JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

SUITABILITY OF COW DUNG ASH AND LIME MIX FOR STABILIZATION OF EXPANSIVE SUBGRADE SOIL

By:

Basha Edeo Kebeto

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering Stream)

July, 2024

Jimma, Ethiopia

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July, 2024

Jimma, Ethiopia

Declaration

I declare that this research entitled "**suitability of cow dung ash and Lime mix for stabilization of expansive subgrade soil**" is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.

Name	signature	Date
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Approval Sheet

I, the undersigned certify that the thesis entitled: ″suitability of cow dung ash and lime mix for stabilization of expansive subgrade soil″:- A Case of Robe Town” is the work Basha Edao Kebeto and has been accepted and submitted for examination with my approval as university advisor in partial fulfillment of the requirements for degree of Master of Science in Highway Engineering.

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As member of Board of Examiners of the MSc Thesis Open Defense Examination, We certify that we have read, evaluated the thesis prepared by Basha Edao Kebeto and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Highway Engineering.

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Abstract

Expansive soil present in its natural state at the construction site may not have suitable strength. The Construction of pavement on expansive subgrade soil is highly risky because such soil is susceptible to differential settlements, poor shear strength, high compressibility due to their swell-shrink behavior, and volume change with changes in moisture content which induces cracking, and overlying causing major structural and geotechnical challenges worldwide. These problems are extensively occurring in Ethiopia. The main aim of this study was to investigate the suitability of Cow Dung Ash (CDA) and Lime mix for stabilization of expansive subgrade soil of Robe town. To achieve this objective disturbed soil samples were collected from three test pits from robe town for different laboratory tests using the purposive sampling method at a 1.5m depth of pit from the ground. Accordingly, expansive soil was stabilized with the mix of cow dung ash by proportioning 0%-15% by an increment of 3% by dry weight to get the optimum percentages of cow dung ash and then activate the mixture by lime in the proportion of (0%-12%) by increments of 3%. Laboratory tests were conducted to determine moisture content, specific gravity, grain size analysis, Atterberg limits, proctor compaction test, free swell test, California Bearing Ratio (CBR), and CBR swell, tests. The test procedures were based on, American Association of State Highway and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM) laboratory test standards. From the study all soil sample at their natural state shows expansive soil, as they all range in A-7-5 according to AASHTO soil classification and CH according to unified soil classification system (USCS) and they having low CBR value and high CBR swell. The result of chemical composition of cow dung ash (CDA) indicates the combined percent composition of main oxides (SiO_2 + Al_2O_3 + Fe_2O_3) was 71.27% which is above the minimum of (70%) specified by ASTM (C618). The result of treated soil shows that decrease in plasticity index, free swelling index, specific gravity, MDD and CBR swell while increase in OMC and CBR value. From this study (6%CDA + 9%Lime) was an optimum ratio which achieved by improving most of the geotechnical properties of soils of Robe town. It is recommended to test additional parameter like unconfined compressive strength and study in different parts of the country by mixing Cow dung ash with other different stabilizers by other researchers.

Keywords: *cow dung ash, expansive soil, optimum percentage, stabilization*

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Table of Contents

Declaration i
Approval ii
Abstract ii
Acknowledgment iv
List of Tables ix
List of Figures x
Acronyms xi
CHAPTER ONE: INTRODUCTION 1
1.1 Background of the Study 1
1.2 Statement of the Problem 3
1.3 Research Questions 4
1.4 Objective of the Study 5
1.4.1 General Objective 5
1.4.2 Specific objectives 5
1.5 Significance of the Study 5
1.6 Scope of the Study 6
CHAPTER TWO 7
LITERATURE REVIEW 7
2.1 General Pavement Performance 7
2.2 Expansive Soil 7
2.2.1 Source of Expansive Soil 8
2.2.2 Mineralogy of Expansive Clay Soils 8
2.2.3 Distribution of Expansive Soils 9
2.2.4 Identification of Expansive Soils 10
2.2.5 Nature of Expansive Clay Soils 11
2.2.6 Soil Classification 13

2.2.7 Physical Properties of Expansive Soil 14
2.3 Soil Stabilization 15
2.3.1 Mechanical Stabilization.. 16
2.3.2 Chemical Stabilization 16
2.3.3 Stabilization by Lime 17
2.4 Previous Similar Works 19
2.4.1 Effects of Cow Dung Ash and Calcium Hydroxide on Geotechnical Properties of Expansive and Loose Soil [35] 19
2.4.2 Stabilization of Alluvial Soil for Subgrade Using Rice Husk Ash, Sugarcane Bagasse Ash and Cow Dung Ash for Rural Roads [7]... 19
2.4.3 Effect of Cow Dung Ash Calcined at Different Temperature on The Geotechnical Properties of Laterite Soil [36] 19
2.4.4 Characterization of Fire Clay Brick Value Added With Cow Dung Ash [37] 20
2.4.5 Study on Durability Properties of Concrete with Partial Replacement of Cement with Cow Dung Ash [9] 20
2.4.6 Soil Stabilization Using Cow Dung [38] 21
2.4.7 Use of Cow Dung Ash as a Partial Replacement for Cement in Mortar................. 21
2.5 Chemical Composition of Cow Dung Ash as Per [9] And [37] 21
CHAPTER THREE 23
METHODS AND MATERIALS 23
3.1 Study Area Description 23
3.2 Study Design 24
3.3 Materials.. 25
3.3.1 Expansive Soil 25
3.3.2 Cow Dung Ash (CDA).. 26
3.3.3 Lime 27

3.4 Study Variables 28
3.4.1 Independent Variable 28
3.4.2 Dependent Variable 28
3.5 Sample Size and Study Population 28
3.6 Nature and Source of Data 28
3.7 Sample Preparation 29
3.8 Sampling Techniques 29
3.9 Data Collection Process 29
3.10 Laboratory Testing 30
3.10.1 Natural Moisture Content 30
3.10.2 Atterberg Limits 30
3.10.3 Grain Size Analysis 31
3.10.4 Soil Classification 32
3.10.5 Specific gravity (Gs) 32
3.10.6 Free Swell 33
3.10.7 Compaction Test (AASHTO T 180-95) 33
3.10.8 California Bearing Ratio (CBR) and CBR Swell 34
CHAPTER 4 36
RESULTS AND DISCUSSION 36
4.1 Introduction 36
4.2 Properties of Material 36
4.2.1 Cow Dung Ash Properties 36
4.2.2 Geotechnical Properties of Natural Soil 38
4.3 Laboratory Test Result of Expansive Soil treated with Cow Dung Ash 47
4.3.1 Effect of Addition of Cow Dung Ash on Atterberg Limit 47
4.3.2 Effect of Addition of Cow Dung Ash on Free Swell Index 48

4.3.3 Effect of addition of cow dung ash on Specific gravity.. 49

4.3.4 Effect of Addition of Cow Dung Ash on Compaction Characteristics 50

4.3.5 Effect of Addition of Cow Dung Ash on CBR and CBR Swell............................ 52

4.3.6 Summary of Test Results for Soil Treated With Cow Dung Ash........................... 52

4.4 Laboratory Test Result of Expansive Soil Treated With Optimum Cow Dung Ash and Lime Mixture 53

4.4.1 Effect of Cow Dung Ash and Lime Mix on Specific Gravity................................ 53

4.4.2 Effect of cow Dung Ash and Lime mix on Free Swell 54

4.4.3 Effect of Cow Dung Ash and Lime Mix on Atterberg Limit 55

4.4.4 Effect of Cow Dung ash - Lime on Compaction Characteristics........................... 55

4.4.5 Effect of Addition of Cow Dung Ash Mixed with Lime on CBR and CBR Swell. 57

4.4.6 Summary of Test Results for Soil Treated With Optimum Cow Dung Ash and Lime Mixture 58

CHAPTER 5 60

CONCLUSION AND RECOMMENDATIONS 60

5.1 Conclusion.. 60

5.2 Recommendation.. 62

REFERENCES 63

APPENDIX A: Geotechnical Properties of Natural Expansive Soil of Study Area 67

APPENDIX B: Laboratory Data Analysis for Expansive Representative Soil Treated With CDA 89

APPENDIX C: Laboratory Data Analysis for Expansive Soil Treated With 6% CDA Mixed With Varied Percentage of Lime... 105

List of Tables

Table 2. 1: Atterberg Limits and Degree of Expansion [21] 11
Table 2. 2: Soil Classification Based on Swell Potential, CEC and PI [24,25] 12
Table 2. 3: Chemical Composition of Cow Dung Ash [9] and [39] 22
Table 3. 1: Chemical Properties Hydrated Lime by [35] 27
Table 3. 2: Details of Mixing Proportion 29
Table 3. 3: Subgrade Strength Classes [41] 35
Table 4. 1: Chemical Composition of Cow Dung Ash (CDA) 37
Table 4. 2: Physical Properties of CDA 38
Table 4. 3: Natural Moisture Content 38
Table 4. 4: Specific Gravity for Natural Soil 39
Table 4. 5: Atterberg Test Results for Both Natural Soil Samples 40
Table 4. 6: Summary of Soil Classifications 43
Table 4. 7: Free Swell Index of Natural Soil Sample 43
Table 4. 8: Compaction Test Result of Natural Soil Sample 44
Table 4. 9: CBR and CBR Swell of Natural Soil Sample 45
Table 4. 10: Summarized Laboratory Test Result for Natural Expansive Soil 46
Table 4. 11: Summary of Effect of Addition of Cow Dung Ash on Atterberg Limit 48
Table 4.12: Summary Effect of Addition of Cow Dung Ash on Free Swell Index 49
Table 4. 13: Effect of Cow Dung Ash on Specific Gravity 50
Table 4. 14: Effect of Cow Dung Ash on Maximum Dry Density and Optimum Moisture Contents 51
Table 4. 15: Effect of Addition of Cow Dung Ash on CBR and CBR Swell 52
Table 4. 16: Summary of All Test Results Performed on Soil with Different Percent of CDA.... 53
Table 4. 17: Effect of Cow Dung Ash and Lime Mix on Free Swell 54
Table 4. 18: Effect of Cow Dung Ash and Lime Mix on Atterberg Limit 55
Table 4. 19: Summary of Effect of Cow Dung Ash – Lime Mix on Compaction Characteristics 56
Table 4. 20: Summary of Effect of Cow Dung Ash Mixed With Lime on CBR and CBR Swell 57
Table 4. 21: Summary of Test Results for Soil Treated With Optimum Cow Dung Ash and Lime Mixture……58

List of Figures

Figure 2.1: USCS Soil Classification Chart [24] 14
Figure 3.1: Map of Study Area (Source: ArcMap, June, 2024) 23
Figure 3.2: Study Design 25
Figure 3.3: Photo Captured During Soil Sampling From Study Area 26
Figure 3.4: Photo of CDA Preparation 27
Figure 3.5: Liquid Limit and Plastic Limit Determination 31
Figure 3.6: Sieve Analysis 32
Figure 3.7: Specific Gravity Determination 33
Figure 3.8: Compaction Test 34
Figure 3.9: California Bearing Ratio (CBR) And CBR Swell 35
Figure 4.1: Grain Size Analysis for All Soil Samples 39
Figure 4.2: Soil Classifications According to USCS System 41
Figure 4.3: Soil Classifications According To AASHTO System 42
Figure 4.4: Compaction Test Result of Natural Soil Sample 44
Figure 4.5: Summary of Atterberg Limit Test 47
Figure 4.6: Effect of addition of cow dung ash on free swell index 49
Figure 4.7: Effect of Cow Dung Ash on Maximum Dry Density and Optimum Moisture Contents 51
Figure 4.8: Summary of Effect of Cow Dung Ash and Lime Mix on Specific Gravity 54
Figure 4.9: Effect of CDA and Lime Mix on Compaction Characteristics 56

Acronyms

AACRA	Addis Ababa City Road Authority
AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Materials
ABPS	Ali Birra Primary School
CBR	California Bearing Ratio
CDA	Cow Dung Ash
CEC	Cation Exchange Capacity
ES	Expansive Soil
ERA	Ethiopian Road Authority
GI	Group Index of AASHTO Soil Classification
LL	Liquid Limit
MWU	Madda Walabu University
MDD	Maximum Dry Density
MWUD	Ministry of Works and Urban Development of Ethiopia
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
RPS	Robe Preparatory School
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Expansive soil is any soil that has the potential to swell when wet and shrinks when dry. Clay mineral smectites found in expansive soils usually exhibit evident volume change with changes in moisture content, causing major structural and geotechnical challenges worldwide. Structures built on expansive soils develop defects due to swell and shrink activities causing cracks in the structure. Each year the damage caused by expansive soil in buildings and infrastructural systems is more than the damage caused by floods, hurricanes, tornadoes, and earthquakes combined [1].

Ethiopia is one of the fasts growing countries in East Africa. One of the popular sectors for Ethiopia's development was construction; which increases the participation of the population during operation that makes beneficial for the society and changes their living standards. Road transport was one of the typical modes of transportation, especially in Ethiopia. The distribution of expansive soil in Ethiopia covers about 40% of the total surface area of the country [2]. For instance, in other part of Oromia region Modjo-Ejerie- Areti Road and Addis-Jimma Road, Addis-modjo, in Wollega, Arsi and Bale zones are some examples of area covered with expansive soil. Robe town, is one city in Bale zones which covered with expansive soil [3].

Subgrade materials refer to the ground or soil underneath a road pavement. Oftentimes, these materials do not have sufficient capacity to support the weight of the road pavement and the traffic loads due to the rest on weak soil; will require some sort of modification and re-engineering to enhance their capacity to support the load. Expansive soils/weak soil can lead to early distress causing the premature failure of the road pavement structure [1]. Such soils need to be improved before stable and safe construction can be carried out on them.

Soil stabilization is a common engineering technique used to improve the physical properties of weak soil and make it capable of achieving the desired engineering requirements[4]. Chemical stabilization is one of the methods used to improve the engineering properties of soil and it involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with viscoelastic materials such as bitumen. Chemical stabilizers can be broadly divided in to three groups: Traditional stabilizers such as hydrated lime, Portland cement and Fly ash; Non-traditional stabilizers comprised of sulfonated oils, ammonium chloride, enzymes, polymers, and potassium compounds; and By-product stabilizers which include cement kiln dust, lime kiln dust etc. Among these, the most widely used chemical additives are traditional stabilizers. Among all traditional stabilizers, lime probably is the most routinely used [5].

The demand for traditional Additives such as lime and cement has been increasing in the construction industry which causes increasing the cost of construction[6]. Therefore from economical point of view Soil stabilization using agricultural and industrial wastes is one of the efficient and cost effective methods. Recent research works in the area of geotechnical engineering and construction materials focuses more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry. These materials may be classified as pozzolanic (fly ash, rice husk ash, wheat husk ash, cow dung ash, etc.), binder (lime, cement, cement kiln dust, lime sludge etc.) and inert (quarry dust, sand, ceramic dust etc.) are added to soil individually or combined [7].

Cow Dung Ash is one of the waste by-products readily available at cattle farms with negligible price and sometimes is almost free of cost. Cow dung ash is obtained by drying cow dung under the sun then burning it at controlled heat. In many parts of the world, cow dung is predominantly used as green manure for farming. It is also used with adobe in brick production, insect repellant and more recently used to produce biogas for electricity and heat generation [8].

Previous studies the partial replacement of cow dung ash in cement paste and concrete. Their results reveal a decrease in compressive strength with increasing ash content. Workability, Setting times and Standard Consistency increased as the CDA content increases [9]. Another study Use of cow dung ash as a Partial replacement for Cement in Mortar. Their findings showed that the compressive strength and replacement of cement combined, The replacement of cement with cow dung ash also reduces the workability of cement and in mortar retards the setting time therefore it can be used as a retarder in mortar in hot weather conditions [6]. In addition to having pozzolanic properties, also have some self-cementing properties in the presence of water [10].

This study was conducted to investigate the suitability of cow dung ash and lime mix for the stabilization of expansive subgrade soil. The different experimental studies were conducted to examine the modified sample according to specifications and standards.

1.2 Statement of the Problem

Expansive soil present in its natural state at construction site sometimes may not have the suitable strength. So, construction of pavement on expansive subgrade soil is highly risky because such soil is susceptible to differential settlements, poor shear strength, and high compressibility due to their swell-shrink behavior. the mineral smectites found in expansive soils usually exhibit evident volume change with changes in moisture content which induces cracking, and overlying causing major structural and geotechnical challenges worldwide. Problems associated with these expansive soil have been reported in Africa, Australia, Europe, India, and South America, the United States as well as some regions in Canada.

The above problems are extensively occurring in Ethiopia. The aerial coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres [11]. As a result, Pavement failure in Ethiopia is becoming a common problem and great challenge, consuming a lot of money. According to [3] expansive clay soil is available in different parts of Ethiopia. Concerning this problem treatment should require before construct the engineering structure by applying an appropriate, cost effective stabilization technique to improve the engineering properties of expansive sub-grade soil. An application of agricultural and industrial wastes are one of the efficient and cost effective methods.

Many researches were done on geotechnical properties of subgrade soil in most cities of the country like Addis Ababa, Bahir Dar, Mekele, Hawassa, Adama, Jimma [12].

However, the engineering property of the soil in Bale Robe town had not been studied widely. Robe Town, which is Capital of Bale Zone it had been noticed that expansive soils covers large parts of the town where recent constructions are carried out. During the past decades rapid expansion of the town and population growth due to migration from different parts of the small town and villages led to the construction of various structures particularly low-cost buildings and many feeder roads. But the existence of expansive soils in the Robe town has induced structural damages on light-weight buildings, asphalt road pavement and utility lines underground [12].

Since most soils which are found in Robe Town have a high plastic index and low CBR value [12]. These soils are a consequence for expansive and unstable subgrade soil. As a result, they make pavement structure failure. Previously there are many additives that were used as stabilization for expansive soil such as Lime, cement, fly ash, bitumen, gypsum, cement kiln dust, etc. Those common additives are of higher cost, various applications for the construction sector, and low accessibility of production in Ethiopia [13].

The robe town has a readily available source of cow dung. Farmers around Robe town practice mixed farming, raising both crops and cattle. This abundance suggests cow dung ash could potentially be utilized for construction purposes, especially if its properties are carefully studied. Furthermore, it is possible to use cow dung ash to reduce the amount and expense of lime required for soil stabilization. As a result, this study was conducted to assess the potential for improving the geotechnical properties of expansive soils by combining waste cow dung ash as a modifier with lime. The hypothesis is that substituting some standard stabilizing agents, like lime, with naturally available materials like cow dung ash, can help to reduce the problem.

Therefore, The objective of this study focused on conducting the effect of CDA and combined effect of cow dung ash and lime mixture on properties of expansive subgrade soil such as atterberg; liquid limit, plastic limit, plasticity index, specific gravity, free swell index, compaction; optimum moisture content (OMC), maximum dry density (MDD), california bearing ratio (CBR) and CBR swelling pressure of an expansive soil.

1.3 Research Questions

- ✓ What are the pozzolanic properties of Cow Dung Ash?
- ✓ What are the Geotechnical properties of the expansive subgrade soil of the study area?
- ✓ What is effect of CDA and combined effect of CDA and lime on properties of expansive subgrade soil?

1.4 Objective of the Study

1.4.1 General Objective

The general objective of this study was to evaluate the effect of cow dung ash and combined effect of cow dung ash and lime mix the stabilization of expansive subgrade soil.

1.4.2 Specific objectives

To achieve the main objective, the research had the following specific objectives;

- To determine pozzolanic properties of cow dung ash.
- To characterize geotechnical properties of natural expansive soil.
- To evaluate the effect of Cow Dung Ash and combined effect of CDA and lime mix on strength properties of expansive soil.

1.5 Significance of the Study

Expansive soil causes an increase in the initial cost of construction due to the need for improving the strength of weak soil. Especially improving/stabilizing subgrade soil using conventional stabilizing agents (cement and lime) has a great effect due to less availability and productivity in Ethiopia. The research was conducted to study alternative stabilization methods and to evaluate the effects of chemical stabilizers on expansive subgrade soil. This study introduces the knowledge of chemical stabilization particularly in agricultural wastes in the county for proper treatment of expansive sub-grade soils. Additionally it helps to improve susceptibility problem of expansive subgrade soil to water, increases stability and durability of pavement. However, this study gives a significant understanding of the suitability of cow dung ash and lime mix for the improvement of the expansive soil. The study also contributes a significant benefit by utilizing waste and locally available natural material in engineering applications as well reducing the problem to a great extent & the cost of construction may be minimized. Moreover, this study gives some insight for future researchers in the area of soil improvement by using cost-effective and locally available materials and was an indicative method of improving such soils using combination of industrial and agricultural wastes in the country.

1.6 Scope of the Study

The scope of this study focuses on the suitability of CDA and lime mix for stabilization of expansive subgrade soils. The experimental program were carried out for soil alone, soil mix with CDA at different percentages (0%, 3%, 6% 9%, 12%, 15%) of CDA and soil with optimum cow dung ash mix with lime at different percentages (0%, 3%, 6%, 9%, 12%) of lime. The index and engineering properties of soil was taken for three test pit at 1.5m depth from robe town by using purposive sampling techniques. The study were done by conducting grain size distribution, Atterberg limits, specific gravity, free swell, compaction, CBR and CBR swell. It is supported by different types of literature and a series of laboratory experiments. The study was limited to determine geotechnical properties of soil and stabilizers at pavement subgrade layer. And to conduct effects of stabilizers CDA and Lime on strength of subgrade soil.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Pavement Performance

The term performance refers to how pavements change in condition or serve their intended function over time. Performance is measured by distress, loss of serviceability index and skid resistance, loss of overall condition, and damage caused by expected traffic. The deterioration builds over time and leads to the breakdown of the pavement structure. There are two types of pavement distress or failure[14]. The first is a structural failure, which occurs when the entire structure collapses or one or more pavement components fail, rendering the pavement incapable of supporting the loads put on its surface. The second sort of failure is functional failure, which occurs when the pavement's roughness prevents it from performing its intended function without causing discomfort to drivers or passengers or imposing severe stress on cars. These failure conditions could be caused by inadequate maintenance, excessive loads, climatic and environmental factors, poor drainage, resulting in poor subgrade conditions, and component material disintegration.

2.2 Expansive Soil

Expansive soil is any soil that has the ability to expand when wet and contract when dry. Clay minerals found in expansive soils typically vary volume with variations in moisture content, posing significant structural and geotechnical issues around the world. Structures built on expansive soils have faults owing to swell and shrink processes, which cause cracks in the structure. Each year, expanding soil does more damage to buildings and infrastructure than floods, hurricanes, tornadoes, and earthquakes combined. Shrink swell characteristics of expansive subgrades are the leading causes of pavement faults that produce movement and differential settlement in the subgrade. When weak subgrade materials come into contact with water, they shrink and expand, resulting in rutting, cracking, raveling, and pothole development [1].

The subgrade in flexible pavement is more sensitive to failure under vehicle traffic loading due to non-uniform load distribution from above layers and the presence of high moisture contents. This layer receives less attention than other layers in pavement, despite the fact that the majority of pavement failures are caused by the subgrade layer's bearing capacity failure. Some subgrade soils, particularly clayey soils, are extremely strong with low moisture content; but, as water content increases above the optimal range, they become highly weak and less workable. Such soil should be replaced with high-quality fill material or treated using an appropriate treatment method[15].

Replacement of subgrade soil may not always be the best solution due to the accompanying hauling costs of excavated materials as well as imported quality materials. In some developing countries, or even metropolitan areas, the unavailability of aggregate or a scarcity of acceptable fill materials make replacing poor subgrade soil uneconomical. In such cases, the current weak subgrade soil's strength/stiffness qualities can be increased through correct compaction techniques and the use of chemical stabilizers [16].

The three most important clay mineral groups are montmorillonite, illite, and kaolinite. Montmorillonite is the clay mineral that is most abundant in expansive soil. When these minerals are exposed to moisture, water is absorbed between the inter-layering lattice structures and exerts an upward pressure, which causes the majority of problems associated with expansive soil [17]

2.2.1 Source of Expansive Soil

The origin of expansive soils may be traced back to a mixture of conditions and processes that cause clay minerals with specific chemical compositions to form when they come into contact with water. Clay mineralogy is determined by the parent material's composition as well as the degree of physical and chemical weathering to which the materials are exposed. The parent material for expansive soil is basic igneous or sedimentary rocks. Basic igneous rocks are generated through the disintegration of feldspar and pyroxene, while sedimentary rocks are built of smectite (montmorillonite), which physically decomposes to form expansive soils. Montmorillonite was most likely formed by weathering and erosion in the highlands, which was then brought by streams to the coastal plains [18].

2.2.2 Mineralogy of Expansive Clay Soils

Expansive soils have a high clay concentration. Various clay minerals are created by stacking basic sheet structures with varying types of bonding between them. The three most prevalent clay minerals are kaolinite, illite, and montmorillonite [19].

Kaolinite: it has a structural unit composed of an alumina sheet joined to a silica sheet and is bonded by hydrogen bonds. The bond that exists between the layers is very tight and hence it is difficult to separate the layers. As a result, kaolinite is relatively stable and water cannot penetrate between the layers. Consequently, kaolinite has a low degree of expansiveness.

Montmorillonite: It is the most prevalent of all clay minerals and is well-known for its swelling abilities. The basic structure consists of an alumina layer sandwiched between two silica sheets. The fundamental montmorillonite units are piled on top of one other, but the link between the individual units is very weak, allowing water to easily permeate between the sheets, causing them to split and swell. Montmorillonite has a high degree of expansiveness.

Illite: It has the same basic structure as montmorillonite. However, the basic illite units are held together by non-exchangeable potassium ions. As a result, the illite units are rather stable, and mineral swelling is significantly lower than in montmorillonite. Hence, illite has a moderate degree of expansiveness.

2.2.3 Distribution of Expansive Soils

Potentially expanding soils can be found practically anywhere on the planet. Many expanding soil problems in developing countries may have gone unnoticed due to the lower intensity of construction. As the amount of building develops, more expansive soil region-related problems are predicted to be reported each year. Expansive soils are abundant in areas where desiccation occurs, or where annual evaporation exceeds precipitation. The problem of expanding soil affects all five continents [30].

Expansive soils occur throughout the African continent, including South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, and Nigeria. In various regions of the world, cases of expansive soils have been frequently recorded, including the United States, Australia, Canada, India, Spain, Israel, Turkey, Argentina, and Venezuela [30]. The distribution of expansive soil in Ethiopia covers about 40% of the total surface area of the country [2]. For example, in other parts of the Oromia region, the Modjo-Ejerie-Areti Road and Addis-Jimma Road, as well as Addis-modjo in the Wollega, Arsi, and Bale zones, are instances of expansive soil [3].

2.2.4 Identification of Expansive Soils

Identification of expansive soil usually consists of two important phases. The first is the visual/field identification and the second is sampling and measurement of material properties to be used as the basis for the design.

2.2.4.1 Field Identification

Expansive soils can be identified in the field through visual inspections. Some of the important field identification methods that indicate the potential for expansive soils are as follow [13].

- ✓ They usually have a black or gray color.
- ✓ When dry, the soils have cracks at the ground surface
- ✓ The wet samples of the soil are sticky and it will be relatively difficult to clean the soil from the hands.
- ✓ High dry strength and low moist strength.
- ✓ Appearance of cracks in nearby structures.

2.2.4.2 Laboratory Identification

In general, there are three different methods of laboratory identification of expansive soils namely; mineralogical identification, direct and indirect methods [20].

Mineralogical Identification

A soil's expansiveness is determined by the type and percentage of clay minerals present. Knowing the type and quantity of clay minerals in a soil can help determine the swelling potential. The swell and shrink behavior of expansive soils is determined by the minerals contained in the clay. The clay mineralogy of expansive soils can be detected in the laboratory using tests such as X-ray diffraction, electron microscopy, differential thermal analysis, and so etc [20].

Direct Methods

Soil swelling pressure and volume changes are measured using representative, undisturbed samples. To calculate swelling pressure, measure the pressure required to prevent sample heaving under specific conditions such as moisture, density, and confinement. Swelling experiments offer total swelling, but it is difficult to predict the swelling that will occur in the field due to different beginning circumstances such as moisture and density. The methods provide quantitative information that is extremely beneficial for design engineers [20].

Indirect Methods

These are simple and more practical methods to identify expansive soils. The indirect tests Conducted include the Atterberg limits and grain size distribution, free swell test and linear shrinkage test.

According to [21]All Greyish and/or brownish clays in Ethiopia with plasticity indices (PI) greater than 25% can be Identified as expansive soils. The classification or rating from low potential to high heaven Potential usually depends on the clay content and plasticity.

Here measurements of the plasticity index and liquid limit are useful indices for the identification of the swelling of expansive soils. The Atterberg limits test results and degrees of expansion on expansive soils are expressed as follows.

Table 2. 1: Atterberg Limits and Degree of Expansion [21]

Swelling potential	**Plasticity**	**Index liquid limit**
Low	0-15	<30
Medium	10-35	30-40
High	20-55	40-60
Very high	55 and above	>60

A free swell test involves immersing a known volume of dry soil in water and measuring the swollen volume at the bottom of a graduated cylinder after the material settles without surcharge. A free swell volume is defined as the difference between the final and starting volumes given as a percentage of the initial volume[22].

2.2.5 Nature of Expansive Clay Soils

Soil elements with a high clay concentration are primarily responsible for expansive behavior. When the moisture content of the material increases, it begins to inflate, shrinks significantly when dried, and develops surface fissures. These soils have a high plasticity index[19]and range in hue from dark grey to black. The general features of black cotton soils are:

Easy to recognize these soils in the field during either dry or wet seasons:

- Shrinkage cracks are visible on the ground surface during dry seasons.
- The maximum width of these cracks may be up to 20 mm or more and they travel deep into the ground.
- Dry black cotton soil requires a hammer to break.
- During rainy seasons, these soils become very sticky and very difficult to traverse.

In nature, each soil particle is surrounded by water. Water molecules behave like dipoles because their positive and negative charge centers do not correspond. The soil particle's surface has a negative charge that attracts the positive (hydrogen) end of water molecules [23].

Clay particle are normally negatively charged. Similarly charged particles repel each other and cause dispersion in soil. These negatively charged clay particles can be held together with positively charged cations. The process is termed as flocculation. Different cations. Have 8 different flocculation powers. Cation exchange is the process in which weak flocculator cations are replaced with cations of high flocculating power [24].

Cation exchange capacity of soil represents the number of exchangeable cations in the clay mineral which can be replaced by the cations of higher replacing power than the absorbed cations. The CEC of a soil is a function of the amount and type of soil colloids present [25].

Swell potential is the measure of volumetric change in various soils on their interaction with water. Different experimental and empirical methods have been developed to determine swell potential of clayey soils [23]and [24].

Table 2. 2: Soil Classification Based on Swell Potential, CEC and PI [24,25]

Soil type	Swell Potential	Cation exchange capacity	Plasticity Index PI
Very High swelling	> 25	> 55	>35
High swelling	5 – 25	37 – 55	20-35
Medium swelling	1.5 – 5	27 – 37	10-25
Low swelling	< 1.5	< 27	0-1

2.2.6 Soil Classification

Soil classification is the grouping of soils into different categories so that the soil in each category behaves similarly. It categorized soils into groups and subgroups based on engineering properties such grain size distribution, liquid limit, and plastic limit etc.

A. AASHTO Classification System

AASHTO classification system is useful for classifying both coarse and fine grained soils for highway purpose. The particle size distribution and the plasticity characteristics are required to classify a soil in AASHTO. In these system the soils are divided in to seven types, designated as A-1 and A-7 are further subdivided in to two categories and the soil A-2 in to four categories. The soil with the lowest number is the most suitable for subgrade. For instance A-1 is better than the soil A-4. Soils rated A-6 or A-7 by AASHTO can be considered potentially expansive soil[3]. Group index (GI) is an important parameter to evaluate the quality of soil as a highway subgrade material. It is given by the equation:[3]

GI = (F200 - 35) [0.2 + 0.005(LL - 40)] + 0.01(F200 - 35) (PI - 10) ------------------------ (1)

Where F200 is percentages passing through sieve No.200 and LL & PI are liquid limit and plasticity index respectively.

B. Unified Soil Classification System (USCS)

The USCS is the most widely used system for determining the suitability of soils for general use based on particle size distribution and plasticity. According to this system the soils are classified into three major groups; course grained, fine grained and highly organic (peat). The soils are grouped as coarse grained, if more than 50% of the soil retained on No.200 (0.075mm) sieve and fine grained, if more than 50% of the soil passes No.200 sieve. The soils are represented by symbols such as, GW or SP, border line materials are represented by a double symbol as GW-GP. The fine grained soils are divided into inorganic silts (M), inorganic clays (C), organic silts and clay (O). The soils are further divided into those having liquid limits lower than 50% (L), or higher (H). The distinction between the inorganic clay and silt is made by the basis of modified plasticity chart.

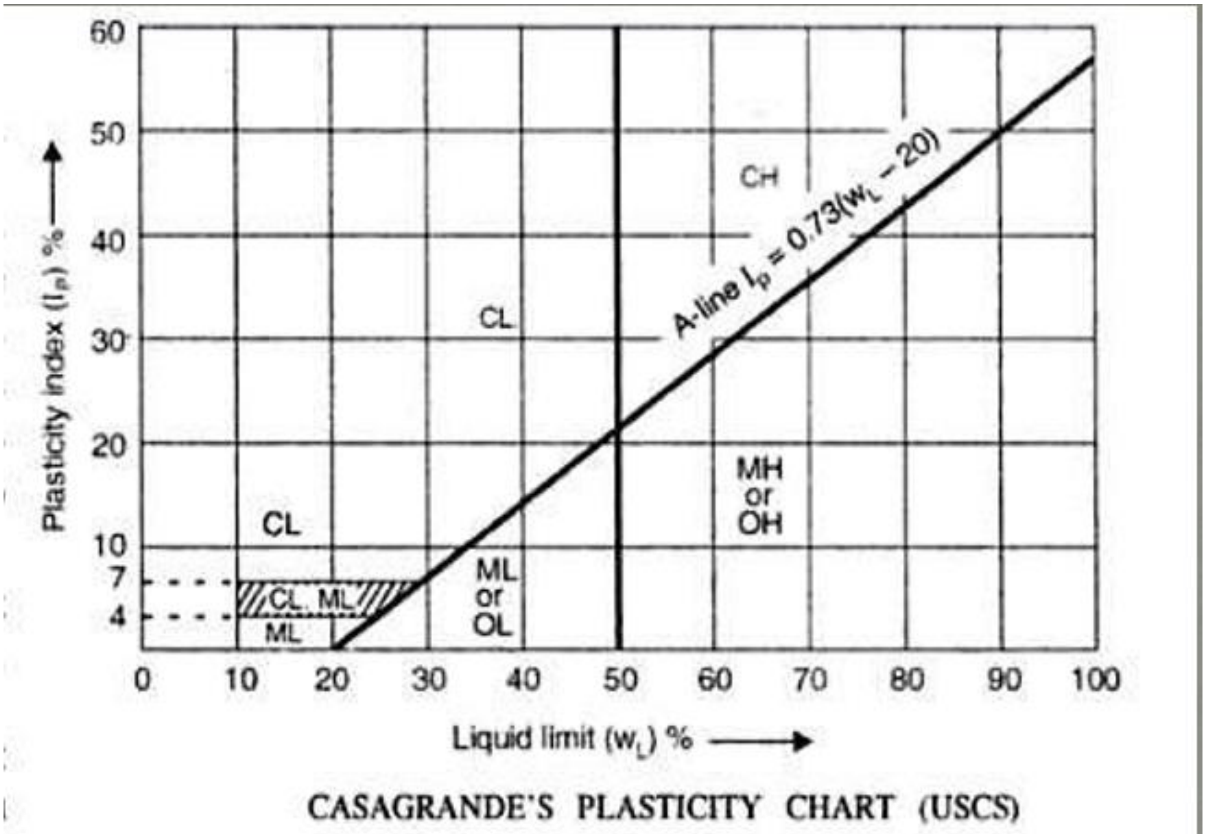

Figure 2.1: USCS Soil Classification Chart [24]

2.2.7 Physical Properties of Expansive Soil

The most important physical properties of expansive soils are moisture content, dry density, index properties, and fatigue of swelling [25].

If the moisture content of the clay remains unchanged, there will be no volume change irrespective of the high swelling potential. When the moisture content of the clay is changed volume expansion both in the vertical and horizontal direction will take place. Complete saturation is not necessary to accomplish swelling. Slight changes of moisture content in the magnitude of only 1 to 2 percent are enough to cause detrimental swelling [25].

Very dry clays with natural moisture content below 15 percent usually indicate danger. Such expansive soils easily absorb moisture as high as 35 percent with a resultant damaging expansion to structures. Conversely clays with moisture contents above 30 percent indicate that most of the expansion has already taken place and further expansion will be small. However moist clays may

desiccate due to lowering of water table or other changes in physical condition and up on subsequent wetting will again exhibit swelling potential [25].
The dry density of the clay is another index property of the expansive soils. Soils with dry density in excess of 110pcf generally exhibit high swelling potential. The dry density of the clays is also reflected by standard penetration resistance test results. Clays with penetration resistance in excess of 15 usually possess some swelling potential [26].
The simplified classification of expansive properties can be conventionally used by Engineers as a guide for the choice of structures on expansive soils. Some of the index properties to be identified and used are Soil Classification, Liquid Limit, Standard penetrations and the likes [25].
A clay sample is subjected to full swelling in the consolidometer, allowed to desiccate to its initial moisture content and is then saturated again. These steps can be repeated for a number of cycles and observed that the soil has shown a sign of fatigue after each cycle of drying and wetting. It has been noted that pavements founded on expansive clays which have undergone seasonal movement due to wetting and drying have a tendency to reach a point of stabilization after a number of years. The fatigue of the swelling can answer the situation [27].

2.3 Soil Stabilization

Stabilization is defined as the process of altering the properties of sub-grade and pavement materials either by blending and improving particle gradation (mechanical stabilization) or by using stabilizing additives to meet the specified engineering properties (Chemical Stabilization). Soils are generally stabilized to increase their strength and durability or to prevent erosion and dust formation in soils. The main aim is the creation of a soil material or system that will hold under the design use conditions and for the designed life of the engineering project. The properties of soil vary a great deal at different places or in certain cases even at one place; the success of soil stabilization depends on soil testing [28].
Various methods are employed to stabilize soil and the method should be verified in the lab with the soil material before applying it on the field [29].
Stabilization can enhance the properties of road materials and pavement layers in the following ways: [30]

- ✓ A substantial proportion of their strength is retained when they become saturated with water.
- ✓ Surface deflections are reduced.

- ✓ Materials in the supporting layer cannot contaminate the stabilized layer.
- ✓ Lime-stabilized material is suitable for use as a capping layer or working platform when the in situ material is excessively wet or weak and removal is not economical.

2.3.1 Mechanical Stabilization

Mechanical stabilization is defined as a process of improving the quality of soil without changing the chemical properties of the soil. It is done by mixing two or more grades of soil to obtain the required specifications. It is the most widely used method where the material is made more stable by adjusting the particle size distribution. This type of stabilization includes: compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation [18].

2.3.2 Chemical Stabilization

Chemical stabilization is a process in which different chemical or additive material is added to the soil. In this method, soil stabilization depends mainly on chemical reactions between stabilizers and soil minerals to achieve the desired property. Chemical stabilization involves mixing or injecting chemically active compounds (such as cement, lime, fly ash, sodium chloride or bitumen) into the soil to improve its stability, strength, and durability, or to control swelling and permeability [31]. Some of chemical additives used for soil stabilization are as follows:

A) Cement Stabilization

Cement stabilization is the most common method of stabilization with additives. Soil cement (mixture of soil and cement) has been used as foundation material in many projects, such as highway pavement, building pad, and slope protection of dams and embankments. Cement stabilization differs from other forms of chemical stabilization in such a way that structural strength is primarily gained from the cementing action rather than from internal friction, cohesion or chemical ion exchange of the materials. Almost all types of soils can be used for cement stabilization except highly organic soils or heavy clay soils [18].

B) Lime stabilization

Lime provides an economical way of soil stabilization. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction. In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes. Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds [32]. The effect can be brought by either quicklime, CaO or hydrated lime, Ca $(OH)_2$. Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction. Quicklime is the most commonly used lime; the followings are the advantages of quicklime over hydrated lime.

-Higher available free lime content per unit mass

- Denser than hydrated lime (less storage space is required) and less dust

- generates heat which accelerate strength gain and large reduction in moisture content

C) Fly ash stabilization

This method of stabilization is gaining more attention in recent times since it has wide spread availability to be used alone or with other cementitious additives. It is inexpensive and has a long history of use as an engineering material and has successfully employed in geotechnical application. Fly ash can improve the California bearing ratio (CBR) and unconfined compression strength (UCS) while lowering the liquid limit and plasticity index [33].

2.3.3 Stabilization by Lime

Lime is in organic chemical compound which is produced by burning of lime stone in kilns. Lime is widely used as a soil modification agent to improve the performance of sub grade soils and also reduce volume change. Lime provides an economical way of soil stabilization which is alone or combination with cement, fly ash for better result and economic stabilization; and the most effective and widely used chemical additive for expansive soils. Effective mixing of lime and soil is critical to ensuring that the expected improvements occur throughout the soil mass. Lime also decreases the apparent amount of fines in a soil by causing flocculation and

agglomeration of the clay particles. Lime stabilization helps in increasing the strength, durability and also minimizes the swelling, moisture variations in the soil and lime must be well compacted for obtaining sufficient strength and durability by maintaining OMC. Lime improves the low load bearing capacity of poor sub-grade soil and lower the plasticity index and percent swell of highly expansive sub-grade soil [32].
Lime decreases soil density and increases soil modulus of elasticity, strength; and cause a decrease in tendency of attraction of water. And also increase in the unconfined compressive strength is some times as high as 60 times. Lime reacts with medium, moderately fine, and fine-grained soils to produce decreased plasticity, increased workability, and increased strength [34]

According to [34]and [7] study the Chemical and physical properties of both quick and hydrated lime given as follow:
Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles. When lime reacts with wet soil, it alters the nature of the adsorbed layer by Base Exchange. Calcium ions replace the sodium or hydrated ions. Lime reacts chemically with available silica and alumina in soils. The quicklime is vulnerable to water; even the moisture in the air produces a destabilizing effect by air slaking. Hydrated lime is more stable since water does not cause a change in its composition. Lime is chemically known as Calcium oxide (CaO). Quick lime is a white, caustic, alkaline crystal solid at room temperature. On hydration, quick lime forms slaked lime or lime water. When water is added to lime it becomes hot and cracks to form a white powder. This is called slaking of lime [34].

$CaO + H_2O \quad Ca(OH)_2$ ………………………. (Slaked lime)

Lime is a white amorphous solid. Physically, quicklime is white of varying degrees of intensity, depending on its chemical purity. The color of lime depends on the presence of impurities within the lime and results in a grayish or yellowish appearance. Hydrated limes reflect as similar relationship between purity and Whiteness [34].

2.4 Previous Similar Works

2.4.1 Effects of Cow Dung Ash and Calcium Hydroxide on Geotechnical Properties of Expansive and Loose Soil [35]

A thorough investigation has been conducted to examine the impacts of CDA and $Ca(OH)_2$ on the geotechnical properties of expansive soil (Sample A) and loose soil (Sample B). The findings of the study lead to the following conclusions: The California Bearing Ratio (CBR) values showed significant improvement with the varying addition of CDA and $Ca(OH)_2$ for Sample A. However, for Sample B, there was no notable enhancement in the CBR values with the addition of CDA and $Ca(OH)_2$. Therefore, it can be concluded that CDA and $Ca(OH)_2$ are effective in stabilizing expansive soil, while their effectiveness is limited in loose soil.

2.4.2 Stabilization of Alluvial Soil for Subgrade Using Rice Husk Ash, Sugarcane Bagasse Ash and Cow Dung Ash for Rural Roads [7]

This paper focuses on the stabilization of subgrade soil using various locally available materials, including rice husk ash (RHA), sugarcane bagasse ash (SCBA), and cow dung ash (CDA). RHA, SCBA, and CDA were mixed with the soil as partial replacements by weight in proportions of 0%, 2.5%, 5%, 7.5%, 10%, and 12.5%. The natural soil was identified as intermediate plastic clay, which exhibited a decrease in dry density and an increase in optimum moisture content after stabilization. The trends observed in the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) displayed an initial increase followed by a decrease, indicating a peak at an optimum ash content of 7.5%. This study demonstrates a significant improvement in CBR and UCS, as well as an ability to control volumetric changes.

In terms of effectiveness, the following priority order can be established for soil stabilization: RHA, followed by SCBA, and then CDA. While CDA is not the most effective stabilizer, it can still enhance the engineering properties of alluvial soil.

2.4.3 Effect of Cow Dung Ash Calcined at Different Temperature on The Geotechnical Properties of Laterite Soil [36]

Lateritic soils were stabilized using 0%, 2%, 4%, 6%, 8%, and 10% cow dung ash (CDA) based on the dry unit weight of the soil samples. The geotechnical properties assessed included Liquid Limit (LL), Plastic Index (PI), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR), both in soaked and unsoaked conditions, across varying temperature conditions. The cow dung was sundried and calcined at temperatures of 600°C and 800°C. The chemical composition of Silica (SiO_2), Alumina (Al_2O_3), and Iron Oxide (Fe_2O_3) was determined. The results showed that the SiO_2, Al_2O_3, and MgO contents of CDA at 600°C were 51.54%, 22.45%, and 1.20%, respectively, while at 800°C, these values were 43.64%, 12.24%, and 5.01%. The CDA at 600°C demonstrated higher pozzolanic properties compared to CDA at 800°C, as indicated by the criterion that $CaO + SiO_2 + Al_2O_3 > 70$.

For the soil stabilized with CDA at 600°C, the MDD and OMC varied from 1.71 to 1.81 g/cm^3 and 9% to 16.5%, respectively. In the case of soil stabilized at 800°C, MDD and OMC ranged from 1.73 to 1.82 g/cm^3 and from 13.5% to 17%, respectively. The CBR values for stabilized soil at 600°C ranged from 15% to 26% in the unsoaked condition and from 5% to 11% in the soaked condition. For CDA at 800°C, the unsoaked CBR values ranged from 20% to 27%, while the soaked CBR values varied from 7% to 14%. Overall, cow dung ash (CDA) exhibited favorable pozzolanic properties and enhanced the geotechnical properties of the lateritic soil.

2.4.4 Characterization of Fire Clay Brick Value Added With Cow Dung Ash [37]

This study investigates clay bricks with partial substitution of Cow Dung Ash (CDA). Five types of clay bricks were manufactured using CDA percentages of 0%, 5%, 10%, 15%, and 20% of the total weight of the mixture, following a traditional method with dimensions of 18.5 × 8.5 × 6.5 cm^3. The results from this analysis revealed that the addition of 10% CDA produced the most favorable values for the physical properties. Specifically, an average density of 1447 kg/m^3 was recorded, along with maximum compressive and flexural strengths of 150 kg/cm^2 and 0.82 kg/cm^2, respectively, which meet the requirements, set by British Standards.

2.4.5 Study on Durability Properties of Concrete with Partial Replacement of Cement with Cow Dung Ash [9]

This study examined the pozzolanic activity of cattle manure ash (CMA) and compared the strength characteristics of cow dung ash concrete to conventional concrete. Cement was replaced with cow dung ash in incremental proportions of 5%, 10%, 15%, and 20% by weight. The compressive strength of the concrete was assessed after 7 and 28 days of curing, while the split tensile strength was measured at 28 days of curing. M30 grade concrete served as the reference mix. Additionally, durability properties of cow dung ash concrete were evaluated. The results indicated that the concrete with a 15% cement replacement using cow dung ash exhibited the highest compressive strength.

2.4.6 Soil Stabilization Using Cow Dung [38]

The researcher has carried out adding cow dung was taken from the past history or historical periods wherein all the construction was carried out with the help of the mixture of cow dung (binder), mud or soil, and dry grass. For e.g. Gadi soils – white soil and many houses in rural villages even today are made with cow dung mixtures. And even after so many centuries the history/world has witnessed these structures which are still standing today even after facing so many natural calamities and consequences through its period. Analysis performed in the laboratory, the compressive strength obtained with cow dung stabilization and the values obtained of the normal soil were almost the same on the basis of the comparison with normal soil rather at high percentages of cow dung mixing the strength and other properties of the soil started to decrease drastically. Therefore for now on the basis of the above results using dry cow dung for stabilization of earth soil is not liable or safe for heavy projects [38].

2.4.7 Use of Cow Dung Ash as a Partial Replacement for Cement in Mortar

Cow dung ash, a readily available by-product from cattle farms, is often inexpensive or even free of cost. In this study, cement was replaced with cow dung ash in incremental proportions of 5%, 10%, 15%, 20%, and 25% by weight. The findings indicated that substituting cement with cow dung ash improved the strength, durability, and workability of the mortar mix compared to conventional formulations, with the optimal performance observed at a 25% replacement level. However, it was also noted that incorporating cow dung ash reduced the overall workability of the cement mix. Additionally, cow dung ash was found to retard the setting time of the mortar, making it a potential retarder for use in hot weather conditions [6].

2.5 Chemical Composition of Cow Dung Ash as Per [9] And [37]

Cow dung ash was obtained from the combustion of cattle manure under natural condition which was sieved to obtain the material smaller than 90 microns. The chemical composition of cow dung ash is shown in table below.

Table 2. 3: Chemical Composition of Cow Dung Ash [9] and [39]

Compound	Result (%) as per[9]	Result (%)as per[37]
SiO_2	69.95	69.5
Al_2O_3	4.36	3.98
Fe2O3	2.78	3.58
CaO	13.85	12.99
Na2O	0.34	0.42
MgO	1.76	2.25
LOI	1.2	
K2O		2.59

CHAPTER THREE
METHODS AND MATERIALS

The research work was intended to check the suitability of cow dung ash (CDA) and lime mix for stabilization of expansive sub-grade soil.

3.1 Study Area Description

The study was conducted in Robe town, also known as Bale Robe, which is approximately 430 kilometers by road from Addis Ababa, Ethiopia. Robe town is located between (7°04′30″N-7°08′40″N,) latitude and (39°59′0″E-40°02′0″E,) longitude at an elevation of between (8088ft-8330ft) above sea level. The average annual rainfall is 1100mm. It has a moderate highland climate, with average minimum and maximum temperatures of 14°C and 26°C, respectively.

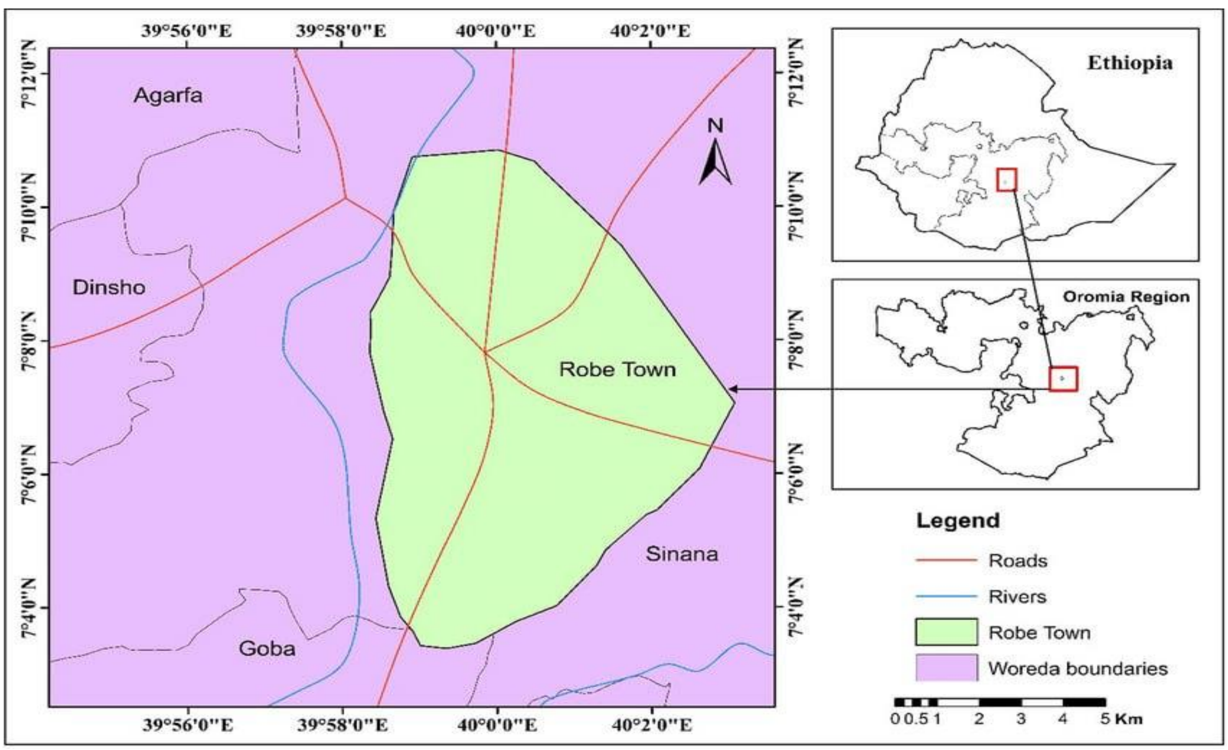

Figure 3.1: Map of Study Area (Source: ArcMap, June, 2024)

Robe town shares Robe airport with neighboring Goba town. An Ethiopian airline operates a four-times-weekly flight, connecting Robe town, the capital Addis Ababa, and the southern city Arba Minch. The primary market day is Thursday, with a secondary market operating at a different location in the town on Tuesdays and Sundays. Notable tourist attractions in the Bale

Robe area include the Sof Omar Caves, Dire Sheikh Hussein Stone, Dinsho National Park, and so on. With 99% of the population engaged in farming, agriculture is one of the area's economic activities. Farmers around Robe town practice mixed farming that incorporates both crops and livestock.

According to the 2007 national census, Robe had a total population of 44,382, with 22,543 males and 21,839 females. The majority of the population identified as Muslim, with 48.08 percent claiming to follow this religion, 45.02 percent claiming to follow Ethiopian Orthodox Christianity, and 6.13 percent claiming to be Protestant.

List of Primary schools in Robe Town according to local history in Ethiopia ;Nordic Africa Institute website provide details: Ali Birra Primary School, Madda Walabu Primary School, Kibxate Primary School, Robe Gelema Primary School, Zeybela Primary School, and General Umar Suleyman Primary School and Numbers of secondary Schools in Bale Robe Town=5; Robe Secondary School, Robe Gelema Secondary School, Madda Walabu Secondary School, General Wako Gutu Secondary School, and General Umar Suleyman Secondary School and has one preparatory school which is called Robe preparatory School.

3.2 Study Design

This study used experimental study designs. Laboratory tests such as natural moisture content, grain size analysis, Atterberg limits, free swell test, specific gravity, modified Proctor compaction tests, CBR value, and CBR swell were performed on natural expansive soil samples treated with varying proportions of cow dung ash and lime and checked against standard specifications.

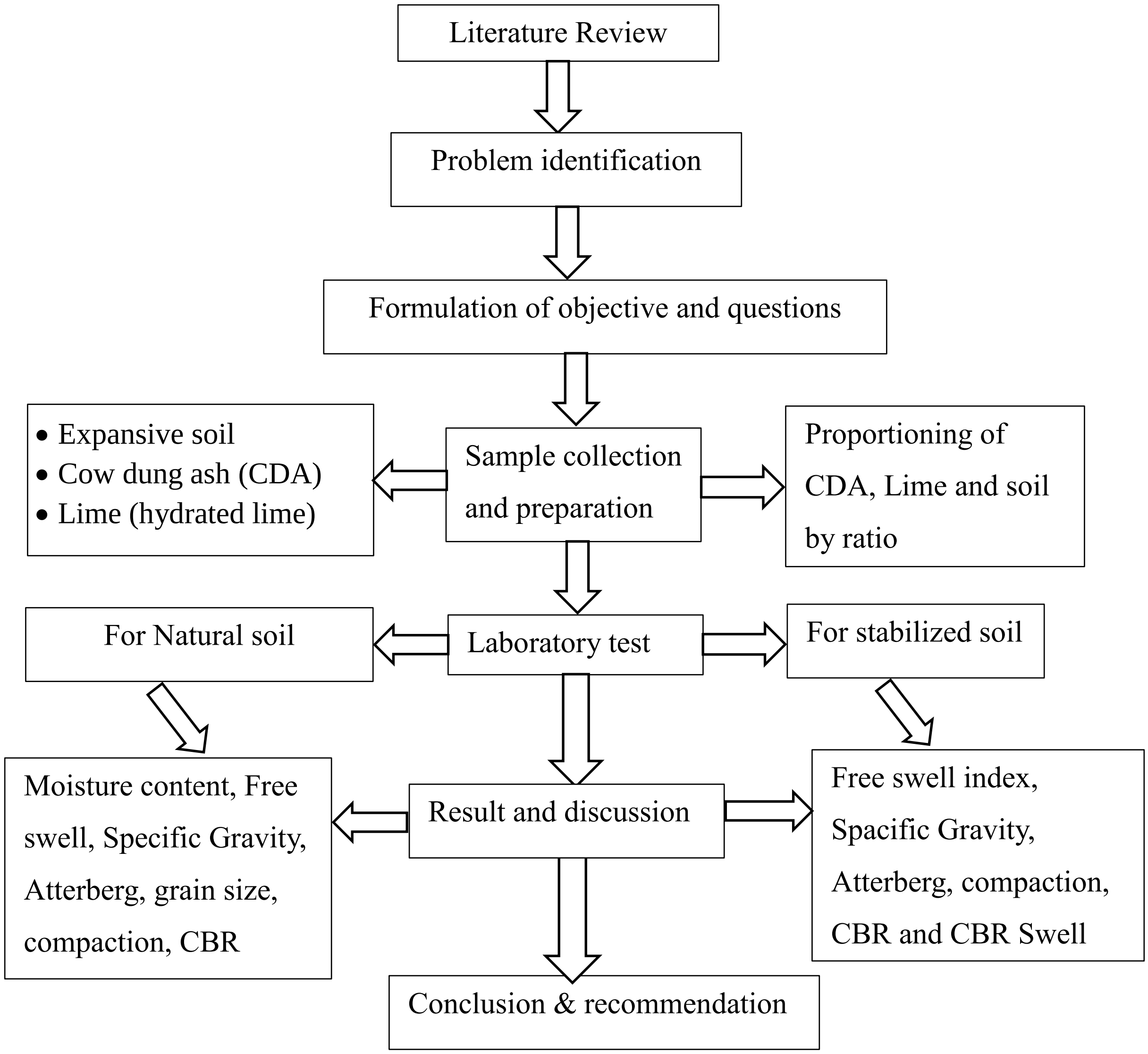

Figure 3.2: Study Design

3.3 Materials

Three materials are used in this study. These are expansive soil, cow dung ash and lime.

3.3.1 Expansive Soil

The soil sample was collected from robe town from three different locations of study area. These locations were Madda Walabu University (MWU) (7°08'32.38"N, and 40°0'8.86"E), Robe Preparatory School (RPS) (7°07'31.07"N, and 40°0'26.55"E) and Ali Birra Primary School (ABPS)

(7°06'46.07"N, and 40°0'3.42"E). The disturbed sample where collected along with the soil profile at the depth of 1.5m to avoid the inclusion of organic matter.


Figure 3.3: Photo Captured During Soil Sampling From Study Area

3.3.2 Cow Dung Ash (CDA)

The cow manure used in this study was gathered from Sinana woreda, which is located near Robe Town. Because of its disintegration properties, cow dung cannot be used in its pure form to stabilize weak soil; thus, we must use ashes of these waste components. Cow dung ash is obtained by drying cow dung in the sun for at least two weeks before burning and burning it till it turns to ash on a metal sheet to prevent dust mixing. The mixture was then chilled and crushed into powder before being sieved through an IS 400 micron sieve (0.075mm).

Figure 3.4: Photo of CDA Preparation

3.3.3 Lime

The lime used in this study was obtained from the Zuway (Batu) lime factory. The hydrated lime is used for this works. The constituent of hydrated lime with percentage by weight studied by [34] is shown in Table 3.1

Table 3. 1: Chemical Properties Hydrated Lime by [34]

Oxides	Percentage
CaO	70
SiO_2	2.5
Al_2O_3	0.81
MgO	1.41
Fe_2O_3	0.48

3.4 Study Variables

The study variables which consist in the research contained both independent and dependent variables.

3.4.1 Independent Variable

The percentage of CDA and lime, sample pit depth, specific gravity, Atterberg limit (PL, PI, LL), MDD, OMC, CBR, CBR swell, and free swell index are among the independent variables in this study.

3.4.2 Dependent Variable

The dependent variable of this research is the strength of stabilized expansive sub-grade soil.

3.5 Sample Size and Study Population

The study's sample size is determined by the number of pits used and the type of laboratory test performed. Soil samples were obtained in Robe Town from three pits (Mada Walabu University, Robe Preparatory School, and Ali Birr Primary School) at a test pit 1.5m from the ground.

The study's population included natural soil, lime, and cow dung ash. The study tried to determine the viability of a cow dung ash and lime mix for stabilizing expansive subgrade soils. For this reason, 7 trial tests were conducted for both 3 pits (21 specimens for natural expansive subgrade soil), 5 trials for one selected pit (25 specimens for CDA treated soil), and 5 trials for the soil-Opt.CDA-Lime treated soil (25 specimen for CDA-lime-soil). A total of 71 soil samples were prepared.

3.6 Nature and Source of Data

This work qualifies as quantitative experimental since it measures the engineering qualities of expanding soil. Systematic purposive sampling is used to collect soil samples from the study region using field observations and some literatures, which are then, evaluated using descriptive statistics to define soil properties using laboratory test findings.

Both primary and secondary data sources were used. Secondary data need for this research pre-fieldwork have been collecting journals, books, web site, etc., and the primary sources of fieldwork are collecting expansive soil, additive (Cow Dung Ash and lime) from selected sites and post-fieldwork where laboratory experimental outputs.

3.7 Sample Preparation

The sample was collected from the study area, air-dried, and mixed with stabilizer (cow dung ash and lime) in the percentages stated in table 3.2 below. These percentage values were used to prepare the sample for all required laboratory tests. The laboratory proportion of the sample investigations are carried out as follows: soil alone, soil + cow dung ash, and soil + optimal CDA + lime with varying percentages, as stated in the table below by weight of the additive.

Table 3. 2: Details of Mixing Proportion

S.no	Sample trail	Composition of soil + ash	Composition of soil + Lime + optimum CDA
1	Trail 1	100% soil	100% soil
2	Trail 2	97% soil + 3% CDA	Soil + 3%lime + Opt.CDA
3	Trail 3	94% soil + 6% CDA	Soil + 6%lime + Opt.CDA
4	Trail 4	91% soil + 9% CDA	Soil + 9%lime + Opt.CDA
5	Trail 5	88% soil + 12% CDA	Soil + 12%lime + Opt.CDA
6	Trial 6	85% soil + 15% CDA	

3.8 Sampling Techniques

The research employed purposive sampling method. This technique was chosen because it allows for the selection of samples that are particularly informative for determining the strength of expansive clay soil.

3.9 Data Collection Process

The data gathering procedures were mostly focused on the tests to be performed on the prepared samples in the laboratory. The data were obtained from three 1.5m deep test pits in Robe Town, cow dung from the Sinana neighborhood of Robe Town, and lime from the Zuway (Batu) lime factory. Laboratory testing was carried out in Addis Ababa’s geochemistry laboratory for silica test analysis, and at Jimma University Institute of Technology's Highway Engineering Laboratories for other tests in accordance with AASHTO and ASTM standards**.**

3.10 Laboratory Testing

To assess the influence of cow dung ash (CDA) and lime on expansive soil properties, laboratory tests were conducted. Initial moisture content, Grain size analysis, Atterberg Limits, compaction, (MDD, OMC), specific gravity, free swell index, CBR value and CBR swell tests were performed on expansive soil samples mixed with varying CDA and lime percentages.

3.10.1 Natural Moisture Content

The initial moisture content of expanding soil was determined using the AASHTO T-265 test technique. The moisture content of disturbed soil samples was determined using the oven-drying method. Small representative natural soil specimens collected from big bulk samples at the site are packed in plastic bags. The samples were then weighed as received, placed in a moisture container, and oven-dried at 105°C for 24 hours. The final dry weight was calculated, and the weight difference was considered to equal the weight of water pushed off during drying. The difference in weight was divided by the weight of the dry soil to determine the disturbed natural soil's initial moisture content.

3.10.2 Atterberg Limits

The Atterberg limit tests include the liquid limit, plastic limit, and plasticity index. The test processes are detailed in the AASHTO materials testing manual. The liquid limit values are determined according to AASHTO T89-96. Similarly, the plastic limit and plasticity index of soil samples are calculated in accordance with AASHTO T90-96. The liquid limit of each soil was determined using an Atterberg limits apparatus with material passing through a 475 µm (No. 40) sieve.

Liquid limit: The boundary between the liquid and plastic states was studied using Casagrande standard procedures (ASTM D4318-93). It was carried out on remolded soil samples, with the fraction passing through No.40 (0.425mm). By convention, the liquid limit is defined as the water content at which the groove cut into the soil pad in the conventional liquid limit device requires 25 blows to close along a 13mm distance (ASTM D4318-93).

Plastic limit: The boundary between the plastic and semi-solid states; the plastic limit of a soil is defined as the water content at which the soil begins to crack when rolled into a thread 3 mm in diameter. The test was performed as per ASTM D4318.

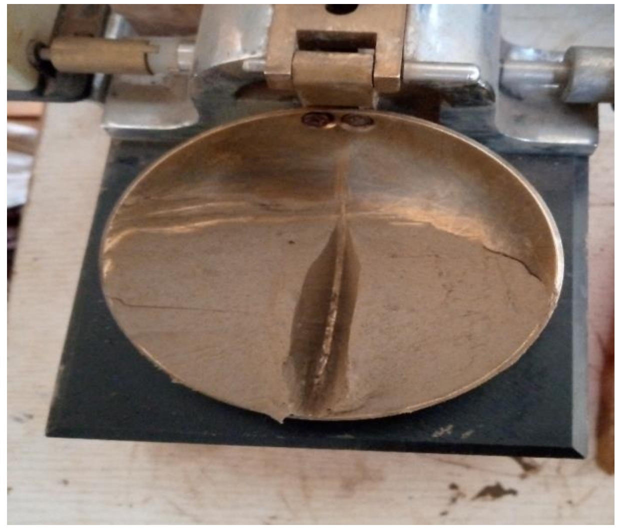

Figure 3.5: Liquid Limit and Plastic Limit Determination

3.10.3 Grain Size Analysis

Particle size analysis is a method used to separate soils into different fractions based on the sizes of particles present. This analysis was performed using both mechanical (sieve) analysis and sedimentation (hydrometer) analysis. Sieve analysis, following the ASTM D422 standard, separates the coarse-grained fraction of soil with particles larger than 75 micrometers (No. 200 sieve). Sedimentation analysis, following the ASTM D1140 standard, is used for the analysis of fine-grained soil (silt and clay) with particles smaller than 75 micrometers (No. 200 sieve). It is performed by hydrometer analysis. For this study, both wet sieve analysis and hydrometer analysis were performed.

Figure 3.6: Sieve Analysis

3.10.4 Soil Classification

The most widely used soil classification systems for engineering purposes are American Association of State High Way and Transportation Officials (AASHTO) and Unified soil classification system (USCS). The AASHTO system of soil classification comprises seven groups of inorganic soils from A-1 to A-7 with 12 subgroups in all. The system is based on particle-size distribution, liquid limit and plasticity index. On the other hand, the Unified Soil classification system is based on the recognition of the type and predominance of the constituents considering grain – size, gradation, plasticity and compressibility. It divides soil in to three major divisions: coarse grained soils, fine grained soils and highly organic soils.

3.10.5 Specific gravity (Gs)

The specific gravity of soil is the weight in air of a given volume of soil particles at a given temperature divided by the weight in air of an equivalent volume of distilled water at that same temperature. The heaviness of soil particles was evaluated using the pycnometer method, with a soil sample passing through a #40 (0.425mm) sieve as per AASHTO T100-95. The test was carried out at 20°C water temperature. The specific gravity (Gs) of a soil is computed as follows:

$$\text{Specific gravity } (G_s) = W2 - W1 / (W4 - W1) - (W3 - W2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where:

W1- Weight of bottle in gms

W2- Weight of bottle + Dry soil in gms

W3- Weight of bottle + Soil + Water in gms

W4- Weight of bottle + Water in gms

The specific gravity at a standard temperature of 20oC.

Figure 3.7: Specific Gravity Determination

3.10.6 Free Swell

A soil free swell is defined as the ratio of the sample volume difference to its original volume. The free swell of soils was calculated using IS: 2720(Part 40) 1977. Approximately 10 g of soil with a BS No 4 sieve (425µm aperture) was oven dried and cooled in a desiccator. One cylinder was filled with distilled water, and the other with kerosene up to the 100ml mark. The final volume of soil is computed after 24 hours to calculate the free swell index.

$$\text{Free swell (Fs)} = \left(\frac{V_f - \mathrm{V_i}}{\mathrm{V_i}}\right) * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.2$$

where V_f −final volume in ml and V_i −Initial volume in ml

3.10.7 Compaction Test (AASHTO T 180-95)

This test was done by modified compaction to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. It was done on the natural expansive soil, on the mixture various percentages of cow dung ash and CDA with lime added on the expansive clay soil and its MDD and OMC were determined.

The apparatus setup consists of (i) cylindrical metal mould (internal diameter- 15.24 cm and internal height-11.7 cm), (ii) detachable base plate, (iii) collar (5 cm effective height), (iv) rammer (4.54 kg). Compaction process helps in increasing the bulk density by driving out the air from the voids. The theory used in the experiment is that for any compactive effort, the dry density depends upon the moisture content in the soil. The maximum dry density (MDD) is achieved when the soil is compacted at relatively high moisture content and almost all the air is driven out, this moisture content is called optimum moisture content (OMC).

Figure 3.8: Compaction Test

3.10.8 California Bearing Ratio (CBR) and CBR Swell

The CBR test indirectly measures the shearing resistance of soil under controlled moisture and density conditions. A soil sample retained on No.19 was discarded from the test. A soil mass is prepared in accordance AASHTO T 193-93 test procedure. For this study three-point CBR test (10, 30, 65 blows) was conducted. The compacted soil samples of the CBR mould are soaked for 96 hours in a water bath to get the soaked CBR value at 95% MDD of the soil and CBR swell of soil. The California bearing ratio test is penetration test meant for the evaluation of subgrade strength of roads and pavements.

Table 3. 3: Subgrade Strength Classes [41]

Class	CBR range in %
S1	<3
S2	3,4
S3	5,6,7
S4	8-14
S5	15-30
S6	>30

Figure 3.9: California Bearing Ratio (CBR) And CBR Swell

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the laboratory results and their discussions. The relevant physical and geotechnical properties of the soil are evaluated for both natural and treated soil samples separately. Tests such as moisture content, specific gravity, Atterberg limits, particle size analysis, free swell index, compaction, soaked California bearing ratio (CBR), and CBR swell were investigated for the natural soil of all three test pits. Subsequently, the one representative soil specimen was selected based on their natural properties then tested by varying the percentage of CDA from 3% to 15% in 3% increments to determine the optimum CDA. Then, the soil was tested by varying lime from 3% to 12% in 3% increments with the optimum CDA, and a complete silica analysis test was conducted.

4.2 Properties of Material

4.2.1 Cow Dung Ash Properties

The chemical and physical properties of cow dung ash (CDA) were investigated using ASTM standards and specifications. A complete silica analysis was conducted in the Geological Institutes of the Ethiopian Survey Chemical Laboratory using LiBO2 fusion, HF attack, gravimetric, colorimetric, and AAS analytical methods. The detailed results are attached in the appendix. The chemical and physical constituents of CDA are stated below. The chemical properties of cow dung ash analyzed for this study are given on Table 4.1 and physical properties of CDA are stated on table 4.2 below.

Table 4. 1: Chemical Composition of Cow Dung Ash (CDA)

Chemical composition	Test result (%)	ASTM (C618) requirement in %	Remark
SiO_2	62.90	35min	
Al_2O_3	5.15		
Fe_2O_3	3.22		
CaO	6.26	15 Max	Satisfied
MgO	2.90	5 Max	Satisfied
Na_2O	0.26	1.5 Max	Satisfied
K_2O	5.72		
MnO	0.14		
P_2O_5	3.92		
TiO_2	0.17		
H_2O	1.21	3 Max	Satisfied
LOI	7.47		
SiO_2+ Al_2O_3+ Fe_2O_3	71.27	70 Min	Satisfied

As the test results indicate, the combined percent composition of the main oxides (SiO_2, Al_2O_3, and Fe_2O_3) was 71.27%, which is above the minimum of 70% specified by ASTM C618. This is acceptable as a good pozzolana that can help mobilize the calcium hydroxide ($Ca\ (OH)_2$) in the soil for the formation of cementitious compounds. The silica and alumina available in the ash react with the calcium present in the soil in the form of calcium hydroxide to form calcium silicates and calcium aluminates, which are very important parameters for cementing behavior.

Table 4. 2: Physical Properties of CDA

Properties	Plasticity index (%)	Specific gravity, G_s
Value/result	Non-plastic	2.424

As shown here the average specific gravity of CDA was 2.424.

4.2.2 Geotechnical Properties of Natural Soil

The laboratory techniques described below were used to determine the geotechnical properties of all natural soil sample collected from three different specimens were Madda Walabu University (MWU), Robe Preparatory School (RPS) and Ali Birra Primary School (ABPS).

4.2.2.1 Natural Moisture Content

For certain soils, water content can be an incredibly useful indicator for determining the relationship between how a soil behaves and its qualities. A fine-grained soil's consistency is mostly determined by its water content. Water content is also used to indicate the phase relationships of air, water, and solids in a specific volume of soil. To improve the accuracy of the test results, three specimens were collected. The average initial moisture content of all soil samples utilized in this investigation is presented in the table 4.3 below.

Table 4. 3: Natural Moisture Content

Test pit location	MWU	RPS	ABPS
Moisture content (%)	44.7	47.2	46.2

The results in Table 4.3 show that these soils can hold a significant level of moisture. As stated by Terzaghi [23] most of the typical values of the natural moisture content of clay soil are within the ranges of 22–70%. The study results are also in agreement with the specified standard. From the test result, the study suggests that the all soil sample are unsuitable for road construction and it needs modification to serve as subgrade.

4.2.2.2 Specific Gravity (Gs) of Natural Soil

The specific gravity of a soil is the ratio of the unit weight of soil to the unit weight of water at various temperatures. A soil's specific gravity is determined by the mineralogy of its grains. Most soils contain a combination of several basic minerals. For the current investigation, soil specific gravity was calculated using a pycnometer in accordance with AASHTO T100-95. The test was performed at a water temperature of 20°C, and the average specific gravity of the all soil samples under consideration was calculated as follows.

Table 4. 4: Specific Gravity for Natural Soil

Sample location	MWU	RPS	ABPS
Specific gravity	2.68	2.67	2.7

According to Das [23]clay and silty clay soils have specific gravity values ranging from 2.67 to 2.90. The test results show that the specific gravity of the all soil samples was classified as clay and weak soil.

4.2.2.3 Grain Size Analysis

Grain size distribution is a common method used for the classification of soils. The distribution of particle sizes greater than 0.075 mm is determined by wet sieving, while the distribution of particle sizes smaller than 0.075 mm is determined by a hydrometer test. Sodium hexametaphosphate is used as a dispersing agent in the hydrometer test. The grain size distribution test results for all MWU, RPS, and ABPS natural soil samples are presented in Figure 4.1 below.The detailed grain size analysis test results of all soil samples are attached in the appendix.

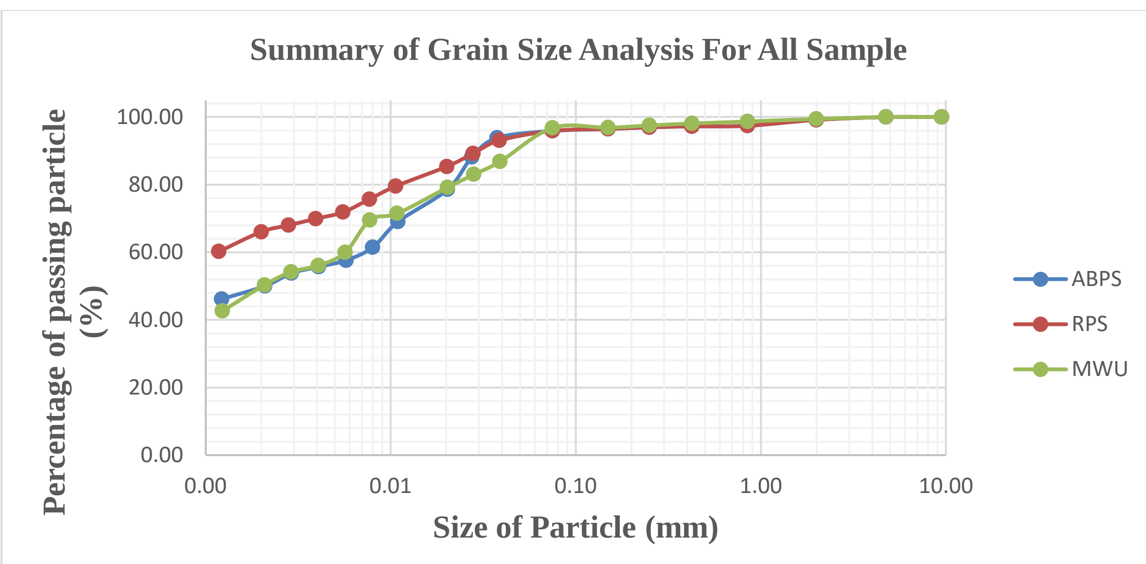

Figure 4.1: Grain Size Analysis for All Soil Samples

As a result, soil samples obtained from various locations in Robe town, including Madda Walabu University, Robe Preparatory School, and Ali Birra Primary School, were dark gray in color, with over 96.2% of the soil passing through a No.200 (0.075mm) sieve. This suggests that practically all of the collected soil samples were clay soil.

4.2.2.4 Atterberg Limit

It measures the essential moisture content of fine grain soil and exists in four states: solid, semi-solid, plastic, and liquid. The liquid limit was the water concentration at which the soil had deteriorated sufficiently to flow like a liquid. In contrast, the plastic limit established the water content at which the soil had become so brittle that it broke. The liquid limit was determined using the Casagrande method, passing through a 475 µm (No. 40) sieve as per AASHTO T-89. The plastic limit was calculated by rolling the soil sample into threads of 1/8" (3mm) thickness, as per AASHTO T-90.

Table 4.5 presents an overview of the Atterberg test results for all natural soil samples. The detailed laboratory data analysis was submitted to the appendix.

Table 4. 5: Atterberg Test Results for Both Natural Soil Samples

pit location	MWU	RPS	ABPS
Liquid Limit (%)	80.7	83.30	80
Plastic Limit (%)	35.3	35.36	36.7
Plasticity Index (%)	45.4	47.94	43.4

The MWU, RPS, ABPS soil samples had liquid limits of (80.7, 83.30, and 80%), plastic limits of (35.3, 35.36, and 36.7), and plasticity index of (45.4, 47.94, and 43.4%), respectively. According to the ERA criteria, all soil samples are unsatisfactory subgrade materials because their plastic index exceeds 30%. According to British practice, the plasticity chart is divided into five zones depending on the clay soil's liquid limit values. Plasticity is classified as low, medium, high, very high, and extremely very high based on the liquid limit (LL) range (<35%, 35-50%, 50-70%, 70-90%, and >90%) [39].

The plastic index of all soil samples indicated poor quality subgrade material. A high PI value indicates a high clay content in the soil sample. Based on the liquid limit, the soil sample is classified as clay soil with strong plasticity or swelling potential. According to ERA criteria, the subgrade soil is considered bad if its PI value exceeds 30%. As a result of these observations, the soil sample appears to be expansive and inappropriate for use as subgrade material in road building. It needs to modify before it could be used as a high-quality material.

4.2.2.5 Soil Classification

The soil was classified based on the AASHTO and USCS systems, and the results are summarized in the table and figure below.

A. USCS soil classification system

According to USCS, the experimental results of soils tested from all over the world were plotted on a graph of plasticity index (ordinate) versus liquid limit (abscissa). It was discovered the plasticity chart. Clays, silts, and organic soils lie in distinct regions of the graph called the plasticity chart (Figure 4.2). The A-line separates clays from silts, and the U-line indicates the upper limit of the relationship between PI and LL. Accordingly, the all soil under study are plotted on the figure 4.2 below.

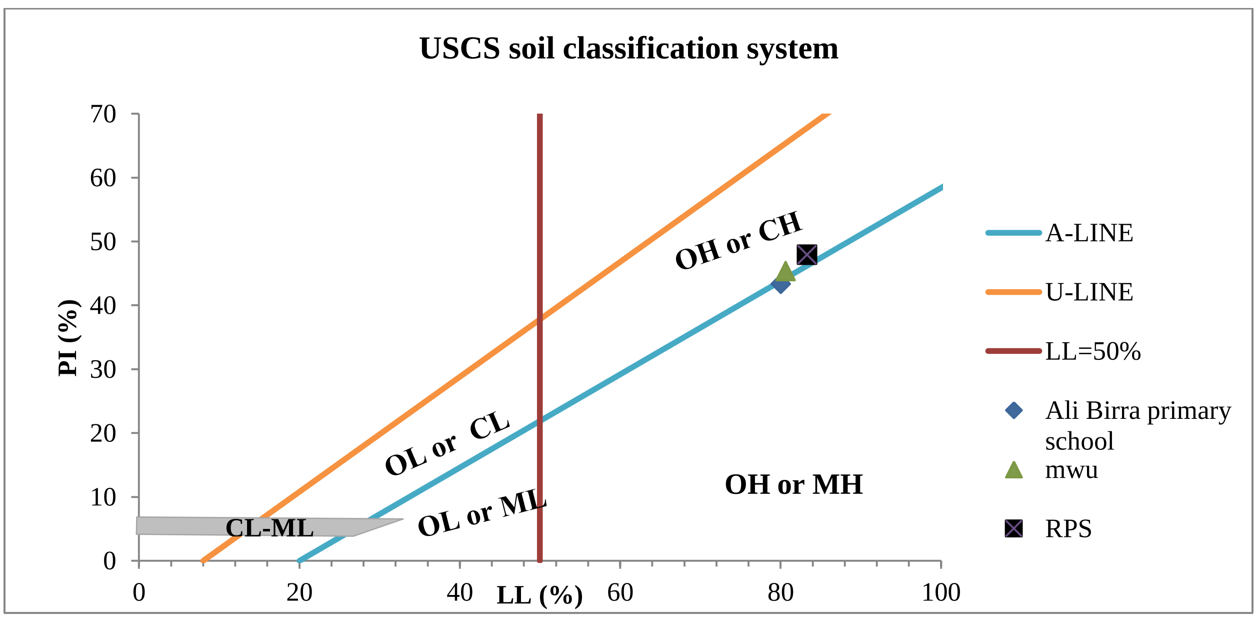

Figure 4.2: Soil Classifications According to USCS System

According to the Unified Soil Classification System (USCS), when a soil's liquid limit exceeds or equals 50%, it is classed as clay, silt, or organic, depending on its position relative to the A-line on a Casagrande chart. Clay soils are defined by the Casagrande chart as having a plasticity index (PI) greater than 4 and mapping on or above the A-line.

According to the classification scheme indicated in figure 4.5, all soil samples are above the A-line in the CH zone, indicating clayey soils with high plasticity.

B. AASHTO soil classification system

This approach divides soil into seven major categories: A-1 through A-7. Soils classed as A-1, A-2, and A-3 are granular materials with 35% or less of the particles passing through a No.200 sieve. Soils with more than 35% passing through the No.200 sieve are classed as A-4, A-5, A-6, and A-7.

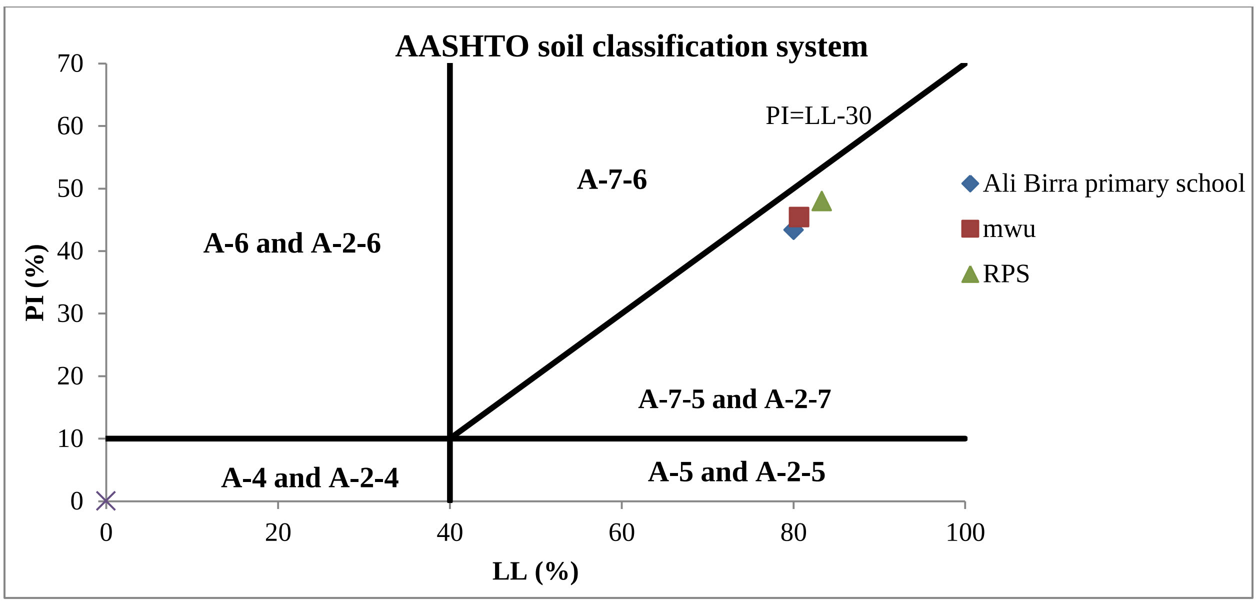

Figure 4.3: Soil Classifications According To AASHTO System

According to the AASHTO soil classification system, all soil samples are classified as A-7-5 with a rating of Fair-to-Poor for usage as subgrade material. Thus, the natural subgrade material is unsuited for use as a subgrade material unless some upgrading procedures are employed.

Table 4. 6: Summary of Soil Classifications

Sample location	Atterberg limit			Soil classification		Color
	LL	PL	PI	USCS	AASHTO	
MWU	80.7	35.3	45.4	CH	A-7-5	Dark Grey
RPS	83.30	35..36	47.94	CH	A-7-5	Dark Grey
ABPS	80	36.7	43.4	CH	A-7-5	Dark Grey

4.2.2.6 Free Swell Index

The test procedure followed for the determination of the free swell index is in accordance with IS:2720 (Part 40) 1977. The free swell index of all soil samples used for the study is tabulated below in Table 4.7.

Table 4. 7: Free Swell Index of Natural Soil Sample

Sample location	Free swell index (%)
MWU	86.36
RPS	95.45
ABPS	90.91

This test is intended to provide a reasonable estimate of a soil sample's degree of expansiveness. Soils with a free swell index below 50% are unlikely to expand. However, soils with free swell index values greater than 50% may cause swelling concerns in lightweight constructions. Values of 100% or higher are associated with clay-rich soils, which can expand greatly. All soil samples from the study area showed free swell index test results greater than 50% (MWU = 86.36%, RPS = 95.45%, and ABPS = 90.91%). As a result, such soils are highly expansive and exhibit volumetric variations, resulting in pavement distortion, cracking, and overall unevenness due to seasonal soaking and drying cycles.

4.2.2.7 Compaction Characteristics

The test was conducted on the expansive soil under consideration to determine the maximum dry density and optimum moisture content of the soils. It was performed using the modified Proctor compaction test as per ASTM D1557 Method A or AASHTO T180-98. The soil sample was first air-dried and pulverized using a hammer. The material was then sieved through a #19 sieve. Four kilograms of the soil sample were weighed and mixed with different percentages of moisture content. The soil sample was compacted in a mold in five layers, with each layer receiving 56 blows. This procedure was repeated until the graph formed a parabolic curve. A summary of the compaction characteristics is provided in Figure 4.4 and tabulated in Table 4.8 below.

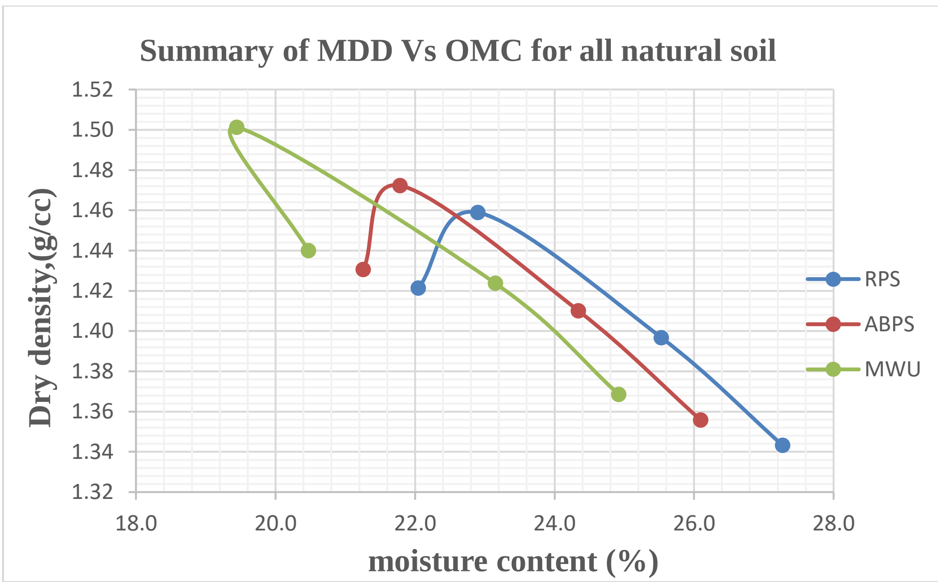

Figure 4.4: Compaction Test Result of Natural Soil Sample

Table 4. 8: Compaction Test Result of Natural Soil Sample

Sample location	MDD, (g/cc)	OMC (%)
MWU	1.501	19.44
RPS	1.459	22.905
ABPS	1.47	21.788

As shown in the graph and table above, the maximum dry density and optimum moisture content for MWU, RPS, and ABPS are 1.501 and 19.44, 1.459 and 22.905, and 1.47 and 21.788, respectively. The maximum dry density and optimum moisture content achieved are utilized to calculate the strength (CBR) required during road construction, particularly in the subgrade layer. Detailed data analysis is provided in the appendix.

4.2.2.8 California Bearing Ratio (CBR) and CBR Swell

This test was carried out utilizing soil sample compaction characteristics data, including maximum dry density and optimum moisture content. The current study used the AASHTO T193 three-point CBR test. The samples were soaked for 96 hours, and the CBR at 95% maximum dry density was measured using a graph of CBR versus dry unit weight. The CBR values and CBR swell of all natural soil samples, are recorded in Table 4.9 below. The detail laboratory results are included in the appendix.

Table 4. 9: CBR and CBR Swell of Natural Soil Sample

Sample location	CBR at 95% MDD (%)	CBR swell (%)
MWU	1.63	10.75
RPS	1.33	13.96
ABPS	1.45	11.67

As shown in Table 4.9 above, the CBR values of all samples were assessed as poor subgrade materials which classified under subgrade class S1 according to the ERA 2013 manual. However, the CBR swell did not meet the minimum requirements of the ERA specification, which allows for a CBR greater than 3% and a CBR swell less than 2%. The results indicate that the soil has a low bearing capacity and a high swelling potential, which do not meet the standard criteria for subgrade in highway construction. As a result, the soil requires early treatment and stabilization to improve its workability and engineering properties.

Table 4. 10: Summarized Laboratory Test Result for Natural Expansive Soil

Properties	Test result		
	MWU	**RPS**	**ABPS**
Natural moisture content (%)	44.7	47.2	46.2
Depth of Sampling, (m)	1.5	1.5	1.5
Grain size distribution (%)			
Gravel (> 4.75mm)	0	0	0
Sand (4.75-0.075mm)	3.18	4.1	4.1
Silt (0.075-0.002mm)	46.47	29.85	45.9
Clay (< 0.002mm)	50.35	66.05	50
Atterberg limits, (%)			
Liquid Limit (LL)	80.7	83.3	80
Plastic Limit (PL)	35.3	35.36	36.7
Plasticity Index (PI)	45.4	47.94	43.4
Soil classification			
AASHTO	A-7-5	A-7-5	A-7-5
USCS	CH	CH	CH
Specific Gravity	2.68	2.67	2.7
Free swell index, (%)	86.36	95.45	90.91
Compaction characteristics			
OMC, (%)	19.44	22.905	21.788
MDD, (g/cm3)	1.501	1.459	1.47
CBR, (%)	1.63	1.33	1.45
CBR Swell, (%)	10.75	13.96	11.67
Color	Dark grey	Dark grey	Dark grey

Overall, the summary in Table 4.10 reveals that natural subgrade soils are classified as expansive soils according to ERA and AASHTO criteria. Natural soil exhibits a high plasticity index and significant free swell. Additionally, the bearing capacity is poor due to the high CBR swell. This indicates that the soil does not meet standard guidelines, particularly for highway construction.

Consequently, the soil requires early modifications to enhance its strength and other engineering properties. In this investigation, cow dung ash mixed with soil and lime was utilized. Based on the characteristics observed in the natural soil sample, including a low California Bearing Ratio (CBR), high Plasticity Index (PI), high clay content, and high swelling potential, the RPS soil sample was selected as the representative sample for further investigation and treatment.

4.3 Laboratory Test Result of Expansive Soil treated with Cow Dung Ash

4.3.1 Effect of Addition of Cow Dung Ash on Atterberg Limit

Basic Atterberg limit lab results, such as liquid limit, plastic limit, and plasticity index tests, were used to investigate the influence of cow dung ash on subgrade soil. The proportions of cow dung ash employed in this study were 3%, 6%, 9%, 12%, and 15%, according to the literature studied for subgrade stabilization.

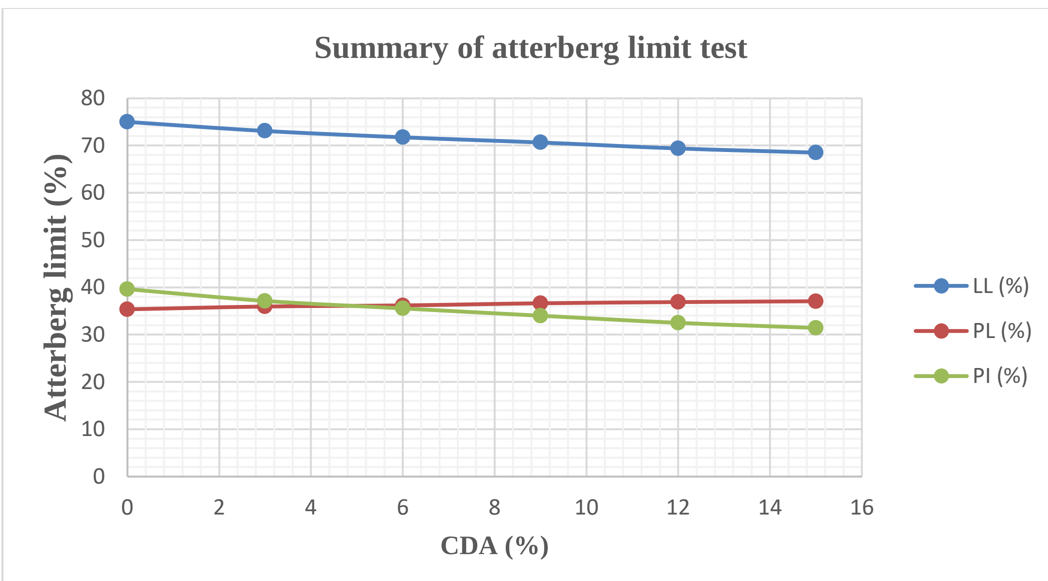

Figure 4.5: Summary of Atterberg Limit Test

Table 4. 11: Summary of Effect of Addition of Cow Dung Ash on Atterberg Limit

Cow dung ash (%) CDA (%)	LL (%)	PL (%)	PI (%)	ERA requirement	Remark
0	74.99	35.36	39.63	PI ≤ 30 (%)	unsatisfied
3	73.08	35.95	37.13		
6	71.74	36.19	35.55		
9	70.64	36.64	34.01		
12	69.38	36.89	32.50		
15	68.50	37.07	31.43		

The test results showed that when cow dung ash was added to expansive soil, the plastic limit increased, whereas the liquid limit and plasticity index of soils decreased as CDA concentration increased. The amount of cow dung ash ranges from 0% to 15%, the liquid limit falls from 74.99% to 68.50%, the plastic index falls from 39.63% to 31.43%, and the plastic limit rises from 35.36% to 37.07%. According to the test results, the plasticity category based on liquid limit shifts slightly from very high to high plastic. The silica content in the cow dung ash is most likely the reason for this result. Silica is a significant component of cow dung ash. Silica is known to improve soil qualities such as compaction and strength [40].

According to ERA specifications, the plasticity index value of cow dung ash treated soil is ≥ 30%, which does not meet the minimum requirement for utilization of the soil as subgrade in road construction. For this reason, cow dung ash treated soil needs additional modifiers.

4.3.2 Effect of Addition of Cow Dung Ash on Free Swell Index

Free swell tests were performed by combining cow dung ash in various proportions of 0%, 3%, 6%, 9%, 12%, and 15% by dry weight of the soil sample.

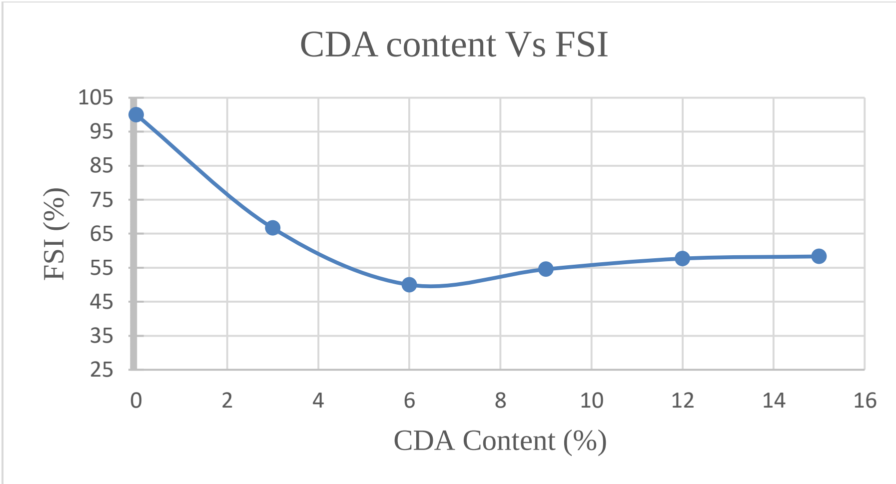

Figure 4.6: Effect of addition of cow dung ash on free swell index

Table 4.12: Summary Effect of Addition of Cow Dung Ash on Free Swell Index

Soil + CDA in %	0	3	6	9	12	15
Free swell index (%)	95.45	66.67	50	54.55	57.69	58.33

The results above demonstrate that adding up to 6% cow dung ash reduced the soil sample's swell potential, with the free swell index value decreasing from 100% to 50%. Beyond this proportion, the free swell index value increased. This result was attained by adding 6% cow dung ash to the soil sample, resulting in a CDA (Cow Dung Ash) of 50%.

4.3.3 Effect of addition of cow dung ash on Specific gravity

The test procedure followed for the determination of specific gravity is in accordance with ASTM D 854. A sample weighing about 25 grams is used in the pycnometer test. Tests were performed with the addition of cow dung ash in proportions of 0%, 3%, 6%, 9%, 12%, and 15% by weight of dry soil. The results of specific gravity with the addition of cow dung ash are tabulated in Table 4.13 below.

Table 4. 13: Effect of Cow Dung Ash on Specific Gravity

CDA %	0	3	6	9	12	15
Specific gravity,G_s	2.67	2.61	2.52	2.49	2.46	2.41

The specific gravity of the soil is reduced from 2.67 to 2.41 by increasing the cow dung ash concentration from 0% to 15%. The drop in specific gravity of the soil-cow dung ash mix is caused by the partial replacement of soil with cow dung ash, which has a lower specific gravity (i.e., 2.42). The specific gravity test findings are detailed in the appendix.

4.3.4 Effect of Addition of Cow Dung Ash on Compaction Characteristics

Air-dried and pulverized soil passing through a #19 filter was used to measure the moisture-density relationship of soil mixed with varied quantities of cow dung ash additions, in compliance with AASHTO T180-97. Table 4.14 shows the results of modified Proctor tests on expansive soil with varying quantities of cow dung ash. The summary of the test results is tabulated, and the laboratory test analysis and plots are provided in the Appendix.

The results of the compaction tests show that the maximum dry density (MDD) of the representative natural soil was 1.459 g/cm³ and the optimum moisture content (OMC) was 22.905%. The addition of cow dung ash (CDA) resulted in a slight decrease in the MDD and an increase in the OMC. Similar results were obtained by [41]for alluvial soil stabilized with RHA, SCBA, and CDA. The reduction in MDD is associated with the addition of ash which has lower specific gravity compared to the specific gravity of soil while an increase in OMC is due to the decrease in clay fraction and increase in mix proportion.

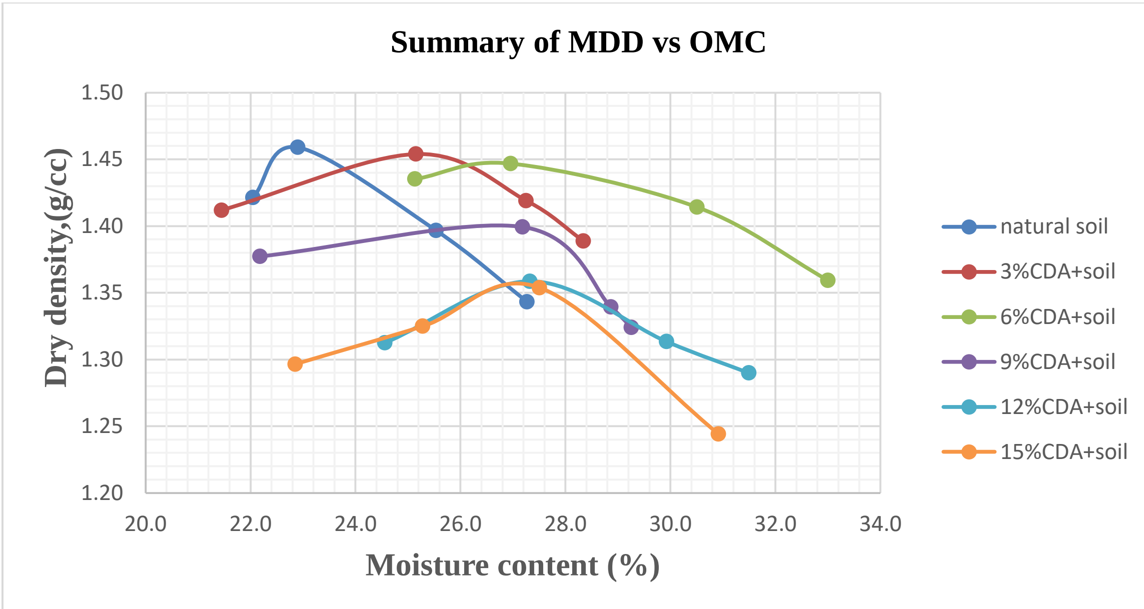

Figure 4.7: Effect of Cow Dung Ash on Maximum Dry Density and Optimum Moisture Contents

Table 4. 14: Effect of Cow Dung Ash on Maximum Dry Density and Optimum Moisture Contents

proportion	MDD (g/cm^3)	OMC (%)
Natural soil	1.459	22.905
BCS +3% CDA	1.454	25.15
BCS +6%CDA	1.447	26.96
BCS +9%CDA	1.399	27.18
BCS +12%CDA	1.359	27.33
BCS +15%CDA	1.354	27.51

4.3.5 Effect of Addition of Cow Dung Ash on CBR and CBR Swell

The CBR measures the material's shearing resistance under regulated density and moisture conditions. The CBR tests in this study were performed in accordance with AASHTO T-193. The study was carried out by taking an air-dried sample that passed through filter No.19 for natural soil mixed with varying percentages of cow dung ash (0%, 3%, 6%, 9%, 12%, and 15%) and applying modified proctor compaction. The value was obtained using three-point CBR methods with modified compaction with 5 layers, 10, 30, and 65 blows, and all samples were soaked for 96 hours. CBR swells were also measured after four days of soaking in varied percentages of cow dung ash added to the soil.

Table 4. 15: Effect of Addition of Cow Dung Ash on CBR and CBR Swell

Cow dung ash (%)	CBR Value (%)	CBR swell (%)
0 (soil alone)	1.33	13.96
3	1.94	10.64
6	2.92	8.32
9	2.7	9.26
12	2.1	10.03
16	1.7	11.78

From the test result it was found that the CBR values increase as the percentage of CDA increase from 0% to 6%, and then decrease gradually after as CDA content increase. The CBR value increases from 1.33% to 2.92%, as the CDA percentage increase from 0% to 6%. Additionally, the CBR swell of the soil decrease from 13.96% to 8.32 % as the ash content increase up to 6%. The decrease in the CBR after 6% CDA is may be due to excess cow dung ash that consume water (much moisture) which reduces bond in the soil by decreasing strength. This variation in soil strength (CBR) with increase in percentage of CDA similar with results were obtained by [36] Detail data analysis for this result are given on appendix.

4.3.6 Summary of Test Results for Soil Treated With Cow Dung Ash

Summary of all test results performed on soil-cow dung ash are tabulated below.

Table 4. 16: Summary of All Test Results Performed on Soil with Different Percent of CDA

Properties	Natural soil	CDA in %					Requirement
		3	6	9	12	15	
Liquid limit (%)	74.99	73.08	71.74	70.64	69.38	68.5	
Plastic limit (%)	35.36	35.95	36.19	36.64	36.89	37.07	
Plastic index (%)	39.63	37.13	35.55	34.01	32.50	31.43	PI≤30%,unsatisfied
Free swell index (%)	95.45	66.67	50	54.55	57.69	58.33	FSI >50very high expansive
Specific gravity	2.67	2.61	2.52	2.49	2.46	2.41	
OMC (%)	22.905	25.15	26.96	27.18	27.33	27.51	
MDD (%)	1.459	1.454	1.447	1.399	1.359	1.354	
CBR (%)	1.33	1.94	2.92	2.7	2.1	1.7	CBR,≥3%,unsatisfied
CBR swell (%)	13.96	10.64	8.32	9.26	10.03	11.78	≤ 2%, unsatisfied

Generally, According to ERA 2002, the minimum requirement of CBR value to be used for Subgrade soil is greater than or equal to 3% and CBR swell to be used for subgrade soil is less than or equal 2%. Here the CBR value of CDA treated expansive soil did not meet the minimum requirement of ERA subgrade manual and CDA does not act alone as a stabilizer. So that the cow dung ash treated expansive soil needs an additional modifier to serve as stabilizer for weak subgrade soil. For this study the optimum percentage of CDA was taken at 6% based on the above results. In this study, lime modifiers were applied to change the expansive subgrade soil.

4.4 Laboratory Test Result of Expansive Soil Treated With Optimum Cow Dung Ash and Lime Mixture

4.4.1 Effect of Cow Dung Ash and Lime Mix on Specific Gravity

In this study, the specific gravity of the soil was determined using a pycnometer, following the procedures outlined in AASHTO T 100-95. The test was conducted at a water temperature of 20°C. Soils with 6% CDA and varying lime percentages (0, 3, 6, 9, and 12% by dry weight) were tested. The results are presented here, with the laboratory data analysis provided in the Appendix.

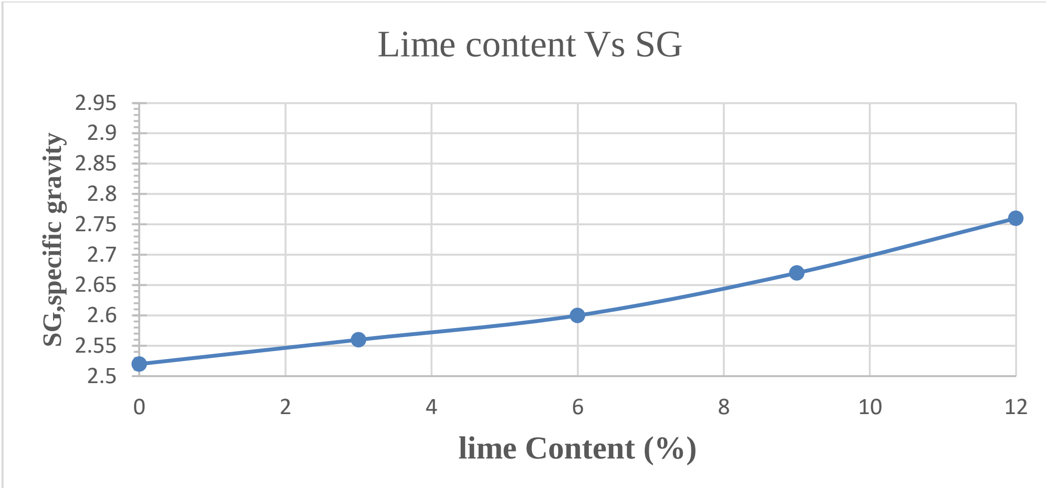

Figure 4.8: Summary of Effect of Cow Dung Ash and Lime Mix on Specific Gravity

The test results indicate that as the lime percentage increased from 0% to 12%, the specific gravity of the soil-CDA-Lime mixture also increased, from 2.52 to 2.76. This increase is likely due to a pozzolanic reaction between the CDA, lime, and soil.

4.4.2 Effect of cow Dung Ash and Lime mix on Free Swell

Based on the findings in the tables, the lime and CDA mixture appears to have stabilized the soil samples, reducing their free swell. This is evident by the decrease in FSI (Free Swell Index) as the lime content increased from 3% to 12%.

Table 4. 17: Effect of Cow Dung Ash and Lime Mix on Free Swell

Opt.CDA+lime(%)	0	3	6	9	12	Requirement FSI≤50%
Free swell index (%)	50	41.67	34.62	23.08	15.38	All are in range

The reduction in free swell likely results from the interaction between the lime, CDA, and clay particles in the soil, potentially reducing their water absorption capacity. The appendix presumably provides a more detailed analysis of this phenomenon.

4.4.3 Effect of Cow Dung Ash and Lime Mix on Atterberg Limit

The variation in soil index properties such as liquid limit, plastic limit and plasticity index of the expansive soil treated with CDA-lime is shown in the table below.

Table 4. 18: Effect of Cow Dung Ash and Lime Mix on Atterberg Limit

6%CDA + Lime (%)	LL %	PL %	PI %	ERA requirement	Remark
Natural soil	74.99	35.36	39.63	PI ≤ 30 %	Unsatisfied
0 (6%CDA)	71.74	36.19	35.55		Unsatisfied
3	66.18	38.99	27.82		satisfied
6	62.96	39.66	23.31		satisfied
9	59.40	40.52	18.88		satisfied
12	58.19	41.81	16.38		

According to the findings of this investigation, the liquid limit and plastic index of the soil-opt.CDA-lime mixture decrease, while the plastic limit increases as the lime component increases from 0% to 12%.This clearly demonstrates that the plasticity index of treated soil decreased with increasing additive quantity. These effects result from the partial replacement of plastic soil particles with CDA, a non-plastic substance, as well as the ionic exchange of the soil's lime and clay minerals. This observed trend also in line with earlier findings [35] and [42].

4.4.4 Effect of Cow Dung ash - Lime on Compaction Characteristics

The compaction characteristics of a soil-lime-CDA mixture were investigated. The results are provided in table 4.19 below, which demonstrates that the MDD values of soil-lime-CDA mixtures are smaller than those of the expansive soil treated with CDA only; however, the OMC values of soil-lime-CDA combinations are bigger than the expansive soil treated with CDA only.

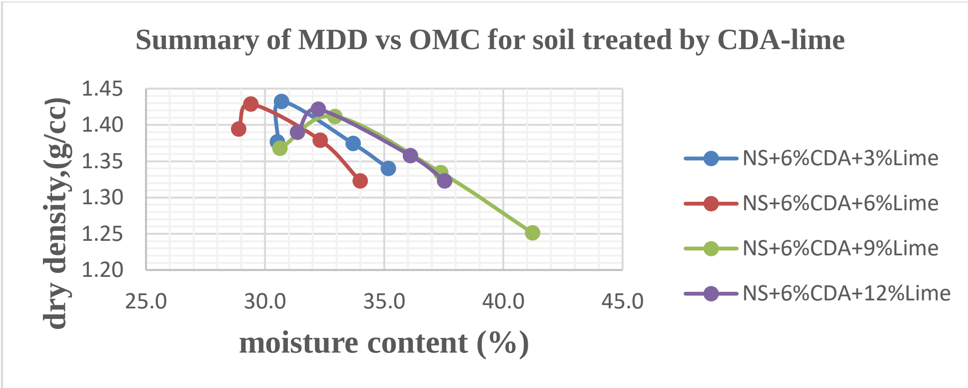

Figure 4.9: Effect of CDA and Lime Mix on Compaction Characteristics

Table 4. 19: Summary of Effect of Cow Dung Ash – Lime Mix on Compaction Characteristics

Lime with opt.CDA	**MDD (g/cm^3)**	**OMC (%)**
Natural Soil	1.459	22.905
Soil +6%CDA(opt.CDA)	1.447	26.96
6%CDA+3% lime	1.432	30.7
6%CDA+6%lime	1.429	29.42
6%CDA+9%lime	1.412	32.94
6%CDA+12%lime	1.421	32.24

The table indicates that the optimum moisture content (OMC) of the soil treated with the lime-CDA mixture increases with increasing lime content. Conversely, the maximum dry density (MDD) of the treated soil decreases as the lime content rises, up to the optimum lime content.

The decrease of MDD of soil treated with lime and CDA attributed to the creation of the coarser particles during the flocculation and agglomeration process due to cation exchange between clay particles, CDA, and lime that leads texture changes. The formed coarser particles occupy the larger spaces in the soil matrix and increase the void volume, which causes the reduction in the dry density of lime-CDA treated clay soil. This reduction of MDD due to the lower specific gravity of CDA and lime than that of the soil. Increase in OMC shows increase in the percentage of fines in soil increases which in turn increase the surface area of soil mass and higher surface area demands higher water. Similar results attained by[42], [36] and[41].

The rise in OMC and decrease in MDD of the soil samples had the advantage of making it easier to compact wet soil. Any adverse effect on strength due to density reduction is unlikely to occur due to the projected significant improvement in strength of treated soils due to the pozzolanic qualities of the soil and lime [43].

4.4.5 Effect of Addition of Cow Dung Ash Mixed with Lime on CBR and CBR Swell

CBR tests were performed utilizing the AASHTO T193-93 technique to assess the CBR value of treated soil samples. Table 4.20 shows the results of the soaked CBR and CBR swell tests for natural soil-CDA-Lime with various lime percentages (3%, 6%, 9%, and 12%).

Table 4. 20: Summary of Effect of Cow Dung Ash Mixed With Lime on CBR and CBR Swell

Opt.CDA+ Lime (%)	CBR Value (%)	CBR swell (%)
0 (soil alone)	1.33	13.96
Opt.CDA(6%CDA)	2.92	8.32
3	5.7	6.67
6	8.2	4.53
9	10.5	1.71
12	9.3	1.60

The test results showed that CBR values increased as the proportion of lime increased from 0% to 9%, and then decreased. The CBR value increases from 2.9% to 9.2% as the lime percentage rises from 0% to 9%. Similarly, as the lime content increased, the soil's CBR swell decreased from 8.32% to 1.60%. The CBR swell is reduced by increasing the lime content in the soil. Reduced swell characteristics are often attributed to the calcium saturated clay's decreased affinity for water and the creation of a cementitious matrix that resists volumetric expansions. According to above result, the optimal lime level is 9% lime. The CBR results of CDA-lime-treated soil indicated a substantial improvement in strength when compared to untreated soil and CDA-treated soil samples.

4.4.6 Summary of Test Results for Soil Treated With Optimum Cow Dung Ash and Lime Mixture

Table 4. 21: Summary of Test Results for Soil Treated With Optimum Cow Dung Ash and Lime Mixture

properties	Natura soil	Opt.CD (6%CDA	Lime in %age				requirement
			3	6	9	12	
Liquid limit (%)	74.99	71.74	66.81	62.96	59.40	58.19	
Plastic limit (%)	35.36	36.19	38.99	39.66	40.52	41.81	
Plastic index (%)	39.63	35.55	27.82	23.31	18.88	16.38	PI<30%
Free swell index (%)	95.45	50	41.67	34.62	23.08	15.38	FSI<50%
Specific gravity	2.67	2.52	2.56	2.60	2.67	2.76	
OMC (%)	22.905	26.96	30.7	29.42	32.94	32.24	
MDD (%)	1.459	1.447	1.432	1.429	1.412	1.421	
CBR (%)	1.33	2.92	5.7	8.2	10.5	9.3	CBR>3%
CBR swell (%)	13.96	8.32	6.67	4.53	1.71	1.60	CBR swell<2%

Generally, the CDA-lime mixture treatment significantly affected the representative soil sample. Liquid limit (74.99 to 58.19), plasticity index (39.63 to 16.38), free swell index (95.45 to 15.38), and MDD (1.459 to 1.421) all decreased as the lime content increased with constant CDA. Conversely, Specific gravity, plastic limit and OMC values exhibited an increase with rising lime percentages at constant CDA. The soaked CBR value displayed a positive trend, increasing with lime addition up to 9% from 1.33% to 10.5%. Similarly, CBR swell decreased from 13.96% to 1.60% as the lime content increased. However, soaked CBR values showed a gradual decline beyond this point.

Therefore, according the results summarized above the subgrade soil class changed in its strength from S1 which are consider as poor subgrade to S4 which is good as subgrade material according to ERA flexible pavement design manual classification [44].

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the test results obtained from the investigation of natural soil, the selected soil treated with CDA and CDA-lime mixture the following conclusions were drawn.

- Chemical composition analysis of the cow dung ash, specifically the silica test, revealed a combined percentage of principal oxides (SiO2 + Al2O3 + Fe2O3) exceeding 70% (71.27%). This surpasses the minimum requirement of 70% set by ASTM C618 for pozzolanic materials. Consequently, based on its chemical composition and a specific gravity of 2.424, the cow dung ash appears to be suitable for use as a good pozzolana.
- All soil samples in their natural state demonstrate expansive soil (i.e., weak strength), since they all fall into A-7-5 according to AASHTO soil classification and CH according to the USCS soil classification. As a result, the majority of soil samples are high plastic clay soil, making them unsuitable for roadway construction.
- All soil samples are highly plastic, with high plasticity indices ranging from 43.4% to 47.94%. They exhibit swelling behavior, as evidenced by their high free swell indices ranging from 86.36% to 95.45%. The specific gravity of the soil samples ranges from 2.67 to 2.7, which indicates that these samples can be classified as clay soils.
- The CBR value of all samples MWU, RPS, ABPS are (1.63%, 1.33%, 1.45%) and the CBR swell (10.75%, 13.96%, 11.67%) respectively, which was rated in poor subgrade soils.
- Expansive soil treated with cow dung ash has drawn the following results: Treatment with cow dung ash (CDA) significantly impacted the representative soil sample. Specific gravity, Liquid limit, plasticity index, and MDD decreased; from 2.67 to 2.41, 74.99 to 68.50, 39.63 to 31.43, and 1.459 to 1.354 respectively. While plastic limit and OMC values increased from 35.36 to 37.07 and 22.905 to 27.51 respectively with increasing CDA content. Interestingly, the free swell index initially decreased up to 6% CDA from 95.45% to 50% but then increased again gradually due water consumption

of CDA. The soaked CBR value exhibited a positive trend, increasing with CDA addition up to 6%, from 1.33% to 2.92% whereas CBR swell decreased from 13.96% to 8.32%. However, soaked CBR values decreased gradually beyond the 6% CDA mark and CBR swell values increased gradually beyond the 6% CDA mark. Based on these observations, 6% CDA was identified as the optimal dosage for this study.

- Generally, according to the ERA and other road requirements manuals, CDA-treated expansive subgrade soil does not meet the minimum criterion. And the CDA does not act alone as a stabilizer. As a result, extra modifiers are required when using it as a subgrade soil stabilizer. this study is also familiar with previous study[41] which results CDA is not a very good stabilizer but can still be used to improve the engineering properties.
- However, the CDA-lime mixture treatment significantly affected the representative soil sample. Liquid limit (74.99 to 58.19), plasticity index (39.63 to 16.38), free swell index (95.45 to 15.38), and MDD (1.459 to 1.421) all decreased as the lime content increased with constant CDA. Conversely, Specific gravity, plastic limit and OMC values exhibited an increase with rising lime percentages at constant CDA. The soaked CBR value displayed a positive trend, increasing with lime addition up to 9% from 1.33% to 10.5%. Similarly, CBR swell decreased from 13.96% to 1.60% as the lime content increased. However, soaked CBR values showed a gradual decline beyond this point.
- Generally, Cow dung ash (CDA) treatment improved some properties of the expansive subgrade soil, but the overall effect did not meet the minimum specifications set by the ERA for subgrade applications. However, combining CDA with lime proved to be a more effective strategy. This approach not only significantly improved various soil properties but also allowed for a reduction in the overall lime consumption required for soil stabilization. This study demonstrates that combining CDA and lime can significantly enhance the strength of expansive soil samples. The test results reveal that the optimal combination, achieving the maximum strength improvement, is 6% CDA and 9% lime.

5.2 Recommendation

- The present study was conducted by taking limited parameters such as Atterberg limit, free swell index, specific gravity, moisture density relation, CBR and CBR swell potential on stabilization by cow dung ash and lime. It is recommended to test additional parameter like unconfined compressive strength and mineralogical tests should also be performed to have more realistic test results.
- This study was done for specific area and specific stabilizers, it is recommended as more investigation shall be performed on different parts of the country by mixing Cow dung ash with other stabilizers.
- In this study cow dung ash was made by uncontrolled burning condition to save cost and time which shows not at constant temperature, for future study its recommended burning cow dung at constant temperature (i.e. by blast furnace) for controlled condition to determine Cow dung ash properties should be performed.

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APPENDIX A: Geotechnical Properties of Natural Expansive Soil of Study Area

1. Natural Moisture Content

A. Natural Moisture Content for Madda Walabu University (MWU) Soil Sample

Trail	1	2	3
Mass of can	37.160	36.080	28.34
mass of can+wet soil	178.130	166.280	174.08
mass of can + dry soil	135.400	122.800	132.1
mass of moisture	42.730	43.480	41.980
mass of dry soil	98.240	86.720	103.760
moisture content	43.496	50.138	40.459
Average	**44.7**		

B. Natural Moisture Content for Robe Preparatory School (RPS) Soil Sample

Trail	1	2	3
Mass of can	36.610	36.449	37.849
mass of can+wet soil	140.765	147.966	175.124
mass of can + dry soil	106.769	112.403	131.739
mass of moisture	33.996	35.563	43.385
mass of dry soil	70.159	75.954	93.89
moisture content	48.456	46.822	46.208
Average	**47.2**		

C. Natural Moisture Content for Ali Birra Primary School (ABPS) Soil Sample

Trail	1	2	3
Mass of can	36.645	33.533	36.611
mass of can+wet soil	151.118	174.797	156.39
mass of can + dry soil	116.552	131.722	115.65
mass of moisture	34.566	43.075	40.736
mass of dry soil	79.907	98.189	79.042
moisture content	43.258	43.869	51.537
Average	**46.2**		

2. Specific Gravity

A. Specific Gravity For Soil Sample Madda Walabu University(MWU) Soil Sample

Code of Pycnometer	1	2	3
Mass of Pycnometer	31.130	28.341	33.925
Mass of Pycnometer with Dry Soil	41.130	37.684	44.270
Mass of Pycnometer with Dry Soil and Water	130.610	130.109	134.732
Mass of Pycnometer and Water	124.350	124.299	128.252
Temperature of Pycnometer with Water($T^0{}_{ci}$)	21	21	21
Density of water at ($T^0{}_{ci}$)	0.99802	0.99802	0.99802
Temperature of Pycnometer with Soil and Water ($T^0{}_{cx}$)	22	22	22
Density of water at ($T^0{}_{cx}$)	0.9978	0.9978	0.9978
Corrected Mass of Pycnometer and Water	124.3226	124.2716	128.2237
Correction Factor, K at $20^0{}_c$	0.9996	0.9996	0.9996
Specific Gravity, Gs at $20^0{}_c$	2.6925	2.6641	2.6952
Average Specific Gravity, Gs at $20^0{}_c$	**2.68**		

B. Specific Gravity For Soil Sample Robe Preparatory School (RPS) Soil Sample

Code of Pycnometer	1	2	3
Mass of Pycnometer	31.200	28.341	33.925
Mass of Pycnometer with Dry Soil	43.928	37.684	44.270
Mass of Pycnometer with Dry Soil and Water	133.951	130.509	134.732
Mass of Pycnometer and Water	126.037	124.699	128.252
Temperature of Pycnometer with Water ($T^0{}_{ci}$)	21	21	21
Density of water at ($T^0{}_{ci}$)	0.99802	0.99802	0.99802
Temperature of Pycnometer with Soil and Water ($T^0{}_{cx}$)	22	22	22
Density of water at ($T^0{}_{cx}$)	0.9978	0.9978	0.9978
Corrected Mass of Pycnometer and Water	126.0092	124.6715	128.2237
Correction Factor, K at $20^0{}_c$	0.9996	0.9996	0.9996
Specific Gravity, Gs at $20^0{}_c$	2.6582	2.6642	2.6952
Average Specific Gravity, Gs at $20^0{}_c$	**2.67**		

C. **Specific Gravity For Soil Sample Ali Birra Primary School (ABPS) Soil Sampl**

Code of Pycnometer	1	2	3
Mass of Pycnometer	29.500	26.500	33.925
Mass of Pycnometer with Dry Soil	54.500	51.500	44.270
Mass of Pycnometer with Dry Soil and Water	136.000	84.500	134.732
Mass of Pycnometer and Water	122.000	77.500	128.252
Temperature of Pycnometer with Water (T^0_{ci})	19	17	21
Density of water at (T^0_{ci})	0.99802	0.99802	0.99802
Temperature of Pycnometer with Soil and Water(T^0_{cx})	22	22	22
Density of water at (T^0_{cx})	0.9978	0.9978	0.9978
Corrected Mass of Pycnometer and Water	121.9731	77.48292	128.2237
Correction Factor, K at 20^0_c	0.9996	0.9996	0.9996
Specific Gravity, Gs at 20^0_c	2.2774	1.3897	2.6952
Average Specific Gravity, Gs at 20^0_c	**2.70**		

D. **Specific Gravity of Pure Lime**

Trials	1	2
Pycnometer code	17	T
Wp= Mass of empty, clean pycnometer (A), g	29.64	27.94
Wps=Mass of pycnometer + dry soil(B), g	55.5	53.45
WB= Mass of pycnometer + dry soil + water (C), g	141.87	96.58
Mass of pycnometer + water (D), g	124	78.5
Temperature, ⁰C	20	20
Mass of dry soil (E), g =B-A	25.86	25.51
Specific gravity=E/(A+(D-C))	2.20	2.59
Average specific gravity	**2.39**	

E. **Specific Gravity of Pure Cow Dung Ash (CDA)**

Trials	1	2
Pycnometer code	O	O3
Wp= Mass of empty, clean pycnometer (A), g	29.5	31
Wps=Mass of pycnometer + dry soil(B), g	55.5	56
WB= Mass of pycnometer + dry soil + water (C), g	143.5	98.38
Mass of pycnometer + water (D), g	124	78.5
Temperature, ⁰C	20	20
Mass of dry soil (E), g =B-A	26	25
Specific gravity=E/(A+(D-C))	2.60	2.25
Average specific gravity	**2.42**	

3. Free Swell Index of All Samples

Sample Location	Measuring Cylinder No.(ml)		Reading after 24 hrs(ml)		Free Swell
	Kerosene	Distilled water	Kerosene	Distilled water	Index, %
ABPS	11	13	11	21	**90.91**
MWU	11	13	11	20.5	**86.36**
RPS	11	13	11	21.5	**95.45**

4. Grain Size Analysis

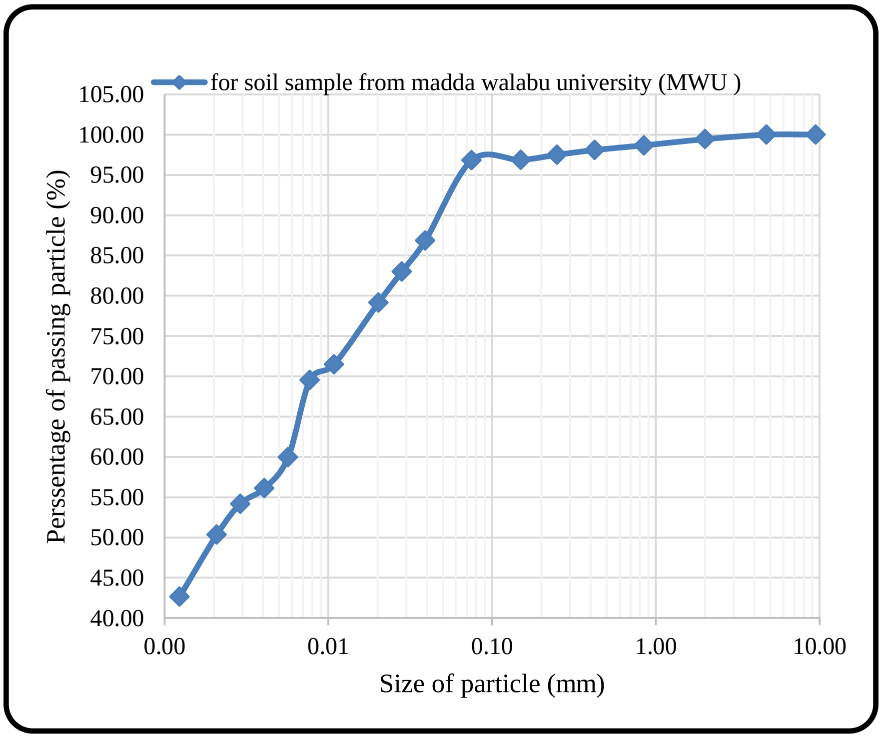
A. Combined Grain Size Analysis (Wet Sieve And Hydrometer Test) For MWU Soil Sample

Test pit Location					**For Soil Sample From Madda Walabu University (MWU)**						
Types of Test Grain Size Analysis Test											
Wet Sieve Analysis					**Hydrometer Analysis-152H**						
Total washed soil specimen mass, g				500	Data for hydrometer analysis						
Sieve Size	Mass of Retaing (g)	Percentage of Retaining	Cumulative Percentage Retaining	Percentage of fine particles	Specific gravity of soil, (Gs)	Dried sample mass, (g)	Meniscus Correction (Cm)	Reading in Dispersant, Ro	Value of K for 21^{o}c	Value of a	
9.50	0	0.00	0.00	100.00	2.684	50	1	2	0.01334	0.99233	
4.75	0	0.00	0.00	100.00	Value of K for Use in Equations for Computing Diameter of Particle in Hydrometer Analysis						
2.00	2.8	0.56	0.56	99.44	T(^{o}C)	Specific Gravity of Soil Particles					
0.850	3.83	0.77	1.33	98.67		2.55	2.6	2.65	2.7	2.75	2.8
0.425	2.9	0.58	1.91	98.09	20	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307
0.250	2.95	0.59	2.50	97.50	21	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291
0.150	3.21	0.64	3.14	96.86	22	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276
0.075	0.23	0.05	3.18	96.82	23	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261
Pan	484.08	96.82	100.00		24	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246
Total	500				25	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232

Hydrometer Analysis											
Time	Elapsed time t in, min	Actual Hydrometer Reading	Eff.depth,L (cm)	Temperature (c0)	K	C_T	Par.diameter D (mm)	Value of 'a' for Gs	Corrected hydrometer reading	Percent of Fine part., (%)	percent fines part.,
10/11/2022/ 3:45:AM	0										
3:46:00 AM	1	46	8.6	21	0.01334	0.2	0.0391	0.992397	45.2	89.7	86.86
3:47:00 AM	2	44	8.9	21	0.01334	0.2	0.0282	0.992397	43.2	85.7	83.01
3:50:00 AM	4	42	9.2	21	0.01334	0.2	0.0203	0.992397	41.2	81.8	79.17
	8	40	9.6	22	0.01334	0.2	0.0146	0.992397	39.2	77.8	75.33
3:53:00 AM	15	38	9.9	21	0.01334	0.2	0.0108	0.992397	37.2	73.8	71.48
4:00:00 AM	30	37	10.1	21	0.01334	0.2	0.0077	0.992397	36.2	71.8	69.56
4:15:00 AM	60	32	10.9	21	0.01334	0.2	0.0057	0.992397	31.2	61.9	59.95
4:45:00 AM	120	30	11.2	21	0.01334	0.2	0.0041	0.992397	29.2	58.0	56.11
5:45:00 AM	240	29	11.4	21	0.01334	0.2	0.0029	0.992397	28.2	56.0	54.19
7:45:00 PM	480	27	11.7	21	0.01334	0.2	0.0021	0.992397	26.2	52.0	50.35
11/11/2022	1440	23	12.4	21	0.01334	0.2	0.0012	0.992397	22.2	44.1	42.66

Combined Sieve Analysis

Grain Size (mm)	% passing	Combined % passing
9.50	100.00	100.00
4.75	***100.00***	***100.00***
2.00	***99.44***	***99.44***
0.850	98.67	98.67
0.425	98.09	98.09
0.250	97.50	97.50
0.150	96.86	96.86
0.075	***96.82***	***96.82***
0.0391	89.7	86.86
0.0282	85.7	83.01
0.0203	81.8	79.17
0.0108	73.8	71.48
0.0077	71.8	69.56
0.0057	61.9	59.95
0.0041	58.0	56.11
0.0029	56.0	54.19
0.0021	***52.0***	***50.35***
0.0012	44.1	42.66



Course Material, %	Sandy Material, %	Silty Mateial, %	Clay Material, %
0.00	3.18	46.47	50.35

B. Combined Grain Size Analysis (Wet Sieve And Hydrometer Test) For RPS Pit

Wet Sieve Analysis

Total washed soil specimen mass, g: 500

Sieve Size	Mass of Retaing (g)	Percentage of Retaing	Cumulative Percentage Retaining	Percentage of fine particles
9.50	0	0.00	0.00	100.00
4.75	0	0.00	0.00	100.00
2.00	4.1	0.82	0.82	99.18
0.850	8.822	1.76	2.58	97.42
0.425	0.88	0.18	2.76	97.24
0.250	1.355	0.27	3.03	96.97
0.150	2.49	0.50	3.53	96.47
0.075	2.86	0.57	4.10	95.90
Pan	479.493	95.90	100.00	
Total	500			

Hydrometer Analysis-152H

Data for hydrometer analysis

Specific gravity of soil, (Gs)	Dried sample mass, (g)	Meniscus Correction (Cm)	Reading in Despersant, Ro	Value of K for $21^{o}c$	Value of a
2.62	50	1	2	0.01361	1.00692

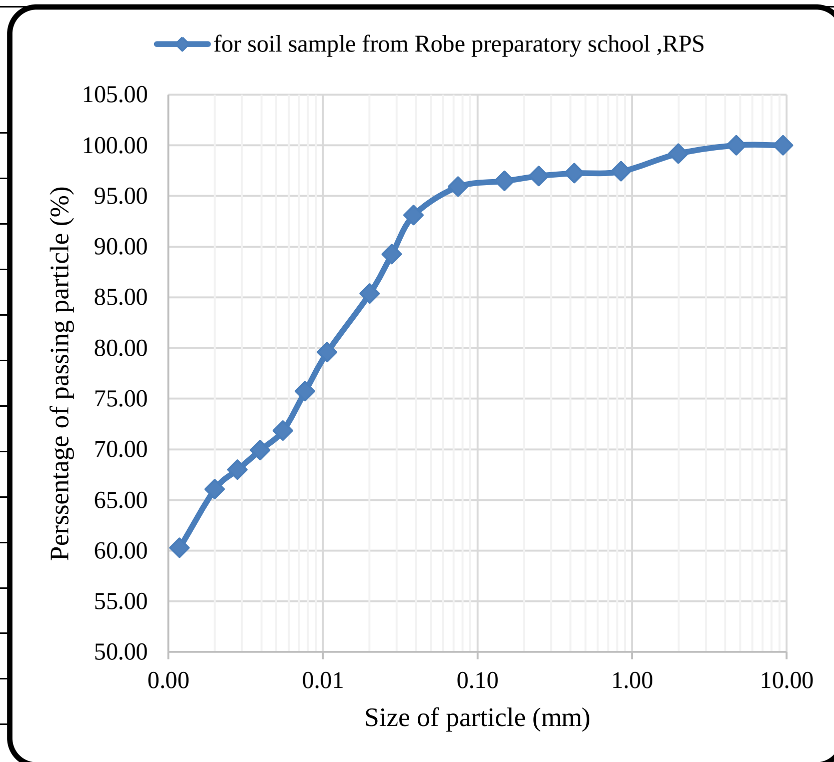
Value of K for Use in Equations for Computing Diameter of Particle in Hydrometer Analysis

Temp.(^{o}C)	Specific Gravity of Soil Particles					
	2.55	2.6	2.65	2.7	2.75	2.8
20	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307
21	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291
22	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276
23	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261
24	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246
25	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232

Hydrometer Analysis											
Time	Elapsed time t in, min	Actual Hydrometer	Eff.depth,L (cm)	Temperature (c0)	K	C_T	Par.diameter D (mm)	Value of 'a' for Gs	Corrected hydrometer reading	Percent of Fine part., (%)	Adjusted percent fines part., (%)
10/11/2022/ 3:45:00 AM	0										
3:46:00 AM	1	49	8.1	21	0.01361	0.2	0.0387	1.006988	48.2	97.1	93.09
3:47:00 AM	2	47	8.4	21	0.01361	0.2	0.0279	1.006988	46.2	93.0	89.23
3:50:00 AM	4	45	8.8	21	0.01361	0.2	0.0201	1.006988	44.2	89.0	85.37
	8	43	9.1	21	0.01361	0.2	0.0145	1.006988	42.2	85.0	81.50
3:53:00 AM	15	42	9.2	21	0.01361	0.2	0.0107	1.006988	41.2	83.0	79.57
4:00:00 AM	30	40	9.6	21	0.01361	0.2	0.0077	1.006988	39.2	78.9	75.71
4:15:00 AM	60	38	9.9	21	0.01361	0.2	0.0055	1.006988	37.2	74.9	71.85
4:45:00 AM	120	37	10.1	21	0.01361	0.2	0.0039	1.006988	36.2	72.9	69.92
5:45:00 AM	240	36	10.2	21	0.01361	0.2	0.0028	1.006988	35.2	70.9	67.98
7:45:00 PM	480	35	10.4	21	0.01361	0.2	0.0020	1.006988	34.2	68.9	66.05
11/11/2022	1440	32	10.9	21	0.01361	0.2	0.0012	1.006988	31.2	62.8	60.26

Combined Sieve Analysis

Grain Size (mm)	% passing	Combined % passing					
9.50	100.00	100.00					
4.75	***100.00***	***100.00***					
2.00	***99.18***	***99.18***					
0.850	97.42	97.42					
0.425	97.24	97.24					
0.250	96.97	96.97					
0.150	96.47	96.47					
0.075	***95.90***	***95.90***					
0.0387	97.1	93.09					
0.0279	93.0	89.23					
0.0201	89.0	85.37					
0.0107	83.0	79.57					
0.0077	78.9	75.71					
0.0055	74.9	71.85					
0.0039	72.9	69.92					
0.0028	70.9	67.98		Course Material, %	Sandy Material, %	Silty Mateial, %	Clay Material, %
0.0020	***68.9***	***66.05***					
0.0012	62.8	60.26		0.00	4.10	29.85	66.05



C. Combined Grain Size Analysis (Wet Sieve And Hydrometer Test) For ABPS Pit

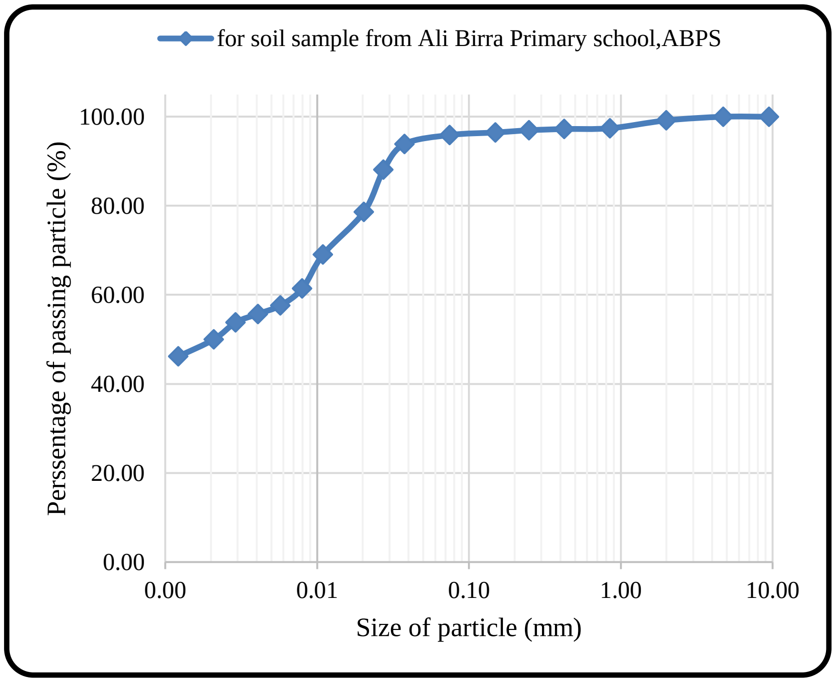
Wet Sieve Analysis					Hydrometer Analysis-152H						
Total washed soil specimen mass, g				500	Data for hydrometer analysis						
Sieve Size	Mass of Retaing (g)	Percentage of Retaing	Commulative Percentage Retaining	Percentage of fine particles	Specific gravity of soil, (Gs)	Dried sample mass, (g)	Meniscus Correction (Cm)	Reading in Despersant, Ro	Value of K for 21°c	Value of a	
9.50	0	0.00	0.00	100.00	2.67	50	1	2	0.01339	0.99485	
4.75	0	0.00	0.00	100.00	Value of K for Use in Equations for Computing Diameter of Particle in Hydrometer Analysis						
2.00	4.1	0.82	0.82	99.18	Temp. (^{o}C)	Specific Gravity of Soil Particles					
0.850	8.822	1.76	2.58	97.42		2.55	2.6	2.65	2.7	2.75	2.8
0.425	0.88	0.18	2.76	97.24	20	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307
0.250	1.355	0.27	3.03	96.97	21	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291
0.150	2.49	0.50	3.53	96.47	22	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276
0.075	2.86	0.57	4.10	95.90	23	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261
Pan	479.493	95.90	100.00		24	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246
Total	500				25	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232

Hydrometer Analysis

Time	Elapsed time t in, min	Actual Hydrometer Reading	Eff.depth,L (cm)	Temperature (c0)	K	C_T	Par.diameter D (mm)	Value of 'a' for Gs	Corrected hydrometer reading	Percent of Fine part., (%)	Adjusted percent fines part., (%)
10/11/2022/ 3:45:00 AM	0										
3:46:00 AM	1	50	7.9	21	0.01339	0.2	0.0377	0.994914	49.2	97.9	93.88
3:47:00 AM	2	47	8.4	21	0.01339	0.2	0.0275	0.994914	46.2	91.9	88.16
3:50:00 AM	4	42	9.2	21	0.01339	0.2	0.0204	0.994914	41.2	82.0	78.62
	8	40	9.6	21	0.01339	0.2	0.0146	0.994914	39.2	78.0	74.80
3:53:00 AM	15	37	10.1	21	0.01339	0.2	0.0110	0.994914	36.2	72.0	69.08
4:00:00 AM	30	33	10.7	21	0.01339	0.2	0.0080	0.994914	32.2	64.1	61.44
4:15:00 AM	60	31	11.0	21	0.01339	0.2	0.0057	0.994914	30.2	60.1	57.63
4:45:00 AM	120	30	11.2	21	0.01339	0.2	0.0041	0.994914	29.2	58.1	55.72
5:45:00 AM	240	29	11.4	21	0.01339	0.2	0.0029	0.994914	28.2	56.1	53.81
7:45:00 PM	480	27	11.7	21	0.01339	0.2	0.0021	0.994914	26.2	52.1	50.00
11/11/2022	1440	25	12.0	21	0.01339	0.2	0.0012	0.994914	24.2	48.2	46.18

Combined Sieve Analysis

Grain Size (mm)	% passing	Combined % passing
9.50	100.00	100.00
4.75	***100.00***	***100.00***
2.00	***99.18***	***99.18***
0.850	97.42	97.42
0.425	97.24	97.24
0.250	96.97	96.97
0.150	96.47	96.47
0.075	***95.90***	***95.90***
0.0377	97.9	93.88
0.0275	91.9	88.16
0.0204	82.0	78.62
0.0110	72.0	69.08
0.0080	64.1	61.44
0.0057	60.1	57.63
0.0041	58.1	55.72
0.0029	56.1	53.81
0.0021	***52.1***	***50.00***
0.0012	48.2	46.18

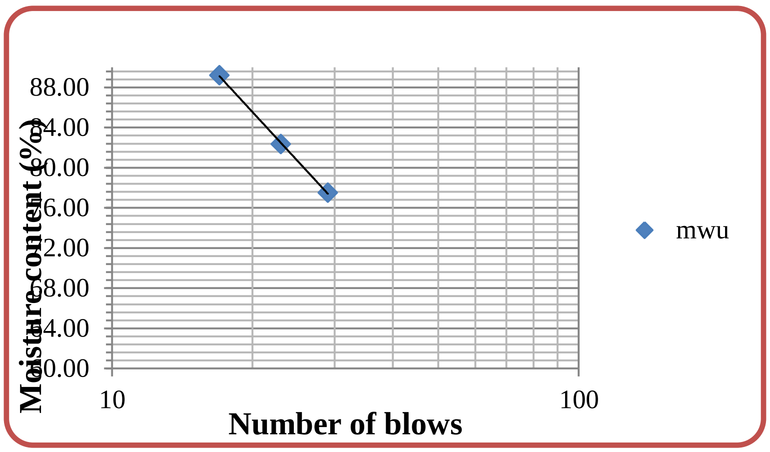


Course Material, %	Sandy Material, %	Silty Mateial, %	Clay Material, %
0.00	4.10	45.90	50.00

5. Atterberg Limit

A. Atterberg Limit Determination for Soil Sample from MWU

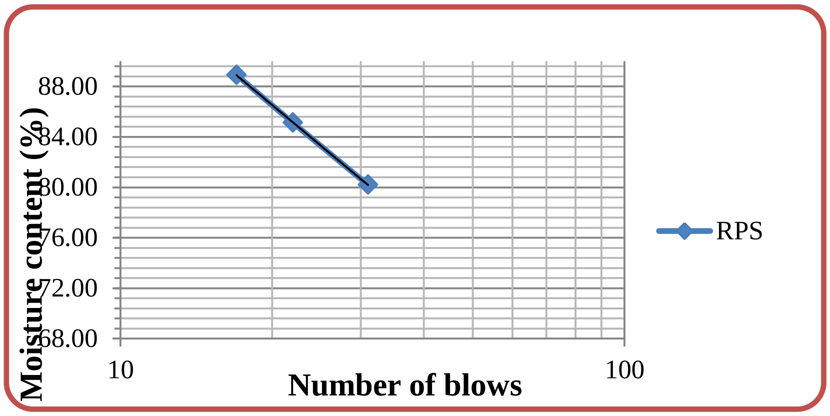
Test pit Location	Robe Town				
Material Type	MWU				
Determination	Liquid Limit (AASHTO T-89)			Plastic Limit (AASHTO T-90)	
Number of blows	29	23	17		
Trial No	01	02	03	01	02
Wt. of Container, (g)	20.062	25.23	22.056	6.075	5.855
Wt. of container + wet soil, (g)	26.61	42.863	32.894	13.026	13.204
Wt. of container + dry soil, (g)	23.751	34.901	27.785	11.237	11.263
Wt. of water, (g)	2.86	7.96	5.11	1.79	1.94
Wt. of dry soil, (g)	3.69	9.67	5.73	5.16	5.41
Moisture container, (%)	77.50	82.33	89.18	34.66	35.89



LL (%)	**80.66**
PL (%)	**35.27**
PI (%)	**45.39**

B. Atterberg Limit Determination for Soil Sample from RPS

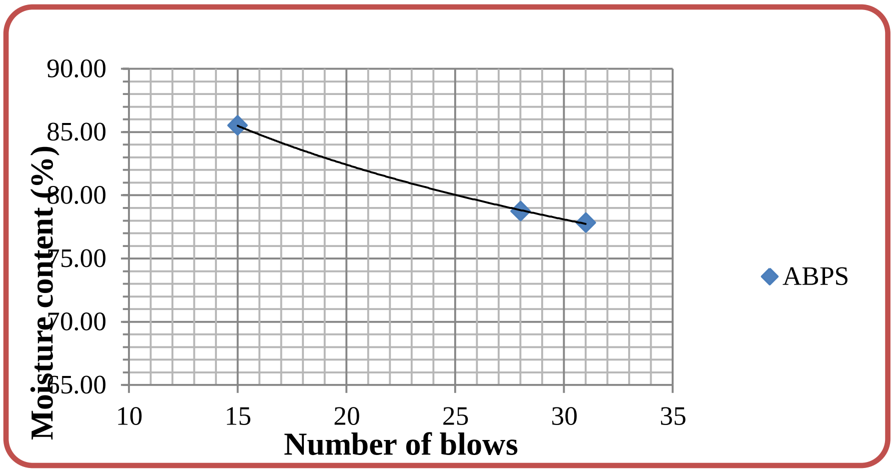
Test pit Location	Robe Town				
Material Type	RPS				
Determination	Liquid Limit (AASHTO T-89)			Plastic Limit (AASHTO T-90)	
Number of blows	31	22	17		
Trial No	01	02	03	01	02
Wt. of Container, (g)	19.95	17.31	20.01	17.520	17.060
Wt. of container + wet soil, (g)	36.6	33.36	38.24	29.640	29.170
Wt. of container + dry soil, (g)	29.19	25.98	29.66	26.500	25.980
Wt. of water, (g)	7.41	7.38	8.58	3.14	3.19
Wt. of dry soil, (g)	9.24	8.67	9.65	8.98	8.92
Moisture container, (%)	80.19	85.12	88.91	34.97	35.76



LL (%)	**83.30**
PL (%)	**35.36**
PI (%)	**47.94**

C. Atterberg Limit Determination for Soil Sample from ABPS

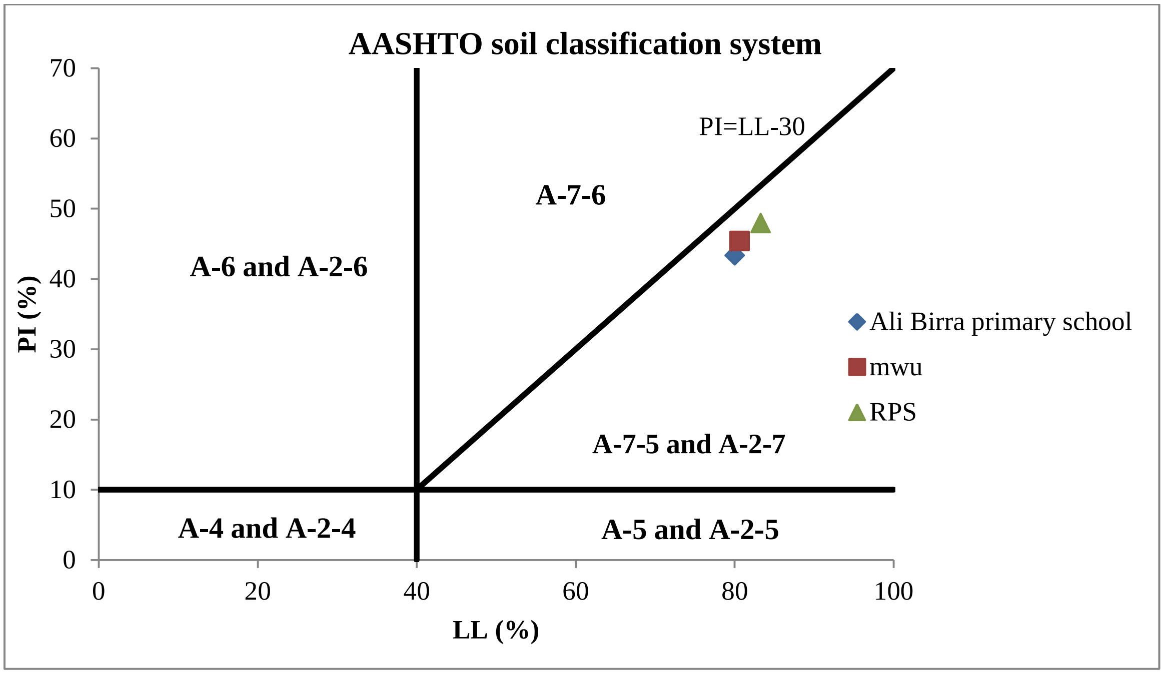
Test pit Location	Robe Town				
Material Type	ABPS				
Determination	Liquid Limit (AASHTO T-89)			Plastic Limit (AASHTO T-90)	
Number of blows	31	28	15		
Trial No	01	02	03	01	02
Wt. of Container, (g)	5.75	6.73	5.84	18.07	16.66
Wt. of container + wet soil, (g)	15.83	17.02	16.36	27.02	24.54
Wt. of container + dry soil, (g)	11.42	12.49	11.51	24.65	22.40
Wt. of water, (g)	4.41	4.53	4.85	2.37	2.14
Wt. of dry soil, (g)	5.67	5.76	5.67	6.58	5.74
Moisture container, (%)	77.83	78.74	85.51	36.05	37.33



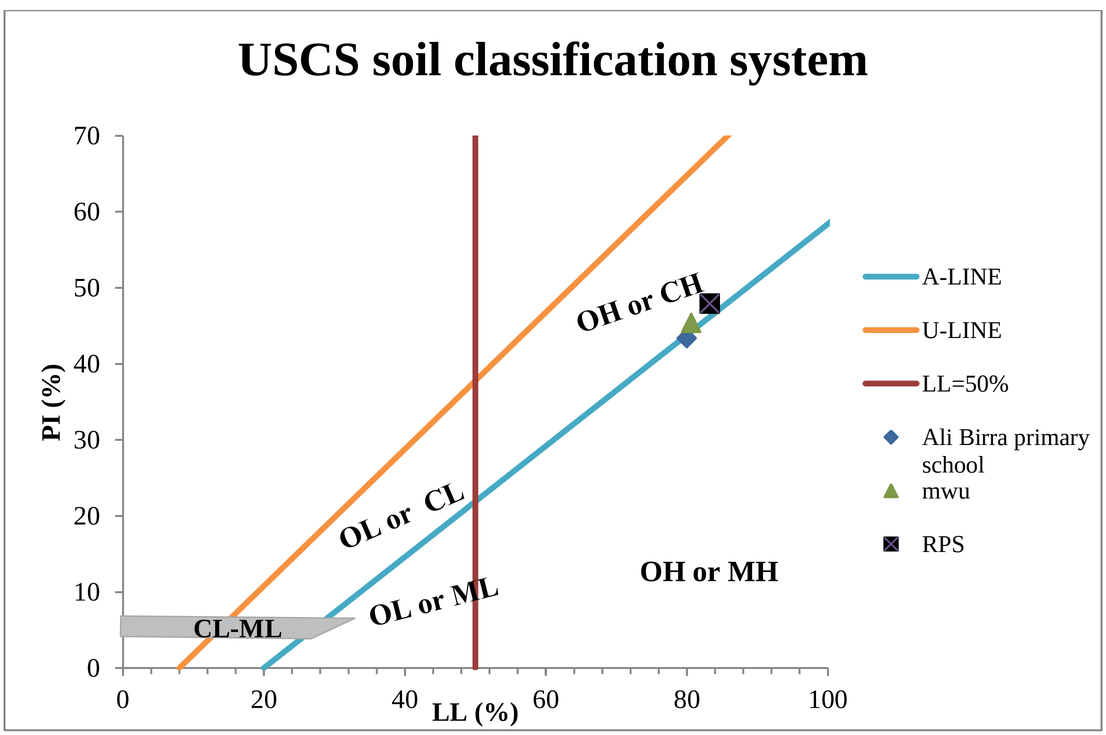
LL (%)	**80.04**
PL (%)	**36.69**
PI (%)	**43.35**

6. Soil Classification

A. AASHTO soil classification



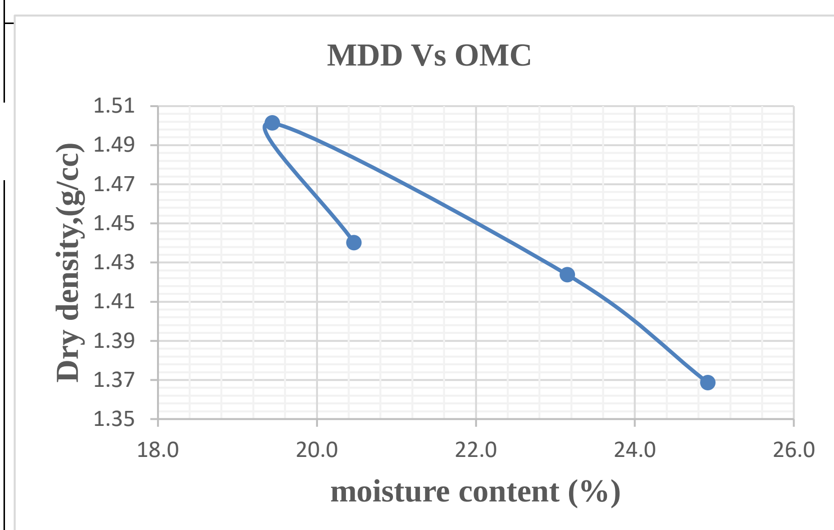
B. USCS unified soil classification system



7. Compaction Characteristics

A. Determination Of MDD And OMC For Soil Sample From MWU

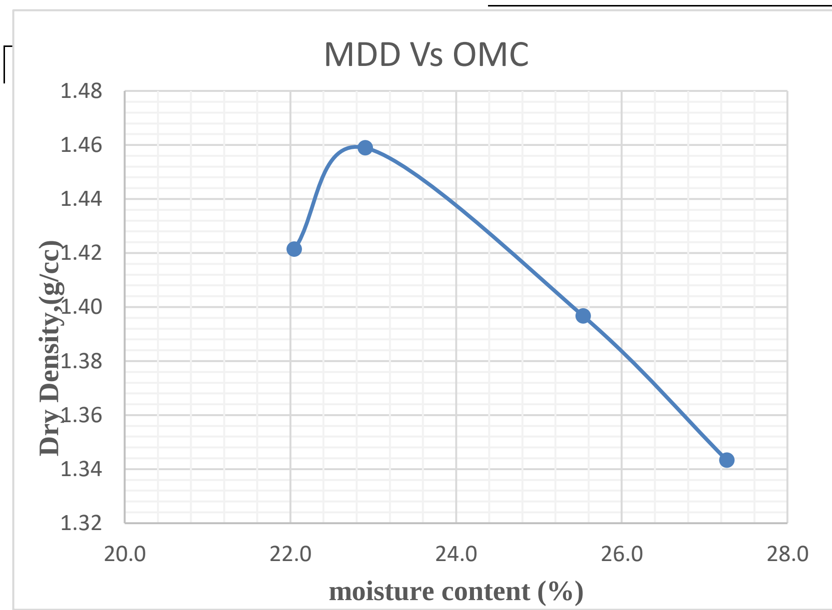
MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-subgrade soil (MWU pit)			Date sampled:-02,jun 2022 Date Tested:- 22, Jun 2022			
DENSITY	Trial Numbers	1	2	3	4	
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6402.5	6526.5	6442	6349	
	Mass of mould (g)=m2	2718	2718	2718	2718	
	Mass of Wet soil (g), m3=m1-m2	3684.5	3808.5	3724	3631.0	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.79	1.75	1.71	
MOISTURE	Container code	G63	LC51	4	02,1	NMC(A)
	Mass of wet soil +cont (g), m4	178.5	133	121	134.73	229.00
	Mass of dry soil + cont (g), m5	152.5	115.5	101.54	113.5	210.50
	Mass of container (g), m6	25.5	25.5	17.5	28.32	40.00
	Mass of moisture (g), m7=m4-m5	26.0	17.5	19.46	21.2	18.50
	Mass of dry soil (g), m8=m5-m6	127	90	84.04	85.18	170.50
	Moisture content (%), w =(m7/m8)*100	20.5	19.44	23.16	24.9	10.85
	Dry density, γd=(ρ/(100+w))*100	1.44	1.50	1.42	1.37	



MDD(g/cm3)= **1.501**
OMC (%) = **19.444**

B. Determination Of MDD And OMC For Soil Sample From RPS

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:- subgrade soil(RPS pit)		Date sampled:-02,jun 2022				
		Date Tested:- 22, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6402.5	6526.5	6442	6349	
	Mass of mould (g)=m2	2718	2718	2718	2718	
	Mass of Wet soil (g), m3=m1-m2	3684.5	3808.5	3724	3631.0	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.79	1.75	1.71	
MOISTURE	Container code	G63	LC51	4	02,1	NMC(A)
	Mass of wet soil +cont (g), m4	180.5	135.5	123	136.73	229.00
	Mass of dry soil + cont (g), m5	152.5	115	101.54	113.5	210.50
	Mass of container (g), m6	25.5	25.5	17.5	28.32	40.00
	Mass of moisture (g), m7=m4-m5	28.0	20.5	21.46	23.2	18.50
	Mass of dry soil (g), m8=m5-m6	127	89.5	84.04	85.18	170.50
	Moisture content (%), w =(m7/m8)*100	22.0	22.91	25.54	27.3	10.85
	Dry density, γd=(ρ/(100+w))*100	1.42	1.46	1.40	1.34	

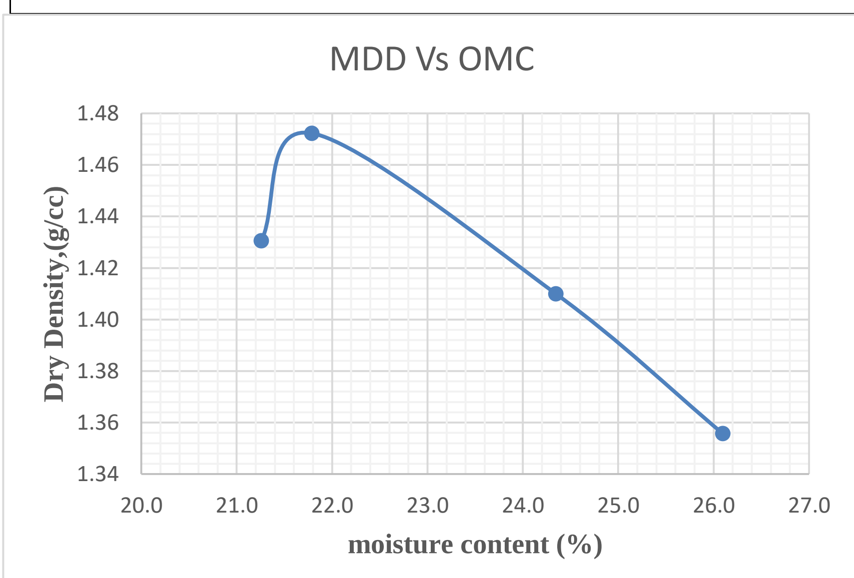


MDD(g/cm3)= **1.459**

OMC (%) = **22.905**

C. Determination of MDD And OMC For Soil Sample From ABPS

MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-subgrade soil(Ali Birra primary school pit)		Date sampled:-02,jun 2022				
		Date Tested:- 22, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6402.5	6526.5	6442	6349	
	Mass of mould (g)=m2	2718	2718	2718	2718	
	Mass of Wet soil (g), m3=m1-m2	3684.5	3808.5	3724	3631.0	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.79	1.75	1.71	
MOISTURE	Container code	G63	LC51	4	02,1	NMC(A)
	Mass of wet soil +cont (g), m4	179.5	134.5	122	135.73	229.00
	Mass of dry soil + cont (g), m5	152.5	115	101.54	113.5	210.50
	Mass of container (g), m6	25.5	25.5	17.5	28.32	40.00
	Mass of moisture (g), m7=m4-m5	27.0	19.5	20.46	22.2	18.50
	Mass of dry soil (g), m8=m5-m6	127	89.5	84.04	85.18	170.50
	Moisture content (%), w =(m7/m8)*100	21.3	21.79	24.35	26.1	10.85
	Dry density, γd=(ρ/(100+w))*100	1.43	1.47	1.41	1.36	



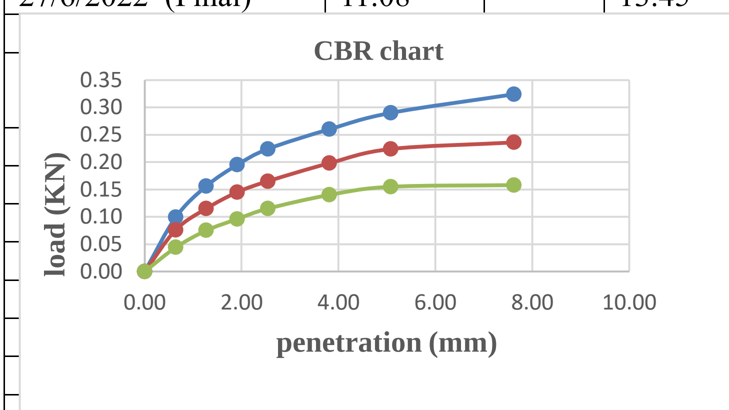
MDD(g/cm3)= **1.472**

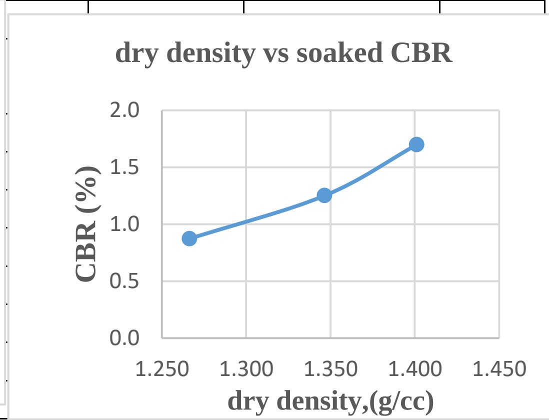
OMC (%) = **21.788**

8. California Bearing Ratio (CBR) and CBR swell

A. Determination of CBR and CBR swell for soil sample from MWU

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG					
Pen.mm	65 Blows		30Blows		10Blows	
	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.10		0.08		0.04	
1.27	0.16		0.12		0.08	
1.91	0.20		0.15		0.10	
2.54	0.22	1.70	0.17	1.25	0.12	0.87
3.81	0.26		0.20		0.14	
5.08	0.29	1.41	0.22	1.09	0.16	0.76
7.62	0.32		0.24		0.16	
ModifiedMDD(g/cc)	1.50			OMC %	19.44	
Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
23/6/2022 (Initial)	0.2	9.35	0.98	10.71	0.88	12.18
27/6/2022 (Final)	11.08		13.45		15.06	

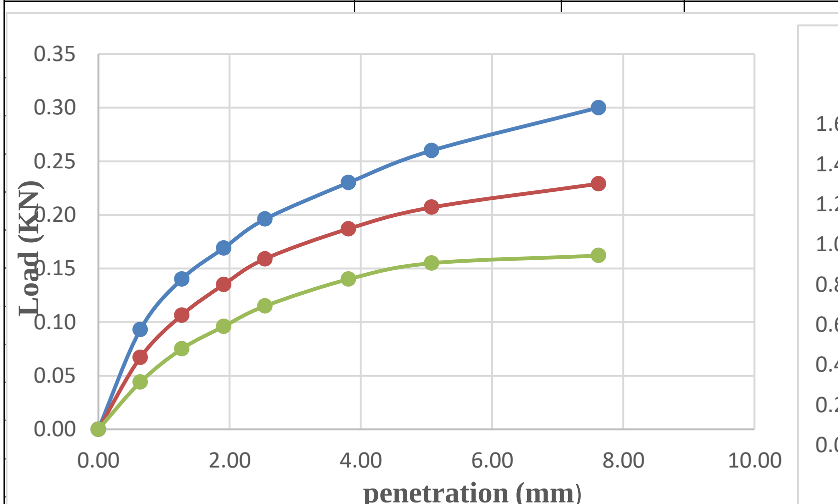


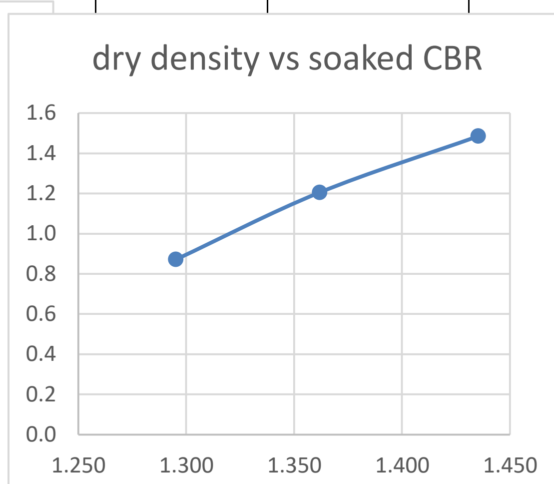


	Dry Density at 95% of MDD:					**1.43**
	No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
	10	28.2	1.266	0.9	84	
	30	29.8	1.347	1.3	90	
	65	30.0	1.401	1.7	93	
	CBR (%) @ 95 % MDD			**1.63**	% Swell	10.75

B. Determination of CBR and CBR Swell for Soil Sample from RPS

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		Surcharge Weight:-4.55 KG				
Pen.mm	**65 Blows**		**30Blows**		**10Blows**	
	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.09		0.07		0.04	
1.27	0.14		0.11		0.08	
1.91	0.17		0.14		0.10	
2.54	0.20	1.48	0.16	1.20	0.12	0.87
3.81	0.23		0.19		0.14	
5.08	0.26	1.27	0.21	1.01	0.16	0.76
7.62	0.30		0.23		0.16	
Modified MDD(g/cc)	**1.46**			OMC (%)	**22.91**	
Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
23/6/2022 (Initial)	0.2	15.98	0.98	15.01	0.88	10.90
27/6/2022 (Final)	18.8		18.45		13.57	



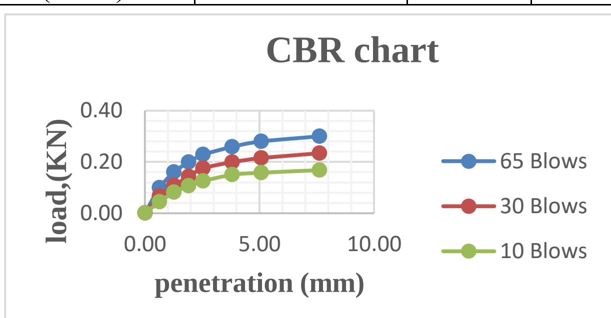


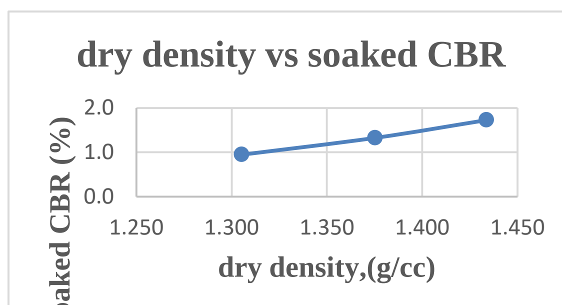
	Dry Density at 95% of MDD:					1.39
	No. of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
	10	25.4	1.295	0.9	89	
	30	28.3	1.362	1.2	93	
	65	26.9	1.435	1.5	98	
	CBR (%) @ 95 % MDD			**1.33**	% Swell	13.96

C. Determination of CBR and CBR swell for Soil Sample from ABPS

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG			
	65 Blows		30Blows		10Blows	
Pen.mm	Load, KN	CBR %	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.10		0.07		0.04	
1.27	0.16		0.11		0.08	
1.91	0.20		0.14		0.11	
2.54	0.23	1.73	0.18	1.33	0.13	0.95
3.81	0.26		0.20		0.15	
5.08	0.28	1.37	0.22	1.05	0.16	0.77
7.62	0.30		0.23		0.17	
Modified MDD (g/cc)	1.47			OMC %	21.79	

Swell Determination						
	65 Blows		30 Blow		10Blows	
Date	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
23/6/2022 (Initial)	0.2	10.82	0.98	11.57	0.88	12.62
27/6/2022 (Final)	12.8		14.45		15.57	





Dry Density at 95% of MDD:					1.40
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	24.4	1.305	0.9	89	
30	27.1	1.375	1.3	93	
65	27.0	1.434	1.7	97	
CBR (%) @ 95 % MDD			1.45	% Swell	11.67

APPENDIX B: Laboratory Data Analysis for Expansive Representative Soil Treated With CDA

1. Specific Gravity

A. Natural soil treated with 3% CDA

Specific Gravity of 3%CDA+ soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	O	O3
Wp= Mass of empty, clean pycnometer (A), g	29.5	31
Wps=Mass of pycnometer +dry soil(B), g	55	56
WB= Mass of pycnometer +dry soil +water (C), g	137.5	135.62
Mass of pycnometer +water (D), g	117.1	115
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25.5	25
Specific gravity=E/(A+(D-C))	2.80	2.41
Average specific gravity	2.61	

B. Natural soil treated with 6% CDA

Specific Gravity of 6%CDA+ soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	B	C
Wp= Mass of empty, clean pycnometer (A), g	21.5	28.5
Wps=Mass of pycnometer +dry soil(B), g	46.5	53.5
WB= Mass of pycnometer +dry soil +water (C), g	87.8	89.69
Mass of pycnometer +water (D), g	76.3	71
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(A+(D-C))	2.50	2.55
Average specific gravity	2.52	

C. Natural soil treated with 9% CDA

Specific Gravity of 9%CDA+ soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	B	C
Wp= Mass of empty, clean pycnometer (A), g	21.5	28.5
Wps=Mass of pycnometer +dry soil(B), g	46.5	53.5
WB= Mass of pycnometer +dry soil +water (C), g	88.58	87.5
Mass of pycnometer +water (D), g	77	69.2
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(A+(D-C))	2.52	2.45
Average specific gravity	2.49	

D. Natural soil treated with 12% CDA

Specific Gravity of 12%CDA+Soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	T	O
Wp= Mass of empty, clean pycnometer (A), g	29.5	29.5
Wps=Mass of pycnometer +dry soil(B), g	54.5	54.5
WB= Mass of pycnometer +dry soil +water (C), g	134.54	136.24
Mass of pycnometer +water (D), g	115.2	116.9
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(A+(D-C))	2.46	2.46
Average specific gravity	2.46	

E. Natural soil treated with 15% CDA

Specific Gravity of 15%CDA+ Soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	C	O3
Wp= Mass of empty, clean pycnometer (A), g	26.5	31
Wps=Mass of pycnometer +dry soil(B), g	51.5	56
WB= Mass of pycnometer +dry soil +water (C), g	88.35	136.6
Mass of pycnometer +water (D), g	72.2	116
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25	25
Specific gravity=E/(A+(D-C))	2.42	2.40
Average specific gravity	2.41	

2. Free swell index

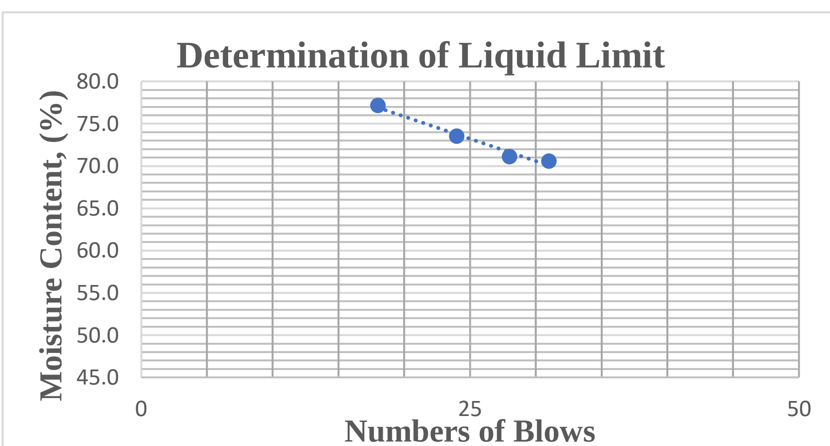
Free Swell Index For Selected Pit At Different %Age Of CDA

STATION	Measuring Cylinder No.(ml)		Reading after 24 hrs(ml)		Free Swell
	Kerosene	Distilled water	Kerosene	Distilled water	Index, %
selected pit(RPS)	11	11	11	21.5	95.45
3%CDA+Soil	12	12	12	20	66.67
6%CDA+Soil	12	12	12	18	50.00
9%CDA+Soil	11	11	11	17	54.55
12%CDA+Soil	13	13	13	20.5	57.69
15%CDA+Soil	12	12	12	19	58.33

3. Atterberg limit determination

A. Natural soil treated with 3% CDA

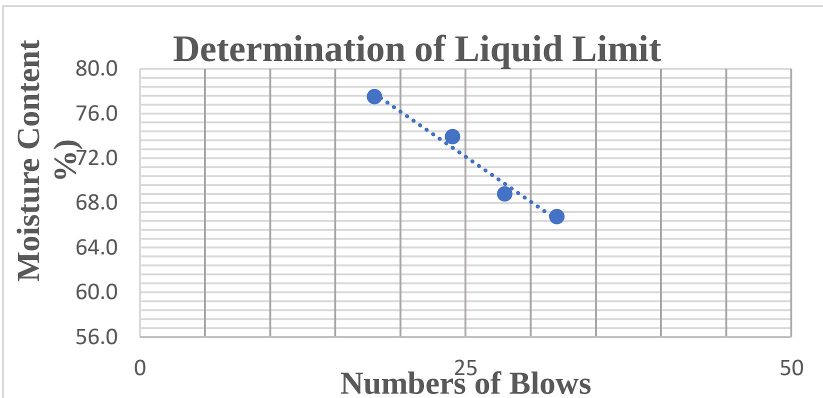
ATTERBERG LIMIT (AASHTO T089-94, T09-96)						
Material description:-Expansive Black cotton soil				Date sampled:-01/2021		
3%CDA+ Soil				Date Tested:- 15/10/2014		
Determination of Liquid limit					Plastic Limit	
Number of blows	**31**	**28**	**24**	**18**		
Trial	1	2	3	4	1	2
Container	3,3	H23	F5	2	C1	A7
Wt. of container + wet soil (g)	43.098	35.12	35.65	38.6	35.89	30.15
Wt. of container + dry soil (g)	35.35	28.26	28.24	30.05	32.05	27.35
Wt. of container (g)	24.37	18.61	18.16	18.97	20.99	19.82
Wt. of water (g)	7.748	6.86	7.41	8.55	3.8	2.8
Wt. of dry soil (g)	10.98	9.65	10.08	11.08	11.06	7.53
Moisture content (%)	**70.6**	**71.1**	**73.5**	**77.2**	34.7	37.2
Average	73				**36**	



LL (%)=	**73.08**
PL (%)=	**35.95**
PI (%)=	**37.13**

B. Natural soil treated with 6% CDA

Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**32**	**28**	**24**	**18**		
Trial	1	2	3	4	1	2
Container	E13	4	C9	A4	B9	3L
Wt. of container + wet soil (g)	35.16	30.47	34.6	37.2	30.11	29.81
Wt. of container + dry soil (g)	28.09	24.98	27.12	28.38	27.5	27.13
Wt. of container (g)	17.5	17	17	17	20	20
Wt. of water (g)	7.07	5.49	7.48	8.82	2.6	2.68
Wt. of dry soil (g)	10.59	7.98	10.12	11.38	7.5	7.13
Moisture content (%)	**66.8**	**68.8**	**73.9**	**77.5**	**34.8**	**37.6**
Average	**72**				**36**	



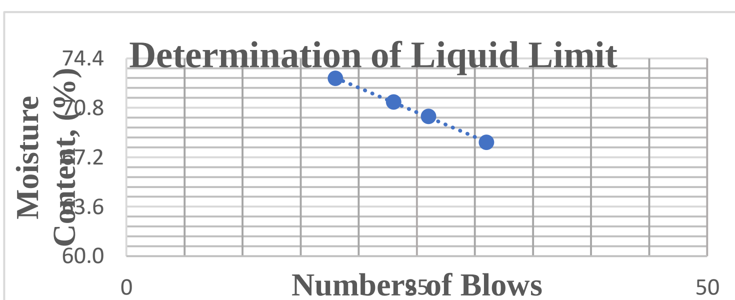
LL= 71.74

PL= 36.19

PI= 35.55

C. Natural soil treated with 9% CDA

Determination of Liquid limit					Plastic Limit	
Number of blows	**31**	**26**	**23**	**18**		
Trial	1	2	3	4	1	2
Container	A7	C1	F5	H23	2	3,3
Wt. of container + wet soil (g)	40.5	42.61	33.41	36.83	30.37	35.36
Wt. of container + dry soil (g)	31.98	33.7	27	29.1	27.12	32.65
Wt. of container (g)	19.5	21	18	18.5	19	24.5
Wt. of water,(g)	8.52	8.91	6.41	7.73	3.3	2.71
Wt. of dry soil,(g)	12.48	12.7	9	10.6	8.12	8.15
Moisture content,(%)	**68.3**	**70.2**	**71.2**	**72.9**	40.0	33.3
Average	71				**37**	



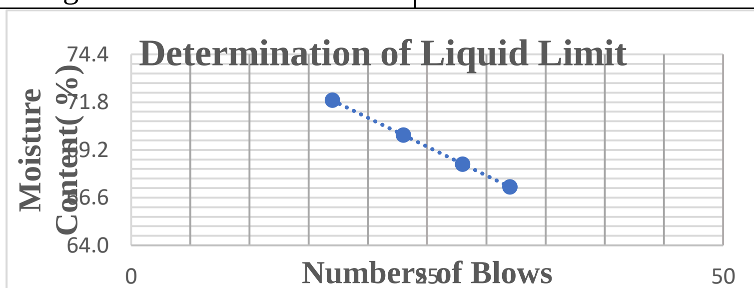
LL (%)= 70.64

PL (%)= 36.64

PI (%)= 34.01

D. Natural soil treated with 12% CDA

Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**32**	**28**	**23**	**17**		
Trial	1	2	3	4	1	2
Container	3L	A17	B9	T4	A	T1
Wt. of container + wet soil,(g)	36.82	38.63	40	24.21	16.06	17.24
Wt. of container + dry soil,(g)	29.9	31.85	31.62	16.58	13.34	14.46
Wt. of container,(g)	19.6	21.94	19.65	5.97	6.4	6.42
Wt. of water,(g)	6.92	6.78	8.38	7.63	2.7	2.78
Wt. of dry soil,(g)	10.3	9.91	11.97	10.61	6.94	8.04
Moisture content,(%)	**67.2**	**68.4**	**70.0**	**71.9**	**39.2**	**34.6**
Average	**69**				**37**	



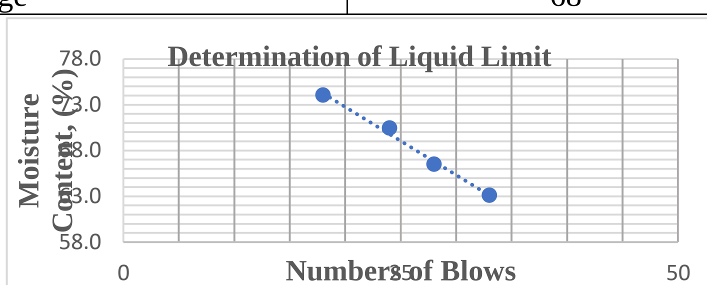
LL= 69.38

PL= 36.89

PI= 32.50

E. Natural soil treated with 15% CDA

Determination of Liquid limit					Plastic Limit	
Number of blows	**33**	**28**	**24**	**18**		
Trial	1	2	3	4	1	2
Container	4,	A4	H23	A7	B1	G8
Wt. of container + wet soil,(g)	32.1	36.3	36.1	39.1	15.96	27.96
Wt. of container + dry soil,(g)	26.27	28.57	28.89	30.87	13.15	25.44
Wt. of container,(g)	17.03	16.94	18.65	19.75	5.48	18.72
Wt. of water,(g)	5.83	7.73	7.21	8.23	2.8	2.52
Wt. of dry soil,(g)	9.24	11.63	10.24	11.12	7.67	6.72
Moisture content,(%)	**63.1**	**66.5**	**70.4**	**74.0**	36.6	37.5
Average	68				**37**	



LL (%)= 68.50

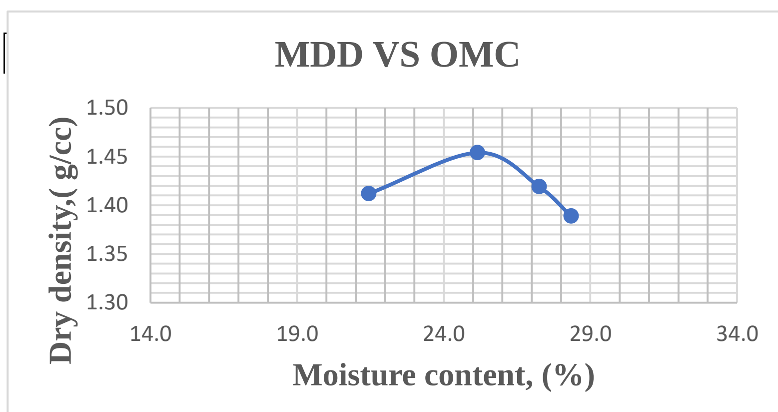
PL (%)= 37.07

PI (%)= 31.43

4. Compaction (MDD and OMC) determination

A. Natural Soil Treated With 3% CDA

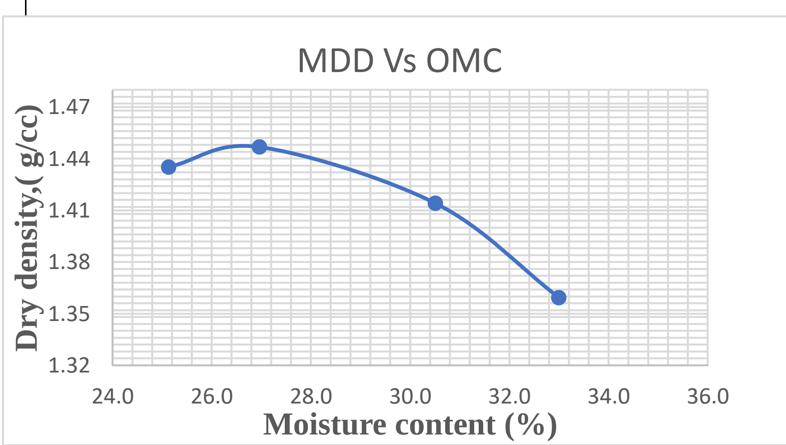
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180						
Material description:-3%CDA +Expansive soil		Date sampled:-02,jun 2022				
		Date Tested:- 22, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	3%CDA +Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	180	360	540	720	
	Mass of mould +Wet soil (g),=m1	6361.5	6584.5	6555	6505.3	
	Mass of mould (g)=m2	2719.5	2719.5	2719.5	2719.5	
	Mass of Wet soil (g), m3=m1-m2	3642.0	3865	3835.5	3785.8	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.82	1.81	1.78	
MOISTURE	Container code	LC5	g	A16	P15	NMC (A)
	Mass of wet soil +cont (g), m4	252.5	174	182.52	214.22	231.00
	Mass of dry soil + cont (g), m5	212.5	145.56	150.5	175.7	210.50
	Mass of container (g), m6	26	32.5	33	39.79	40.00
	Mass of moisture (g), m7=m4-m5	40.0	28.44	32.02	38.52	20.50
	Mass of dry soil (g), m8=m5-m6	186.5	113.06	117.5	135.91	170.50
	Moisture content (%), w =(m7/m8)*100	21.4	25.15	27.25	28.34	12.02
	Dry density, γd=(ρ/(100+w))*100	1.41	1.45	1.42	1.39	



MDD (g/cm3)	**1.454**
OMC (%)	**25.15**

B. Natural Soil Treated With 6% CDA

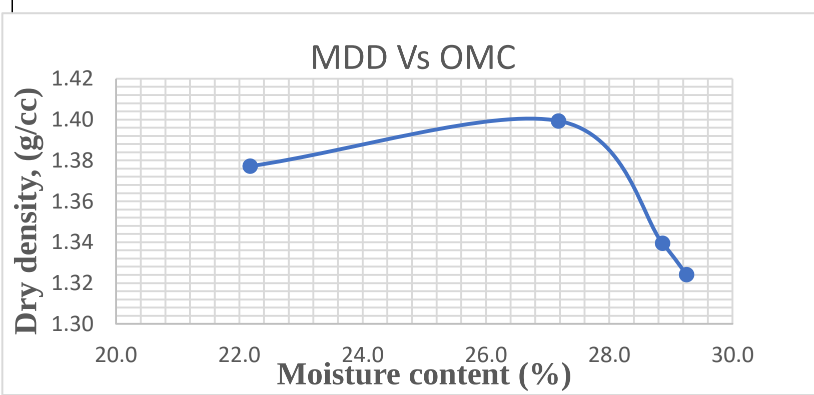
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive soil+6%CDA		Date sampled:-02,jun 2022				
		Date Tested:- 27, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	6%CDA+ Expansiv e soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6532. 5	6619.5	6638	6558	
	Mass of mould (g)=m2	2718	2718	2718	2718	
	Mass of Wet soil (g), m3=m1-m2	3814. 5	3901.5	3920	3840.0	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.8	1.84	1.85	1.81	
MOISTURE	Container code	C15	G	A16	02,1	NMC(T1
	Mass of wet soil +cont (g), m4	215.8 9	202.5	197	186.83	225.50
	Mass of dry soil + cont (g), m5	177.6 5	166.4	162.52	147.5	205.50
	Mass of container (g), m6	25.5	32.5	49.5	28.32	38.00
	Mass of moisture (g), m7=m4-m5	38.2	36.1	34.48	39.3	20.00
	Mass of dry soil (g), m8=m5-m6	152.1 5	133.9	113.02	119.18	167.50
	Moisture content (%), w =(m7/m8)*100	25.1	26.96	30.51	33.0	11.94
	Dry density, γd=(ρ/(100+w))*100	1.44	1.45	1.41	1.36	



MDD (g/cm3)	**1.447**
OMC (%)	**26.96**

C. Natural Soil Treated With 9% CDA

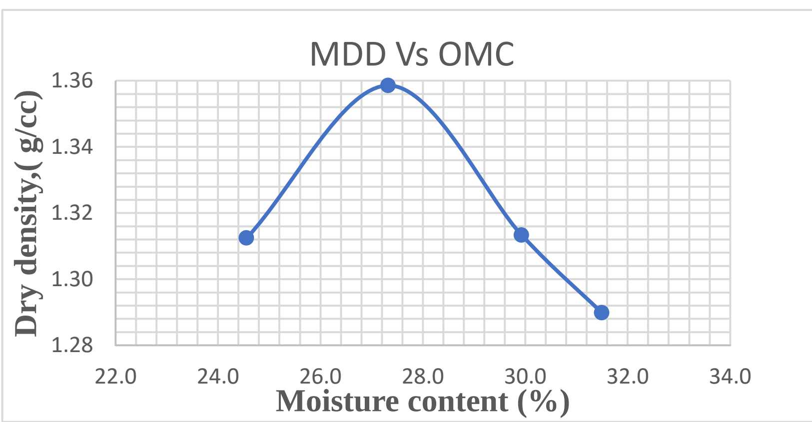
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Black cotton soil+9%CDA		Date sampled:-02,jun 2022 Date Tested:- 27, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	9%CDA+ Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6290.0	6496	6382	6351	
	Mass of mould (g)=m2	2716	2716	2716	2716	
	Mass of Wet soil (g), m3=m1-m2	3574.0	3780.0	3666.0	3635.0	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.7	1.78	1.73	1.71	
MOISTURE	Container code	A-2	G3T2	J41	02,1	NMC(T1)
	Mass of wet soil +cont (g), m4	199.5	229.5	209.55	168.73	225.50
	Mass of dry soil + cont (g), m5	170	187.93	169.89	136.95	205.50
	Mass of container (g), m6	37	35	32.5	28.32	38.00
	Mass of moisture (g), m7=m4-m5	29.5	41.57	39.66	31.8	20.00
	Mass of dry soil (g), m8=m5-m6	133	152.93	137.39	108.63	167.50
	Moisture content (%), w =(m7/m8)*100	22.2	27.18	28.87	29.3	11.94
	Dry density, γd=(ρ/(100+w))*100	1.38	1.40	1.34	1.32	



MDD (g/cm3)	**1.399**
OMC (%)	**27.18**

D. Natural Soil Treated With 12% CDA

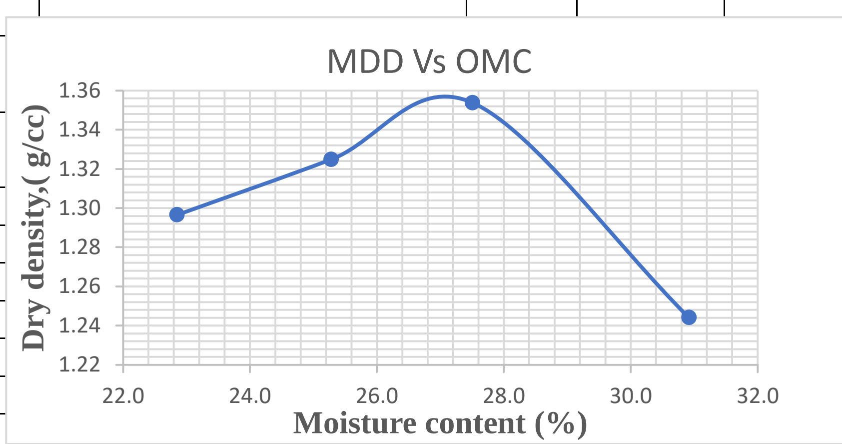
MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Black cotton soil+12%CDA		Date sampled:02, jun 2022				
		Date Tested:- 27, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	12%CDA +Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6188.3	6390.13	6340.42	6318.5	
	Mass of mould (g)=m2	2716	2716	2716	2716	
	Mass of Wet soil (g), m3=m1-m2	3472.3	3674.13	3624.42	3602.5	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.6	1.73	1.71	1.70	
MOISTURE	Container code	G63	A16	P65	A2	NMC(T1)
	Mass of wet soil +cont (g), m4	212.34	232.85	222.5	205.15	225.50
	Mass of dry soil + cont (g), m5	175.5	189.96	180	162	205.50
	Mass of container (g), m6	25.5	33	38	25	38.00
	Mass of moisture (g), m7=m4-m5	36.8	42.89	42.5	43.2	20.00
	Mass of dry soil (g), m8=m5-m6	150	156.96	142	137	167.50
	Moisture content (%), w =(m7/m8)*100	24.6	27.33	29.93	31.5	11.94
	Dry density, γd=(ρ/(100+w))*100	1.31	1.36	1.31	1.29	



MDD (g/cm3)	**1.359**
OMC (%)	**27.33**

E. Natural Soil Treated With 15% CDA

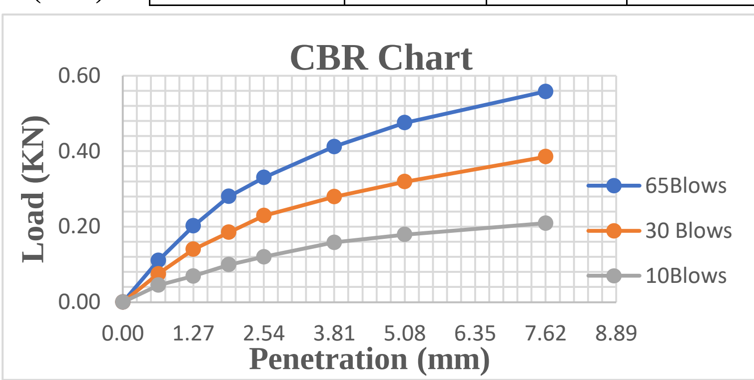
MOISTURE DENSITY RELATIONSHIP OF SOIL						
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-Expansive Black cotton soil+15%CDA			Date sampled: 02, jun 2022			
			Date Tested:- 27, Jun 2022			
DENSITY	Trial Numbers	1	2	3	4	15%CDA+Expansive soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6101.1	6243.35	6384.45	6177.25	
	Mass of mould (g)=m2	2718	2718	2718	2718	
	Mass of Wet soil (g), m3=m1-m2	3383.1	3525.35	3666.45	3459.3	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.6	1.66	1.73	1.63	
MOISTURE	Container code	B	G19	A	G3T3	NMC(T1)
	Mass of wet soil +cont (g), m4	196.31	204.2	208.45	198.53	225.50
	Mass of dry soil + cont (g), m5	165.56	170.26	172	160.5	205.50
	Mass of container (g), m6	31	36	39.5	37.5	38.00
	Mass of moisture (g), m7=m4-m5	30.8	33.94	36.45	38.0	20.00
	Mass of dry soil (g), m8=m5-m6	134.56	134.26	132.5	123	167.50
	Moisture content (%), w =(m7/m8)*100	22.9	25.28	27.51	30.9	11.94
	Dry density, γd=(ρ/(100+w))*100	1.30	1.32	1.35	1.24	
					MDD (g/cm3)	**1.354**
					OMC (%)	**27.51**

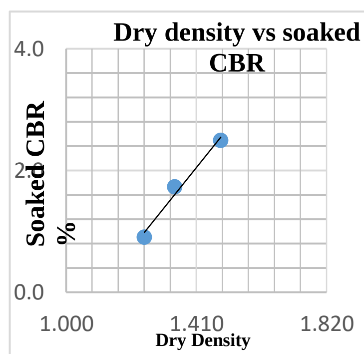


5. California bearing ratio (CBR) and CBR swell determination

A. Natural soil treated with 3% CDA

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		Surcharge Weight:-4.55 KG				
	65 Blows		30Blows		10Blows	
Pen.mm	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.11		0.08		0.05	
1.27	0.20		0.14		0.07	
1.91	0.28		0.19		0.10	
2.54	0.33	2.50	0.23	1.73	0.12	0.91
3.81	0.41		0.28		0.16	
5.08	0.48	2.31	0.32	1.55	0.18	0.87
7.62	0.56		0.39		0.21	
Modified MDD (g/cc)	1.45			OMC %	25.15	
Swell Determination						
	65 Blows		30 Blow		10Blows	
Date	Gauge reading (mm)	Swell in %	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %
23/6/2022 (Initial)	**0.31**	9.38	0.31	11.72	**0.22**	10.81
27/6/2022 (Final)	11.23		13.95		12.80	



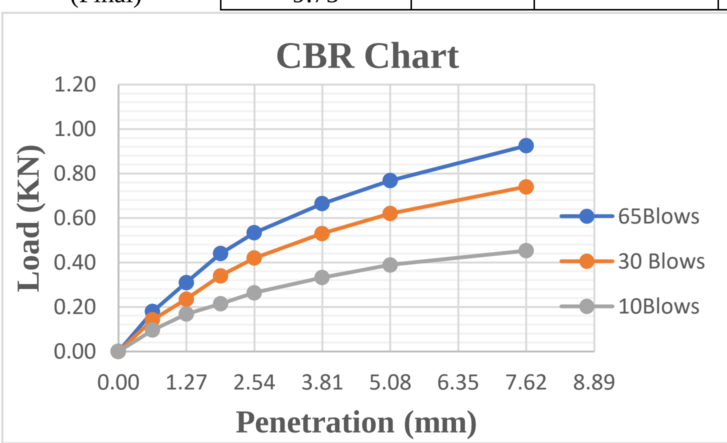


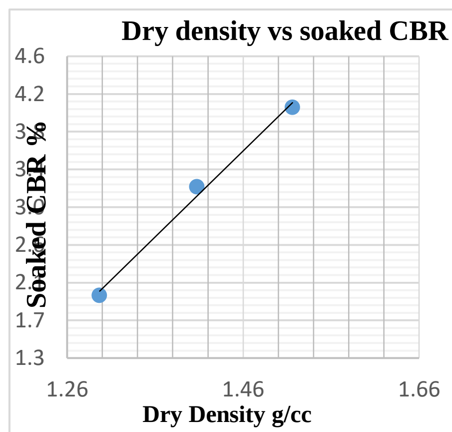
Dry Density at 95% of MDD:					1.38
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	20.1	1.246	0.9	86	
30	20.1	1.342	1.7	92	
65	20.0	1.487	2.5	102	
CBR (%) @ 95 % MDD			1.94	% Swell	10.64

B. Natural soil treated with 6% CDA

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		Surcharge Weight:-4.55 KG				
	65 Blows		30Blows		10Blows	
Pen.mm	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.18		0.14		0.10	
1.27	0.31		0.24		0.17	
1.91	0.44		0.34		0.21	
2.54	0.53	4.05	0.42	3.18	0.26	2.00
3.81	0.67		0.53		0.33	
5.08	0.77	3.75	0.62	3.02	0.39	1.90
7.62	0.93		0.74		0.45	
Modified MDD (g/cc)	1.45			OMC %	26.96	

Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
28/6/2022 (Initial)	0.3	8.12	0.20	8.57	0.4	8.26
02/07/2022 (Final)	9.75		10.18		10.02	

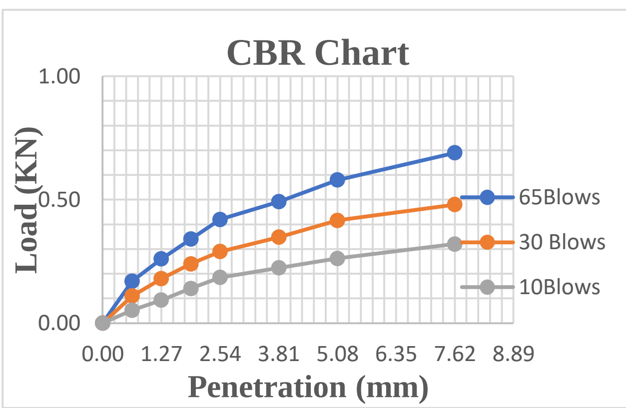


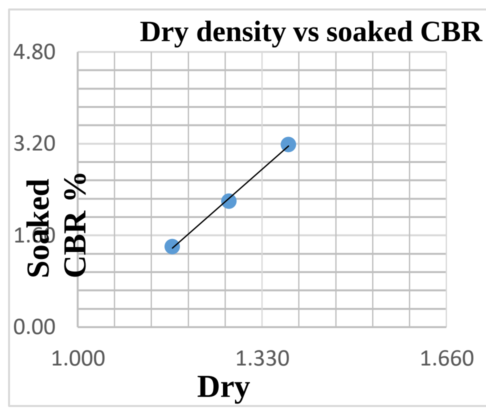


Dry Density at 95% of MDD:					1.37
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	19.4	1.30	2.0	90	
30	20.3	1.41	3.2	97	
65	21.4	1.52	4.0	105	
CBR (%) @ 95 % MDD			2.92	% Swell	8.32

C. Natural soil treated with 9% CDA

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		Surcharge Weight:-4.55 KG				
Pen.mm	65 Blows		30Blows		10Blows	
	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.17		0.11		0.05	
1.27	0.26		0.18		0.09	
1.91	0.34		0.24		0.14	
2.54	0.42	3.18	0.29	2.20	0.19	1.40
3.81	0.49		0.35		0.22	
5.08	0.58	2.82	0.42	2.02	0.26	1.27
7.62	0.69		0.48		0.32	
Modified Max.Dry Density g/cc	1.40			OMC %	27.18	
Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
28/6/2022 (Initial)	0.2	8.32	0.28	9.21	0.3	10.26
02/07/2022 (Final)	9.89		11.00		12.24	



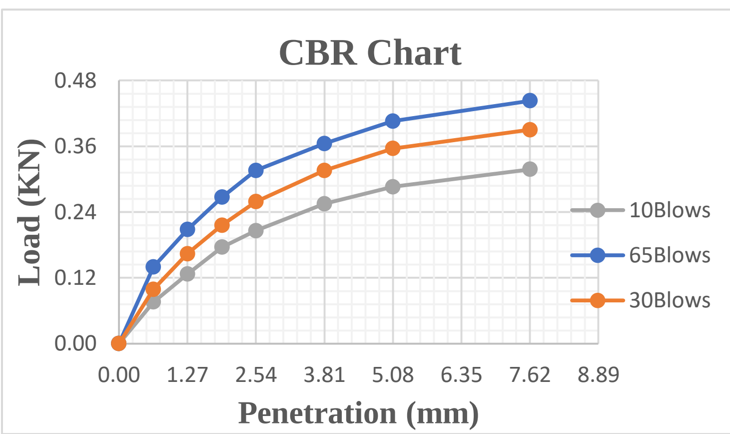


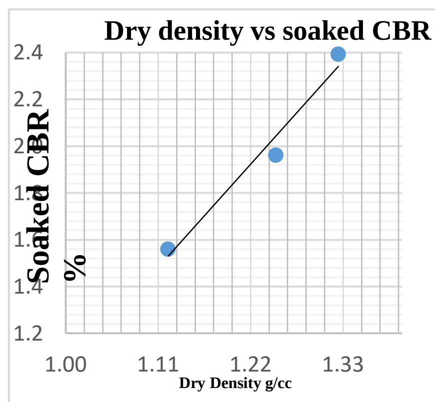
Dry Density at 95% of MDD:					1.33
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	31.3	1.169	1.40	84	
30	29.8	1.270	2.20	91	
65	25.1	1.377	3.18	98	
CBR (%) @ 95 % MDD			2.7	% Swell	9.26

D. Natural soil treated with 12% CDA

CBR Penetration Determination

Penetration after 96 hrs Soaking Period			**Surcharge Weight:-4.55 KG**			
	65 Blows		**30Blows**		**10Blows**	
Pen.mm	**Load, KN**	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.14		0.10		0.08	
1.27	0.21		0.16		0.13	
1.91	0.27		0.22		0.18	
2.54	0.32	2.39	0.26	1.96	0.21	1.56
3.81	0.37		0.32		0.26	
5.08	0.41	1.97	0.36	1.73	0.29	1.40
7.62	0.44		0.39		0.32	
Modified Max.Dry Density g/cc	**1.36**			**OMC %**	**27.33**	
Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
28/6/2022 (Initial)	0.2	8.55	0.20	10.48	0.2	11.05
02/07/2022 (Final)	10.15		12.40		13.06	





Dry Density at 95% of MDD:					**1.29**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	31.9	1.12	1.6	83	
30	30.4	1.25	2.0	92	
65	27.7	1.32	2.4	97	
CBR (%) @ 95 % MDD			**2.1**	**% Swell**	**10.03**

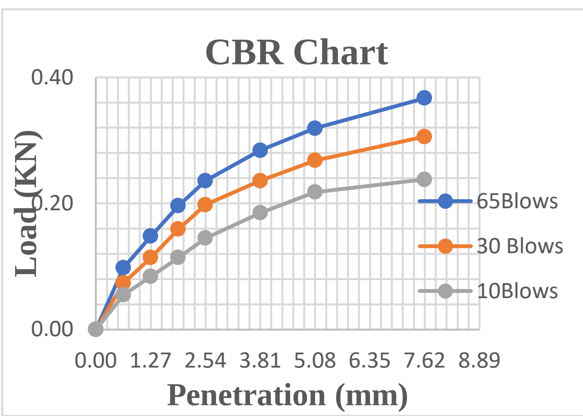
E. Natural soil treated with 15% CDA

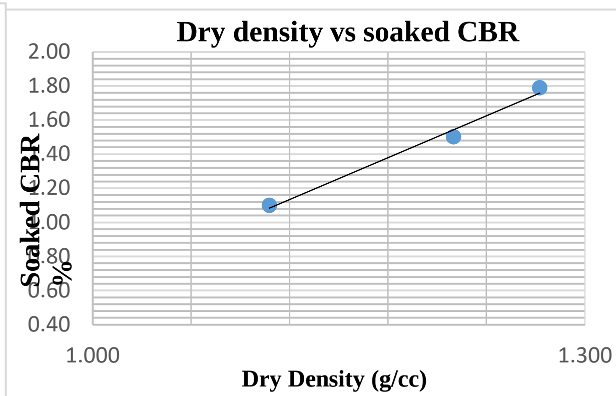
CBR Penetration Determination

Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG				
Pen.mm	**65 Blows**		**30Blows**		**10Blows**	
	Load, KN	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.10		0.07		0.06	
1.27	0.15		0.11		0.08	
1.91	0.20		0.16		0.11	
2.54	0.24	1.79	0.20	1.50	0.15	1.10
3.81	0.28		0.24		0.19	
5.08	0.32	1.55	0.27	1.30	0.22	1.06
7.62	0.37		0.31		0.24	
Modified Max.Dry Density g/cc	**1.35**			**OMC %**	**27.51**	

Swell Determination

Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
28/6/2022 (Initial)	**0.24**	11.01	0.32	11.77	**0.21**	12.54
02/07/2022 (Final)	13.06		14.02		14.81	





Dry Density at 95% of MDD:					**1.29**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	32.4	1.108	1.10	82	
30	32.9	1.220	1.50	90	
65	33.0	1.273	1.79	94	
CBR (%) @ 95 % MDD			**1.7**	**% Swell**	**11.78**

6. Chemical composition result

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name:- Basha Edao

Sample type :- Powder

Sample Preparation: -200 Mesh

Date Submitted:- 24/03/2023

Issue Date:-03/04/2023

Request No:- GLD/RQ/1032/23

Report No:- GLD/RN/1619/23

Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
BE-1	62.90	5.15	3.22	6.26	2.90	0.26	5.72	0.14	3.92	0.17	1.21	7.47	300 gm

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Haimanot Bayeh
Gadisa Wakuma
Nigist Fikadu

Checked By
Lidet Endeshaw

Approved By
Yohannes Getachew

Quality Control
Negash Worku

APPENDIX C: Laboratory Data Analysis for Expansive Soil Treated With 6% CDA Mixed With Varied Percentage of Lime

1. **Specific Gravity**

A. CDA mixed with 3% lime + Expansive soil

Specific Gravity of 3%Lime+OPT CDA(6%)+ Soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	C	T
Wp= Mass of empty, clean pycnometer (A), g	26.53	27.94
Wps=Mass of pycnometer +dry soil(B), g	51.5	52.5
WB= Mass of pycnometer +dry soil +water (C), g	97.5	90.8
Mass of pycnometer +water (D), g	81.2	72
Temperature, ^oC	20	20
Mass of dry soil (E), g =B-A	24.97	24.56
Specific gravity=E/(A+(D-C))	2.44	2.69
Average specific gravity	2.56	

B. CDA mixed with 6% lime + Expansive soil

Specific Gravity of 6%Lime+OPT CDA+ Soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	O3	O
Wp= Mass of empty, clean pycnometer (A), g	31.18	30.37
Wps=Mass of pycnometer +dry soil(B), g	56	55.5
WB= Mass of pycnometer +dry soil +water (C), g	136.5	135.5
Mass of pycnometer +water (D), g	115.4	114.3
Temperature, ^oC	20	20
Mass of dry soil (E), g =B-A	24.82	25.13
Specific gravity=E/(A+(D-C))	2.46	2.74
Average specific gravity	2.60	

C. CDA mixed with 9% lime + Expansive soil

Specific Gravity of 9%Lime+OPT CDA+ Soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	B	C
Wp= Mass of empty, clean pycnometer (A), g	21.37	17
Wps=Mass of pycnometer +dry soil(B), g	46.5	29.64
WB= Mass of pycnometer +dry soil +water (C), g	88.45	55.6
Mass of pycnometer +water (D), g	76.8	43.2
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	25.13	12.64
Specific gravity=E/(A+(D-C))	2.59	2.75
Average specific gravity	2.67	

D. CDA mixed with 12% lime + Expansive soil

Specific Gravity of 12%Lime+OPT CDA+ Soil		
METHOD: STANDARD:ASTM D 854-00		
Trials	1	2
Pycnometer code	O	O3
Wp= Mass of empty, clean pycnometer (A), g	30.87	31.18
Wps=Mass of pycnometer +dry soil(B), g	55.5	56
WB= Mass of pycnometer +dry soil +water (C), g	136.8	136.89
Mass of pycnometer +water (D), g	115.8	113.9
Temperature, ºC	20	20
Mass of dry soil (E), g =B-A	24.63	24.82
Specific gravity=E/(A+(D-C))	2.50	3.03
Average specific gravity	2.76	

2. free swell index for of soil treated 6% CDA with different lime percentage

STATION	Measuring Cylinder No.(ml)		Reading after 24 hrs(ml)		Free Swell
	Kerosene	Distilled water	Kerosene	Distilled water	Index, %
3%Lime+opt CDA%+Soil	12	12	12	17	**41.67**
6%Lime+opt CDA%+Soil	13	13	13	17.5	**34.62**
9%Lime+opt CDA%+Soil	13	13	13	16	**23.08**
12%Lime+opt CDA%+Soil	13	13	13	15	**15.38**

3. Atterberg limit determination

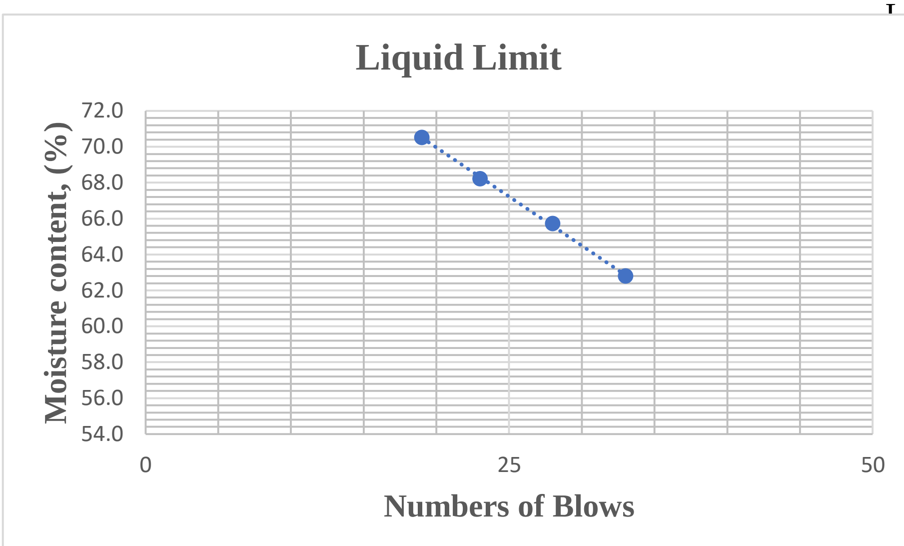
A. 6% CDA mixed with 3% Lime + Expansive soil

Determination of Liquid limit					Plastic Limit	
Numbers of Blows	**33**	**28**	**23**	**19**		
Trial	1	2	3	4	1	2
Container	A4	H23	B9	G8	A7	A17
Wt. of container + wet soil, (g)	32.4	33	34	34	29.5	32.5
Wt. of container + dry soil,(g)	26.46	27.25	28.12	27.59	26.69	29.56
Wt. of container,(g)	17	18.5	19.5	18.5	19.5	22
Wt. of water,(g)	5.94	5.75	5.88	6.41	2.8	2.94
Wt. of dry soil,(g)	9.46	8.75	8.62	9.09	7.19	7.56
Moisture content,(%)	**62.8**	**65.7**	**68.2**	**70.5**	**39.1**	**38.9**
Average	**67**				**39**	

LL= 66.81

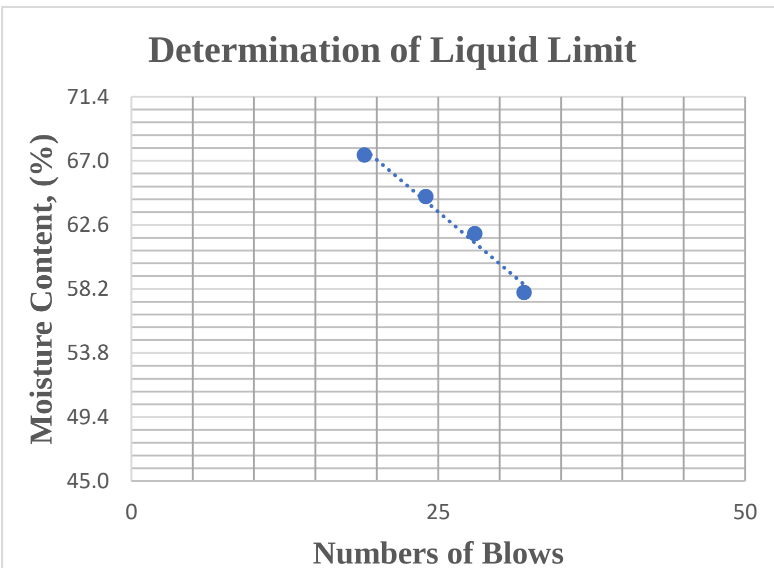
L= 38.99

I= 27.82



B. 6% CDA mixed with 6% Lime + Expansive soil

Determination of Liquid limit					Plastic Limit	
Number of blows	**32**	**28**	**24**	**19**		
Trial	1	2	3	4	1	2
Container	E-11	4	16	B1	T4	A
Wt. of container + wet soil,(g)	35	32	23.5	21	17.6	15.09
Wt. of container + dry soil,(g)	28.58	26.26	17.42	14.76	14.39	12.59
Wt. of container,(g)	17.5	17	8	5.5	6	6.5
Wt. of water,(g)	6.42	5.74	6.08	6.24	3.2	2.5
Wt. of dry soil,(g)	11.08	9.26	9.42	9.26	8.39	6.09
Moisture content,(%)	**57.9**	**62.0**	**64.5**	**67.4**	38.3	41.1
Average	63				**40**	



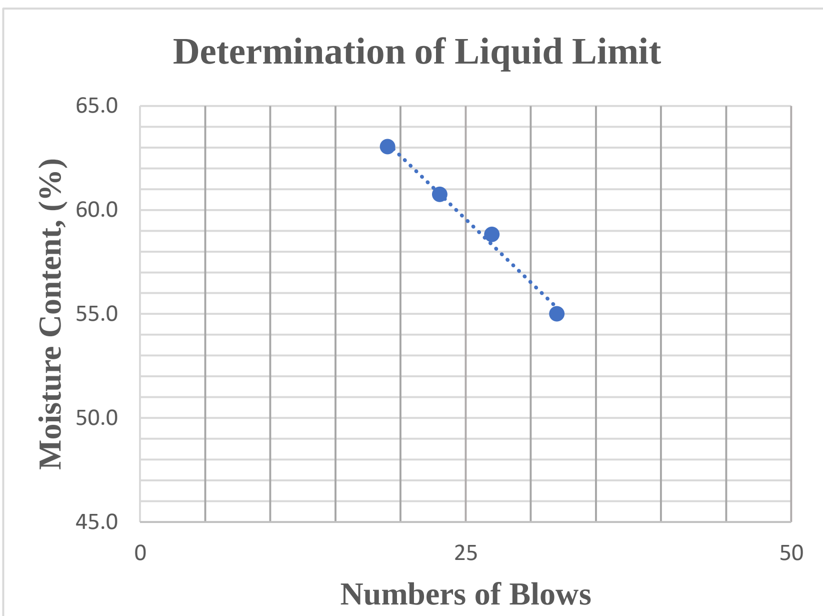
LL (%)= 62.96

PL (%)= 39.66

PI (%)= 23.31

C. 6% CDA mixed with 9% Lime + Expansive soil

Determination of Liquid limit					Plastic Limit	
Number of blows	**32**	**27**	**23**	**19**		
Trial	1	2	3	4	1	2
Container	G8	A4	H23	B9	16	B1
Wt. of container + wet soil,(g)	36	32.5	37.5	40.4	18.28	17.59
Wt. of container + dry soil,(g)	29.79	26.76	30.32	32.32	15.22	14.05
Wt. of container,(g)	18.5	17	18.5	19.5	7.5	5.5
Wt. of water,(g)	6.21	5.74	7.18	8.08	3.1	3.54
Wt. of dry soil,(g)	11.29	9.76	11.82	12.82	7.72	8.55
Moisture content,(%)	**55.0**	**58.8**	**60.7**	**63.0**	39.6	41.4
Average	59				**41**	



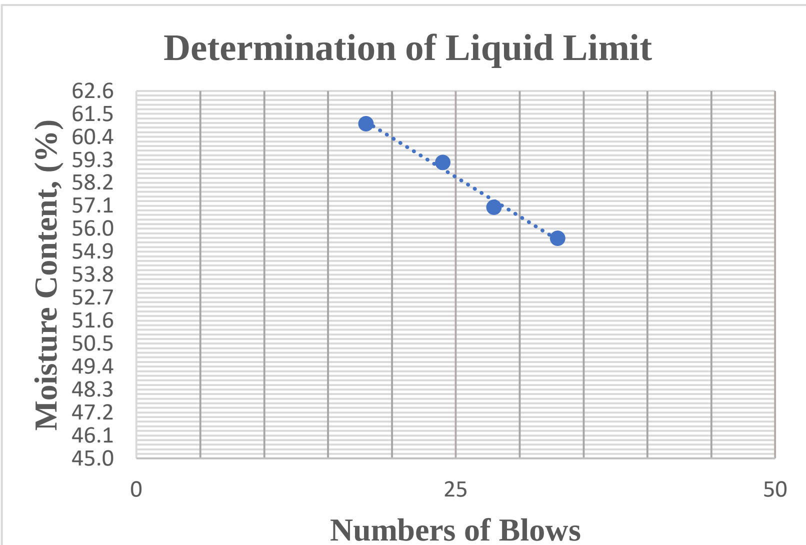
LL (%)= 59.40

PL (%)= 40.52

PI (%)= 18.88

D. 6% CDA mixed with 12% Lime + Expansive soil

Determination of Liquid limit					Plastic Limit	
Number of blows	**33**	**28**	**24**	**18**		
Trial	1	2	3	4	1	2
Container	4,	A7	A17	E-11	T4	A
Wt. of container + wet soil,(g)	34.7	37.7	39.7	32.7	15.5	15.3
Wt. of container + dry soil,(g)	28.38	31.09	33.12	26.94	13	12.45
Wt. of container,(g)	17	19.5	22	17.5	6	6.5
Wt. of water,(g)	6.32	6.61	6.58	5.76	2.5	2.85
Wt. of dry soil,(g)	11.38	11.59	11.12	9.44	7	5.95
Moisture content,(%)	**55.5**	**57.0**	**59.2**	**61.0**	35.7	47.9
Average	58				**42**	

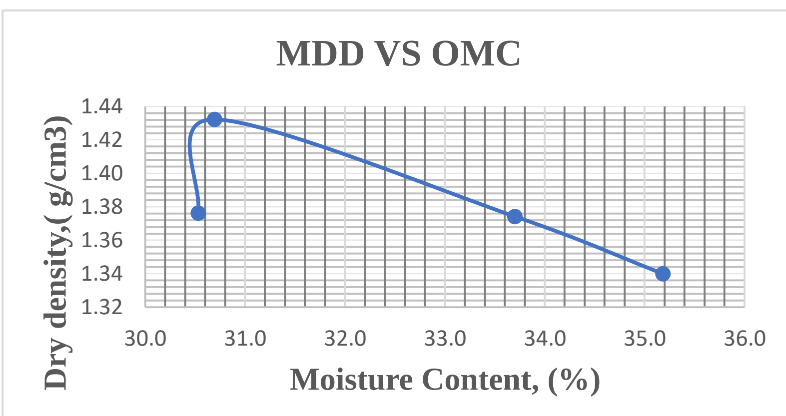


LL (%)= 58.19
PL (%)= 41.81
PI (%)= 16.38

4. Compaction (MDD and OMC) determination

A. 6% CDA mixed with 3% Lime + expansive soil

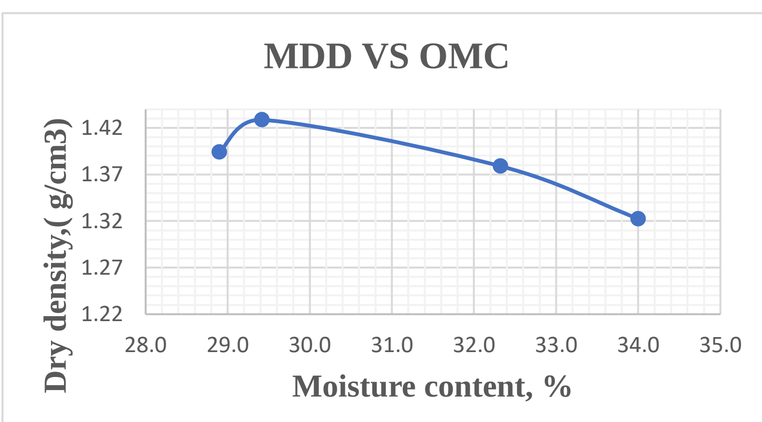
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -95						
Material description:-3%Lime+Opt CDA+Soil		Date sampled:-02, jun 2022 Date Tested:- 22, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	3%Lime+Opt CDA+Soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6534.2	6694.43	6621.02	6566	
	Mass of mould (g)=m2	2718.5	2718.5	2718.5	2718.5	
	Mass of Wet soil (g), m3=m1-m2	3815.7	3975.93	3902.52	3847.5	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.8	1.87	1.84	1.81	
MOISTURE	Container code	g	G3T2	ZE	N	NMC(A)
	Mass of wet soil +cont (g), m4	210.02	260.45	214.5	246.25	230.00
	Mass of dry soil + cont (g), m5	168.5	207.5	168.75	192.14	212.50
	Mass of container (g), m6	32.5	35	33	38.34	40.00
	Mass of moisture (g), m7=m4-m5	41.5	52.95	45.75	54.1	17.50
	Mass of dry soil (g), m8=m5-m6	136	172.5	135.75	153.8	172.50
	Moisture content (%), w =(m7/m8)*100	30.5	30.70	33.70	35.2	10.14
	Dry density, γd=(ρ/(100+w))*100	1.38	1.43	1.37	1.34	



MDD (g/cm3)	**1.432**
OMC (%)	**30.70**

B. 6% CDA mixed with 6% Lime + expansive soil

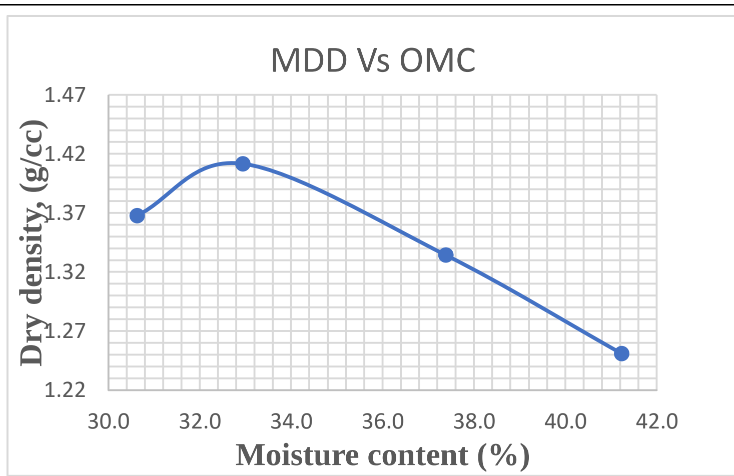
TEST METHOD : MODIFIED PROCTOR TEST AASHTO T						
Material description:-6%Lime+Opt CDA+Soil			Date sampled:-02, jun 2022			
			Date Tested:- 22, Jun 2022			
DENSITY	Trial Numbers	1	2	3	4	6%Lime+ Opt CDA+Soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6532 .0	6642.5	6591	6482	
	Mass of mould (g)=m2	2715 .5	2715.5	2715.5	2718	
	Mass of Wet soil (g), m3=m1-m2	3816 .5	3927	3875.5	3764.0	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.8	1.85	1.82	1.77	
MOISTURE	Container code	g	E11	OZ1	02,1	NMC (A1C)
	Mass of wet soil +cont (g), m4	227. 5	240.5	186.06	154.52	261.00
	Mass of dry soil + cont (g), m5	183. 78	194.13	147.45	122.5	243.00
	Mass of container (g), m6	32.5	36.5	28	28.32	49.50
	Mass of moisture (g), m7=m4-m5	43.7	46.37	38.61	32.0	18.00
	Mass of dry soil (g), m8=m5-m6	151. 28	157.63	119.45	94.18	193.50
	Moisture content (%), w =(m7/m8)*100	28.9	29.42	32.32	34.0	9.30
	Dry density, γd=(ρ/(100+w))*100	1.39	1.43	1.38	1.32	



MDD (g/cm3)	**1.429**
OMC (%)	**29.42**

C. 6% CDA mixed with 9% Lime + expansive soil

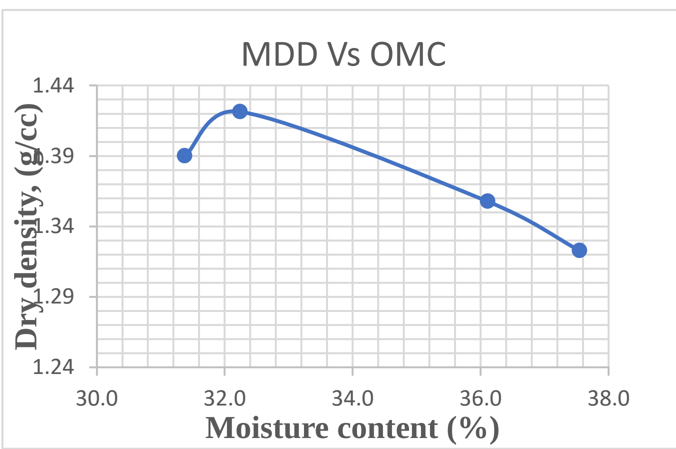
TEST METHOD : MODIFIED PROCTOR TEST AASHTO						
Material description:-9%Lime+Opt CDA+Soil		Date sampled:-02, jun 2022				
		Date Tested:- 22, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	9%Lime +Opt CDA +Soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6510.5	6701.5	6609	6468	
	Mass of mould (g)=m2	2715.5	2715.5	2715.5	2715.5	
	Mass of Wet soil (g), m3=m1-m2	3795.0	3986	3893.5	3752.5	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.8	1.88	1.83	1.77	
MOISTURE	Container code	G3T2	ZE	T1	02,1	NMC (A1C)
	Mass of wet soil +cont (g), m4	221.5	238.4	249.76	157.73	261.00
	Mass of dry soil + cont (g), m5	177.65	187.5	192	119.95	243.00
	Mass of container (g), m6	34.5	33	37.5	28.32	49.50
	Mass of moisture (g), m7=m4-m5	43.9	50.9	57.76	37.8	18.00
	Mass of dry soil (g), m8=m5-m6	143.15	154.5	154.5	91.63	193.50
	Moisture content (%), w =(m7/m8)*100	30.6	32.94	37.39	41.2	9.30
	Dry density, γd=(ρ/(100+w))*100	1.37	1.41	1.33	1.25	



MDD (g/cm3)	**1.412**
OMC (%)	**32.94**

D. 6% CDA mixed with 12% Lime + expansive soil

TEST METHOD : MODIFIED PROCTOR TEST AASHTO T180 -9						
Material description:-12%Lime+Opt CDA +Soil		Date sampled:-02, jun 2022				
		Date Tested:- 22, Jun 2022				
DENSITY	Trial Numbers	1	2	3	4	12%Lime +Opt CDA+Soil
	Mass of sample (g)	4000	4000	4000	4000	
	Water Added (cc)	360	540	720	900	
	Mass of mould +Wet soil (g),=m1	6594.0	6708	6640.6	6580	
	Mass of mould (g)=m2	2715.5	2715.5	2715.5	2715.5	
	Mass of Wet soil (g), m3=m1-m2	3878.5	3992.5	3925.1	3864.5	
	Volume of Mould (cc), V	2124	2124	2124	2124	
	Bulk Density (g/cc), ρ=m3/V	1.8	1.88	1.85	1.82	
MOISTURE	Container code	P15	C10	A16	02,1	NMC (C)
	Mass of wet soil +cont (g), m4	230.5	229	249	159.24	261.00
	Mass of dry soil + cont (g), m5	183.45	181.7	191.56	123.5	240.00
	Mass of container (g), m6	33.5	35	32.5	28.32	49.50
	Mass of moisture (g), m7=m4-m5	47.1	47.3	57.44	35.7	21.00
	Mass of dry soil (g), m8=m5-m6	149.95	146.7	159.06	95.18	190.50
	Moisture content (%), w =(m7/m8)*100	31.4	32.24	36.11	37.5	11.02
	Dry density, γd=(ρ/(100+w))*100	1.39	1.42	1.36	1.32	

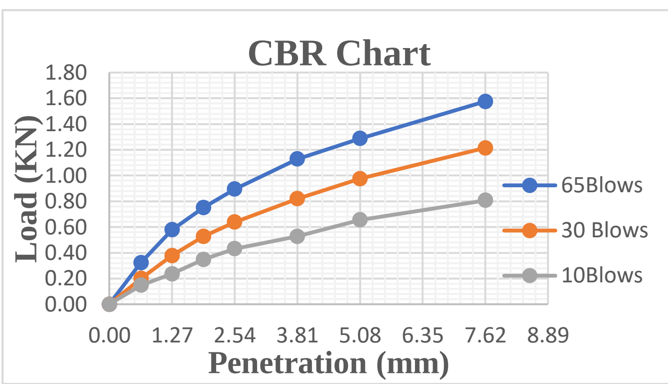


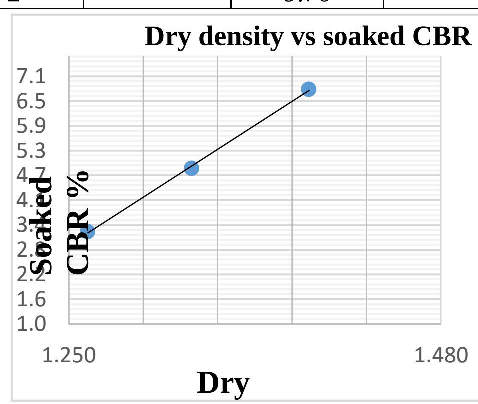
MDD (g/cm3)	**1.421**
OMC (%)	**32.24**

5. California Bearing Ratio (CBR) And CBR Swell Determination

A. 6% CDA mixed with 3% Lime + expansive soil

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		Surcharge Weight:-4.55 KG				
	65 Blows		30Blows		10Blows	
Pen.mm	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.32		0.20		0.15	
1.27	0.58		0.38		0.24	
1.91	0.75		0.53		0.35	
2.54	0.90	6.78	0.64	4.83	0.43	3.27
3.81	1.13		0.82		0.53	
5.08	1.29	6.28	0.98	4.76	0.66	3.20
7.62	1.58		1.22		0.81	
Modified Max.Dry Density (g/cc)	1.43			OMC %	30.70	
Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
07/07/2022 (Initial)	0.56	5.58	0.45	6.25	0.24	8.18
11/07/2022 (Final)	7.06		7.72		9.76	



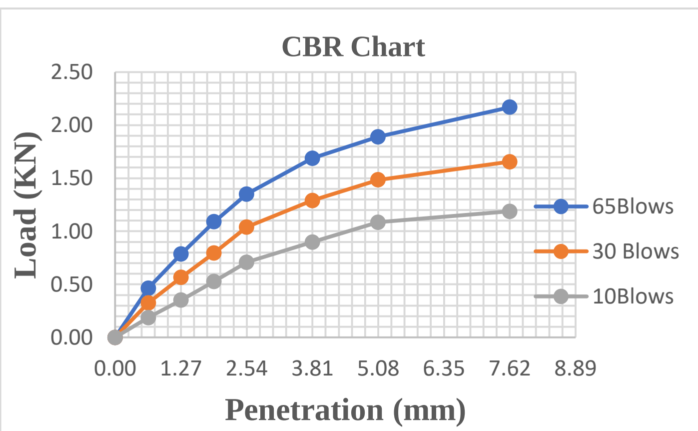


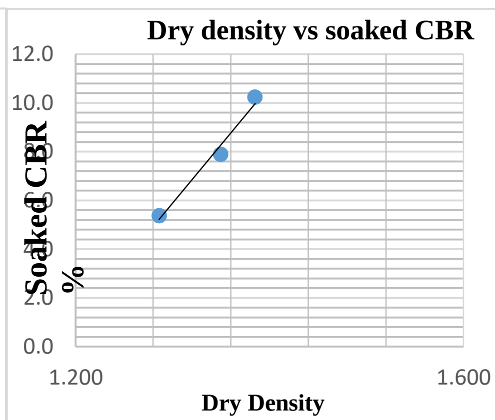
Dry Density at 95% of MDD:					1.36
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	29.1	1.262	3.3	88	
30	31.9	1.326	4.8	93	
65	30.5	1.398	6.8	98	
CBR (%) @ 95 % MDD			5.7	% Swell	6.67

B. 6% CDA mixed with 6% Lime + expansive soil

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period	Surcharge Weight:-4.55 KG					
Pen.mm	65 Blows		30Blows		10Blows	
	Load, KN	CBR %	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.47		0.33		0.19	
1.27	0.79		0.57		0.35	
1.91	1.09		0.80		0.53	
2.54	1.35	10.23	1.04	7.88	0.71	5.36
3.81	1.69		1.29		0.90	
5.08	1.89	9.17	1.48	7.20	1.09	5.27
7.62	2.17		1.65		1.19	
Modified Max.Dry Density (g/cc)	**1.43**			**OMC %**	**29.42**	

Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
11/07/2022 (Initial)	**0.11**	4.22	0.20	4.30	**0.13**	5.08
15/07/2022 (Final)	5.02		5.20		6.04	



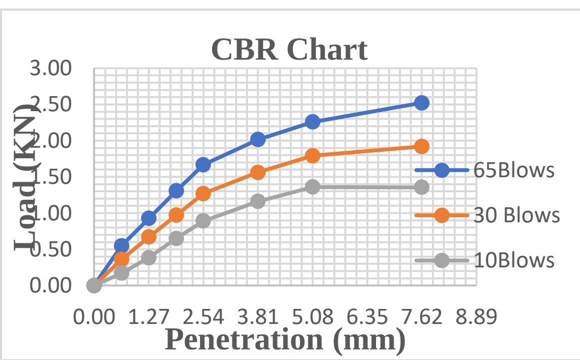


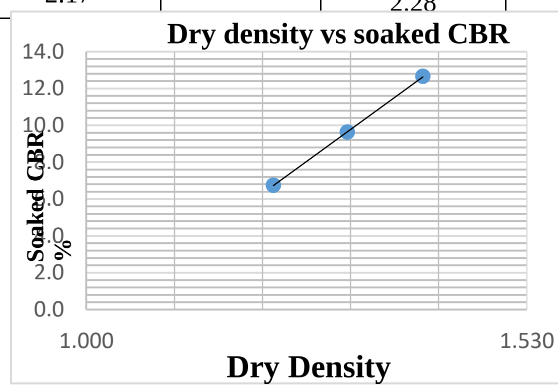
Dry Density at 95% of MDD:					**1.36**
No.of blows	MCBS %	DDBS g/cm3	Corrected CBR %	% Compaction	
10	25.0	1.286	5.4	90	
30	32.5	1.350	7.9	94	
65	33.9	1.385	10.2	97	
CBR (%) @ 95 % MDD			**8.2**	**% Swell**	**4.53**

C. 6% CDA mixed with 9% Lime + expansive soil

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		**Surcharge Weight:-4.55 KG**				
	65 Blows		**30Blows**		**10Blows**	
Pen.mm	**Load, KN**	**CBR%**	**Load, KN**	**CBR%**	**Load, KN**	**CBR %**
0.00	0.00		0.00		0.00	
0.64	0.55		0.36		0.17	
1.27	0.93		0.67		0.39	
1.91	1.31		0.97		0.65	
2.54	1.67	12.64	1.27	9.61	0.89	6.74
3.81	2.02		1.56		1.16	
5.08	2.26	10.96	1.79	8.69	1.36	6.60
7.62	2.52		1.92		1.36	
Modified Max.Dry Density(g/cc)	**1.41**			**OMC %**	**32.94**	

Swell Determination						
Date	**65 Blows**		**30 Blow**		**10Blows**	
	Gauge reading (mm)	**Swell in %**	**Gauge reading(mm)**	**Swell in %**	**Gauge reading(mm)**	**Swell in %**
11/07/2022 (Initial)	**0.11**	1.68	0.21	1.68	**0.22**	1.77
15/07/2022 (Final)	2.06		2.17		2.28	



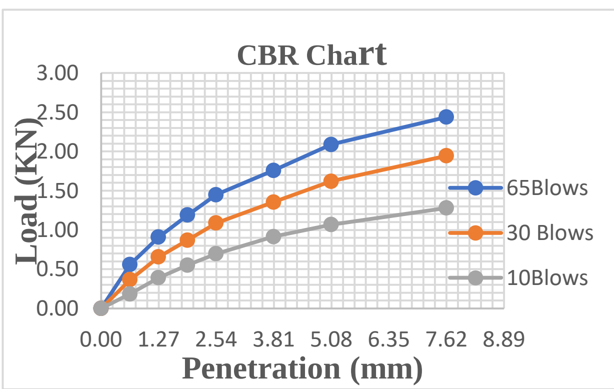


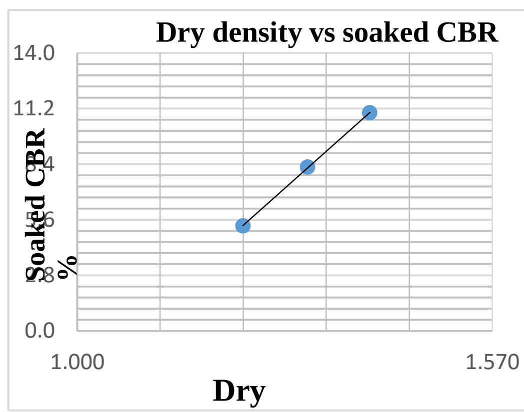
Dry Density at 95% of MDD:					**1.34**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	32.2	1.225	6.7	87	
30	32.8	1.314	9.6	93	
65	33.0	1.405	12.6	100	
CBR (%) @ 95 % MDD			**10.5**	**% Swell**	**1.71**

D. 6% CDA mixed with 12% Lime + expansive soil

CBR Penetration Determination						
Penetration after 96 hrs Soaking Period		Surcharge Weight:-4.55 KG				
Pen.mm	65 Blows		30Blows		10Blows	
	Load, KN	CBR%	Load, KN	CBR%	Load, KN	CBR %
0.00	0.00		0.00		0.00	
0.64	0.56		0.37		0.19	
1.27	0.91		0.66		0.39	
1.91	1.19		0.87		0.55	
2.54	1.45	10.98	1.09	8.24	0.70	5.29
3.81	1.76		1.36		0.92	
5.08	2.09	10.15	1.62	7.87	1.07	5.18
7.62	2.44		1.95		1.28	
Modified Max.Dry Density (g/cc)	**1.42**			**OMC %**	**32.24**	

Swell Determination						
Date	65 Blows		30 Blow		10Blows	
	Gauge reading (mm)	Swell in %	Gauge reading(mm)	Swell in %	Gauge reading(mm)	Swell in %
11/07/2022 (Initial)	**0.25**	1.37	0.13	1.62	**0.18**	1.80
15/07/2022 (Final)	1.85		2.02		2.27	





Dry Density at 95% of MDD:					**1.35**
No.of blows	**MCBS %**	**DDBS g/cm3**	Corrected CBR %	% Compaction	
10	32.8	1.228	5.3	86	
30	30.4	1.316	8.2	93	
65	35.2	1.402	11.0	99	
CBR (%) @ 95 % MDD			**9.3**	**% Swell**	**1.60**