Civil Engineering Department
Wolkite University, College of Engineering and Technology

Modifying Properties of Black-cotton Soil by Wood-ash

Atirsagn Alemu Ademo[1], Gemtesa Beza Kebeda [2]

[1]Wolkkite University, Civil Engineering Department, ID Number ENGR/133/08
[2]Wolkkite University, Civil Engineering Department, ID Number ENGR/402/08

Advisors

Mustefa Teha (M.Sc.)

Damiso Abire (M.Sc.)

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As members of the examining board of the final B.Sc. open defense, we verify that we have read and evaluated the final BSc thesis/project prepared by Atirsagn Alemu and Gemtesa Beza entitled **Modifying Properties of Black-cotton Soil by Wood-ash**, and recommended for acceptance as a fulfillment of the requirement of **B.Sc. in Civil Engineering**

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Chairman/Coordinator	Signature	Date
______________________	______________________	______________________
Advisor	Signature	Date
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Preface

This document is a report as a part of fulfilment for a Bachelor of Science in Civil Engineering. The study is conducted by Atirsagn Alemu and Gemtesa Beza.

Abstract

Soil is a base of structure, which actually supports the structure from beneath and distributes the load effectively. If the stability of the soil is not adequate then failure of structure occurs in form of settlement, cracks etc. Expansive soil also known as black cotton soil is more responsible for such situations and this is due to presence of montmorillonite mineral in it, which has ability to undergo large swelling and shrinkage. To overcome this, properties of soil must be improved by artificial means known as 'Soil Stabilization'. It is a technique which improvises one or more soil properties by mechanical, cementing and chemical use. Many research has been conducted for stabilization of soil by using cementing, chemical materials e.g. fly ash, cement, Calcium chloride, Sodium chloride etc. Most of Ethiopian population uses fire wood. Combustion of wood produces ash after burnt, the resultant ash is known as 'Wood Ash'. It is a material that can be used to improve the existing properties of black cotton soil. In this study laboratory experiments were conducted on black cotton soil with partial replacement by Wood Ash (5%, 10%, and 15%). This paper highlights significant increase in properties of black cotton soil obtained at 10% replacement of Wood Ash without any chemical or cementing material.

KEYWORDS: Black cotton Soil, wood ash, moisture content, specific gravity, dry density.

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Table of Contents

Preface..II

Abstract.. III

Acknowledgement IV

Table of Contents V

1 Introduction... 1

1.1 Background of the study 1

1.2 Statement of problem 2

1.3 Research question.. 2

1.4 Objectives of the Study 2

1.4.1 General Objective 2

1.4.2 Specific Objectives 2

1.5 Significance of the Study 3

1.6 Scope of the study 3

1.7 Limitation of the Study 3

1.8 Organization of the Paper... 3

2 Literature Review.. 5

2.1 Introduction 5

2.2 Mechanical stabilization techniques.. 6

2.3 Chemical stabilization techniques 6

2.3.1 Engineering Properties of Black cotton soil Modified with Fly ash and Cement 6

2.3.2 Effect of Expansive Soil on Foundation and Its Remedies...................................... 6

2.3.3 Geotechnical properties of Black Cotton Soil Stabilized with Furnace Dust and Dolomitic Lime 6

3 Research Methodology 8

3.1 Introduction 8

3.2 Research Design 8

3.2.1 Study Area 9

3.3 Sample Size and Sampling Technique 9

3.4 Mix design 10

3.5 Tests 11

3.5.1 Compaction Test (Moisture-Density Relation) 11

3.5.2 Atterberg limits 12

3.6 Method of Data Analysis 12

4 Results and Discussions 13

4.1 Introduction 13

4.2 Laboratory test result of none treated and treated of back cotton soil samples 13

4.2.1 Results of moisture content 13

4.2.2 Results of specific gravity 14

4.2.3 Plastic limit results 15

4.2.4 Liqiud limit 16

4.2.5 Plasticity Index 19

4.2.6 Compaction Test Result 19

5 Conclusions and Recommendations 22

5.1 Conclusions 22

5.2 Recommendations 23

References 24

Appendix 25

Appendix A: Experiment 1: Water Content Determination 25

Appendix B: Experiment 2: specific gravity determination 30

Appendix C: Experiment 3: Atterberg Limits 32

Appendix D: Experiment 4: Moisture-density Relation (compaction) test 42

Appendix E: Laboratory Pictures.. 52

List of tables

Table 4.1 Water contents of blackcotton soil with and without wood ash 13

Table 4.2 Results of specific gravity... 14

Table 4.3 Plastic limit with 0% of ash content 15

Table 4.4 plastic limit with 5% wood ash.. 15

Table 4.5 plastic limit with 10% wood ash.. 15

Table 4.6 plastic limit with 15% wood ash.. 16

Table 4.7 liqiud limit with 0% wood ash content 17

Table 4.8 liquid limit with 5% wood ash... 17

Table 4.9 liquid limit with 10% wood ash... 17

Table 4.10 liquid limit with 15% wood ash... 17

Table 4.11 plasticity and liquidity index.. 19

List of Figures

Figure 1.1Flow Chart of the Thesis 4

Figure 3.1Overall framework of the study 8

Figure 3.2Study Area: Gubrea, Wolkite, Ethiopia 9

Figure 3.3 Sampling from site 10

Figure 4.1 Graph for wood ash content Vs moisture content 13

Figure 4.2 Gaph of results of specific gravity 14

Figure 4.3 plastic limit Vs wood ash content 16

Figure 4.4 Water content Vs number of drops 18

Figure 4.5 Liquid limit Vs wood ash content 18

Figure 4.6 Dry density Vs water content 20

Figure 4.7 Dry density Vs wood ash content 20

1 Introduction

1.1 Background of the study

The fact that expansive soils are a major engineering problem due to the accruing cost involved in terms of economic loss when construction is undertaken without due consideration to the probability of their presence. The lack of information about the presence of expansive soils may lead to the mistake in structural foundation design, resulting in one of the factors of damage. The most obvious way in which expansive soils can damage foundations is by uplift as they swell with moisture increases. Swelling soils lift up and crack lightly-loaded, continues strip footings, and frequently cause distress in floor slabs. Because of the different building loads on different portions of a structure's foundation, the resultant uplift will vary in different areas. The biggest problem is that of differential water content. (Arindam, 2014)

Black Cotton soil: The property of volumetric changes with the change of atmospheric conditions makes black cotton soil dangerous to founded buildings. It swells excessively when wet and shrinks excessively when dry resulting terrible cracks in soil without any warning. It has a great affinity to water. During swelling, structure has uplift pressure and produces heave in the foundations, plinth beams, bottom of floors of buildings and canals, roads surfaces etc. and on shrinkage, cracks develop in walls, slabs, plinth protection, floors etc.(Uba Uge, 2017)

Wood ash is obtaining from wood charcoal. it is freely available and also having less compendious value due to which it act as a pozzalanic material, it is non-plastic material and hence it is good stabilizer material as it reduces the pollutant in certain amount, it increases the properties of soil when reacting with soil. In present study, wood ash was chosen which is suitable for fine grained soil. To increase the properties of soil, adding wood ash in percent to increase the properties of Black Cotton soil. (Arindam, 2014)

It is found from the literature that the chemical composition of wood ash implies that it can be used as a substitute of CaO (that contains about 30% CaO) for soil stabilization. Also it found the PH value of wood ash greater than 6 and specific gravity 1.67.(Nath et al., 2018)

The objective for study was to determine properties of virgin and treated black cotton soil, and to minimize the cost of construction.

1.2 Statement of problem

During the last decades, some construction difficulties of foundation resting on soft clay have been observed. These soils are treated as problematic soils as they have high compressibility and low shear strength. These soils pose higher strength at dry state and lose their strength when there is an increase in moisture content. These types of dispersive soils are also highly prone to erosion. Therefore, these soils are not fit for the construction of infrastructure on them as they have a high risk of settlement. Moreover, the available land for construction is very limited. Hence, it has become a challenging task for a foundation engineer to design and construct a foundation on such soft soil. Wood that is widely used as a fuel and energy sources has led to a strong increase in the amount of combustion residue. Wood ash is a gray material produced from the combustion of wood. It is generally discarded as waste and dumped outside of house or land†fill, which increase the volume of land fill. Therefore as an alternative solution, this ash can be used as a potential soil stabilizer through the chemical reaction.(Nath et al., 2018)

1.3 Research question

This research will answer the following main research question;

- What are the properties of black cotton soil without treatment?
- What are the properties of black cotton soil treated with different percentage of wood ash?

1.4 Objectives of the Study

1.4.1 General Objective

- The main objective of the study is to modify the properties of black cotton soil by wood ash.

1.4.2 Specific Objectives

The specific objectives of the study are the following: -

- To determine the properties of black cotton soil without treatment.
- To determine the properties of black cotton soil with treatment by different percentage of wood ash.

1.5 Significance of the Study

Since moisture change in the soils bring about severe movements of the mass, any structure built on such soils experiences recurring cracking and progressive damage. The study may come up the solution for such problems by replacing wood ash with similar volume. In addition, this study believed to be beneficiary since it aims at modifying properties of black cotton soil that cause to the increment cost of construction and settlement. Wood ash locally available, Rather than replacing, mixing wood ash with black cotton soil may reduce the cost of construction.

1.6 Scope of the study

The main objective of this study is to modify the properties of black cotton soil in Gubre town. There are many mechanisms to modify the properties of black cotton soil. However, the scope of this study is limited to wood ash.

1.7 Limitation of the Study

For this study, the researcher proposed to perform compaction test, Atterberg limit test, unconfined compression test, CBR test and triaxial test and study chemical properties of wood ash. Since, the apparatus are not available, due to the limitation of time and resource we are obligated to perform compaction test and Atterberg limit test and reduced the sample size to one.

1.8 Organization of the Paper

This study organized into five chapters. The first chapter focused on the introductory part of the study, which includes background of the study, statement of the problem, objectives, significance, scope and limitation of the study. The second chapter contains literature review part of the study in which theoretical and empirical literatures related with the issue were incorporated. The third chapter deals about the research methodology: research design, approach and method; sampling design, sources of data, data collection methods, analysis and presentation were incorporated. The fourth chapter is all about the data analysis and interpretation, and finally the fifth chapter wind up by conclusion and gives recommendations to the modification of black cotton soil by wood ash.

The following figure shows the organization and structure of the paper

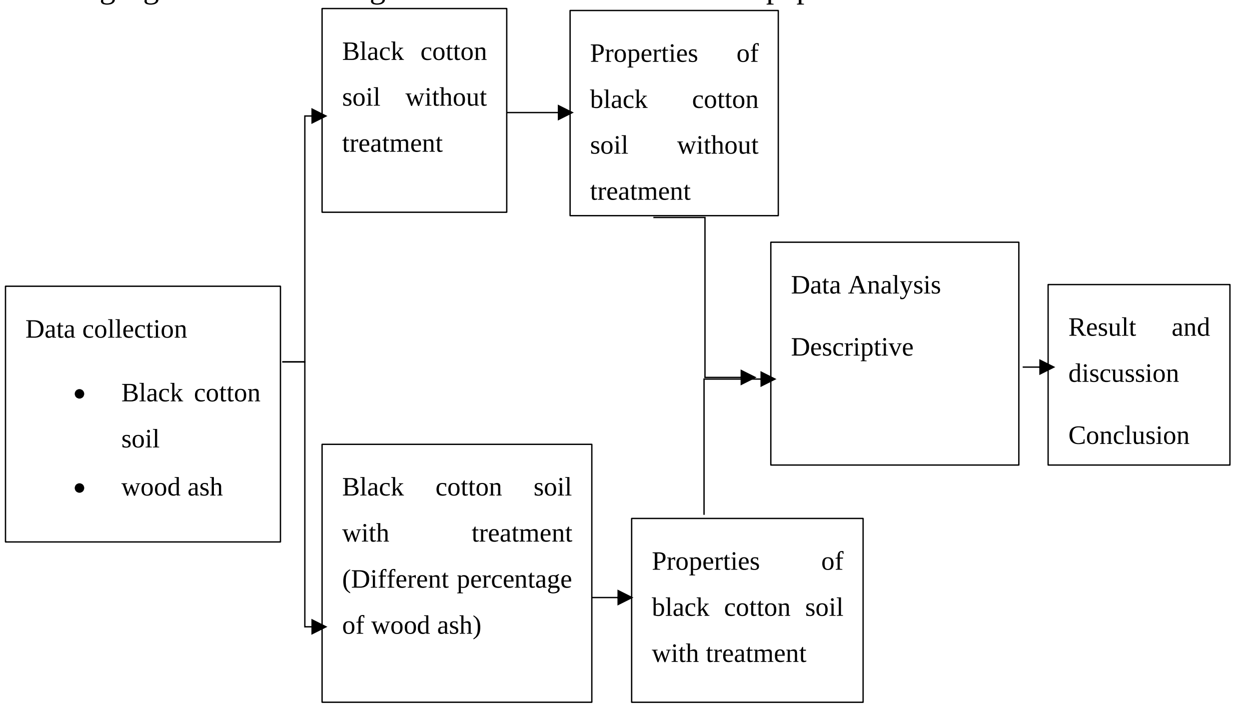

Figure 1.1Flow Chart of the Thesis

2 Literature Review

2.1 Introduction

Soil stabilization may be defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. Stabilization, in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. Soil stabilization refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties.(Haresh, 2015)

One may achieve stabilization by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture or by adding stabilizing material to an undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids. Soil stabilizing additives are used to improve the properties of less-desirable rood soils. When used these stabilizing agents can improve and maintain soil moisture content, increase soil particle cohesion and serve as cementing and water proofing agents. (Jaya Prakash, 2016)

A difficult problem in Civil Engineering works exists when the sub-grade is found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase. Many research have been done on the subject of soil stabilization using various additives, the most common methods of soil stabilization of clay soils in pavement work are cement and lime stabilization. The high strengths obtained from cement and lime stabilization may not always be required, however, and there is justification for seeking cheaper additives which may be used to alter the soil properties. Lime or calcium carbonate is oldest traditional chemical stabilizer used for soil stabilization.(Jaya Prakash, 2016)

2.2 Mechanical stabilization techniques

Mechanical Stabilization is the process of improving the properties of the soil by changing its gradation. This process includes soil compaction and densification by application of mechanical energy using various sorts of rollers, rammers, vibration techniques and sometime blasting. The stability of the soil in this method relies on the inherent properties of the soil material. Two or more types of natural soils are mixed to obtain a composite material which is superior to any of its components. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. (Arindam, 2014)

2.3 Chemical stabilization techniques

2.3.1 Engineering Properties of Black cotton soil Modified with Fly ash and Cement

Jaya Prakash Babu.V, Satyanarayana.P.V.V, Surya Manikantha and Abdul Moin (2016) Investigated Engineering Properties of Black cotton soil Modified with Fly ash and Cement and concluded that High Expansive Black cotton soil can be effectively utilized as a Geo technical material by addition of 30-40% fly ash and 6-10% cement. At these dosage of admixtures the Black cotton soil can be behaves non-plastic and non-swelling can reduce the problems of volume change.(Jaya Prakash et al., 2016)

2.3.2 Effect of Expansive Soil on Foundation and Its Remedies

Arindam Das and Sabyasachi Roy (2014) Studied Effect of Expansive Soil on Foundation and Its Remedies On the basis of their study, the following conclusions are made: 1. Foundation on expansive soil with proper study of the expansive soil and measures can be safe. 2. Fly ash or lime can reduce the expansion of the soil. 3. Fiber reinforcement also can be a good alternative in case of foundation in expansive soil.(Arindam and Sabyasachi, 2014)

2.3.3 Geotechnical properties of Black Cotton Soil Stabilized with Furnace Dust and Dolomitic Lime

Haresh D. Golakiya, and Chandresh D. Savani studied on Geotechnical properties of Black Cotton Soil Stabilized with Furnace Dust and Dolomitic Lime from their study they concluded that, the use of recycled material in the stabilization of soil gives better option to disposal of waste material. Plasticity index of black cotton soil decrease with increase in EAF (Electric Arc Furnace) dust content and lime fine content.

Free swell index of black cotton soil decreases with increase in dolomitic lime fine content.68.09% reduction is found due to stabilization of black cotton soil with 30% EAF dust and 12% dolomitic lime. Optimum moisture content increases as increase the dolomitic lime fine content and maximum dry density decrease with increase in dolomitic lime fine content. Optimum moisture content decrease as EAF dust content increase and maximum dry density increase with increase in EAF dust content. (Haresh, 2015)

The unconfined compressive strength value of black cotton soil increases with increase in dolomitic lime fine content. The unconfined compressive strength value of black cotton soil increases with increase in EAF dust content up to 6% dolomitic lime fine and then decrease with increase in EAF dust content. The unconfined compressive strength value of black cotton soil increases with increase in curing period. The modulus of elasticity value is highest for sample stabilized with 12% dolomitic lime fine and intermediate for black cotton soil stabilized with 30% EAF dust and 12% dolomitic lime. The soaked CBR value of BC soil is tremendously increase with addition of 30% EAF dust and 12 % lime for 28 days of curing period.(Haresh and Chandresh, n.d.)

3 Research Methodology

3.1 Introduction

In this study different properties of black cotton soil would be tested by laboratory tests. The tests would be performed for different soil samples and different percent of wood ash mixed samples. The test includes compaction test and Atterberg limit test.

The overall proposed research framework is demonstrated below (Figure 3.1).

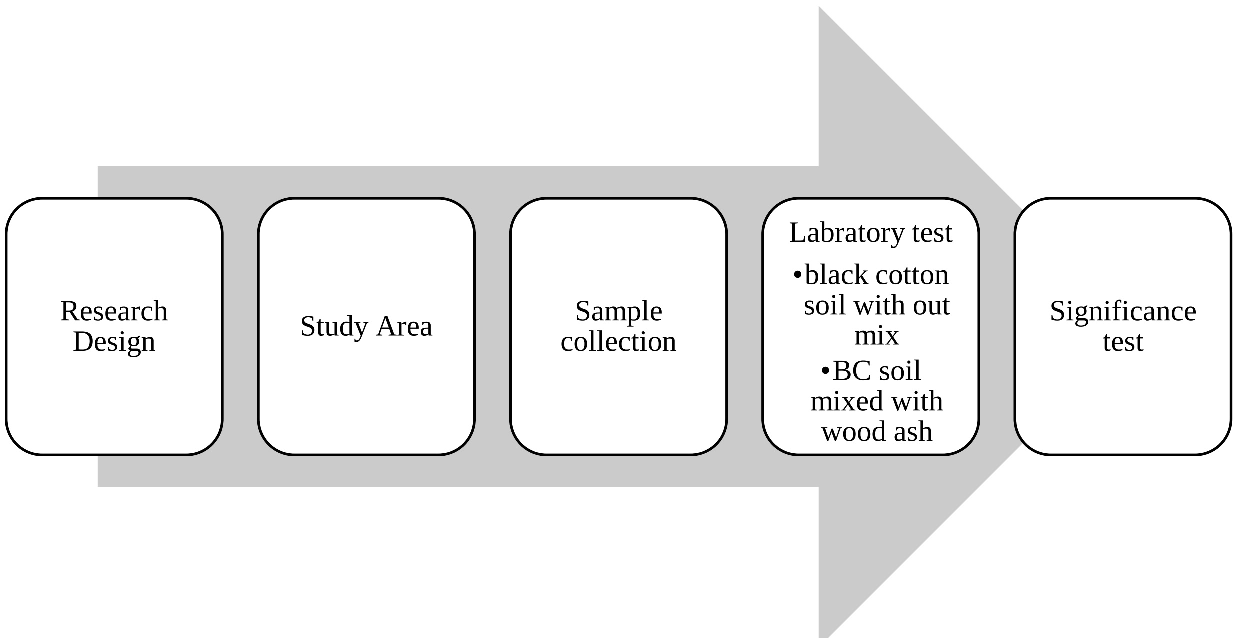

Figure 3.1Overall framework of the study

3.2 Research Design

There are two types of research approaches, namely: quantitative, qualitative. Quantitative study is a study where purely quantitative data and analysis techniques are adopted while qualitative approach makes use of purely qualitative data and analysis. In our case we are following the approach of quantitative analysis.

3.2.1 Study Area

This research is going to taste the properties of black cotton soil located in Wolkite Gubre town and in Wolkite University.

Figure 3.2Study Area: Gubrea, Wolkite, Ethiopia

3.3 Sample Size and Sampling Technique

Soil sample was collected from Gubre sub city (elevated at 3 m), in a disturbed state, by manual excavation. It was then dried and pulverized using a manual hammer. The pulverized soil was sieved through a sieve of 4.75mm aperture. Wood floor was collected from the locally available and was simply burned to prepare ash.

Figure 3.3 Sampling from site

3.4 Mix design

Soils and wood ashes were kept in an oven at 105°C overnight to remove moisture and repress microbial activity. The pulverized soil and ash contents were mixed manually in a large tray in a dry state with proper care because there is a possibility of non-uniform mixing.

To study the influence of the wood ash on the mechanical properties of the treated samples, it is crucial to maintaining consistency between the sample preparations. It was decisive that consistency among the samples could be achieved by controlling the mixing water. In this investigation, samples were prepared using their corresponding optimum moisture content (OMC) in order to maintain the consistency.

Before conducting tests, the no treated and ash-treated soils (5, 10%, and 15% ash content) were mixed with water for about ten minutes by hand. After that, the mixtures were put into polyethylene bags and mixing was continued by shaking, overturning, and pressing the bag to squeeze out the air from the soil voids.(Kavish et al., 2014)

3.5 Tests

A series of laboratory test was conducted including index testing and compaction test for both none treated and treated soil.

3.5.1 Compaction Test (Moisture-Density Relation)

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction.(Prof. Krishna, 2015)

3.5.1.1 Water content determination

Purpose: This test is performed to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

Significance: For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil.(Prof. Krishna, 2015)

3.5.1.2 Density (unit weight) determination

Purpose: This lab is performed to determine the in-place density of undisturbed soil obtained by pushing or drilling a thin-walled cylinder. The bulk density is the ratio of mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil to the volume the soil sample.

Significance: This test is used to determine the in-place density of soils. This test can also be used to determine density of compacted soils used in the construction of structural fills, highway embankments, or earth dams. This method is not recommended for organic or friable soils.(Prof. Krishna, 2015)

3.5.2 Atterberg limits

Purpose: This lab is performed to determine the plastic and liquid limits of a fine-grained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.(Prof. Krishna, 2015)

Significance: The Swedish soil scientist Albert Atterberg originally defined seven “limits of consistency” to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit, is used occasionally.) The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state.

The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these.(Prof. Krishna, 2015)

3.6 Method of Data Analysis

We used statistics data analysis method. Statistics help us turn quantitative data into useful information to help with decision making. We could use statistics to summarize our data, describing patterns, relationships and connections. Statistics can be descriptive or inferential. Descriptive statistics helped us to summarize our data. During this module our focus would be on descriptive rather than inferential statistics: this would also help to give a short introduction to the most common descriptive statistics.

4 Results and Discussions

4.1 Introduction

This chapter outlines the laboratory test results on non-treated and treated black cotton soil with wood ash. Also it outlines the results of significance of improvement in some engineering properties of black cotton soil with wood ash such as moisture content, specific gravity, plastic limit, liqiud limit, and moisture-density relationship.

4.2 Laboratory test result of none treated and treated of back cotton soil samples

4.2.1 Results of moisture content

The water content of a soil is an important parameter that controls its behavior. It is quantitative measure of the wetness of a soil mass.(DR. K.R., 2004)The moisture content results of black cotton soil with and without wood ash were tabulated in the table and graph below.

Table 4.1 Water contents of black cotton soil with and without wood ash

Ash contents(%)	0	5	10	15
Moisture contents(%)	50	44.44	43.45	33.61

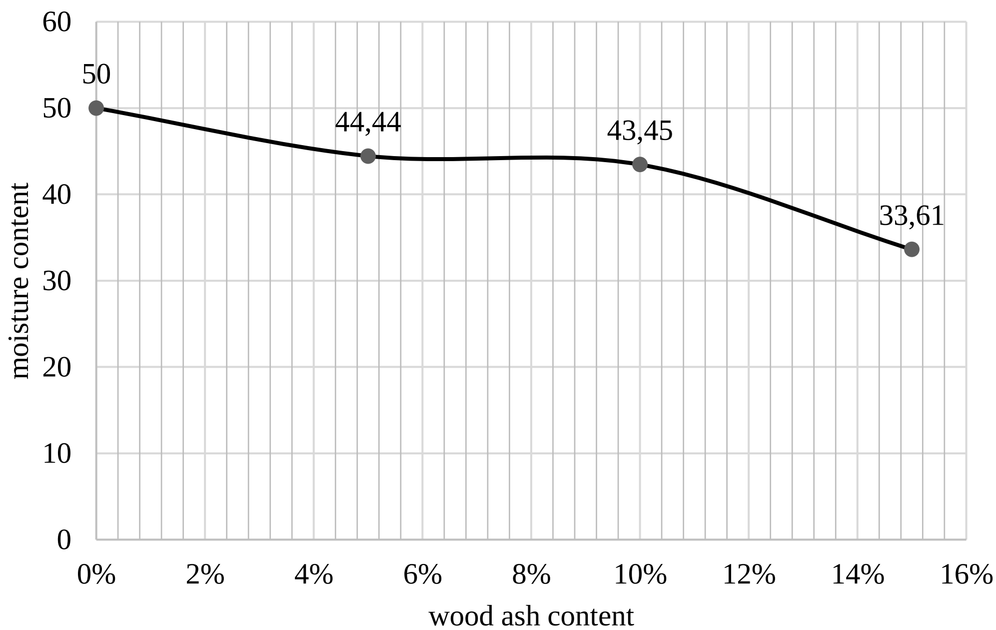

Figure 4.1 Graph for wood ash content Vs moisture content

As it shown on the graph, the natural moisture content of black cotton soil is 50% and it reduced when wood ash replaced. As the percentage of wood ash replacement increase, the moisture content of black cotton soil reduced as shown. This shows that the moisture content of black cotton soil improved by replacing similar volume of wood ash.

4.2.2 Results of specific gravity

The specific gravity of solid particles is the ratio of the mass density of solids to that of water(DR. K.R., 2004).The specific gravity of treated and none treated black cotton soil shown the following table and graph.

Table 4.2 Results of specific gravity

Ash contents(%)	0	5	10	15
Specfic gravity	2.28	2.45	2.63	2.52

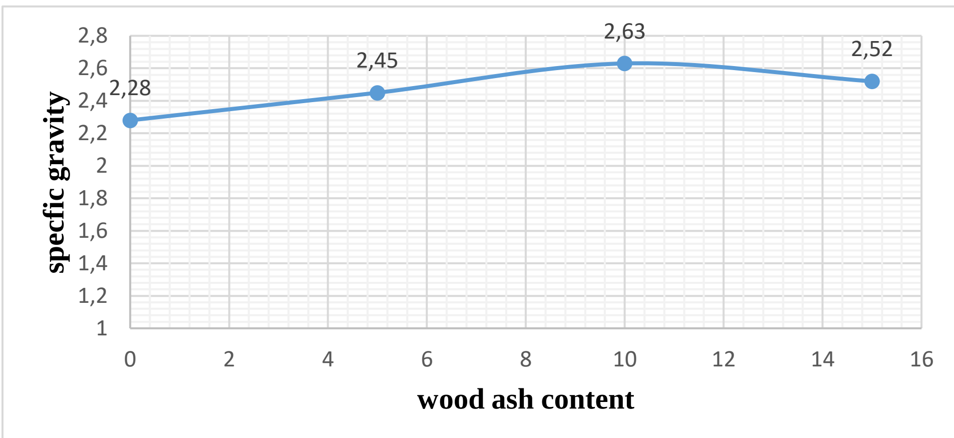

Figure 4.2 Gaph of results of specific gravity

From the graph it determined that the specific gravity of natural black cotton soil was 2.28 and it increase to 2.63 and then reduced at 15% of wood ash content. This may also be due to the replacement of the relatively same volume soil particles with wood ash having lower specific gravity.

4.2.3 Plastic limit results

Plastic limit is the water content below which the soil stops behaving as a plastic material.(DR. K.R., 2004)

4.2.3.1 With 0% of wood ash content

Table 4.3 Plastic limit with 0% of ash content

Container No.	1	2	3
Wt. of container,W1 (gm)	10.01	9.84	9.92
Wt. of container + wet soil , W2(gm)	19.67	18.71	19.32
Wt. of container +dry soil,W3(gm)	17.09	16.33	16.78
Water content(%) ={(W2-W3)/(W3-W1)}*100	36.44	36.67	36.83
Plastic limit (mean value,%)=36.65%			

4.2.3.2 With 5% wood ash content

Table 4.4 plastic limit with 5% wood ash

Container No.	1	2	3
Wt. of container,W1 (gm)	28.83	25.75	27.85
Wt. of container + wet soil , W2(gm)	30.12	30.01	32.15
Wt. of container +dry soil,W3(gm)	29.14	28.78	30.91
Water content(%) ={(W2-W3)/(W3-W1)}*100	42.42	40.59	40.52
Plastic limit (mean value,%)=41.18%			

4.2.3.3 With 10% wood ash content

Table 4.5 plastic limit with 10% wood ash

Container No.	1	2	3
Wt. of container,W1 (gm)	9.9	9.91	9.99
Wt. of container + wet soil , W2(gm)	20.25	20.53	20.69
Wt. of container +dry soil,W3(gm)	17.03	17.19	17.34
Water content(%) ={(W2-W3)/(W3-W1)}*100	45.16	45.88	45.59
Plastic limit (mean value,%)=45.54%			

4.2.3.4 With 15% wood ash content

Table 4.6 plastic limit with 15% wood ash

Container No.	1	2	3
Wt. of container,W1 (gm)	26.85	25.74	27.84
Wt. of container + wet soil , W2(gm)	34.19	35.03	36.32
Wt. of container +dry soil,W3(gm)	31.86	32.13	33.68
Water content(%) ={(W2-W3)/(W3-W1)}*100	46.5	46.95	45.2
Plastic limit (mean value,%)=46.22%			

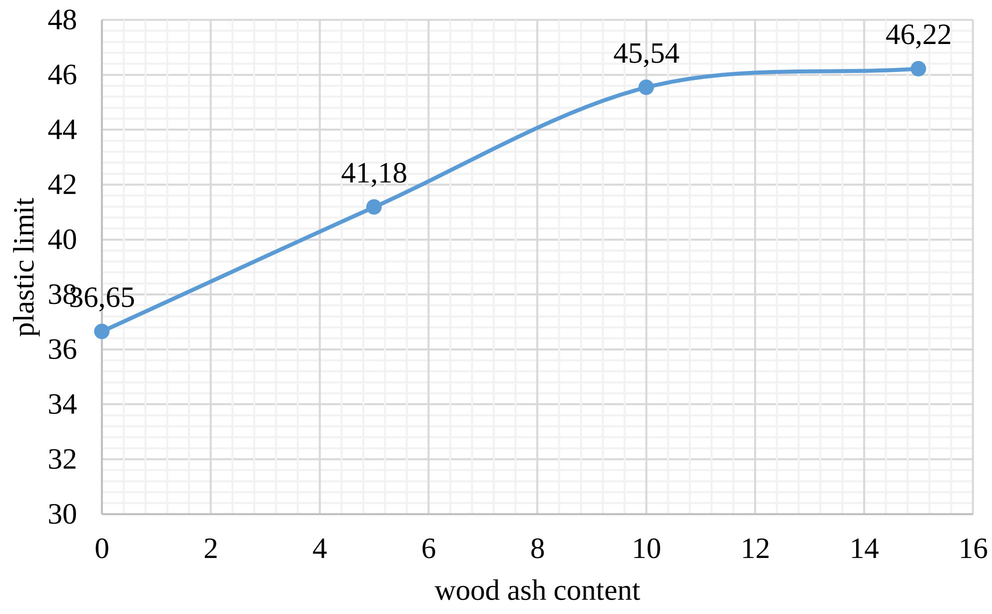

Figure 4.3 plastic limit Vs wood ash content

The variations of plastic limit with the varying percentages of wood ash are shown in Figure 4.3. The plastic limit results show that plastic limit increase with increasing percentages of wood ash, which ranged from 36.65% to 46.22%.

4.2.4 Liqiud limit

The liquid limit is the water content at which the soil changes from the liquid state to the plastic state.(DR. K.R., 2004)

4.2.4.1 With 0% of wood ash content

Table 4.7 liqiud limit with 0% wood ash content

No. Of blows	Moisture content(%)
15	58.53
23	52.36
30	51.25

4.2.4.2 With 5% of wood ash content

Table 4.8 liquid limit with 5% wood ash

No. Of blows	Moisture content(%)
20	58.8
25	57.15
35	52.78

4.2.4.3 With 10% of wood ash content

Table 4.9 liquid limit with 10% wood ash

No. Of blows	Moisture content(%)
20	70
26	69.45
29	68.99

4.2.4.4 With 15% of wood ash content

Table 4.10 liquid limit with 15% wood ash

No. Of blows	Moisture content(%)
19	74.37
28	71.74
34	69.72

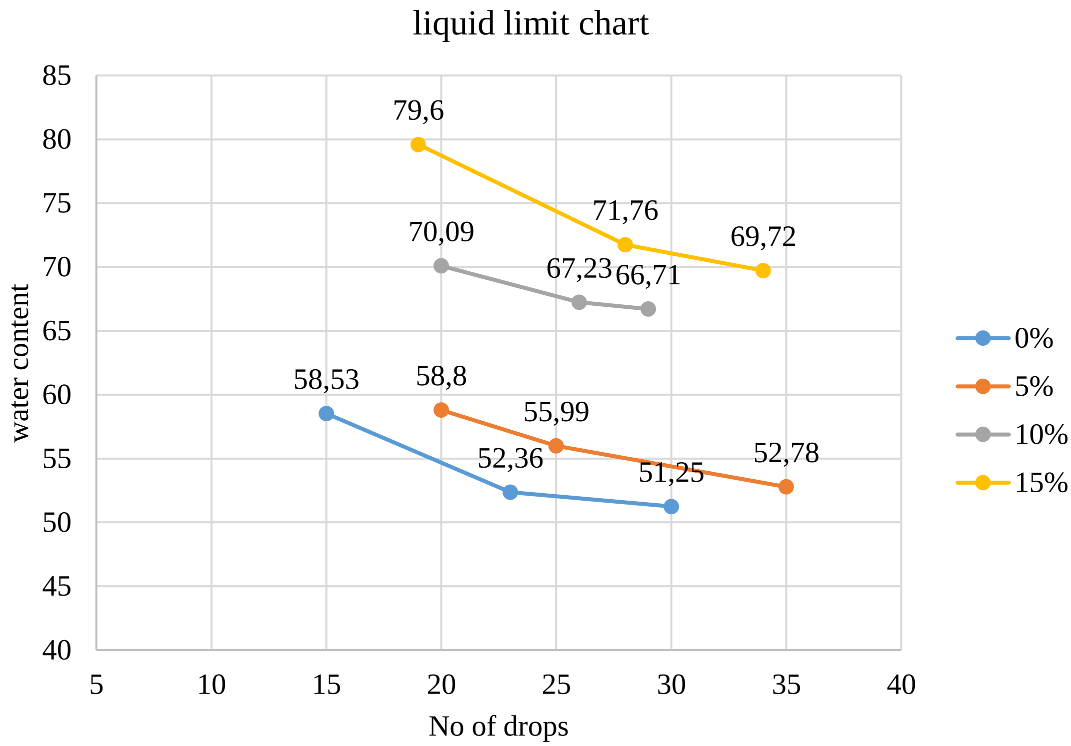

Figure 4.4 Water content Vs number of drops

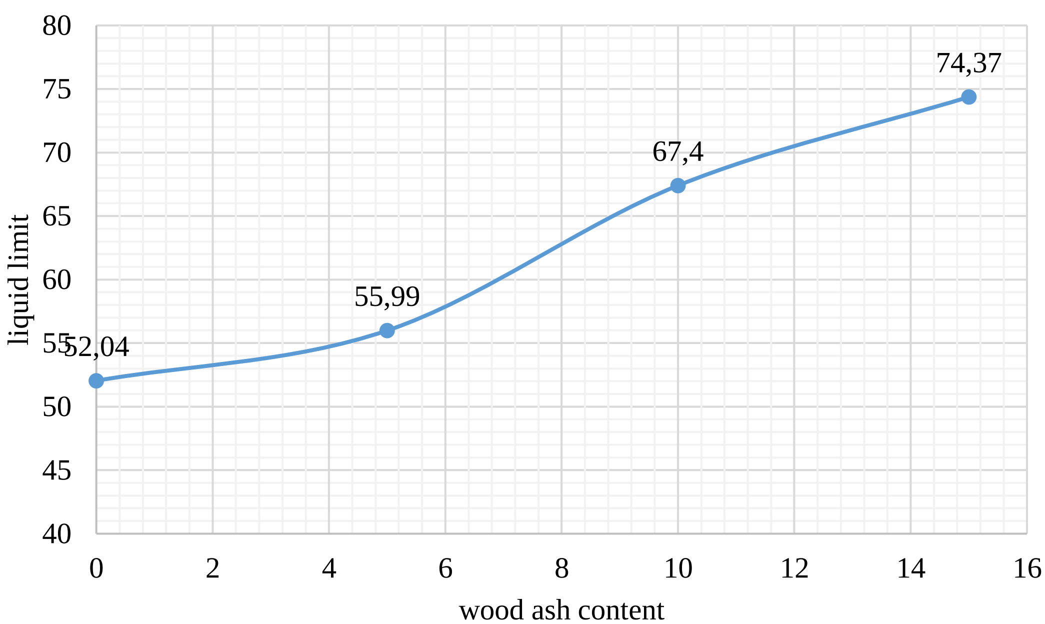

Figure 4.5 Liquid limit Vs wood ash content

The variations of liquid limit with the varying percentages of wood ash are shown in Figure 4.5. Liquid limit increase with increasing percentages of wood ash from 52.04% to 74.37%.

4.2.5 Plasticity Index

Plasticity index is the range of water content over the soil remains in the plastic state. It is the difference between the liquid and plastic limit. The plasticity index of blackcotton soil with and without wood ash content tabulated (Table 4.11).

Table 4.11 plasticity and liquidity index

Wood ash content (%)	Plastic limit,PL(%)	Liquid limit at 25 blows,LL (%)	Plasticity index,Ip=LL-PL(%)	Liquidity index,IL=(W-PL)/(LL-PL)(%)
0	41.18	51.98	10.8	81.7
5	43.52	57.15	13.63	47.5
10	45.54	69.54	24	18.58
15	45.69	72.62	26.93	16

The Atterberg limits are very important for the characterization of soil within a broad category. Atterberg limit results show that both the liquid limit and plastic limit increase with increasing percentages of wood ash. The liquid limit ranged from 51.98% to 72.62% and the plastic limit from 41.18% to 45.69%, thus resulting in a increase of the plasticity index values ranging from 10.8 to 26.93%.

4.2.6 Compaction Test Result

Wood ash content (%)	Dry density(g/cm3)
0	1.224
5	1.209
10	1.16
15	1.157

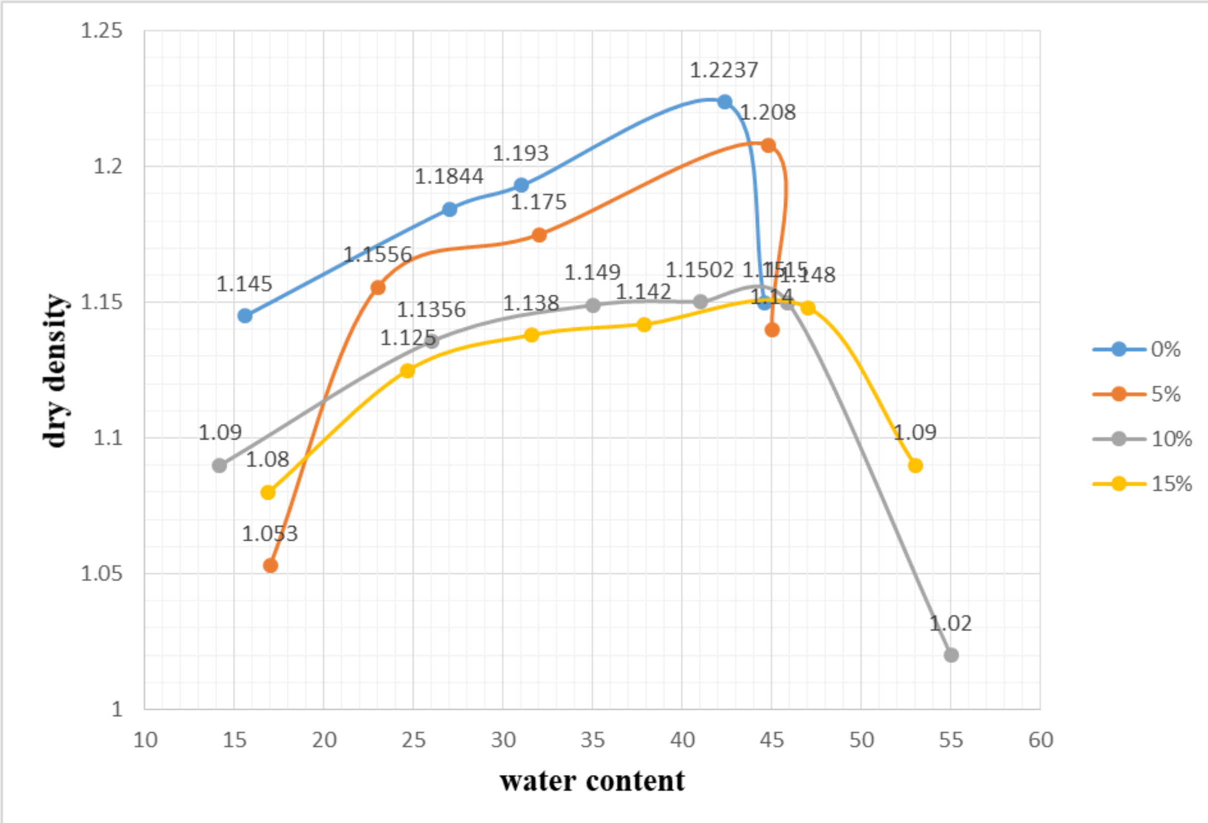

Figure 4.6 Dry density Vs water content

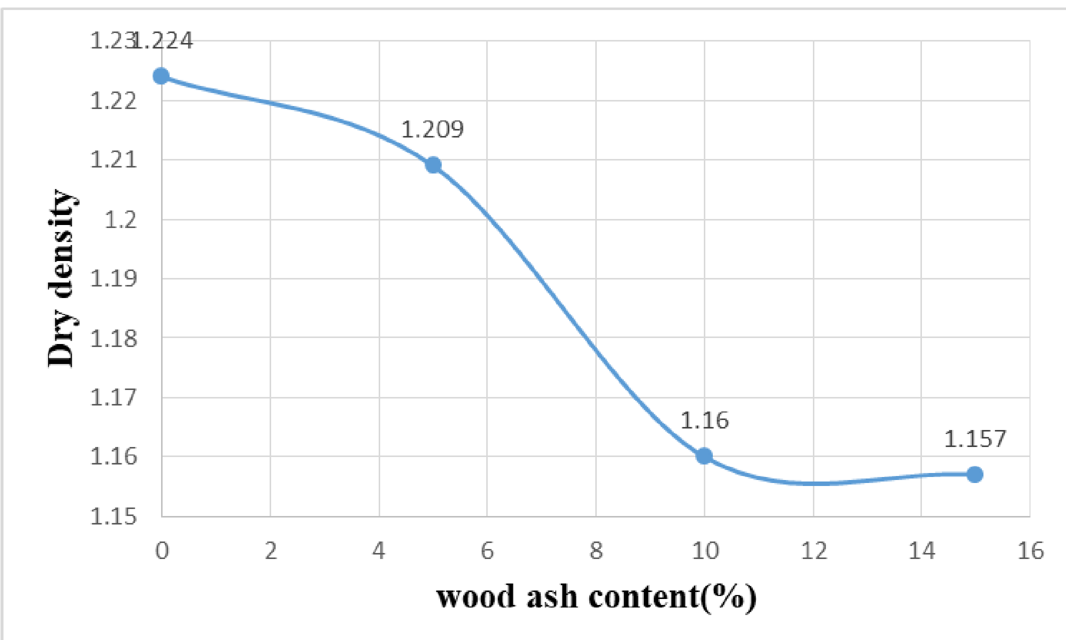

Figure 4.7 Dry density Vs wood ash content

Figure 4.7 shows the effect of wood ash on the optimum moisture content (OMC) and maximum dry density of soil. It can be seen while maximum dry density decreasing with the increasing amount of wood ash, the optimum moisture content gradually increases from 42.4% to 46.8% with the addition of 15% ash. This trend is similar with Grytan Sarkar(Nath et al., 2018), and it described that the decrease in maximum dry density is attributed by the agglomeration and flocculation of clay particles through cation exchange reaction, leading to occupy larger space as well as reducing the weight: volume ratio. This may also be due to the replacement of the relatively same volume soil particles with wood ash having lower specific gravity (1.67). For example, the specific gravity of soil is decreased from 2.7 to 2 after the addition of 15% ash content.

On the other hand, the optimum moisture content of soil increases with the increase of wood ash content as more water is required for the formation of the lime-like product, Ca(OH)2, and dissolution of this product into Ca2+ and OH−ions, in order to supply more Ca2+ ions for the cation exchange reaction. Besides that the more the fines, the more the surface area, so more water is required to provide good lubrication. The ash content also decreases the quantity of free silt and clay fraction, forming coarser materials, which occupy larger spaces for retaining water.(Nath et al., 2018)

5 Conclusions and Recommendations

5.1 Conclusions

This study has evaluated the extent to which wood ash can modify some properties such as moisture content, specific gravity, Atterberg limit and compaction characteristics of untreated and wood ash-based black cotton soil. The soil was stabilized through 5%, 10%, and 15% wood ash content. It is observed that there is an improvement of geotechnical properties of the ash-treated soil. Based on the results obtained after completing the experimental program, the following conclusions can be drawn:

(i) From the specific gravity test, the specific gravity is gradually increasing up to the addition of 10% wood ash and decreased to 2.52 at the addition of 15% wood addition.

(ii) Wood ash reduces the maximum dry density of black cotton soil, while more water is required for the agglomeration and flocculation of clay particles through cation exchange reaction and coagulation with the consequent reduction in the amount of fines.

(iii) The Atterberg limits, both liquid limit and plastic limit increases with increment of wood ash content.

5.2 Recommendations

Wood ash is one of the common wastes from residential, but this material which is regarded as waste can be used for value added purpose by mixing it with in black cotton soil as improving materials. Since, it is low cost and readily available material. The government (concerned government body) shall focus or device directives on the means of collecting waste wood ash and utilizing it for the replacement purpose. Research centers should be established which focus on the study of wastes which can be recycled. Future focuses of study which should be continued as part of the extension of this study are listed as follows:

a. Tests not included on this study like CBR test, unconfined compression test, triaxial test and others should have to be investigated in the future to know other geotechnical properties of the black cotton soil modified with wood ash.
b. Further intensive study should be carried out by academic institutions to investigate the long term properties and effects of the wood ash on the black cotton soil.

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Appendix

Appendix A: Experiment 1: Water Content Determination

Test Procedure:

(1) Record the moisture can and lid number. Determine and record the mass of an empty, clean, and dry moisture can with its lid (MC)

(2) Place the moist soil in the moisture can and secure the lid. Determine and record the mass of the moisture can (now containing the moist soil) with the lid (MCMS).

(3) Remove the lid and place the moisture can (containing the moist soil) in the drying oven that is set at 105 °C. Leave it in the oven overnight.

(4) Remove the moisture can. Carefully but securely, replace the lid on the moisture can using gloves, and allow it to cool to room temperature. Determine and record the mass of the moisture can and lid (containing the dry soil) (MCDS).

(5) Empty the moisture can and clean the can and lid.

Data Analysis:

(1) Determine the mass of soil solids.

$$M_S = M_{CDS} - M_{SC}$$

(2) Determine the mass of pore water.

$$M_W = M_{CMS} - M_{CDS}$$

(3) Determine the water content.

$$W = \left(\frac{MS}{MW}\right) * 100$$

WATER CONTENT DETERMINATION DATA SHEET

1. For untreated soil sample or natural moisture content

Date Tested: December, 15, 2020

Tested By: Atirsagn & Gemtesa

Project Name: research

Sample Number: 1

Sample Description: black cotton soil

Specimen number	1	2	3
Moisture can and lid number	1	2	3
MC = Mass of empty, clean can + lid (grams)	50	25	35
MCMS = Mass of can, lid, and moist soil (grams)	95	80	85
MCDS = Mass of can, lid, and dry soil (grams)	80	60	70
MS = Mass of soil solids (grams)	30	35	35
MW = Mass of pore water (grams)	15	20	15
w = Water content, w%	50	57.14	42.86

Calculation

1. M_C = 50g, M_{CMS} = 95g, M_{CDS} = 80g, M_S = 80-50 = 30g, M_W = 95-80 = 15g

$$W = \frac{MW}{MS} * 100 = \frac{25}{30} * 100$$

W=50%

2. M_C = 25g, M_{CMS} = 80g, M_{CDS} = 60g, M_S = 60-25 = 35g, M_W = 80-60=20g

$$W = \frac{MW}{MS} * 100 = \frac{20}{35} * 100$$

W=57.14%

3. M_C = 35g, M_{CMS} = 85g, M_{CDS} = 70g, M_S = 85-70 = 15g, M_W = 70-35 = 35g

$$W = \frac{MW}{MS} * 100 = \frac{15}{35} * 100$$

W=42.86%

Therefor the average water content $= \frac{50+57.14+42.866}{3}$ = 50%

2. Black cotton soil treated with 5% wood ash

Specimen number	1	2	3
Moisture can and lid number	1	2	3
MC = Mass of empty, clean can + lid (grams)	35	35	30
MCMS = Mass of can, lid, and moist soil (grams)	70	75	70
MCDS = Mass of can, lid, and dry soil (grams)	60	65	55
MS = Mass of soil solids (grams)	25	30	25
MW = Mass of pore water (grams)	10	10	15
w = Water content, w%	40	33.33	60

Calculation

1. M_C = 35g, M_{CMS} = 70g, M_{CDS} = 60g, M_S = 70-35 = 35g, M_W = 70-60 = 10g

$W = \frac{MW}{MS} * 100 = \frac{10}{25} * 100$

W=40%

2. M_C = 35g, M_{CMS} = 75g, M_{CDS} = 65g, M_S = 65-35 = 30g, M_W = 75-65=10g

$W = \frac{MW}{MS} * 100 = \frac{10}{30} * 100$

W=33.33%

3. M_C = 30g, M_{CMS} = 70g, M_{CDS} = 55g, M_S = 55-30= 25g, M_W = 70-55 = 15g

$W = \frac{MW}{MS} * 100 = \frac{15}{25} * 100$

W=60%

Therefor the average water content $= \frac{40+33033+60}{3} = 44.44\%$

3. Black cotton soil treated with 10% wood ash.

Specimen number	1	2	3
Moisture can and lid number	A	B	C
MC = Mass of empty, clean can + lid (grams)	20	25	25
MCMS = Mass of can, lid, and moist soil (grams)	75	80	80
MCDS = Mass of can, lid, and dry soil (grams)	60	60	65
MS = Mass of soil solids (grams)	35	40	40
MW = Mass of pore water (grams)	15	20	15
w = Water content, w%	42.86	50	37.5

Calculation

1. M_C = 25g, M_{CMS} = 75g, M_{CDS} = 60g, M_S = 60-25 = 35g, M_W = 75-60 = 15g

$W = \frac{MW}{MS} * 100 = \frac{15}{35} * 100$

W=42.86%

2. M_C = 20g, M_{CMS} = 80g, M_{CDS} = 60g, M_S =60-20 = 40g, M_W = 80-60=20g

$W = \frac{MW}{MS} * 100 = \frac{20}{40} * 100$

W=50%

3. M_C = 25g, M_{CMS} = 80g, M_{CDS} = 65g, M_S = 65-25= 40g, M_W = 80-65 = 15g

$W = \frac{MW}{MS} * 100 = \frac{15}{40} * 100$

W=37.5%

Therefor the average water content $= \frac{42.86+50+37.5}{3}$ = 43.45%

4. Black cotton soil treated with 15% wood ash

Specimen number	1	2	3
Moisture can and lid number	a	b	c
MC = Mass of empty, clean can + lid (grams)	25	20	25
MCMS = Mass of can, lid, and moist soil (grams)	80	85	85
MCDS = Mass of can, lid, and dry soil (grams)	65	70	70
MS = Mass of soil solids (grams)	40	50	45
MW = Mass of pore water (grams)	15	15	15
w = Water content, w%	37.5	30	33.33

Calculation

1. M_C = 25g, M_{CMS} = 80g, M_{CDS} = 65g, M_S = 65-25 = 40g, M_W = 80-65 = 15g

$W = \frac{MW}{MS} * 100 = \frac{15}{40} * 100$

W=37.5%

2. M_C = 20g, M_{CMS} = 85g, M_{CDS} = 70g, M_S = 70-20 = 50g, M_W = 85-70=15g

$W = \frac{MW}{MS} * 100 = \frac{15}{50} * 100$

W=30%

3. M_C = 25g, M_{CMS} = 85g, M_{CDS} = 70g, M_S = 70-25= 45g, M_W = 85-75 = 15g

$W = \frac{MW}{MS} * 100 = \frac{15}{45} * 100$

W=33.33%

Therefor the average water content $= \frac{37.5+30+33.33}{3}$ = 33.61%

Appendix B: Experiment 2: specific gravity determination

Test Procedure:

(1) Determine and record the weight of the empty clean and dry pycnometer, WP.

(2) Place 10g of a dry soil sample (passed through the sieve No. 10) in the pycnometer. Determine and record the weight of the pycnometer containing the dry soil, WPS.

(3) Add distilled water to fill about half to three-fourth of the pycnometer. Soak the sample for 10 minutes.

(4) Apply a partial vacuum to the contents for 10 minutes, to remove the entrapped air.

(5) Stop the vacuum and carefully remove the vacuum line from pycnometer.

(6) Fill the pycnometer with distilled (water to the mark), clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and contents, WB.

(7) Empty the pycnometer and clean it. Then fill it with distilled wateronly (to the mark). Clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and distilled water, WA.

(8) Empty the pycnometer and clean it.

Data Analysis:

Calculate the specific gravity of the soil solids using the following formula:

Specific Gravity, $GS = \frac{WO}{WO+(WA-WB)}$

Where:

W0 = weight of sample of oven-dry soil, g = WPS - WP

WA = weight of pycnometer filled with water

WB = weight of pycnometer filled with water and soil

1. For untreated soil sample

Date Tested: December, 16, 2020

Tested By: Atirsagn & Gemtesa

Project Name: research

Sample Number: 2

Sample Description: black cotton soil

Specimen number	1(0%)	2(5%)	3(10%)	4(15%)
Pycnometer bottle number	a	b	C	d
WP = Mass of empty, clean pycnometer (grams)	465	465	465	465
WPS = Mass of empty pycnometer + dry soil (grams)	660	680	685	695
WB = Mass of pycnometer + dry soil + water (grams)	1619.47	1637.25	1595.03	1588.68
WA = Mass of pycnometer + water (grams)	1510	1510	1510	1510
Specific gravity (GS)	2.28	2.45	2.63	2.52

Calculations:

1. WP = 465 g, WPS = 660 g, WB = 1580 g, WA =1510 g WO = 660-465 = 195 g
   $GS = \frac{WO}{WO+(WA-WB)} = GS = \frac{195}{195+(1510-1619.47)}$=2.28
2. WP = 465g, WPS = 680 g, WB = 1625 g, WA =1510 g WO = 680-465= 215 g
   $GS = \frac{215}{215+(1510-1637.25)}$=2.45
3. WP = 465g, WPS = 685g, WB = 1640 g, WA =1510 g WO = 685-465= 220 g
   $GS = \frac{220}{220+(1510-1595.03)}$=2.63
4. WP = 465g, WPS = 695g, WB = 1635 g, WA =1510 g WO = 695-465=230 g

   $GS = \frac{230}{230+(1510-1588.68)}$=2.52

Appendix C: Experiment 3: Atterberg Limits

Test Procedure:

Liquid Limit:

(1) Take roughly 3/4 of the soil and place it into the porcelain dish.

Assume that the soil was previously passed though a No. 40 sieve, air-dried, and then pulverized. Thoroughly mix the soil with a small amount of distilled water until it appears as a smooth uniform paste. Cover the dish with cellophane to prevent moisture from escaping.

(2) Weigh four of the empty moisture cans with their lids, and record the respective weights and can numbers on the data sheet.

(3) Adjust the liquid limit apparatus by checking the height of drop of the cup. The point on the cup that comes in contact with the base should rise to a height of 10 mm. The block on the end of the grooving tool is 10 mm high and should be used as a gage. Practice using the cup and determine the correct rate to rotate the crank so that the cup drops approximately two times per second.

(4) Place a portion of the previously mixed soil into the cup of the liquid limit apparatus at the point where the cup rests on the base. Squeeze the soil down to eliminate air pockets and spread it into the cup to a depth of about 10 mm at its deepest point. The soil pat should form an approximately horizontal surface (See Photo B).

(5) Use the grooving tool carefully cut a clean straight groove down thecenter of the cup. The tool should remain perpendicular to the surface of the cup as groove is being made. Use extreme care to prevent sliding the soil relative to the surface of the cup (See Photo C).

(6) Make sure that the base of the apparatus below the cup and the underside of the cup is clean of soil. Turn the crank of the apparatus at a rate of approximately two drops per second and count the number of drops, N, it takes to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13 mm (1/2 in.)

(See Photo D). If the number of drops exceeds 50, then go directly to step eight and do not record the number of drops, otherwise, record the number of drops on the data sheet.

(7)Take a sample, using the spatula, from edge to edge of the soil pat.

The sample should include the soil on both sides of where the groove came into contact. Place the soil into a moisture can cover it.

Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours. Place the soil remaining in the cup into the porcelain dish. Clean and dry the cup on the apparatus and the grooving tool.

(8) Remix the entire soil specimen in the porcelain dish. Add a small amount of distilled water to increase the water content so that the number of drops required to close the groove decrease.

(9) Repeat steps six, seven, and eight for at least two additional trials producing successively lower numbers of drops to close the groove.

One of the trials shall be for a closure requiring 25 to 35 drops, one for closure between 20 and 30 drops, and one trial for a closure requiring

15 to 25 drops. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

Plastic Limit:

(1) Weigh the remaining empty moisture cans with their lids, and record the respective weights and can numbers on the data sheet.

(2) Take the remaining 1/4 of the original soil sample and add distilled water until the soil is at a consistency where it can be rolled without sticking to the hands.

(3) Form the soil into an ellipsoidal mass (See Photo F). Roll the mass between the palm or the fingers and the glass plate (See Photo G).Use sufficient pressure to roll the mass into a thread of uniform diameter by using about 90 strokes per minute. (A stroke is one complete motion of the hand forward and back to the starting position.) The thread shall be deformed so that its diameter reaches 3.2 mm (1/8 in.), taking no more than two minutes.

(4) When the diameter of the thread reaches the correct diameter, break the thread into several pieces. Knead and reform the pieces into ellipsoidal masses and re-roll them. Continue this alternate rolling, gathering together, kneading and re-rolling until the thread crumbles under the pressure required for rolling and can no longer be rolled into a 3.2 mm diameter thread.

(5) Gather the portions of the crumbled thread together and place the soil into moisture can, and then cover it. If the can does not contain at least 6 grams of soil, add soil to the can from the next trial. Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours.

(6) Repeat steps three, four, and five at least two more times. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

Analysis:

Liquid Limit:

(1) Calculate the water content of each of the liquid limit moisture cans after they have been in the oven for at least 16 hours.

(2) Plot the number of drops, N, (on the log scale) versus the water content (w). Draw the best-fit straight line through the plotted points and determine the liquid limit (LL) as the water content at 25 drops.

Plastic Limit:

(1) Calculate the water content of each of the plastic limit moisture cans after they have been in the oven for at least 16 hours.

(2) Compute the average of the water contents to determine the plastic limit, PL. Check to see if the difference between the water contents is greater than the acceptable range of two results (2.6%).

(3) Calculate the plasticity index, PI=LL-PL.

Report the liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation.

Date Tested: December, 18, 2020

Tested By: Atirsagn & Gemtesa

Project Name: research

Sample Number: 3

Sample Description: Black cotton soil and wood ash

Plastic limit

Specimen number	1	2	3
Moisture can and lid number	1	2	3
MC = Mass of empty, clean can + lid (grams)	26.83	25.75	27.85
MCMS = Mass of can, lid, and moist soil (grams)	30.12	30.01	32.15
MCDS = Mass of can, lid, and dry soil (grams)	29.14	28.78	30.91
MS = Mass of soil solids (grams)	2.31	3.03	3.06
MW = Mass of pore water (grams)	0.98	1.23	1.24
w = Water content, w%	42.42	40.59	40.52

Therefore average moisture content= $\frac{42.42+40.59+40.52}{3}$=41.18%

Liquid limit for number of blows 15-25

Specimen number	1	2	3
Moisture can and lid number	A	B	C
MC = Mass of empty, clean can + lid (grams)	9.96	9.99	9.75
MCMS = Mass of can, lid, and moist soil (grams)	25.64	28.77	26.10
MCDS = Mass of can, lid, and dry soil (grams)	19.77	21.82	20.16
MS = Mass of soil solids (grams)	9.82	11.83	10.41
MW = Mass of pore water (grams)	5.87	6.95	5.94
w = Water content, w%	59.77	58.75	57.06

Therefore average moisture content= $\frac{59.77+58.75+57.06}{3}$=58.53%

For number of blows 20-30

Specimen number	1	2	3
Moisture can and lid number	I.	II.	III.
MC = Mass of empty, clean can + lid (grams)	23.9	20.35	20.42
MCMS = Mass of can, lid, and moist soil (grams)	42.49	43.85	40.43
MCDS = Mass of can, lid, and dry soil (grams)	36.12	35.73	33.57
MS = Mass of soil solids (grams)	12.22	15.38	13.15
MW = Mass of pore water (grams)	6.37	8.12	6.86
w = Water content, w%	52.13	52.79	52.17

Therefore average moisture content= $\frac{52.13+52.79+51.17}{3}$=52.36%

For number of blows 25-35

Specimen number	1	2	3
Moisture can and lid number	a	b	c
MC = Mass of empty, clean can + lid (grams)	13.01	13.47	13.4
MCMS = Mass of can, lid, and moist soil (grams)	36.66	41.15	34.56
MCDS = Mass of can, lid, and dry soil (grams)	28.01	31.93	27.31
MS = Mass of soil solids (grams)	15.6	18.46	13.91
MW = Mass of pore water (grams)	8.05	9.22	7.25
w = Water content, w%	51.6	49.94	52.21

Therefore average moisture content= $\frac{51.6+49.94+52.21}{3}$=51.25%

Black cotton soil treated with 5% wood ash

Plastic limit

Specimen number	1	2	3
Moisture can and lid number	1	2	3
MC = Mass of empty, clean can + lid (grams)	10.01	9.84	9.92
MCMS = Mass of can, lid, and moist soil (grams)	19.67	18.71	19.32
MCDS = Mass of can, lid, and dry soil (grams)	17.09	16.33	16.79
MS = Mass of soil solids (grams)	7.08	6.49	6.87
MW = Mass of pore water (grams)	2.58	2.38	2.53
w = Water content, w%	36.44	36.67	36.83

Therefore average moisture content= $\frac{36.44+36.67+36.83}{3}$=36.65%

Liquid limit
For number of blows 25-35

Specimen number	1	2	3
Moisture can and lid number	A	B	C
MC = Mass of empty, clean can + lid (grams)	26.41	26.60	26.38
MCMS = Mass of can, lid, and moist soil (grams)	35.67	34.42	38.39
MCDS = Mass of can, lid, and dry soil (grams)	32.49	31.69	34.26
MS = Mass of soil solids (grams)	6.08	5.09	7.88
MW = Mass of pore water (grams)	3.18	2.73	4.13
w = Water content, w%	52.3	53.63	52.4

Therefore average moisture content= $\frac{52.3+53.63+52.4}{3}$=52.78%

For number of blows 20-30

Specimen number	1	2	3
Moisture can and lid number	a	b	c
MC = Mass of empty, clean can + lid (grams)	27.62	27.48	27.8
MCMS = Mass of can, lid, and moist soil (grams)	36.44	36.3	36.77
MCDS = Mass of can, lid, and dry soil (grams)	33.31	33.08	33.57
MS = Mass of soil solids (grams)	5.69	5.6	5.77
MW = Mass of pore water (grams)	3.13	3.22	3.2
w = Water content, w%	55.01	57.5	55.46

Therefore average moisture content= $\frac{55.01+57.5+55.46}{3}$=55.99%

For number of blows 15-20

Specimen number	1	2	3
Moisture can and lid number	1	2	3
MC = Mass of empty, clean can + lid (grams)	26.17	27.34	26.3
MCMS = Mass of can, lid, and moist soil (grams)	33.08	34.61	36.34
MCDS = Mass of can, lid, and dry soil (grams)	30.48	31.92	32.68
MS = Mass of soil solids (grams)	4.31	4.58	6.38
MW = Mass of pore water (grams)	2.6	2.69	3.66
w = Water content, w%	60.32	58.7	57.37

Therefore average moisture content= $\frac{60.32+58.7+57.37}{3}$=58.8%

Black cotton soil treated with 10% wood ash

Plastic limit

Specimen number	1	2	3
Moisture can and lid number	4	5	6
MC = Mass of empty, clean can + lid (grams)	26.85	25.74	27.84
MCMS = Mass of can, lid, and moist soil (grams)	34.19	35.03	36.32
MCDS = Mass of can, lid, and dry soil (grams)	31.86	32.13	33.68
MS = Mass of soil solids (grams)	5.01	6.39	5.84
MW = Mass of pore water (grams)	2.33	3	2.64
w = Water content, w%	46.5	46.95	45.21

Therefore average moisture content= $\frac{46.5+46.95+45.21}{3}$=46.22%

Liquid limit: For number of blows 15-20

Specimen number	1	2	3
Moisture can and lid number	D	E	F
MC = Mass of empty, clean can + lid (grams)	9.96	9.76	9.98
MCMS = Mass of can, lid, and moist soil (grams)	25.08	19.68	23.64
MCDS = Mass of can, lid, and dry soil (grams)	18.85	15.6	18
MS = Mass of soil solids (grams)	8.89	5.84	8.02
MW = Mass of pore water (grams)	6.23	4.08	5.64
w = Water content, w%	70.08	69.86	70.32

Therefore average moisture content= $\frac{70.08+69.86+70.32}{3}$=70.09%

For number of blows 20-30

Specimen number	1	2	3
Moisture can and lid number	D	e	f
MC = Mass of empty, clean can + lid (grams)	13	13.47	13.34
MCMS = Mass of can, lid, and moist soil (grams)	22.45	21.69	22.56
MCDS = Mass of can, lid, and dry soil (grams)	18.9	18.32	18.80
MS = Mass of soil solids (grams)	5.6	4.85	5.46
MW = Mass of pore water (grams)	3.55	3.37	3.76
w = Water content, w%	63.36	69.48	68.86

Therefore average moisture content= $\frac{63.36+69.48+68.86}{3}$=67.23%

For number of blows 25-35

Specimen number	1	2	3
Moisture can and lid number	4	5	6
MC = Mass of empty, clean can + lid (grams)	20.37	20.44	23.92
MCMS = Mass of can, lid, and moist soil (grams)	28.55	31.03	34.84
MCDS = Mass of can, lid, and dry soil (grams)	25.20	26.68	30.7
MS = Mass of soil solids (grams)	4.83	6.24	6.78
MW = Mass of pore water (grams)	3.35	4.35	4.14
w = Water content, w%	69.36	69.71	61.06

Therefore average moisture content= $\frac{69.36+69.71+61.06}{3}$=66.71%

Black cotton soil treated with 15% wood ash

Plastic limit

Specimen number	1	2	3
Moisture can and lid number	7	8	9
MC = Mass of empty, clean can + lid (grams)	9.9	9.91	9.99
MCMS = Mass of can, lid, and moist soil (grams)	20.25	20.53	20.69
MCDS = Mass of can, lid, and dry soil (grams)	17.03	17.19	17.34
MS = Mass of soil solids (grams)	7.13	7.28	7.35
MW = Mass of pore water (grams)	3.22	3.34	3.35
w = Water content, w%	45.16	45.88	45.58

Therefore average moisture content= $\frac{45.16+45.88+45.58}{3}$=45.54%

Liquid limit

For number of blows 15-20

Specimen number	1	2	3
Moisture can and lid number	7	8	9
MC = Mass of empty, clean can + lid (grams)	7.54	12.92	7.82
MCMS = Mass of can, lid, and moist soil (grams)	20.19	23.06	18.21
MCDS = Mass of can, lid, and dry soil (grams)	14.8	18.71	13.80
MS = Mass of soil solids (grams)	7.26	4.79	5.98
MW = Mass of pore water (grams)	5.39	4.35	4.41
w = Water content, w%	74.24	90.81	73.75

Therefore average moisture content= $\frac{74.24+90.81+73.75}{3}$=79.6%

For number of blows 20-30

Specimen number	1	2	3
Moisture can and lid number	G	H	I
MC = Mass of empty, clean can + lid (grams)	26.77	26.92	26.41
MCMS = Mass of can, lid, and moist soil (grams)	37.706	36.12	39.25
MCDS = Mass of can, lid, and dry soil (grams)	32.88	32.38	34.06
MS = Mass of soil solids (grams)	6.11	5.46	7.65
MW = Mass of pore water (grams)	4.826	3.74	5.19
w = Water content, w%	78.98	68.5	67.8

Therefore average moisture content= $\frac{78.98+68.5+67.8}{3}$=71.76%

For number of blows 25-35

Specimen number	1	2	3
Moisture can and lid number	g	h	I
MC = Mass of empty, clean can + lid (grams)	27.11	27.16	26.46
MCMS = Mass of can, lid, and moist soil (grams)	35.48	33.34	35.24
MCDS = Mass of can, lid, and dry soil (grams)	32.06	30.79	31.63
MS = Mass of soil solids (grams)	4.95	3.63	5.17
MW = Mass of pore water (grams)	3.42	2.55	3.61
w = Water content, w%	69.09	70.25	69.83

Therefore average moisture content= $\frac{69.09+70.25+69.83}{3}$=69.72%

Appendix D: Experiment 4: Moisture-density Relation (compaction) test

Test Procedure:

(1) Depending on the type of mold you are using obtain a sufficient quantity of air-dried soil in large mixing pan. For the 4-inch mold take approximately 10 lbs, and for the 6-inch mold take roughly 15lbs. pulverize the soil and run it through the # 4 sieve.

(2) Determine the weight of the soil sample as well as the weight of the compaction mold with its base (without the collar) by using the balance and record the weights.

(3) Compute the amount of initial water to add by the following method:

(a) Assume water content for the first test to be 8 percent.

(b) Compute water to add from the following equation:

Water to add (in ml) $= soil\ mass\ in\ grams * \frac{8}{100}$

Where "water to add" and the "soil mass" are in grams. Remember that a gram of water is equal to approximately one milliliter of water.

(4) Measure out the water, add it to the soil, and then mix it thoroughly into the soil using the trowel until the soil gets a uniform color.

(5) Assemble the compaction mold to the base, place some soil in the mold and compact the soil in the number of equal layers specified by the type of compaction method employed.

The number of drops of the rammer per layer is also dependent upon the type of mold used. The drops should be applied at a uniform rate not exceeding around 1.5 seconds per drop, and the rammer should provide uniform coverage of the specimen surface. Try to avoid rebound of the rammer from the top of the guide sleeve.

(6) The soil should completely fill the cylinder and the last compacted layer must extend slightly above the collar joint. If the soil is below the collar joint at the completion of the drops, the test point must be repeated. (Note: For the last layer, watch carefully, and add more soil after about 10 drops if it appears that the soil will be compacted below the collar joint.)

(7) Carefully remove the collar and trim off the compacted soil so that it is completely even with the top of the mold using the trowel. Replace small bits of soil that may fall out during the trimming process.

(8) Weigh the compacted soil while it's in the mold and to the base, and record the mass. Determine the wet mass of the soil by subtracting the weight of the mold and base.

(9) Remove the soil from the mold using a mechanical extruder and take soil moisture content samples from the top and bottom of the specimen. Fill the moisture cans with soil and determine the water content.

(10) Place the soil specimen in the large tray and break up the soil until it appears visually as if it will pass through the # 4 sieve, add 2 percent more water based on the original sample mass, and re-mix as in step 4. Repeat steps 5 through 9 until, based on wet mass, a peak value is reached followed by two slightly lesser compacted soil masses.

Analysis:

(1) Calculate the moisture content of each compacted soil specimen by using the average of the two water contents.

(2) Compute the wet density in grams per cm3 of the compacted soil sample by dividing the wet mass by the volume of the mold used.

(3) Compute the dry density using the wet density and the water content determined in step 1. Use the following formula:

$$\rho_d = \frac{\rho}{1+w}$$

Where: w = moisture content in percent divided by 100, and

ρ = wet density in grams per cm3

(4) Plot the dry density values on the y-axis and the moisture contents on the x-axis. Draw a smooth curve connecting the plotted points.

(5) On the same graph draw a curve of complete saturation or "zero air voids curve". The values of dry density and corresponding moisture contents for plotting the curve can be computed from the following equation:

$$\boldsymbol{\rho_d = \rho w / \left(\left(\frac{W}{100} \right) + \left(\frac{1}{Gs} \right) \right)}$$

where:

ρd = dry density of soil grams per cm3

Gs = specific gravity of the soil being tested (assume 2.70 if not given)

ρw = density of water in grams per cm3

(approximately1 g/cm3)

wsat = moisture content in percent for complete saturation.

(6) Identify and report the optimum moisture content and the maximum dry density. Make sure that you have recorded the method of compaction Nused (e.g., Standard Proctor, Method A) on data sheet.

Moisture-Density (Compaction) Test

Data Sheets

Test Method: Standard Proctor, Method A

Date Tested: December, 22, 2020

Tested By: Atirsagn & Gemtesa

Project Name: research

Sample Number: 4

Visual Classification of Soil: Black cotton soil

Water Content Determination: For non-treated soil sample

Compacted Soil - Sample no	**1**		**2**		**3**		**4**		**5**	
Water content - Sample no.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Moisture can number - Lid number	1	2	A	B	a	b	3	4	5	6
MC = Mass of empty, clean can + lid (grams)	25.3	24.07	58.95	59.92	17.62	17.68	22.98	24.50	17.7	23.4
MCMS = Mass of can, lid, and moist soil (grams)	56.56	49.61	92.46	105.04	56.17	51.97	60.73	52.92	67.4	75.9
MCDS = Mass of can, lid, and dry soil (grams)	52.13	46.34	85.28	95.34	47.11	43.86	50.35	45.22	52.21	59.58
MS = Mass of soil solids (grams)	26.83	22.27	26.33	35.42	29.49	26.18	27.37	20.72	34.51	36.18
MW = Mass of pore water (grams)	4.43	3.27	7.18	9.7	9.06	8.11	10.38	7.7	15.19	16.32
w = Water content, w%	16.5	14.68	27.27	27.38	30.72	30.98	37.16	37.9	44	45.1

Density Determination:

Mold Volume=944 cm

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	14	17	20	25
Actual average water content, w%	15.6	27	31	42.4	44.6
Mass of compacted soil and mold (grams)	4590	4760	4815	4985	4915
Mass of mold (grams)	3340	3340	3340	3340	3340
Wet mass of soil in mold (grams)	1250	1420	1475	1645	1575
Wet density, ρ , (g/cm3)	1.254	1.424	1.479	1.65	1.58
Dry density, ρd , (g/cm3)	1.085	1.121	1.129	1.159	1.09

Water Content Determination: For black cotton soil treated with 5% wood ash

Compacted Soil - Sample no	**1**		**2**		**3**		**4**		**5**	
Water content - Sample no.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Moisture can number - Lid number	I	II	7	8	9	10	11	12	13	14
MC = Mass of empty, clean can + lid (grams)	24.21	23.45	24.21	17.77	23.11	22.93	23.60	17.13	17.80	17.73
MCMS = Mass of can, lid, and moist soil (grams)	48.25	49.34	54.87	45.37	49.35	52.25	54.03	48.89	74.36	66.65
MCDS = Mass of can, lid, and dry soil (grams)	45.31	46.56	50.68	41.73	43.35	45.51	45.90	40.29	56.56	51.40
MS = Mass of soil solids (grams)	21.1	22.11	26.47	23.96	20.24	22.58	22.3	23.16	38.76	33.67
MW = Mass of pore water (grams)	2.94	2.78	4.19	3.64	6	6.74	8.13	8.6	17.8	15.25
w = Water content, w%	13.9	12.6	15.8	15.2	29.6	29.8	36.5	37.1	45.9	45.3

Density Determination:

Mold Volume=944 cm

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	14	17	20	25
Actual average water content, w%	11.7	15.5	29.7	36.8	45
Mass of compacted soil and mold (grams)	4450	4600	4740	4900	4890
Mass of mold (grams)	3340	3340	3340	3340	3340
Wet mass of soil in mold (grams)	1110	1260	1400	1560	1550
Wet density, ρ , (g/cm3)	1.136	1.29	1.433	1.597	1.59
Dry density, ρd , (g/cm3)	1.017	11.11	1.12	1.17	1.1

Water Content Determination: For black cotton soil treated with 10% wood ash

Compacted Soil - Sample no	1		2		3		4		5	
Water content - Sample no.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Moisture can number - Lid number	15	16	17	18	19	20	21	22	23	24
MC = Mass of empty, clean can + lid (grams)	25.25	25.2	25.25	25.48	25.41	25.36	25.38	25.08	25.60	25.52
MCDS = Mass of can, lid, and dry soil (grams)	53.41	51.32	57.79	53.40	52.02	47.58	53.35	53.18	57.85	59.08
MCMS = Mass of can, lid, and moist soil (grams)	59.28	56.73	66.65	61.22	61.05	55.15	66.13	65.61	75.40	77.44
MS = Mass of soil solids (grams)	28.16	26.12	32.54	27.92	26.61	22.22	27.97	28.1	32.25	33.56
MW = Mass of pore water (grams)	5.87	5.41	8.86	7.82	9.03	7.57	12.78	12.43	17.55	18.36
w = Water content, w%	20.8	20.7	27.2	28	33.9	34.1	45.7	44.2	54.4	54.7

Density Determination:

Mold Volume=944 cm

Compacted Soil - Sample no.	**1**	**2**	**3**	**4**	**5**
w = Assumed water content, w%	**8**	**14**	**17**	**20**	**25**
Actual average water content, w%	14.2	20.8	24	31.7	45
Mass of compacted soil and mold (grams)	4635	4685	4770	4915	4835
Mass of mold (grams)	3340	3340	3340	3340	3340
Wet mass of soil in mold (grams)	1295	1345	1430	1575	1495
Wet density, ρ , (g/cm3)	1.299	1.349	1.434	1.58	1.5
Dry density, ρd , (g/cm3)	1.075	1.088	1.089	1.09	0.97

Water Content Determination: For black cotton soil treated with 15% wood ash

Compacted Soil - Sample no	**1**		**2**		**3**		**4**		**5**	
Water content - Sample no.	**1A**	**1B**	**2A**	**2B**	**3A**	**3B**	**4A**	**4B**	**5A**	**5B**
Moisture can number - Lid number	**aa**	**bb**	**d**	**e**	**25**	**26**	**27**	**28**	**29**	**30**
MC = Mass of empty, clean can + lid (grams)	**24.52**	**24.58**	**24.5**	**23.61**	**24.5**	**23.61**	**46.22**	**44.21**	**60.60**	**59.57**
MCMS = Mass of can, lid, and moist soil (grams)	62.6	61.58	56.62	55.64	53.37	55.53	88.39	81.37	118.19	117.86
MCDS = Mass of can, lid, and dry soil (grams)	59.56	58.59	53.58	51.98	47.77	49.40	76.99	71.39	98.25	97.76
MS = Mass of soil solids (grams)	35.04	34.01	29.08	28.37	23.27	25.79	30.77	27.18	37.65	38.19
MW = Mass of pore water (grams)	3.04	2.99	3.04	3.66	5.6	6.13	11.4	9.98	19.94	20.1
w = Water content, w%	8.7	8.8	10.5	12.9	24.1	23.8	37	36.7	53	52.6

Density Determination:

Mold Volume=944 cm

Compacted Soil - Sample no.	**1**	**2**	**3**	**4**	**5**
w = Assumed water content, w%	**8**	**14**	**17**	**20**	**25**
Actual average water content, w%	12	20	24	37	53
Mass of compacted soil and mold (grams)	4700	4815	4875	4905	4865
Mass of mold (grams)	3340	3340	3340	3340	3340
Wet mass of soil in mold (grams)	1360	1475	1535	1565	1525
Wet density, ρ , (g/cm3)	1.364	1.479	1.54	1.57	1.53
Dry density, ρd , (g/cm3)	1.218	1.233	1.242	1.15	1

Appendix E: Laboratory Pictures

Pictures on work progress

a) Soil sample sieveing

b) Wood ash samole sieving

c) Specific gravity test

d) Liquid limit test

e) Plastic limit test

f) Drying sample in oven dry

g) Compaction test

h) Extruding

i) Extruded sample