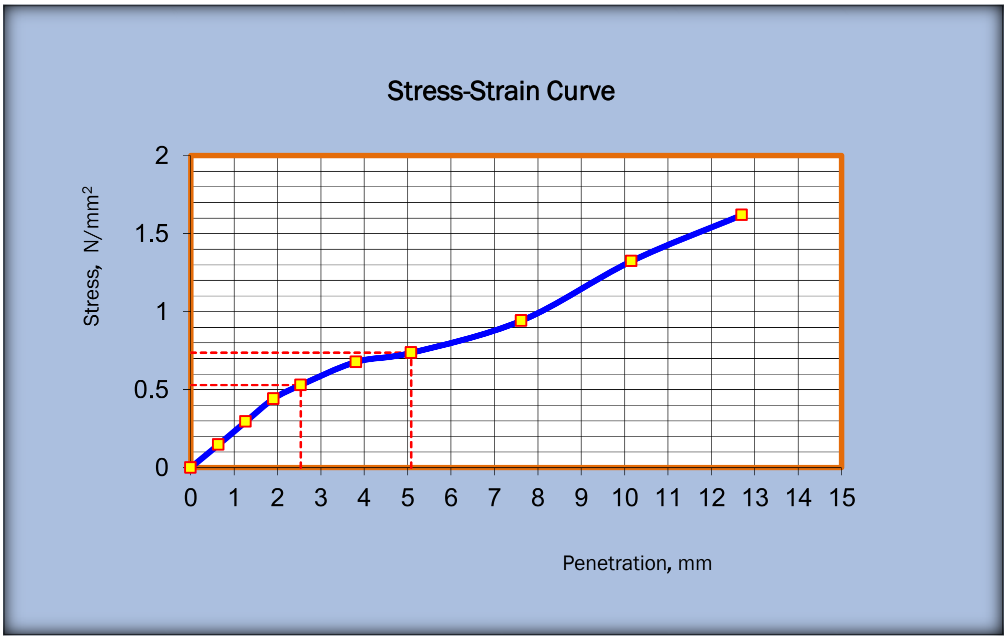

Figure G-3: Stress-strain curve (0.5%, 15mm)

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm²⁾	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-4.CBR (0.5%,30mm)

Blow/ Layer	56/5	Optimum MC.	26.5
CBR Value, %	**9.47**	Max. Dry Density	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	11.8	300	0.16		
1.27	27.9	710	0.37		
1.91	34.6	881	0.46		
2.54	49.7	1265	0.65	6.9	9.47
3.81	66.3	1687	0.87		
5.08	73.5	1871	0.97	10.3	9.39
7.62	80.0	2036	1.05		
10.16	114.9	2924	1.51		
12.70	142.5	3627	1.87		

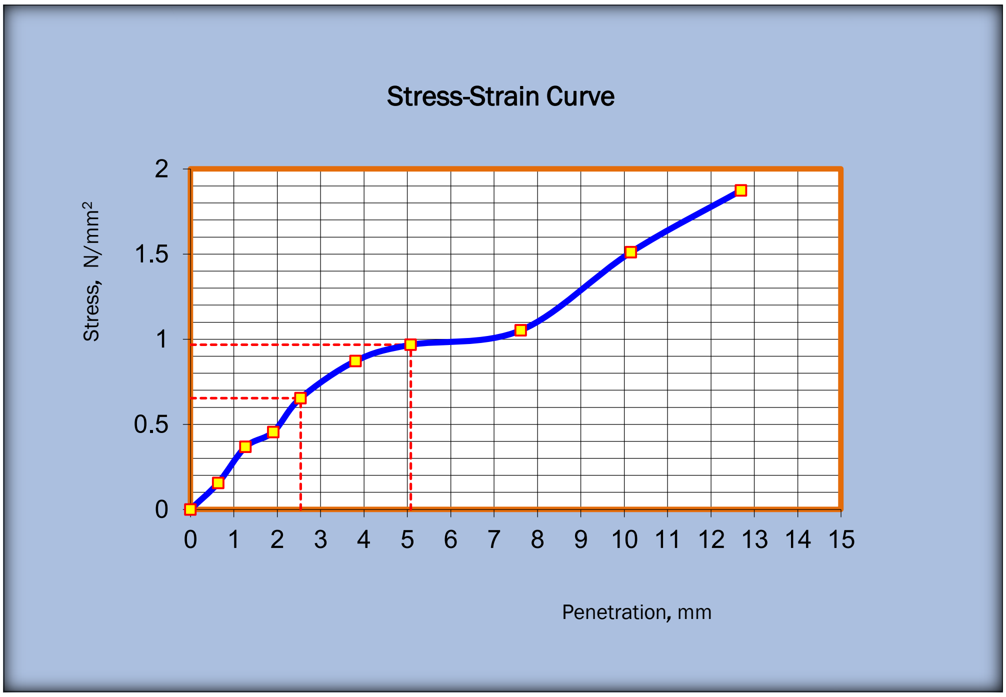

Figure G-4: Stress-strain curve (0.5%, 30mm)

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm$^{2)}$	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-5.CBR (0.5%,45mm)

Blow/ Layer	56/5		
CBR Value, %	**11.76**	Optimum MC.	26.5
		Max. Dry Density	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	12.4	316	0.16		
1.27	31.8	809	0.42		
1.91	40.8	1038	0.54		
2.54	61.7	1570	0.81	6.9	11.76
3.81	70.6	1797	0.93		
5.08	84.0	2138	1.10	10.3	10.73
7.62	96.0	2443	1.26		
10.16	121.4	3090	1.60		
12.70	160.2	4077	2.11		

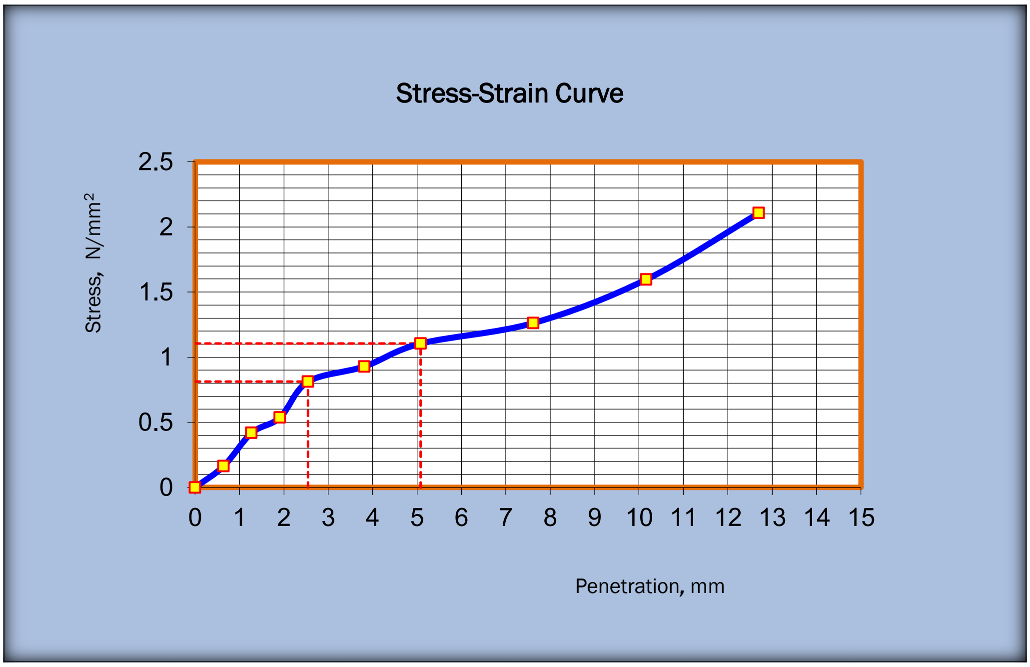

Figure G-5: Stress-strain curve (0.5%, 45mm)

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm$^{2)}$	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-6.CBR(1%,15mm)

Blow/ Layer	56/5	Optimum MC.	26.5
CBR Value, %	**14.12**	Max. Dry Density	1.3

Penetration (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	23.7	603	0.31		
1.27	45.4	1154	0.60		
1.91	60.9	1549	0.80		
2.54	74.1	1885	0.97	6.9	14.12
3.81	95.5	2431	1.26		
5.08	108.6	2765	1.43	10.3	13.87
7.62	139.7	3555	1.84		
10.16	187.4	4770	2.47		
12.70	234.0	5956	3.08		

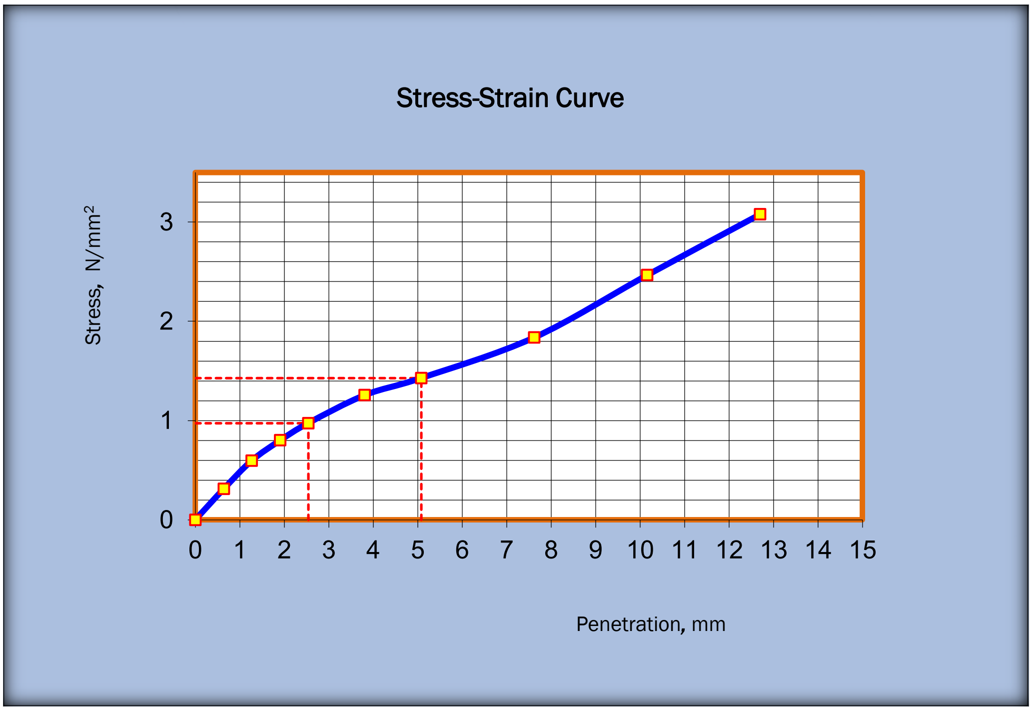

Figure G-6: Stress-strain curve (1%, 15mm)

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,(mm$^{2)}$	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-7.CBR (1%,30mm)

Blow/ Layer	56/5	Optimum MC.	26.5
CBR Value, %	**14.69**	Max. Dry Density	1.3

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	21.5	547	0.28		
1.27	48.4	1231	0.64		
1.91	68.0	1732	0.89		
2.54	77.0	1961	1.01	6.9	14.69
3.81	93.1	2370	1.22		
5.08	112.8	2871	1.48	10.3	14.40
7.62	139.7	3555	1.84		
10.16	179.1	4558	2.36		
12.70	225.7	5743	2.97		

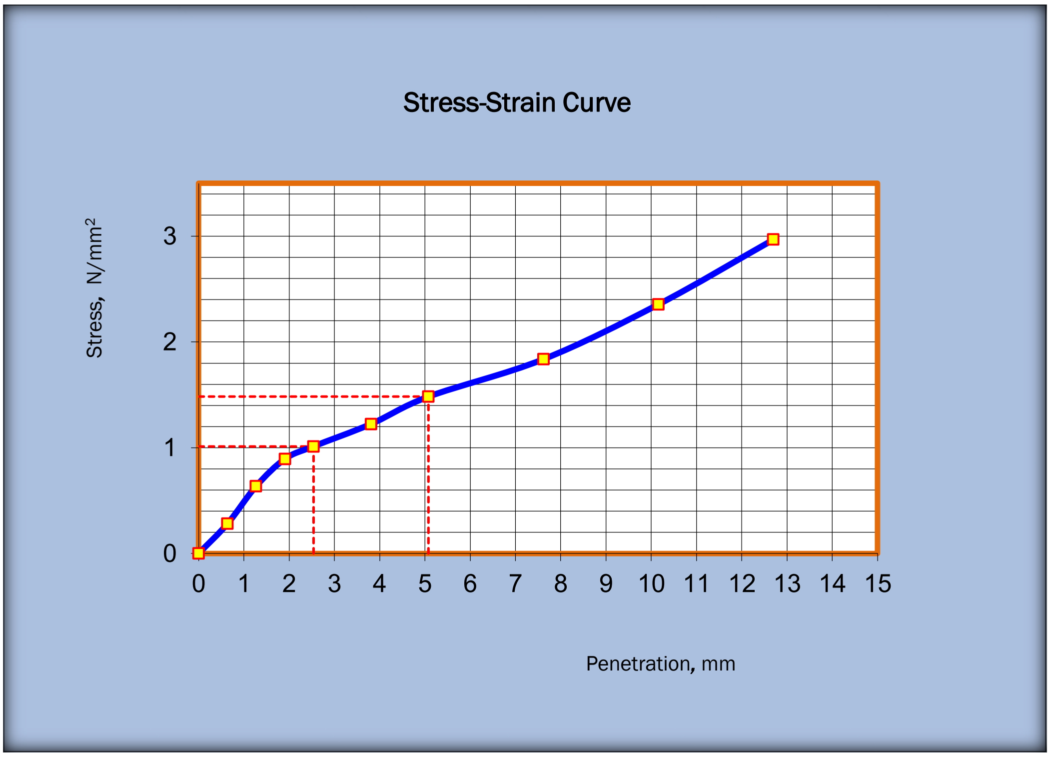

Figure G-7: Stress-strain curve (1%, 30mm)

Ring Calibration Factor, (N/Div.)	25.450
Plunger Area,($mm^{2)}$	1935
Rate of strain,(mm/min)	1.27
Rammer wt. (kg)	2.5

Table G-8.CBR(1%,45mm)

Blow/ Layer	56/5	Optimum MC.	26.5
CBR Value, %	**17.75**	Max. Dry Density	1.3

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	28.6	727.9	0.38		
1.27	53.7	1367	0.71		
1.91	76.4	1944	1.00		
2.54	93.1	2370	1.22	6.9	17.75
3.81	109.8	2795	1.44		
5.08	136.1	3464	1.79	10.3	17.38
7.62	152.8	3889	2.01		
10.16	199.4	5075	2.62		
12.70	244.8	6229	3.22		

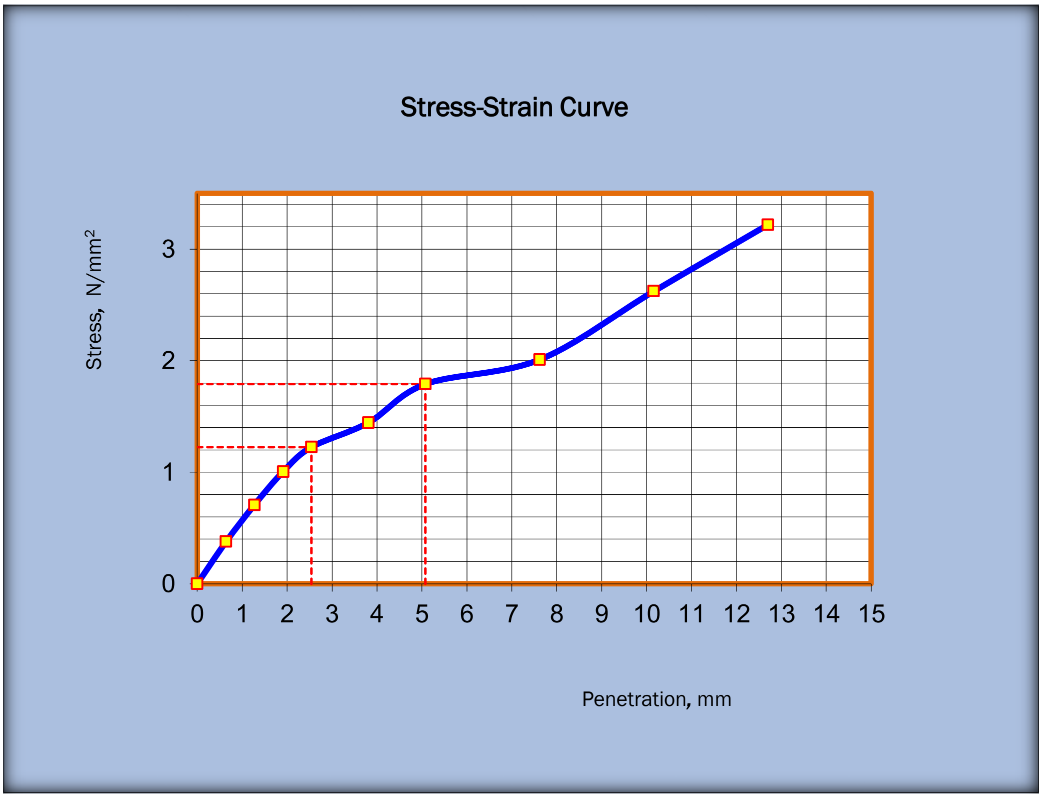

Figure G-8: Stress-strain curve (1%, 45mm)

The shear strength can be computed from the following equation:

Total Shear stress = $C + \sigma \tan\emptyset$ $\sigma = \frac{N}{A}$

Where: N = normal vertical force A=Corrected area

C= cohesion $\sigma = normal\ stress$

Ø=Angle of internal frictions

Shear load (N) = Proving reading * Ring calibration factor (0.7N/dial)

Shear Stress (N/mm^2) = Shear Load / corrected area

Corrected area (mm^2) = Initial area (60 x 60) – (1-horizontal strain)

$$\text{Horizontal strain } (\epsilon) = \frac{\Delta L}{L0}$$

The CBR can be computed from the following equation:

Load (N) = Ring Reading (div.)* Ring calibration factor (25.45N/div.)

Stress (N/mm^2) =Load (N)/Plunger area (mm^2)

$$\boxed{\text{CBR} = \frac{\text{Stress}}{\text{Standard stress}} \text{x100}}$$