Jimma University

Jimma Institute of Technology

School of Graduate Studies

Faculty of Civil and Environmental Engineering

Geotechnical Engineering Chair

Stabilization of Expansive Soil Using a Mixture of Saw Dust Ash and Lime in Jimma Town, Ethiopia

A Research Submitted to School of Graduate Studies of Jimma University in Partial Fulfilment of the Requirement of Degree of Master of Science in Civil Engineering (Geotechnical Engineering).

By:

Tigist Tadesse

January,2020

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Main Advisor: Kifle Woldearegay(PHD)

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January, 2020

Jimma, Ethiopia

Declaration

I, the undersigned, declare that this thesis entitled: **"Stabilization of Expansive Soil Using a Mixture of Saw Dust Ash and Lime in Jimma Town, Ethiopia"** is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have been duly acknowledged.

Candidate:

Tigist Tadesse ____________________ ___/01/2020

Signature Date

As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by Ms. Tigist Tadesse entitled: Stabilization of Expansive Soil Using a Mixture of Saw Dust Ash and Lime in Jimma Town, Ethiopia.

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Chairperson Signature Date

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Abstract

Expansive soils are always characterized by their high water absorption, high compressibility, high shrinkage on drying and high swelling/expansion on wetting. These expansive soils cause several problems to civil engineering structures. Different methods are often adopted to improve the engineering properties of expansive soils before use for construction purposes.

The focus of this study was to evaluate suitability of Sawdust ash(SDA) and lime for stabilization of expansive soils in Jimma town, western Ethiopia. Expansive soil samples were collected from three test pits in Jimma town (Kochi, Shenan Gibe Hospital and Teknicsefer, localities). Various preliminary tests for index properties and strength were determined in the laboratory beside this grain size analysis were done and the test results indicate that the soil samples are expansive soils. leftover of wood processing sawdust (SD) were collected from Jimma town wood processing enterprises and left in an open area for air drying in order to remove its moisture and facilitate easy way of burning. The Sawdust was burnt to ash and the ash was collected and lime is bought from open market.

To determine the effect of SDA and lime on engineering properties of expansive soil different laboratory tests were carried out which include: moisture content, Atterberg limits, compaction, specific gravity, grain size,UCS and CBR. Tests were performed on natural and treated soil samples as per the AASHTO and ASTM laboratory test standards. The selected soil samples were characterized and were found A-7-5 category of soil based on the AASHTO soil classification system and CH as per USCS soil classification system which is clay soil of poor engineering properties. The soils were treated with varied proportions of SDA (3%, 5%, 10%, and 15%)and lime (1.5%, 2.5%, 5% and 7.5%)by dry weight of the soil.

The results from the analysis show improvement of the geotechnical properties of expansive soil with SDA and lime. The plasticity index and free swelling index, reduced with an increase in CBR and UCS value and better improvement was found when using 5% SDA and 2.5% lime. It can be concluded from the present investigation that expansive soil could properly be stabilized for use as subgrade material. Adequate strength was achieved with 5% SDA and 2.5% lime and which is found to be the optimum SDA and lime contents for improving the engineering properties of the expansive soils.

Keyword: Expansive soil, Stabilization, sawdust ash, lime

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List of Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials.
CaO	Calcium Oxide
CBR	California Bearing Ratio
CEC	Cation Exchange Capacity
ERA	Ethiopian Road Authority
EREDPC	Ethiopian Rural Energy Development and Promotion Centre
IS	Indian Standard
JiT	Jimma University Institute of Technology
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
SDA	Sawdust Ash
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
Vf	Final Volume
Vi	Initial Volume
SDA	Saw Dust Ash

List of symbols

S1	Sample1
S2	Sample 2
S3	Sample3
Sda	Sawdust ash
lm	lime

CHAPTER ONE

1 INTRODUCTION

1.1 Back Ground

Expansive soils are generally characterized by the presence of clay minerals of the montmorillonite (smectite) group. Such soils give rise to problems in civil engineering work because of their capacity to undergo large volume changes with changes in moisture content, which expand and shrink when the moisture in the soil changes(Zumrawi, 2017a).

Expansive soil deposits occur in the arid and semi-arid regions of the world and are problematic to engineering structures because of their tendency to swell during the wet season and shrink during the dry season. Expansive soils present significant geotechnical and structural engineering challenges the world over, with costs associated with expansive behavior estimated to run into several billion annually (Mokhtari, 2012).

Expansive soil covers an appreciable part of Ethiopia. It constitutes a real financial risk and disruption to the quality of life. Most of the roads constructed, lightly loaded residential and commercial buildings, airfield and proposed as well as a substantial amount of the newly planned railway routes in the country pass through terrains dominated by expansive soils. Engineering design of such structures in and on this soil must recognize and accept the complexity of the material behavior of the ground (Toryila, 2016; Uge, 2017).

Control of the swell-shrink behavior can be accomplished in several ways, for example by Replacing existing expansive soil with non-expansive soil, Maintaining constant moisture content and Improve the expansive soils by stabilization (Mokhtari, 2012; Zumrawi, 2017b).

Soil stabilization is a technique employed for improving soil properties by blending and mixing other materials. Improvements include better soil gradation, reduction of plasticity index or swelling potential, increase in durability and strength to strengthen road surfaces and other geotechnical applications(Firoozi *et al.*, 2017; Sabzi, 2018).This study was conducted to improve the engineering properties of expansive soil of Jimma town by using a mixture of SDA and Lime.

Pozzolanas are siliceous and aluminous materials, which itself have little or no cementitious value, but in the presence of water and lime, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties and have been used as a cementitious material in construction (Sabzi, 2018).

Sawdust is the term given to the product formed after grinding of wood log. It occurs in various sizes and shapes depending upon the way it is cut. It occurs in abundant quantity in the universe as the wood is cut for human purposes especially in mills and when it is processed in a fine powdered form. About 10-13 % of the total volume of the wood log is processed into sawdust. Such a proficient amount of sawdust waste is mostly fed to the landfill disposals. The dust is commonly used as domestic fuel. The resulting ash is a form of pozzolana known as sawdust ash (SDA)(Khan and Khan, 2015).

The total number of sawmills in Ethiopia is approximately 39, with a total of 5-10 factories involved in the production of plywood. Most of the saw mills are located in the southern and south-western parts of the country. The total residue potential from the four saw mills included in Table 2.4 below is about 4,600 tons/year. At Tiro Botor Betcho and Ethio Plywood Enterprise (Jimma), the off-cuts and slabs are used for firing the boilers, while sawdust is disposed of into the river or piled up in fields; at the Ethio Plywood Enterprise in Jimma, the sawdust is freely given to workers (Seboka et.al, 2009).

Lime has been found to react successfully with medium, moderately fine and fine-grained soils causing a decrease in plasticity and swell potential of expansive soils, and an increase in their workability and strength properties (Little, 2009).

1.2 Statement of the problem

Many parts of Ethiopia are covered with expansive soils. Many parts of the country (Central, Western, Northern and South-Western regions) are covered with expansive soils, there was a need to validate possibility of improving soils using available materials (Alene, 2010). Most of the roads constructed, lightly loaded residential and commercial buildings, airfield and proposed as well as a substantial amount of the newly planned railway routes in the country pass through the heart of expansive soils. Engineering design of such structures in and on this soil must recognize and accept the complexity of the material behavior of the ground(Uge, 2017). Expansive soils pose problems to civil engineers in general and also geotechnical engineers in particular. They undergo severe volume changes corresponding to changes in moisture content. They swell or increase in their volume when they imbibe water and shrink or reduce in their volume on evaporation of water (Phanikumar, 2009).

To address this problem, a need arises to search for a suitable technology that can be used to stabilize these soils and use them for construction, as much as possible, in order to minimize, the costs that could be incurred, had another mechanism been used. Jimma town is dominated by expansive soils. These soils require improvement prior to using them for construction purposes. This study evaluated the suitability of Sawdust ash and Lime for the stabilization of expansive soil by using different concentrations of both materials; with the case of expansive soils in Jimma town, South Western Ethiopia.

1.3 Research Questions

The research is aimed to answer the following research questions:

1. What are the index properties of soils in Jimma town?
2. Does SDA and Lime has effect in improving the engineering properties of soil?
3. What is the optimum amount of SDA and Lime that should be added to stabilize soil?

1.4 Objectives

1.4.1 General Objective

The general objective of the study was to evaluate the suitability of SDA and Lime as a stabilizing agent for soil in Jimma town, Ethiopia.

1.4.2 Specific objectives

- To determine the index properties of soil in Jimma town.
- To determine the effect of SDA and Lime on the engineering properties of soil.
- To determine the optimum amount of SDA and Lime that was required to stabilize soil.

1.5 Scope of the study

This study aimed at evaluating the suitability of SDA and lime as stabilizing agent of expansive soil in Jimma town. Representative disturbed soil samples were taken from the identified three test pits at 3m depth. Various geotechnical laboratory tests like; moisture content, Atterberg limit, compaction, specific gravity, grain-size analysis, CBR, and UCS tests were performed on natural and treated expansive soil samples to determine the improvement that was achieved. Result of the different tests were analyzed and discussed. Finally, conclusion and recommendation are drawn from this study.

1.6 Significance of the study

This research gave an insight on the possibility of improving the engineering properties of expansive soils using SDA and lime. Result of this research could be used by stakeholders who are involved in construction work. This research also highlighted the possibility of minimizing cost of construction materials, transportation (both waste and/or selected fill materials), and minimize environmental pollution.

1.7 Limitations of the study

The major limitations of this research were shortage of time, financial resources and lack of water around laboratory area. Despite these limitations maximum effort was made to produce quality data through proper field and laboratory analysis.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Expansive soil

Expansive soils or active soils are those containing clayey materials which shrink as their moisture content decreases (as they dry out) and swell as their moisture content increases (when they get wet) (Panthi, 2006). As they get wet, the clay minerals would absorb water molecules and expand tremendously; conversely, as they dry, they shrink, leaving a large void in the soil mass(Mokhtari, 2012). This continuous volumetric change in soil would cause structures on this soil to move unevenly and crack. Each year in the United States, expansive soils cause $2.3 billion in damage to houses, other buildings, roads, pipelines, and other structures. It indicates more than twice the damage from floods, hurricanes, tornadoes, and earthquakes combined (Kerrane 2011) U.S. Housing and Urban Development (HUD) estimated $9 billion damages in 1981, resulting from expansive soils. It indicated that shrink-swell problems were the second most likely problem a homeowner would encounter, after insects (Tessema, 1984; Zumrawi and Hamza, 2014).

Expansive soil covers an appreciable part of Ethiopia. It constitutes a real financial risk and disruption to the quality of life. Most of the roads constructed, lightly loaded residential and commercial buildings, airfields and proposed as well as a substantial amount of the newly planned railway routes in the country pass through the heart of expansive soils. Jimma town is one of Ethiopian town which is dominated by expansive soil and needs a solution to improve problems resulting from expansive soil.

2.2 Identification of Expansive Soils

Investigation of expansive soils generally consists of two important phases. The first is the visual identification and recognition of the soil as expansive and the second is sampling and measurement of material properties to be used as the basis for the design.

2.2.1 Field Identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages (Makusa, 2012). Important observations include, usually have a color of black or grey, Wide or deep shrinkage cracks, high dry strength and low wet strength, Stickiness and low traffic ability when wet, cut surfaces have a shiny appearance, and the appearance of cracks in nearby structures. Arid and semiarid areas are particular trouble spots because of large variations in rainfall and temperature.

2.2.2 Laboratory Identification

Laboratory identification of expansive soils can be categorized into mineralogical, indirect and direct methods.

2.2.2.1 Mineralogical Identification

Clay mineralogy is a fundamental factor controlling expansive soil behavior. Clay minerals can be identified using a variety of techniques. The techniques that can be used are X-ray diffraction, differential thermal analysis, dye adsorption, Chemical analysis and Electron microscope resolution (Teferra, 1986; Panthi, 2006). But these methods are not suitable for routine tests because of the following reason;

• They are time consuming

• They require expensive test equipment and

• The results can only interpret by specially trained technicians.

2.2.2.2 Direct Methods

These methods offer the most useful data by direct measurement, and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer (Reddy et.al, 2009)

2.2.2.3 Indirect Methods

In this method, simple soil property tests can be used for the evaluation of swelling potential of expansive soils. Such tests are easy to perform and should be included as routine tests in the investigation of expansive soils. Such tests may include, Atterberg Limit test, free Swell test, free swell index test, free swell ratio test, and Cation Exchange Capacity (CEC).

2.3 Classification of expansive soil

The classification system used in expansive soil can be grouped into two categories as follows,

2.3.1 AASHTO Classification system

The classification depends on particle size analysis and plasticity characteristics of the soil. The AASHTO classification system classify soils into seven major groups from A-1 to A-7 with 12 subgroups (Arora, 2004) Table 2.1.

Table 2.1 AASHTO Classifications System(Arora, 2004)

General Classification	Granular Materials (35% or less Passing No.200 sieve(.075 mm))							Silt-clay Materials More than 35%PassingNo.200 Sieve 0.075 mm)				
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7	
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5	A-7-6
(a) Sieve analysis: Percent passing												
(i) 2.00mm (No.10)	50M											
(ii) 0.425 mm (No.40)	30M	50M	51m									
(iii) 0.075mm (No.200)	15M	25M	10M	35M	35 M	35M	35M	36m	36m	36m	36 m	36m
(b) Characteristics of fraction passing 0.425 mm(No. 40)												
(i) Liquid limit	6 max		N.P	40M	41m	40M	41M	40 M	41m	40M	41m	
(ii) Plasticity index				10M	10 M	11m	11m	10m	10 M	11m	11m*	
(c) Usual types of Significant constituent materials	Stone Fragments Gravel and Sand		Fine sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils		
(d) General rating as subgrade	Excellent to Good							Fair to Poor				

If plasticity index is equal to or less than (liquid limit -30), the soil is A7-5 (i.e. PL>30%) If plasticity index is greater than (liquid limit -30), the soil is A7-6 (i.e. PL<30%)

2.3.2 Unified soil classification system

This system as developed by Casagrande in 1948.and later, in 1952, it was modified by Bureau of Reclamation and Corps of Engineers of the United states of America. The system has also been adopted by American Society of Testing Materials (ASTM). The system is the most popular system for use in all types of engineering problems involving soils. The system is based on particle size analysis and plasticity characteristics of the soils. The USCS system is based on grain size, gradation, plasticity and compressibility. The various symbols used are given in Table 2.2 below.

Table 2.2: Symbols used in USC system(Arora, 2004)

	Symbol	Description
Primary	G	Gravel
	S	Sand
	M	Silt(Symbol M obtained from the Swedish word 'mo')
	C	Clay
	O	Organic
	Pt	Peat
Secondary	W	Well graded
	P	Poorly graded
	M	Non plastic fines
	C	Plastic fines
	L	Low plasticity
	H	High plasticity

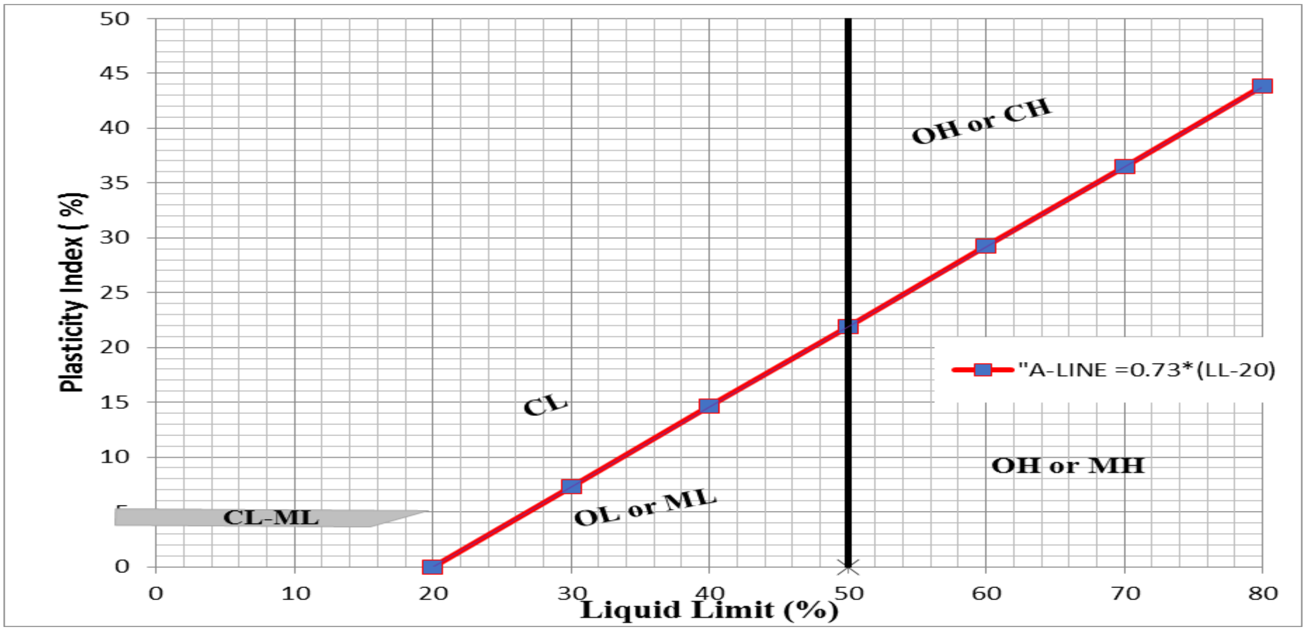

Figure 2.1 Plasticity Chart (USCS)

2.4 Soil Stabilization

Soil stabilization is a general term for any physical, chemical, biological, or combined method of changing a natural soil to meet an engineering purpose. Improvements include increasing the weight-bearing capabilities and performance of in-situ subsoils, sands, and other waste materials in order to strengthen road surfaces (Wubshet and Tadesse, 2014).

2.5 Soil Stabilization Methods

2.5.1 Mechanical Stabilization

Mechanical Stabilization is the process of improving the properties of the soil by changing its gradation. This process includes soil compaction and densification by application of mechanical energy using various sorts of rollers, rammers, vibration techniques, and sometimes blasting. The stability of the soil in this method relies on the inherent properties of the soil material. Two or more types of natural soils are mixed to obtain a composite material which is superior to any of its components. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification(Afrin, 2018).

2.5.2 Chemical Stabilization

Chemical compounds are other major type of soil stabilization remedy. All of these techniques rely on adding additional material to the soil that would physically interact with it and change its properties. There are a number of different types of soil stabilization techniques that rely on chemical additives or compound of one sort or another. Frequently encountered compounds are those that utilize lime, cement, fly ash, or kiln dust. Most of the reactions sought are either cementitious or pozzolanic in nature, depending on the nature of the soil present at the particular site you are investigating (Makusa, 2012).

Soil improvement by means of chemical stabilization can be grouped into three chemical reactions; Cation exchange, flocculation-agglomeration and pozzolanic reactions (Little, 2009).

2.5.2.1 Cation Exchange

Cation exchange capacity (CEC) is the total capacity of a soil to hold exchangeable cations. CEC is an inherent soil characteristic and is difficult to alter significantly. Soils with a higher clay fraction tend to have a higher CEC(Brown, 2007). Negatively charged clay particles adsorb cations of specific type and amount. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valence cations easily replace cations of lower valence. For ions of the same valence, the size of the hydrated ion becomes important; the larger the ion, the greater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations.

A typical replaceability series is:

$$Na^{+} < Li^{+} < K^{+} < Rb^{+} < Cs^{+} < Mg^{2+} < Ca^{2+} < Ba^{2+} < cu^{+2} < Al^{3+} < Fe^{3+} < Th^{4+}$$

An example of the cation exchange;

$Ca^{2+} + Na^{+}\text{-Clay} \longrightarrow Ca^{2+}\text{-Clay} + Na^{+}$

The exchangeable cations may be present in the surrounding water or be gained from the stabilizers. The thickness of the diffused double layer decreases as replacing the divalent ions (Ca^{2+}) from stabilizers with monovalent ions (Na^{+}) of clay. Thus, swelling potential decreases (Braja, 2007).

2.5.2.2 Flocculation and Agglomeration

Cation exchange reactions result in the flocculation and agglomeration of the soil particles with a consequent reduction in the amount of clay-sized materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Due to the change in texture, a significant reduction in the swelling of the soil occurs (Little, 2009).

2.5.2.3 Pozzolanic Reactions

Pozzolanas are siliceous and aluminous materials, which in itself possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (ASTM 595). Artificial pozzolanas such as ashes are products obtained by heat treatment of natural materials containing pozzolanas such as clays, shales, and certain silicious rocks. Plants when burnt, silica taken from soils as nutrients remain behind in the ashes contributing to the pozzolanic element. Rice husk ash, sawdust ash, wheat husk ash, rice straw, and bagasse are rich in silica and make an excellent pozzolana (Makusa, 2012).

Sawdust ash is a pozzolanic material as confirmed by A.A. Raheem et al. The chemical composition proves that sawdust ash has a sufficient amount of silica and alumina. Silica content gives the ash its pozzolanic properties which makes it a useful cementitious material(Ahmad *et al.*, 2013).

Time-dependent pozzolanic reactions play a major role in the stabilization of the soil since they are responsible for the improvement in the various soil properties. Pozzolanic constituents produce calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

$Ca^{2+} + 2(OH)^{-} + SiO_2$ (Clay Silica) $\longrightarrow$ CSH

$Ca^{2+} + 2(OH)^{-} + Al_2O_3$ (Clay Alumina) $\longrightarrow$ CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure which increases the soil strength.

Lime Stabilization

Lime has been found to react successfully with medium, moderately fine and fine-grained soils causing a decrease in plasticity and swell potential of expansive soils, and an increase in their workability and strength properties. Research has proven that lime may be an effective stabilizer in soils with clay content as low as 7 percent and in soils with plasticity indices below (10 or 15). The National Lime Association recommends a plasticity index of 10 or greater for lime to be considered as a potential stabilizer whereas the U.S Army Corps of Engineers recommends a plasticity Index of 12 or greater for successful lime stabilization. Based on AASHTO classification, soil types A-4, A-5, A-6, A-7 and some of A-2-6 and A-2-7 are suitable for stabilization with lime(Little, 2009).In the present study Lime Stabilization is used for improving CBR value of soil. Lime Stabilization has the potential to reduce initial construction costs through improved subgrade stability and reductions in pavement structure. Lime can also provide greater long term stability of the pavement structure and lower pavement life-cycle costs through reduced pavement maintenance.

Table 2.3 Specifications of Quick lime produced at Derba lime and Chemicals PLC(Derba,2017)

Chemical and physical specifications	
SiO_2	2.00 % max
Al_2O_3	1.00 % max
Fe_2O_3	1.00 % max
CaO	90.00 % max
MgO	1.00 % max
LOI	1.00% max
Appearance	White
Size	2 mm to 25 mm
Packing	Loose or in Laminated Bags of 50Kg each

Derba lime and Chemicals PLC was used because of commercial availability in Ethiopia.

2.6 Sawdust potential of Ethiopia

The total number of sawmills in Ethiopia is about thirty-nine, with a total of 5-10 factories concerned within the production of plywood. A total of 200-300 joinery and furnishings factories conjointly operate in different parts of the country. Most of the sawmills are located in the southern and south-western parts of the country. Sawmill residue is estimated to total about 25,000tons each year. Residues generated in sawmills located in remote areas of the country have insignificant economic value and are typically drop or congregated and allowed to rot. Although no recent surveys have been conducted at the national level, EREDPC conducted one in some of the sawmills in the Oromia region in 2000. According to this survey, the average annual log(wood) processed in these mills varies from as little as 1,000m^3 to a high of 3,500m^3/year. The total residue potential from the four sawmills included in Table 2.4 below is about 4,600tons/year. At Tiro Botor Betcho and Ethio Plywood Enterprise (Jimma), the off-cuts and slabs are used for firing the boilers, while sawdust is disposed of into the river or piled up in fields; at the Ethio Plywood Enterprise in Jimma, the saw dust is freely given to workers. Some of the sawmills located in remote areas (away from large towns) might nonetheless be of interest as these mills have already piled up a considerable amount of residue for lack of alternative uses(Seboka et.al, 2009).

Table 2.4 Sawmill Residues from Selected Saw Mills in Oromia Region, 1990/2000 (Kebede, 2001)

Location	**Logs-Input(m^3)**	**Estimated residue(tons)**
Tiro Botor Betcho (Jimma Zone)	1000	500
Ethio plywood Enterprise (Arsi)	1182	591
Sigmo wood Enterprise	3500	1750
Ethio plywood Enterprise(Jimma zone)	3500	1750
Total	9182	4591

Table 2.5 Chemical composition of SDA (Khan and Khan, 2015)

No	Chemical Elements present	Percentage composition
1	(Silica) SiO2	65.42
2	(Alumina) Al2O3	5.69
3	(Iron oxide) Fe2O3	2.16
4	(Lime)CaO	9.82
5	(magnesium Oxide)MgO	4.23
6	(Sulfur trioxide)SO3	1.06
7	(Sodium oxide)Na2O	0.04
8	(Potassium Oxide)K2O	2.38
9	(Calcium carbonate)CaCO3	7.89

2.7 Previous Studies

For the past several years' researchers have recognized the use of locally available materials that are cost-effective and abundantly available as byproducts from industrial and agricultural activities to enhance the properties of expansive soil to reduce stabilization costs, related to conventional stabilizing agents such as cement and lime.

Ash and Ali, 2016; investigated the effect of marble dust and bagasse ash on the stabilization of expansive soils found in Pakistan. Different lab tests on expansive soil without the addition of this waste and with the addition of these waste were performed and their effect on swelling and Dry density of expansive soil also increased with the addition of marble dust and bagasse ash and remained maximum approximately at 8% addition but again decline with the addition of 12% marble dust and bagasse ash. Finally, marble dust and bagasse ash were recommended to be utilized to treat and stabilize the expansive soil as an economical alternative to Portland cement and other (expensive) chemical stabilizers. The use of bagasse ash and marble dust for stabilization applications is an economical and environmental solution to the problems associated with its disposal process(Ash and Ali, 2016).

Venkatesh and Reddy,2016; investigate the effect of waste sawdust ash on compaction an permeability of black cotton soil in Kopparthy(India). The purpose was to evaluate the effective utilization of Waste Saw Dust Ash as a stabilizer to address landfill problems. Waste Saw Dust Ash was mixed in soil in 2%, 4%, and 6% in dry weight of the soil.

Standard Proctor compaction test and falling head permeability test were conducted on varying percentages of Waste Saw Dust Ash. It is observed that 5.4% of dry density was increased in addition to 2% of SDA and then dried density was reduced gradually on increasing the percentage of Waste Saw Dust Ash. Permeability of soil was also reduced (Venkatesh and Reddy, 2016).

Singh and Sharma, 2017 performed; research on the safe disposition of industrial waste like wheat husk ash (WHA), and sugarcane straw ash (SCSA). Efforts have been made using WHA and SCSA to revamp the quality of the soil. The study was conducted using the expansive soil by taking varying amount, which is then mingled with the different ratios of stabilized material for Atterberg limit tests, Unconfined compressive strength(UCS) test and soil retained within 7 days curing period for California bearing ratio(CBR) test. The study revealed that the inclusion of wheat husk ash and sugarcane straw ash gave more consistent results as compared to the individual addition to the specimen. The values obtained after a plethora of experimentation clear that these values are used as an index for the designing, and laying the base and sub-base material for infrastructure development and pavements.(Singh and Sharma, 2017).

James,2019 evaluated; the Strength benefit of sawdust/wood ash amendment in cement stabilization of an expansive soil. Two cement contents of 2% and 6% by weight of soil were adopted to stabilize the soil. The SDA amended cement stabilized samples adopted SDA contents of 5%, 10% and 20% by weight of soil. Strength gain trends for the amended samples were also fitted based on the results of the UCS tests. To analyze benefits in pavement design and thickness reduction, the UCS values were used to predict the CBR value of the specimens based on which the reduction in pavement thickness was calculated for different traffic densities. The investigation revealed that a 5% SDA amendment of cement stabilization can result in up to 26% increase in early strength and 20% increase in delayed strength. Based on the predicted CBR values, pavement thickness can be reduced up to 8.3%. Then conclude that SDA amended cement stabilized soil can also develop enough strength to be used as sub-base material in the actual construction of the pavement but fails to meet the requirements for use as stabilized base courses.(James, 2019)

Butt,et.al 2016; carried out an extensive experimental study to demonstrate the soil improvement prospective of sawdust ash (SDA) by performing California bearing ratio (CBR) and unconfined compression strength tests. The experimental study has revealed that the addition of SDA results in a significant increase in CBR and unconfined compressive strength. Therefore from the study it is concluded that SDA, associate industrial waste, could be a cheap satisfactory helpful stabilizing agent for sub-base and base course in clayey fills; though its performance can be improved by combining it with alternative bonding materials like lime, and becomes an alternatives use of industrial waste to reduce the construction cost of road particularly in the rural areas of the country.(Butt, Gupta and Jha, 2016).

Zumrawi and Hamza,2014, investigated the influence of using lime, fly ash and lime-fly ash admixtures on the characteristics of expansive subgrade soils by performing Index property, compaction, California Bearing Ratio (CBR), Unconfined Compression Strength (UCS), swell and swelling pressure tests. The results show that lime and fly ash played an important role in improving the strength characteristics and swelling behavior of expansive soil.

The observations and conclusions can be summarized as follows:

Addition of lime significantly improved consistency, swelling and strength properties of the expansive soil. However, the presence of fly ash fundamental to further improve the soil behavior, due essentially to the occurrence of a larger amount of time-dependent pozzolanic reactions. Moreover, it is always encouraged to use fly ash for stabilization where easily and economically available. Some factors such as curing and compaction parameters have considerable effect on strength measured by the CBR and unconfined compression strength of the treated soil with time and have to be taken in account when executing earth work with such materials.

Based on the tests results, it can be stated that, as the percentage of lime-fly ash increases the swelling decreases and the strength increases and the optimum lime-fly ash content at 8% lime with 10% fly ash.

On the basis of economic considerations, use of good quality fly ash alone is recommended for treatment of clays with low to medium expansiveness. Whereas, for treating highly expansive clays, a combination of fly ash with small percentage of lime is recommended, so it is valuable option in Sudan to use lime-fly ash as a stabilizer(Zumrawi and Hamza, 2014).

Amadi and Okeiyi 2017, studied on the use of quick and hydrated lime in stabilization of lateritic soil. The purpose was to evaluate and compare the stabilization effectiveness of different percentages (0, 2.5, 5, 7.5,10%) of quick and hydrated lime when applied separately to locally available lateritic soil. Performance evaluation experiments carried out includes: Atterberg limits, compaction, unconfined compression tests, California bearing ratio (CBR), swelling potential using CBR instrument and hydraulic conductivity. It was found that treatment with lime on plasticity characteristics resulted in a reduction of plasticity index (PI) of soil mixtures while the quicklime caused the soil to have lower plasticity. The addition of either quick or hydrated lime resulted in a decrease in the maximum dry unit weight and a slight increase in the optimum moisture content while hydrated lime treated specimens exhibited higher dry unit weight than that achieved with quick lime addition. There is generally an increase in strength with lime content regardless of the type and higher UCS especially at higher dosages (7.5 and 10%) was produced when soil sample was treated with quicklime. Results of CBR test for the stabilized soil show that the addition of either the quicklime or hydrated lime significantly improved the bearing strength (CBR) of the soil while quicklime-stabilized soil have superior load bearing capacity. Finally, they concluded the two types of lime be effective in reducing swelling potential; quicklime treated specimens reached slightly lower swelling values than the hydrated lime while no appreciable distinction in hydraulic conductivity values of specimens treated with the two types of lime was observed. They concluded that quicklime is adjudged to have exhibited somewhat superior engineering properties and therefore creates a more effective stabilization alternative for the soil (Deboch, 2018).

Alemneh sorsa (2014) performed his research to quantify the improvements achieved on the engineering properties of expansive soils due to cement and lime stabilization by collecting two sub grade soils from Jimma Town around Shanen Gibe Hospital along Seka road and around Kidanemhret Church. The conducted Laboratory tests were moisture content, specific gravity, grain size analysis, Atterberg limits, proctor test, free swell test, California Bearing Ratio and CBR swell tests. The collected samples of the soils were stabilized using 2, 4, 5, 6, 7 and 8% of hydrated lime and 10, 12, 14 and 16% of cement by weight of soil. The observations and conclusions: were made (Alemneh sorsa, 2014):

The optimum ratio for the studied expansive soils were 5% using hydrated lime and 14% using cement. The improvement of sub grade soil properties was increased with increased ratios of hydrated lime and cement. The maximum improvements on engineering properties were observed on CBR and minimum improvements were on liquid limits. The result indicated that the two stabilizers were very effective in improving strength parameters than index parameters. It was observed that cement was better than hydrated lime in improving sub grade soil properties. But using cement is not economical due to its highest optimum ratio and current market cost compared to cost of hydrated lime. The results of this study show that the cement and hydrated lime stabilized soils under optimum ratio full fill the standard requirements as sub grade soils.

For the practical applicability of the stabilized soils further detail investigations including chemical and mineralogical analysis of the treated soils will of paramount.

Kufre et.al,2017 Evaluate the effect of waste disposal especially sawdust on the geotechnical properties of any soil by using both the burnt and unburnt sawdust by adding separately to the uncontaminated soil samples in varying percentages of 0, 1, 3, 5, 10 and 15% by weight of soil sample. Indiscriminate disposal of sawdust on soil poses serious challenges to civil engineering works. The sawdust from any logging industries needs to be properly handled and adequately disposed of. Sawdust though an inert material could portend serious danger to the geotechnical properties of soil wherever they are found because it is highly biodegradable.

The test results indicate that the liquid limit for the unburnt sawdust increased with increase in sawdust content while the plastic limit shows a decreasing trend with increase in unburnt sawdust content. The variation of maximum dry density (MDD) and optimum moisture contents (OMC) of lateritic clay soil treated with unburnt and burnt saw dust was generally observed that the MDD decreased with increasing percentage content of unburnt and burnt sawdust respectively but Comparatively, the MDD of soil treated with unburnt sawdust are generally lower than MDD of same soil treated with burnt sawdust for all percentage concentrations considered. Further addition beyond the optimum value of either burnt or unburnt sawdust does not bring about any improvement in the clay soil. Finally from the geotechnical experiment investigated on the soil samples with both the burnt and burnt sawdust, it can be correctly asserted that soil containing burnt sawdust will greatly improve the geotechnical properties of soils when compared with that of the unburnt sawdust (Kufre *et al.*, 2017).

CHAPTER THREE

3 MATERIALS AND RESEARCH METHODOLOGY

3.1 Introduction

In this chapter the materials used and the methods adopted for the research are described with respect to their source. Laboratory tests were done in Jimma University, Civil Engineering Laboratory.

3.2 Study area

The study area is found in southwestern Ethiopia, Jimma town, Jimma is located 353km Southwest of Addis Ababa capital city of Ethiopia and it is a specialized zone of Oromia Region (Figure 3.1). It has latitude and longitude of 7°41'N and 36°50' E respectively. Its average elevation range from1780 m to 2000m above sea level. The climatic classification of Jimma Town is classified as "Wayna Dega" which is considered ideal for agriculture as well as human settlement. The town covers a total area of 18,412.54 square kilometers. The Town has a temperature that ranges from 20-30°C. (https://en.wikipedia.org/wiki/Jimma#cite_note-1).

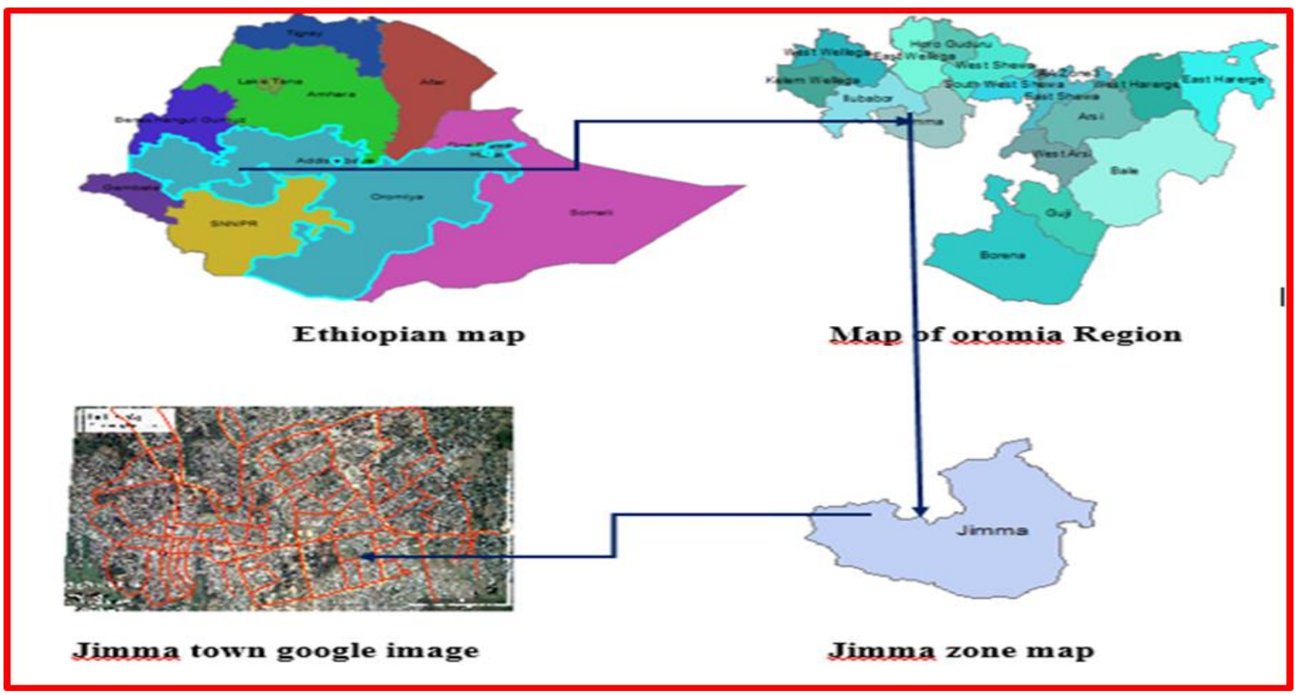

Figure 3.1 Location of Jimma Town, Ethiopia

3.3 Research design

A study design/frame is the process that guides researchers on how to collect, analyze and interpret observations. Therefore, the objective of the research was achieved by following the methodology outlined below (Figure 3.2).

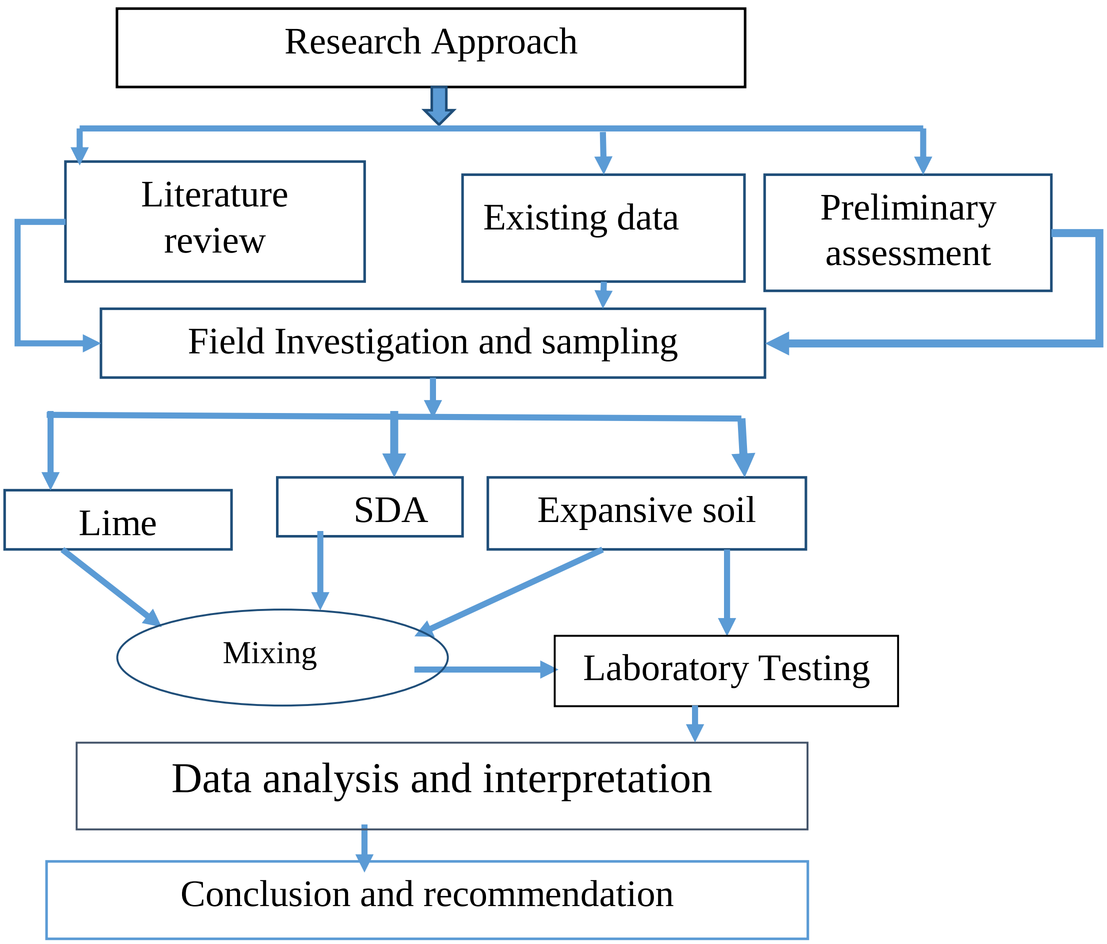

Figure 3.2 Research design

3.4 Materials

3.4.1 Soil

The soil samples were collected from Jimma town from three test pits (Kochi, Shanen Gibe Hospital and Technic Sefer). Various preliminary tests for index properties and strength were determined in the laboratory beside this grain size analysis were done and the test results indicate that the soil samples are expansive soils.

Figure 3.3 Excavated test pits

3.4.2 Sawdust Ash(SDA)

Leftover by wood processing SD was collected from Jimma town wood processing enterprises and left in an open area for air dry to remove its moisture and facilitate the easy way of burning (Figure 3.3). Then the dried sawdust is burnt for three hours per five kilograms, and then it cooled after completion of burning then finally the ash was collected. The SDA was then sieved through 425 micron sieves to remove the lumps, gravels, unburnt particles and other materials which are deleterious to soil. The SDA passing through 425 microns sieve was used for the laboratory work.

Figure 3.4 sawdust and sawdust ash used for this research.

3.4.3 Lime

Lime which contains calcium oxide(CaO) commonly known as burnt lime, or quicklime, is a white, caustic and alkaline crystalline solid at room temperature. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of aluminum oxide and iron oxide(Jonah, 2015). Lime for the present study was purchased from the open market.

3.5 Methods

3.5.1 Sample Preparation

Prior to treatment and testing, the sample was prepared in accordance with the method described in AASHTO T87-86. This method involves:

1. Air drying of samples and/or oven drying at 60ºC or less;
2. Breaking up the soil aggregates by rubber covered mallet. Then, sieve analysis is performed to separate the dried soils into two groups. The first group involves preparing uniform samples for Atterberg limits, free swell, free swell index and free swell ratio tests. And the other for compaction and California bearing ratio tests.
3. Then, soil, SDA and Lime is mixed manually to get uniform mix ratio for each test.

Figure 3.5 Air drying, crushing and Mixing of soil samples

3.5.2 Laboratory Tests

3.5.2.1 Moisture Content

The test was conducted in accordance with AASHTO T265 and ASTM D 4318. Small representative sample of the natural soil specimen is taken and oven-dried at 105 ± 5°C for at least 16 hours. The samples were then reweighed, and the difference in weight was assumed to be the weight of the water driven off during drying. The difference in weight was divided by the weight of the dry soil, giving the water content of the soil a dry weight basis.

3.5.2.2 Atterberg Limits Testing

The test included the determination of the liquid limits, plastic limits and the plasticity index for the natural soil and the soil-SAD-Lime mixtures. The tests were conducted in accordance with STM D 4318 -98 standard test method.

3.5.2.2.1 Liquid Limit

The soil sample for liquid limit was air dried and 200g of the material passing through No. 40 sieve (425µm aperture) was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture was then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the center of the hinge. The cup is then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The number of blows at which that occurred was recorded and a little quantity of the soil was taken and its moisture content determined. The test was performed for well–spaced out moisture content from the drier to the wetter states. The values of the moisture content (determined) and the corresponding number of blows is then plotted on a semi-logarithmic graph and the liquid limit was determined as the moisture content corresponding to 25 blows. The same procedure was also carried out for the treated soil with increment of SDA-Lime content.

3.5.2.2.2 Plastic Limit

A portion of the natural soil and the soil–SDA-Lime mixture used for the liquid limit test was retained for the determination of plastic limit. The ball of the natural soil and the soil- SDA-Lime mixture was molded between the fingers and rolled between the palms of the hand until it dried sufficiently, even though the soil was already relatively drier than the ones used for liquid limit. The sample was then divided into approximately two equal parts. Each of the parts was rolled into a thread between the first finger and the thumb.

The thread is then rolled between the tip of the fingers of one hand and the glass. This continued until the diameter of the thread was reduced to about 3mm. The movement continued until the thread shears both longitudinally and transversely. The crumbled natural soil-SDA-Lime mixture was then put in the moisture container and the moisture content determined. The same procedure was also carried out for the treated soil with increment of SDA-Lime content.

3.5.2.2.3 Plasticity Index

The plasticity index of the natural soil and the soil-SDA-Lime mixture was the difference between the liquid limits and their corresponding plastic limits.

The plasticity indexes of the sample Samples were calculated as:

PI =LL–PL**……………………………………… (3.1)**

Where PI=plasticity index

LL=liquid limit

PL=plastic limit

Figure 3.6 Sample prepared for Atterberg Limits Test

3.5.2.3 Particle Size Distribution

The test includes the determination of the particle size distribution for the natural soil. The tests were conducted following AASHTO T88-93 testing procedures. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method was used to determine the distribution of the finer particles.

3.5.2.4 Specific Gravity

Specific gravity which is the measure of heaviness of the soil particles are determined by the method of pycnometer method using a soil sample passing No. 10 sieve and oven dried at 105℃. The test was conducted in accordance with AASHTO T100-93 testing procedure.

3.5.2.5 Compaction

The test included the determination of the maximum dry density and the optimum moisture content for the natural soil and the soil-SDA-Lime mixture for specified compactive effort. The tests were conducted in accordance with AASHTO T99-94 testing procedures.

Figure 3.7 Sample prepared for Compaction test

3.5.2.6 CBR Test

The CBR and CBR-swell tests were conducted in accordance with AASHTO T193-93 for the natural soils and soil- SDA-Lime mixture. The CBR is expressed by the force exerted by the plunger and the depth of its penetration into the specimen; it is aimed at determining the relationship between force and penetration. 5.0 kg of the natural soil and the soil-SDA-Lime mixture are mixed at their respective optimum moisture contents in 2060 cubic centimeters mold. The CBR test indirectly measures the shearing resistance of soil under controlled moisture and density conditions. The CBR is obtained as the ratio of load required to affect a certain depth of penetration of a standard penetration piston into a compacted specimen of the soil at some water content and density to the standard load required an equivalent depth of penetration on a typical sample of crushed stone.

In equation form, this is:

$$\text{CBR} = \frac{\text{Test load on the sample}}{\text{standard load on the crushed stone}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

CBR tests were conducted on the compacted specimens at the optimum moisture content using modified compaction test. The compacted soil samples of the CBR mold are soaked for 96 hours in a water bath to get the soaked CBR value and the CBR swell of the soil. The CBR swell of the soil is measured by placing the tripod with the dial indicator on the top of the soaked CBR mold. The initial dial reading of the dial indicator on the soaked CBR mold is taken just after soaking the sample. At the end of 96 hours the final dial reading of the dial indicator is taken hence the swell percentage of the initial sample length is given by:

$$\text{CBR swell} = \frac{\text{Change in Length in mm during Soaking}}{116.3\text{mm}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Figure 3.8 compacted sample and soaked sample for CBR test.

3.5.2.7 Unconfined Compression Strength Test

The test was conducted following AASHTO T-208 standard. The Samples were compacted in proctor compaction mold. The compaction procedure was using 2.5 kg rammer, applying 25 blows evenly distributed blows to each of the three equal thick layers. After the specimen was formed, it was extruded from compaction mold by the Shelby tube sampler and cut the height-to-diameter ratio of 2. The mass of the specimen, the length of the specimen, and the diameter of the specimen at mid-height were determined and recorded. Having determined the mass and dimension of the specimens, then it was placed in the loading device. A strain rate of 2 percent per minute was used with measurements taken every 10 divisions on deformation until the load values decreased with increasing strain. The specimen was removed from the compression device and a sample for water content determination was taken.

Figure 3.9 UCS Test: sample preparation procedure and specimen with compression device.

3.6 Mixture Design and Strength Characteristics

When using lime as a stabilizer, the goal of the mixture design is to find the optimum lime content to adequately stabilize the soil to meet desired strength requirements. The most common approach to mixture design is to determine the optimum lime content that provides the maximum strength. The optimum lime content is first estimated by measuring the PH of several soil -SDA-lime mixtures with varying lime contents. The standard test method, ASTM D 6276, is used to determine the amount of lime needed to achieve the design pH at 25℃ (77°F), which is about 12.4, depending on specific soil characteristics. The lowest lime content that provides a pH of 12.4 is then used as the starting point for determining the optimum lime content. First step in assessing the optimum lime content to ensure optimal long term strength gain is to perform the Eades and Grim pH test. The pH test is only a first step. The optimum lime content must be validated based on strength testing (Little, 2009).

3.6.1 Optimum Dosage of Lime and SDA

In order to determine the minimum amount of lime and SDA required for the proper stabilization of the expansive soil, the pH of the samples was determined using a pH meter. The process proposed by Eades and Grim (1966) involves testing a mixture of 25 g of soil passed through the 425μm sieve, a certain percentage of lime and SDA, and 100g of distilled water shaken periodically and tested for PH.

The lime fixation point represents the quantity of lime added to achieve a pH value of 12.4 for the lime–soil mix. This was achieved at a combination of 5% SDA and 2.5% lime which gave a maximum pH value. Subsequent increases in the lime content beyond 2.5% result in reduction of HP value.

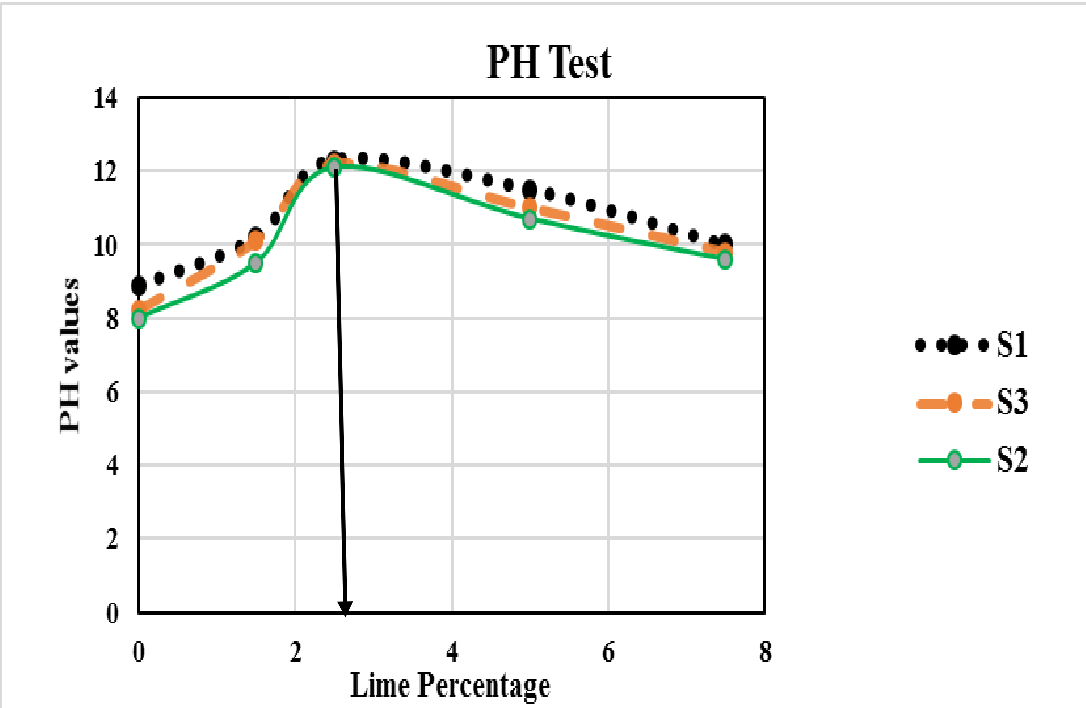

Figure 3.10 Estimation of optimum lime content using PH method

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results of laboratory tests and discusses results of the research. The relevant engineering property of the soil is evaluated for both natural and stabilized soil samples separately. The tests include Grainsize analysis, Atterberg limits, free swell index, compaction, unconfined compression, and California bearing ratio (CBR).

4.2 Properties of natural soils used in the study

4.2.1 Natural Moisture Content

The in-situ moisture content tests were performed for the three Soil samples.

Table 4.1 Natural Moisture Content of the Soils

Samples name	Natural moisture content(%)
S1	51.18
S2	50.13
S3	50.52

4.2.2 Atterberg Limits

The results of the tests conducted for identification and/or determination of properties of the Expansive soil before applying SDA and Lime are presented in Table 4.2 (Plasticity behavior) and Figure 4.1 particle size distribution curve. Results of the study show that:

- For S1 soil almost 93.5% of the soil passed through No. 200 sieve and a liquid limit of 95%, a plastic limit of 31.03% and a plasticity index of 63.97% exhibited;
- For S2 soil almost 94.7% of the soil passed through No. 200 sieve and a liquid limit of 92.5%, a plastic limit of 33.6% and plasticity index of 59% exhibited;
- For S3 soil almost 94.4% of the soil passed through No. 200 sieve and a liquid limit of 93.5%, a plastic limit of 32.49% and plasticity index of 61.01% exhibited.

Table 4.2 Soil classification

Samples name	Atterberg Limits(natural)			soil classifications		Color
	LL	PL	PI	USCS	AASHTO	
S1	95	31.03	63.97	CH	A-7-5	Grayish Black
S2	92.5	33.6	58.9	CH	A-7-5	Grey
S3	93.5	32.49	61.01	CH	A-7-5	Grey

Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity (Whitlow, 1995). Hence, these values indicate that the soils are highly plastic clay. Accordingly, the soils fall under the A-7-5 soil class based on AASHTO soil classification system and CH soil class based on USCS soil classification system. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material. Therefore, the soil requires initial modification and/or stabilization to improve its workability and engineering property.

4.2.3 Grain Size Analysis

Sieve Analysis was carried out to determine the percentage of different grain sizes contained within a soil samples and used in the classification of the soil. Accordingly, the wet sieve analysis was employed to determine the Grain size distribution of soil samples by following AASHTO T88-93 Test Method for Particle-Size Analysis of Soils. Also, Hydrometer Analysis was conducted. Details of the Grain size analysis results are shown in Appendix (2.1,3. 1and 4.1).

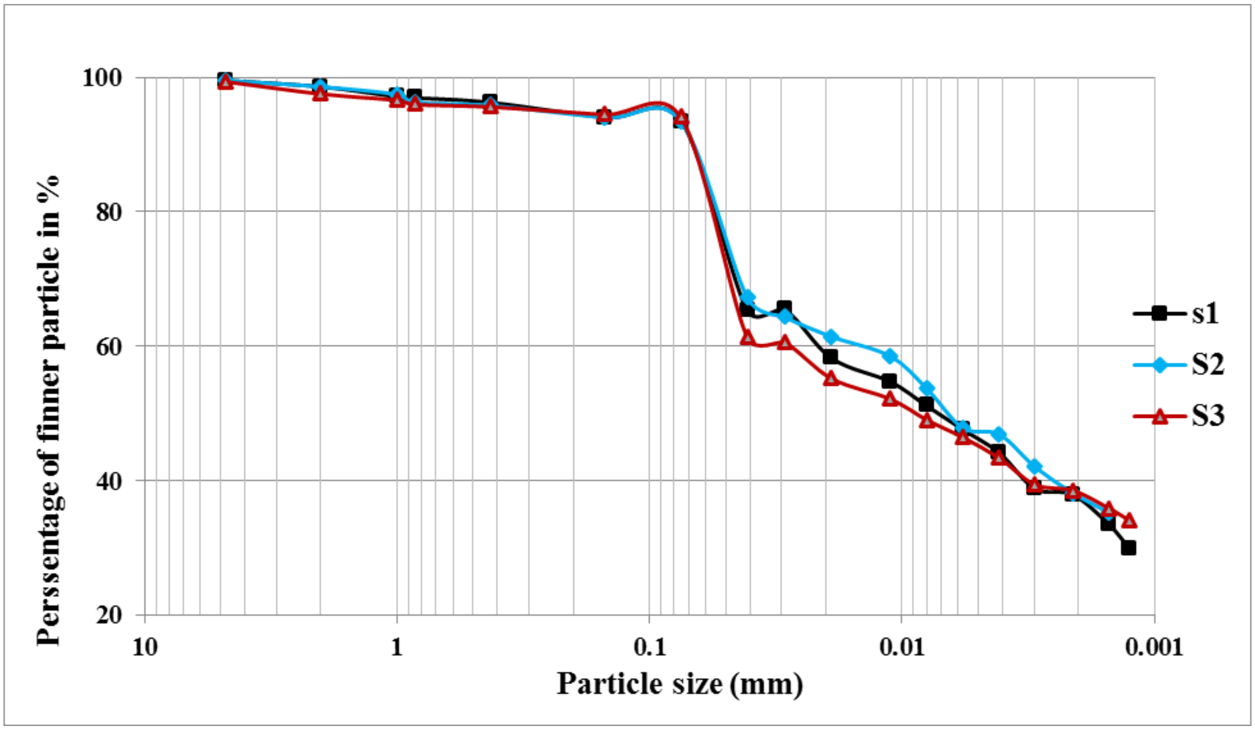

Figure 4.1 Particle size distribution curve of the natural soil (S1, S2 and S3)

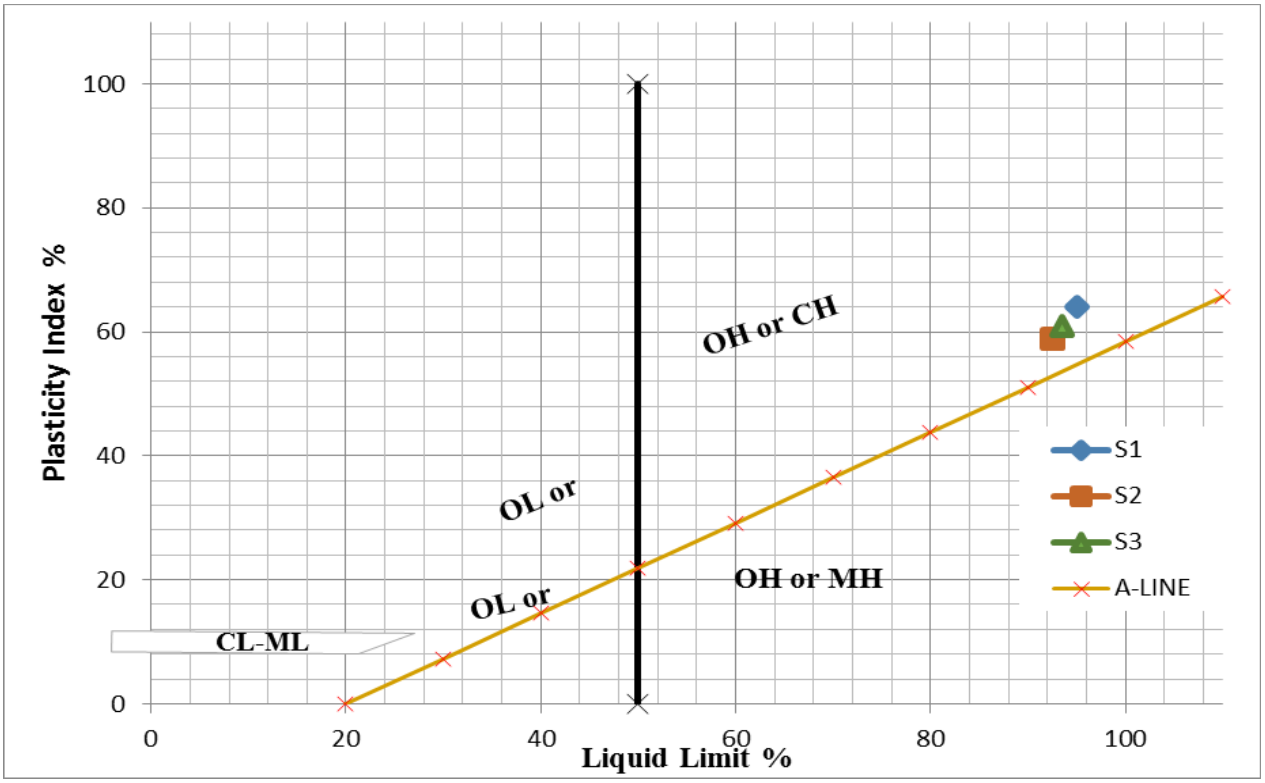

Figure 4.2 Plasticity chart of the natural soil using USCS

4.2.4 Specific Gravity test

It is the ratio of the mass of a unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity value was found to be 2.71, 2.62 and 2.58 for S1, S2 and S3 types of soils respectively and the specific gravity of SDA is 2.01.

4.3 Effect of SDA and Lime on Atterberg limits

The results of the tests carried out on the natural soil samples and soil samples mixed with different proportions of SDA and lime are given in Table 4.4 (below). Results indicate that the LL and PI decreased and later increased for all samples.

- For the first sample (S1) LL decreased from 95% at 0% SDA and lime to 61.4% at 5%,2.5% SDA and lime
- For the second sample (S2) LL decreased from 92.5% at 0% SDA and lime to 53.5% at 5%,2.5% SDA and lime
- For the third sample (S3) LL decreased from 93.5% at 0% SDA and lime to 62% at 5%,2.5% SDA and lime.

This observed trend also in line with earlier findings (Shawl, 2017). The significant reduction of liquid limit and plasticity index is indicative of improvement. This clearly shows the fact that the plasticity index of treated soil decreased with increasing additive quantity until it reaches the optimum contents. These effects are due to the partial replacement of plastic soil particles with SDA which is non-plastic material and the ionic exchange of lime and clay minerals of the soil.

These led to flocculation and agglomeration of the clay particles which in turn reduced the plasticity of the treated soil (as discussed in section 2.5.2.2). Details of the Atterberg limits test results are shown in Appendices (2.2,3.2 and 4.2).

Table 4.3 Effect of Addition of SDA and Lime on Atterberg limits of expansive soil.

SDA percentage	Lime percentage	SAMPLES NAME								
		S1			S2			S3		
		LL	PL	PI	LL	PL	PI	LL	PL	PI
0	0	95	31.03	63.97	92.5	33.6	58.9	93.5	32.49	61.01
3	1.5	77.5	31.87	45.63	78	34.56	43.4	75.5	32.6	42.9
5	2.5	61.4	31.97	29.43	58.5	34.64	23.9	62	32.65	29.35
10	5	73.5	31.85	42.65	75.5	34.9	40.6	78	32.39	45.61
15	7.5	77.5	31	46.5	80.5	31.56	48.9	79	31.77	47.23

4.4 Effect of SDA and Lime on Compaction Characteristics

As shown in Table 4.6 (below) with the addition of varying percentage of SDA and lime maximum dry density decreased from 1.51g/cm^3 at 0% SDA and lime to 1.35g/cm^3 at 15% SDA and 7.5% lime contents for S1, from 1.56g/cm^3 at 0% SDA and lime to 1.30g/cm^3 at 15% SDA and 7.5% lime contents for S2 and from 1.49 g/cm^3 at 0% SDA and lime to 1.32g/cm^3 at 15% SDA and 7.5% lime contents for S3, and optimum moisture content increased from 22.5% at 0% SDA and lime to 25.5 at 15% SDA and 7.5% lime contents for S1, from 22.5% at 0%SDA and lime to 26 at 15% SDA and 7.5% lime con tents for S2 and from 23% at 0% SDA and lime to 26 at 15% SDA and 7.5% lime contents for S3. This observed trend also in line with earlier findings(Shawl, 2017).

A decrease in the dry density is due to the lower specific gravity of the saw dust ash, the partial replacement of comparatively heavy soils with the light weight SDA, while an increase in the optimum moisture content is due to pozzolanic reaction of silica and alumina in SDA and soil with calcium of the lime to form calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) which are the cementing agents. Additional water is also required for wetting the large surface area of the fine SDA particles or is absorbed by the fine particles of the SDA. Another reason could be due to the increasing surface area caused by the higher amount of the additives, which required more water for the lubrication. This trend is consistent with the report of (Wubshet and Tadesse, 2014). (Details of maximum dry density and optimum moisture content results are shown in Appendices 2.3,3.3,4.3).

Table 4.4 Variation of OMC and MDD for expansive soil stabilized with varying percentage of SDA and Lime.

SDA percentage	Lime percentage	SAMPLES NAME					
		S1		S2		S3	
		OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)
0	0	22.5	1.51	22.5	1.56	23	1.49
3	1.5	23	1.51	23.5	1.51	24	1.48
5	2.5	24.5	1.50	24	1.48	24.5	1.43
10	5	25	1.47	26	1.33	25	1.41
15	7.5	25.5	1.35	26	1.3	26	1.32

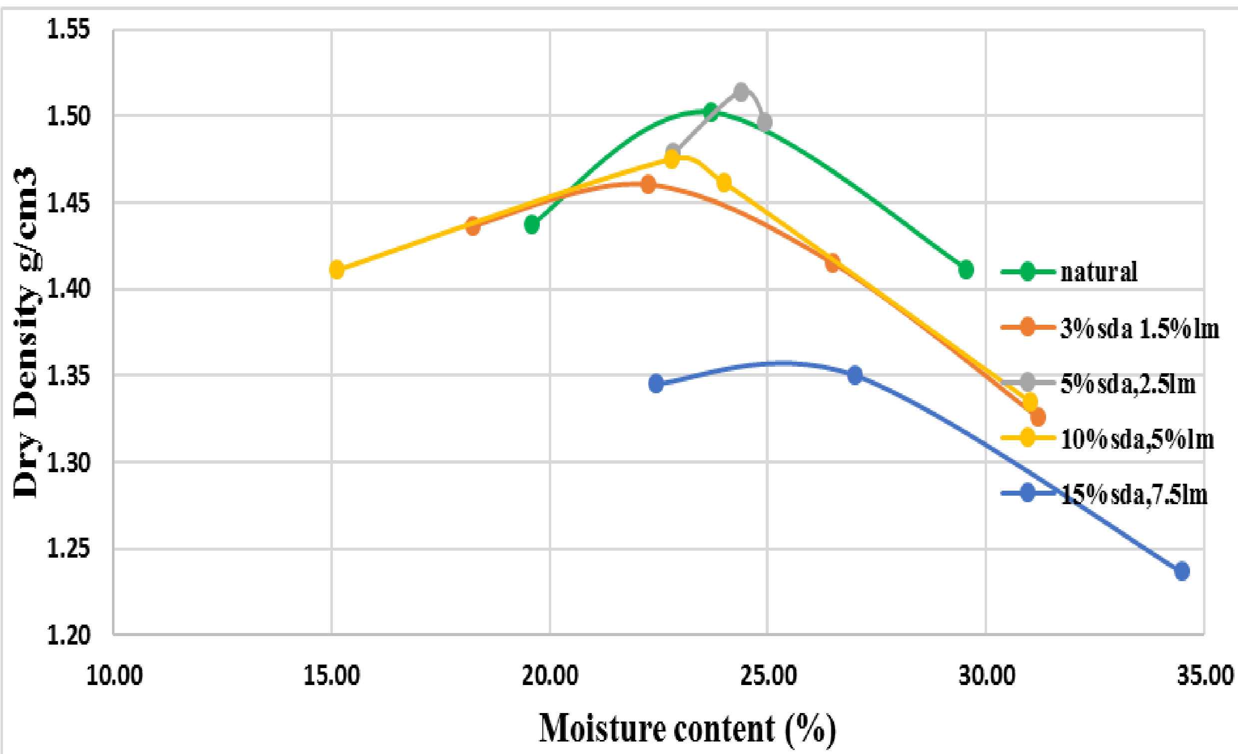

Figure 4.3 Variation of OMC and MDD for expansive soil stabilized with varying percentage of SDA and Lime. (sample1)

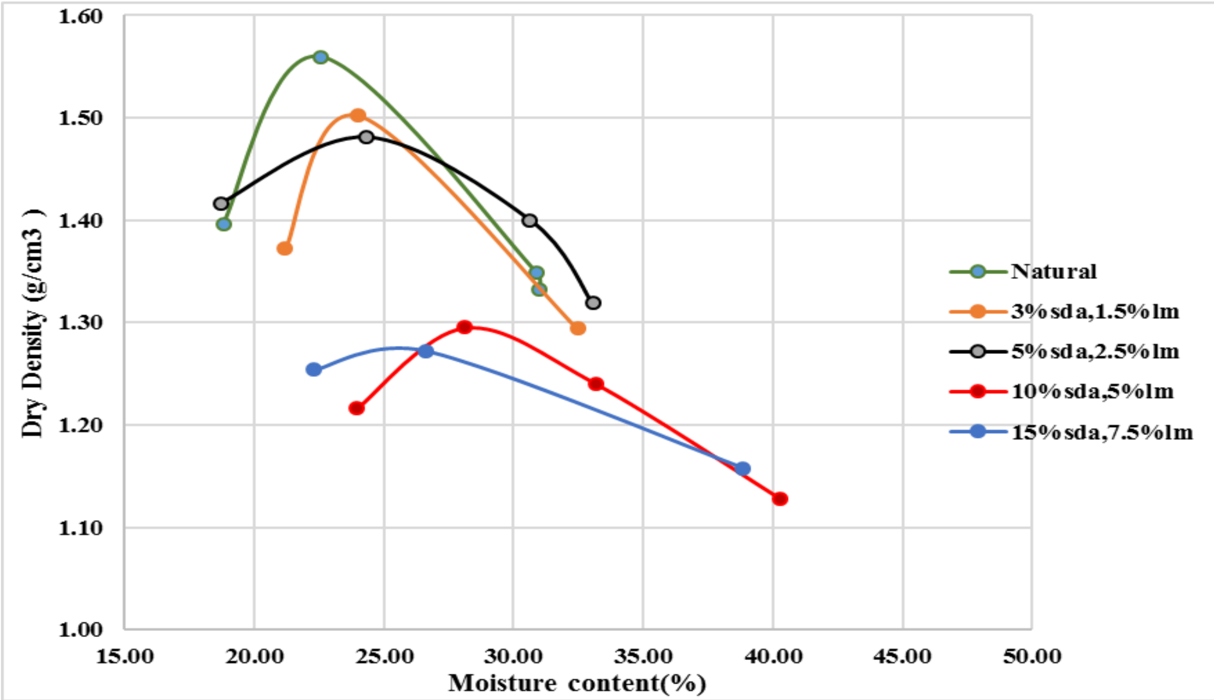

Figure 4.4 Variation of OMC and MDD for expansive soil stabilized with varying percentage of SDA and Lime. (sample2)

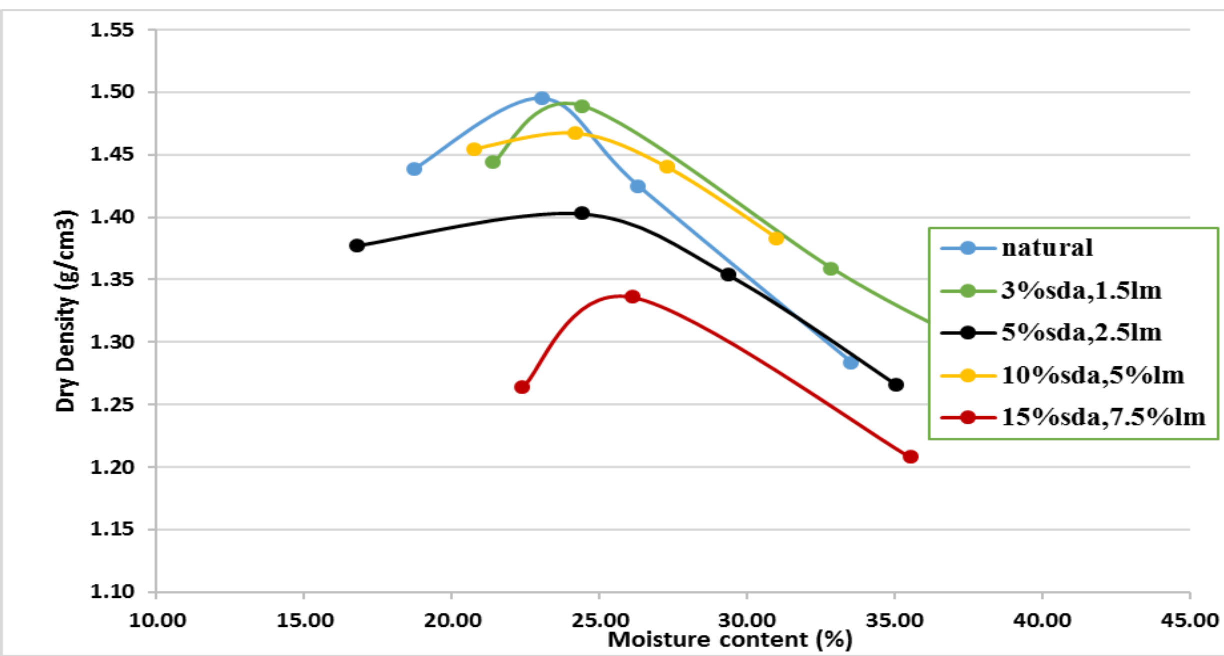

Figure 4.5 Variation of OMC and MDD for expansive soil stabilized with varying percentage of SDA and Lime. (sample3)

4.5 Effect of SDA and Lime on CBR Value and CBR Swell

4.5.1 CBR Value

CBR test was conducted using AASHTO T193-93 procedure and conducted to determine the CBR value of the soil samples. The results of the soaked CBR test for natural soils and soils mixed with varying percentages of SDA and lime are shown in Table 4.7 below.

Table 4.5 CBR values of stabilized and natural expansive soil.

SDA Percent age	Lime Percent age	**SAMPLES NAME**								
		S1			**S2**			**S3**		
		CBR %			CBR %			CBR %		
		65Blo ws	30Blo ws	10Bblo ws	65Blo ws	30Blo ws	10Blo ws	65Blo ws	30Blo ws	10Blo ws
0	0	1.49	0.92	0.83	1.42	0.82	0.75	1.55	0.9	0.81
3	1.5	5.78	2.12	1.54	2.37	2.62	1.78	2.7	2.5	1.81
5	2.5	10.08	3.32	2.25	10.84	6.41	2.39	10.46	4.73	2.5
10	5	7.46	5.68	3.25	3.74	3.45	2.3	5.6	4.65	2.73
15	7.5	7.19	5.2	2.1	2.39	2.4	1.9	4.79	3.1	2.1

Table 4.6 The general relationship between CBR values and the quality of the subgrade soils used in pavement applications is as follows (Bowles, J., 1992).

No	CBR-values	Quality of subgrade
1	0 – 3 %	very poor subgrade
2	3 – 7 %	poor to fair subgrade
3	7 – 20 %	fair subgrade
4	20 – 50 %	good subgrade
5	> 50	excellent subgrade

Hence, the natural soils were found to be highly plastic expansive clay with low bearing capacity when it is soaked and high swelling potential and fell below the standard recommendations for most geotechnical construction works especially highway construction. The results of treated soil samples show increase of soaked CBR and when treating the expansive soil using both stabilizing agent peak CBR values were recorded 6.1%,7%and 7.23% CBR at 5% SDA and 2.5% lime content for S1, S2 and S3 respectively. Further addition of SDA and lime, decreased the CBR of the Soil samples.

When the soils are stabilized at 5% SDA and 2.5% lime the soils fulfil ERA standard (CBR 3%) be used as subgrade soils. Hence,5% SDA and 2.5% lime can potentially stabilize expansive soil from problematic poor layer to fair subgrade layer and the stabilized soil is used as sub-grade material in road construction. Details of the test results are given in (Appendix 2.4,3.4 and 4.4)

4.5.2 CBR Swell

The effect of SDA and lime on the CBR swell for the soil-SDA and lime mixtures are shown in Table 4.9 (below). The result shows decrease in the CBR swell from 7.73.02% to 1.73%, for S1,7.23 to 1.85 for S2 and 7.3 to 1.8 for S3 with the addition of 5% SDA and 2.5% lime. So the minimum CBR swell value were obtained at 5% SDA and 2.5% lime and further addition of SDA and lime, causes an increase in the CBR swell of the expansive Soil for all samples. ERA (2002) Manual recommend that sub-grade soil should have CBR swell less than 2 percent so the stabilized soil satisfy this standard and it is possible to use the stabilized soil for sub-grade material in road construction.

Table 4.7 CBR swell test result of stabilized and natural expansive soil.

SDA Percentage	Lime Percentage	SAMPLES NAME								
		S1			S2			s3		
		CBR Swell in %			CBR swell in %			CBR swell in %		
		65Blows	30Blows	10Bblows	65Blows	30Blows	10Blows	65Blows	30Blows	10Blows
0	0	7.23	7.39	7.73	7.23	7.39	7.73	7.3	7.4	7.5
3	1.5	4.45	5.27	5.42	4.81	5.23	6.88	4.5	5.3	6.2
5	2.5	1.73	1.89	3.66	1.85	1.98	2	1.8	1.9	1.95
10	5	2.42	3.21	4.4	2.42	2.9	3.8	2.34	3.12	3.56
15	7.5	5.22	6.08	7.31	5.22	6.08	6.4	5.22	6.08	6.75

4.6 Effect of SDA and lime on UCS Values

Unconfined compression test is quick and simple testing to determine the compressive strength. The samples were mixed and compacted at maximum dry density and at optimum moisture content and the tests were performed on remolded untreated specimens and remolded specimens treated with different concentrations of SDA and lime contents. Table 4.10 and Figures 4.8,4.9, and 4.10

show the laboratory test results of unconfined compression test for expansive soils stabilized varying percentage of SDA and lime.

Table 4.8 Effect of SDA and lime on UCS of expansive soils

SDA Percentage	Lime Percentage	SAMPLES Name		
		S1	S2	S3
		qu (KN/m^2	qu (KN/m^2	qu (KN/m^2
0	0	54.25	46.41	52.74
3	1.5	94.44	83.34	83.11
5	2.5	115.45	90.28	101.76
10	5	77.44	74.04	70.86
15	7.5	51.16	38.6	40.93

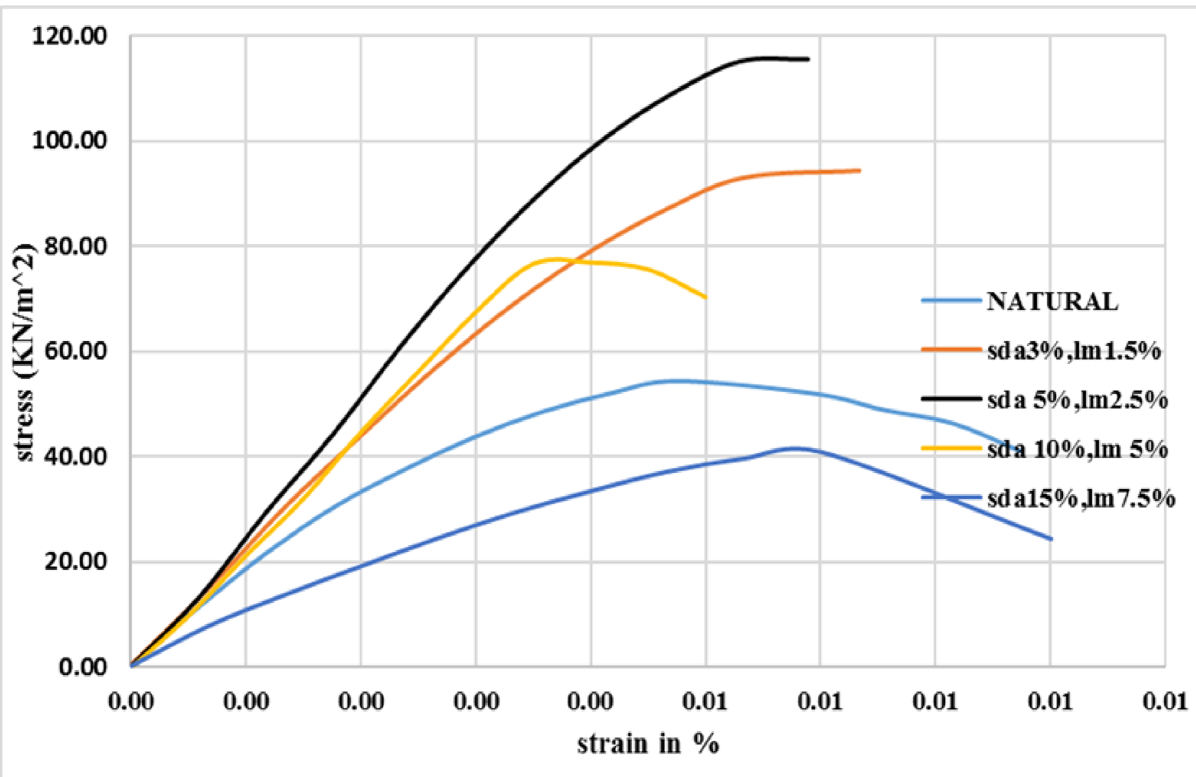

Figure 4.6 Variation of UCS values of Expansive soil with various proportion of SDA and lime for sample1

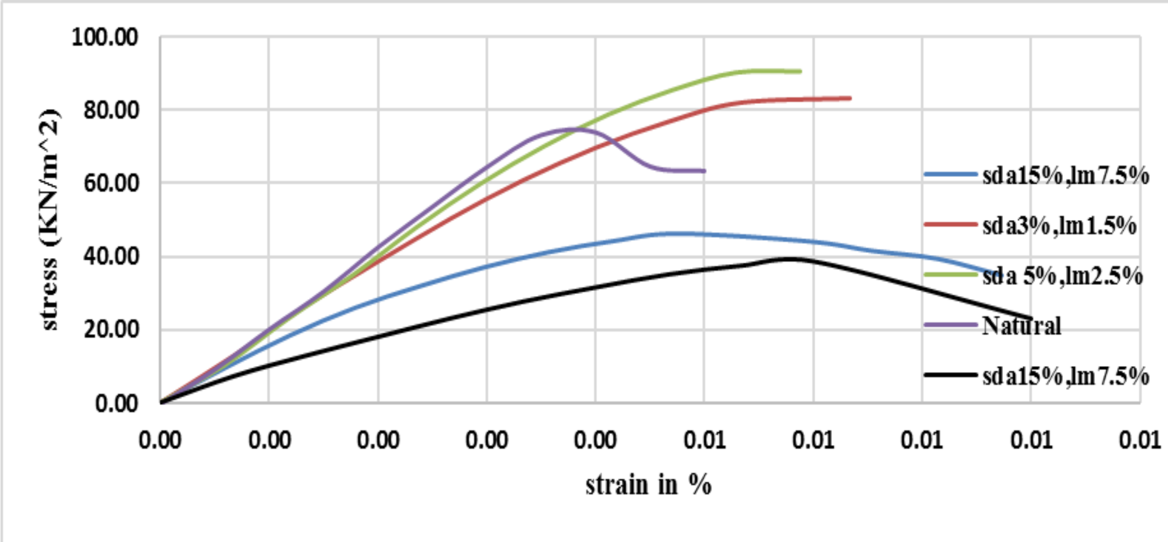

Figure 4.7 Variation of UCS values of Expansive soil with various proportion of SDA and lime for sample2.

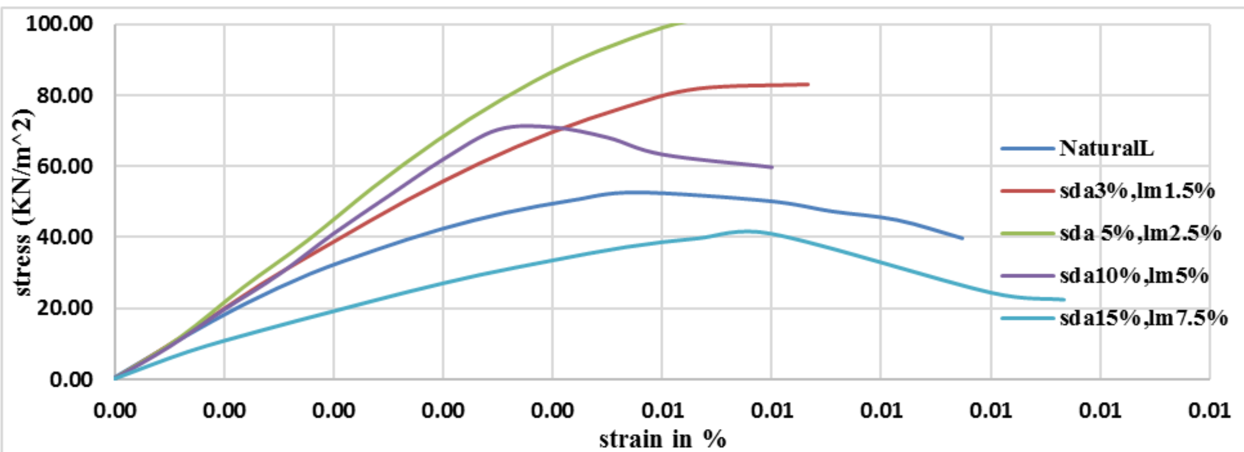

Figure 4.8 Variation of UCS values of Expansive soil with various proportion of SDA and lime for sample 3

As shown in Table 4.10 the Unconfined Compressive Strength of the soils without the addition of SDA and lime is 54.25 KN/m^2 for S1, 46.41 KN/m^2 for S2 and 52.74 KN/m^2 for S3. This shows that the soils are soft and low in strength, but the addition of SDA and lime gave highest strength value at 5% SDA and 2.5% lime content for the three samples. The increase in the UCS is attributed to the formation of cementitious compounds between the lime and soil and the pozzolans present in the SDA. Hence,5% SDA and 2.5% lime can stabilize expansive soil and change the soil from soft to medium(firm) consistency.

CHAPTER 5

5 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The following conclusions are drawn from the results of the study/investigation carried out within the scope of the study.

1. The test results showed that the three soil samples are expansive soils and A-7-5 as per the AASHTO soil classification system and CH as per the USCS system.

- The addition of different proportion of SDA and lime on soil samples show reduction of PL and LL. But increasing of SDA and lime in a mixture of expansive soil more than 5% SDA 2.5% lime has resulted in an increase in plasticity index for all samples.
- The OMC increased and MDD decreased, a decrease in the dry density is due to the lower specific gravity of the saw dust ash, while an increase in the optimum moisture content is as a result of water needed to be hydrated.
- The addition of SDA and lime increased the unconfined compressive strength of the stabilized soils. The maximum value of unconfined compressive strength was attended at 5% SDA and 2.5% lime content and the unconfined compressive strength decrease when the SDA and lime content increases beyond the optimum contents.
- The CBR values of soaked samples increased with the addition of SDA and lime and the peak values are achieved at 5% SDA and 2.5% lime contents; this increment changed the behavior of natural soils from poor to fair standard. The CBR swell potential of soil also showed improvement at 5% SDA and 2.5% lime contents and satisfy ERA standard to be used as sub-grade material in road construction.
- It can be concluded from this investigation that unlike other lime stabilization cases where higher quantities of lime (higher construction cost) were required for the optimum stabilization of expansive soils, suitable results were achieved at just 5% SDA and 2.5 % lime contents these two values are optimum SDA and lime contents. Sawdust is an inexpensive by product of wood processing industries, and its utilization greatly minimizes environmental pollution.

5.2 Recommendations

Based on the results of this research, the following recommendations are forwarded:

- Sawdust ash investigated in the present study can be used as a soil stabilizing material in combination with lime with economic and environmental benefits. Therefore, concerned bodies like wood processing industries should be made aware of this potential soil stabilizing material and promote its standardized production and usage.
- Studies should be made using controlled burning of the sawdust ash at different temperatures in furnace and the large scale production of the ash is possible using higher quality furnaces, such as those for coal combustion, which comply with the Clean Air Act or the Clean Coal Technology are associated with negligible environmental pollution.
- For the future study further detail investigations including chemical and mineralogical analysis of the treated soils should be performed.
- The impacts of Curing time on stabilized expansive soil property should be studied.

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APPENDICES

Appendix 1 Natural Moisture contents

Samples Name	**S1**		**S2**		**S3**	
Container (Can) No.	1	2	1	2	1	2
Mass of container ,g	17.19	17.66	32.87	17.96	25.03	17.81
Mass of Container + wet specimen, Mcws, g	114.8	82.82	165.6	194.8	140.2	138.8
Mass of container + oven-dried specimen, Mcs,g	81.34	61.05	120.8	136.4	101.1	98.73
Mass of water, Mw , g	33.49	21.77	44.8	58.4	39.16	40.09
Mass of solid particles, Ms,g	64.16	43.4	87.93	118.5	76.04	80.92
Moisture content, %	52.2	50.17	50.95	49.3	51.5	49.54
Average moisture content,%		51.18		50.13	50.52	

APPENDEX 2 Laboratory Test Result Analysis of Sample 1

APPENDIX 2.1 Grain size Analysis

Wet sieve analysis

Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage passing
9.5	0	0	0	100
4.75	2	0.4	0.4	99.6
2	4.7	0.94	1.34	98.66
0.85	5.7	1.14	2.48	97.52
0.425	6	1.2	3.68	96.32
0.3	2.3	0.46	4.14	95.86
0.15	8.9	1.78	5.92	94.08
0.075	2.9	0.58	6.5	93.5

Hydrometer Analysis

Time	Elapsed time t in,	Actual Hydrometer	Eff.depth,L (cm)	Temperature (c0)	K	C_T	Par.diameter D (mm)	Value of 'a' for Gs=2.71	Corrected hydrometer reading for	% Finer D,P(%)=Rd +a/Mo	corrected (Passing)
9:32	1	42	9.2	23	0.01297	0.7	0.040553	0.9825	35.7	70.1	69.21
9:33	2	41	9.4	23	0.01297	0.7	0.028985	0.9825	34.7	68.2	67.27
9:37	5	39	9.7	23	0.01297	0.7	0.018622	0.9825	32.7	64.3	63.39
9:47	15	36	10.2	23	0.01297	0.7	0.011025	0.9825	29.7	58.4	57.58
4:01	30	34	10.6	23	0.01297	0.7	0.007947	0.9825	27.7	54.4	53.70
4:31	60	32	10.9	23	0.01297	0.7	0.005699	0.9825	25.7	50.5	49.82
5:31	120	31	11.0	23	0.01297	0.7	0.004048	0.9825	24.7	48.5	47.88
7:31	240	28	11.5	23	0.01297	0.7	0.002927	0.9825	21.7	42.6	42.07
11:31	480	27	11.7	23	0.01297	0.7	0.002087	0.9825	20.7	40.7	40.13
9:31	1440	25	12.0	23	0.01297	0.7	0.00122	0.9825	18.7	36.7	36.25

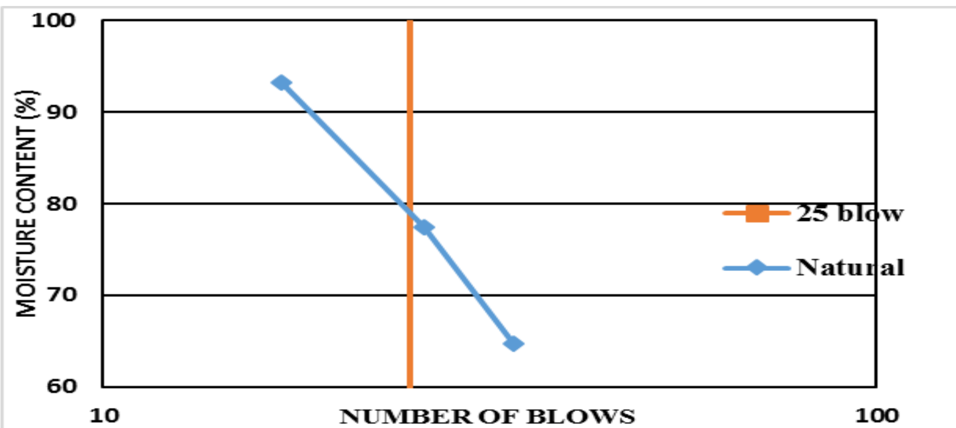
Combined Sieve Analysis

Grain Size (mm)	% passing	Combined % passing
4.75	99.6	99.6
2	98.66	98.66
1	97.52	97.52
0.85	96.32	96.32
0.425	95.86	95.86
0.15	94.08	94.08
0.075	93.5	93.5
0.040553	69.2	69.21
0.028985	67.27	67.27
0.018622	63.39	63.39
0.011025	57.58	57.58
0.007947	53.7	53.70
0.005699	49.82	49.82
0.004048	47.88	47.88
0.002927	42.07	42.07
0.002087	40.13	40.13
0.00122	36.25	36.25

APPENDIX 2.2 Atterberg Limit Test Result

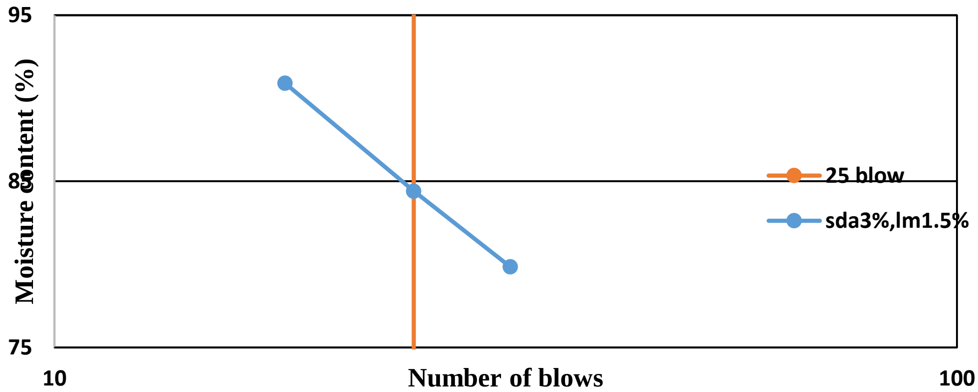
A Natural

Material location:	Jimma (kochi)				
Pit Number	sample 1 (natural)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	34	26	17		
Test No	1	2	3	1	2
Wt. of Container, (g)	17.71	17.4	28.3	29.6	18.2
Wt. of container + wet soil, (g)	26.16	30.9	45	38.4	27.1
Wt. of container + dry soil, (g)	22.84	25	36.9	36.2	25.1
Wt. of water, (g)	3.32	5.87	8.03	2.15	2.06
Wt. of dry soil, (g)	5.13	7.58	8.61	6.64	6.93
Moisture content, (%)	64.72	77.4	93.2	32.3	29.7
Average				31.0327432	

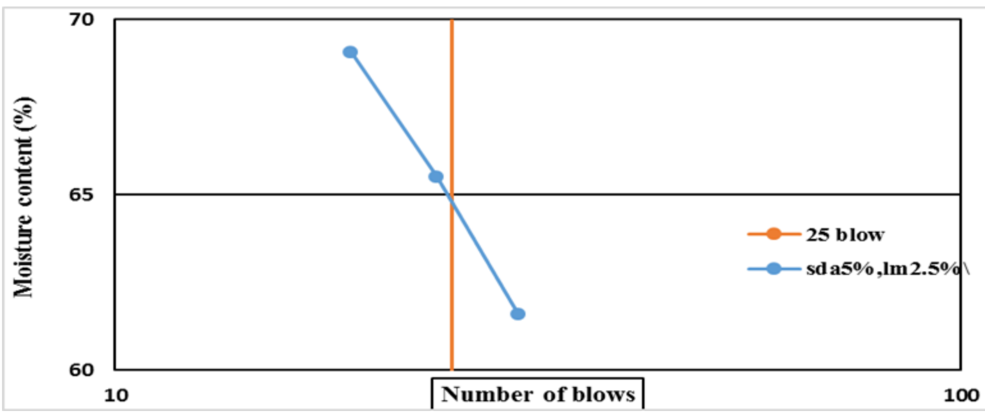


2. B SDA3% and lime 1.5%

Material location:	Jimma (kochi)				
Pit Number	sample 1 (sda 3%,lm1.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	32	25	18		
Test No	1	2	3	1	2
Wt. of Container, (g)	17.38	17.5	23	18	18.9
Wt. of container + wet soil, (g)	29.25	31.7	37.7	27.6	28.5
Wt. of container + dry soil, (g)	23.98	25.2	30.7	25.3	26.3
Wt. of water, (g)	5.27	6.5	7	2.3	2.2
Wt. of dry soil, (g)	6.6	7.7	7.7	7.3	7.4
Moisture content, (%)	79.848	84.42	90.91	31.51	29.73
Average moisture content(%)				30.61828952	



3. C. SDA 5% and lime 2.5%



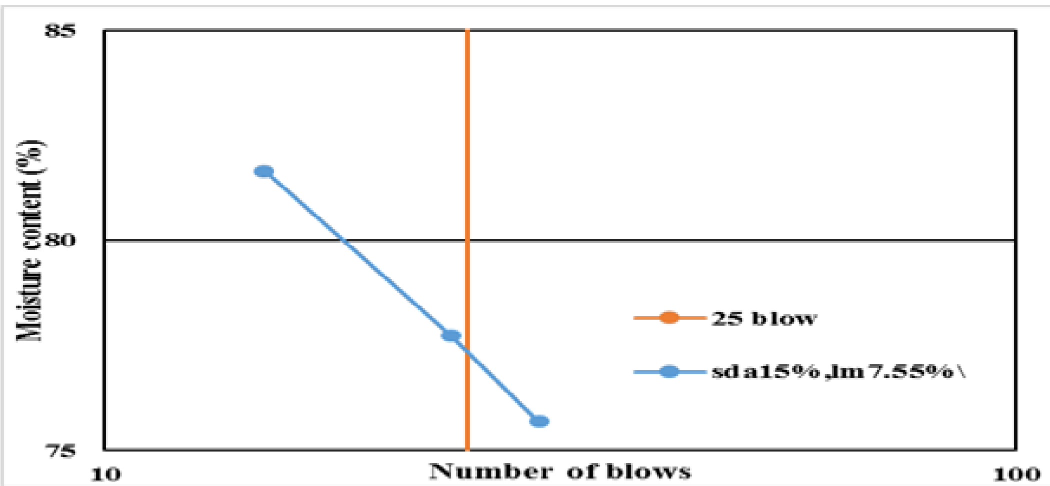
Material location:	Jimma(kochi)				
Pit Number	sample1 sda 5% & Lm 2.5%				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	30	24	19		
Test No	1	2	3	1	2
Wt. of Container, (g)	17.02	17.59	17.65	6.498	19.68
Wt. of container + wet soil, (g)	31.53	31.9	29.59	16.79	29.89
Wt. of container + dry soil, (g)	26	26.24	24.71	14.36	27.45
Wt. of water, (g)	5.531	5.665	4.879	2.432	2.44
Wt. of dry soil, (g)	8.98	8.645	7.063	7.862	7.77
Moisture content, (%)	61.59	65.53	69.08	30.93	31.403
Average moisture content (%)				31.16821804	

4. D. SDA10% and lime 5%

Material location:	Jimma(kochi)				
Pit Number	sample1 sda 10% & Lm 5%				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	32	28	19		
Test No	1	2	3	1	2
Wt. of Container, (g)	17.682	17.595	37.692	32.86	37.896
Wt. of container + wet soil, (g)	34.69	32.57	54.06	42.09	47.516
Wt. of container + dry soil, (g)	27.819	26.274	46.753	39.986	45.335
Wt. of water, (g)	6.871	6.296	7.307	2.104	2.181
Wt. of dry soil, (g)	10.137	8.679	9.061	7.126	7.439
Moisture content, (%)	67.78139	72.54292	80.642	29.52568	29.3184568
Average contents(%)				29.42206869	

5. E. SDA15% and lime 7.5%

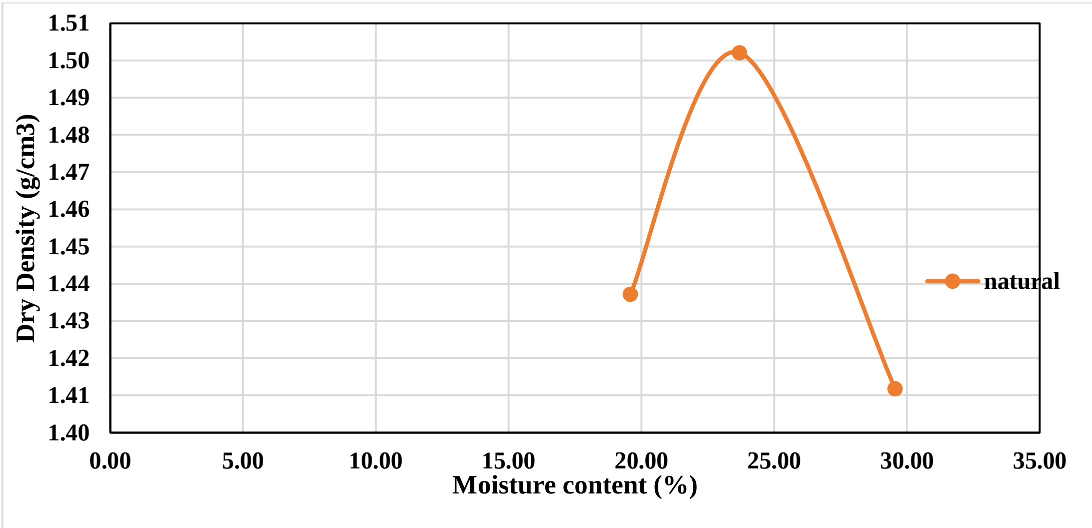
Material location:	Jimma(kochi)				
Pit Number	sample1 sda 15% & Lm 7.5%				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	30	24	15		
Test No	1	2	4	1	2
Wt. of Container, (g)	5.984	20.216	6.161	17.65	41
Wt. of container + wet soil, (g)	24.844	38.23	23.267	23.4	47.76
Wt. of container + dry soil, (g)	16.719	30.351	15.578	21.962	46.22
Wt. of water, (g)	8.125	7.879	7.689	1.438	1.54
Wt. of dry soil, (g)	10.735	10.135	9.417	4.312	5.22
Moisture content, (%)	75.687	77.7405	81.65021	33.349	29.50192
Average moisture contents(%)				31.42535489	



APPENDIX 2.3 Compaction Test Result

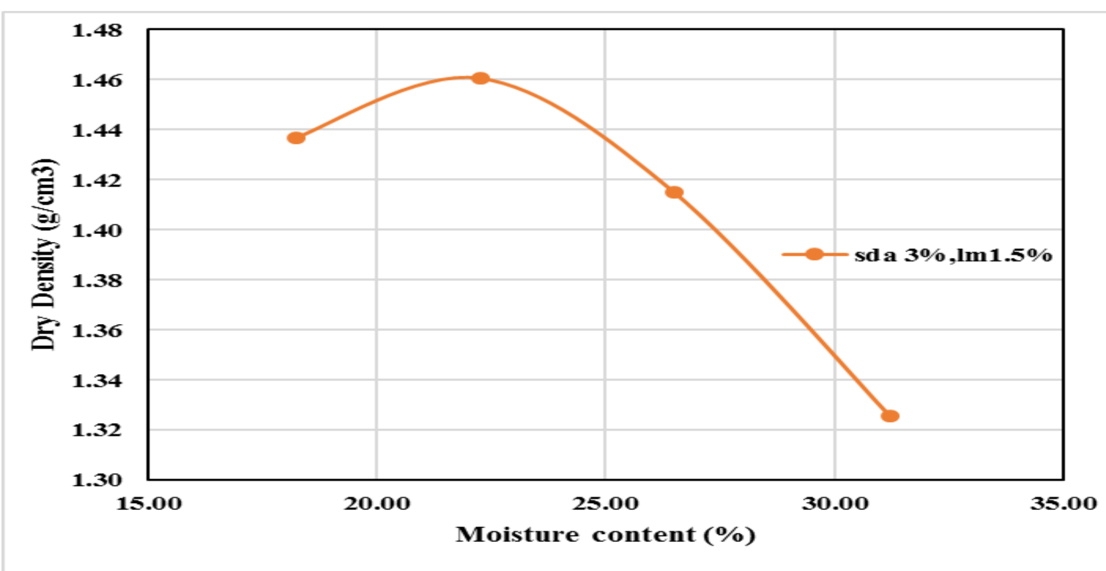
A. Natural

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%	Average Moisture content,%	Dry density (g/cm^3)
1	10440.8	3540.6	1.72	NC 23	37.91	139.82	122.02	17.80	84.11	21.16	19.58	1.44
				D31	17.65	124.49	108.19	16.30	90.54	18.00		
2	10361.1	3827.9	1.86	B-1	40.792	154.18	132.2	21.98	91.41	24.05	23.70	1.50
				HC12	18.224	97.456	82.46	15.00	64.24	23.35		
3	10301.5	3768.3	1.83	LB1	33.56	174.26	142.27	31.99	108.71	29.43	29.55	1.41
				G73	17.83	104.51	84.67	19.84	66.84	29.68		
										From plot OMC = 22.5 %		
										MDD = 1.50 g/cm^3		



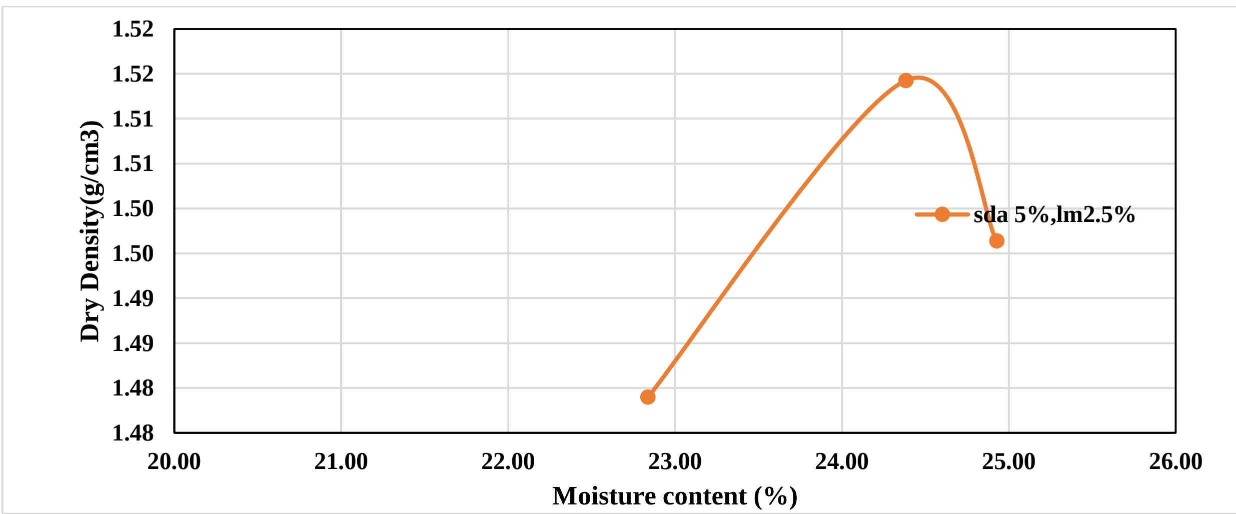
B SDA3% and lime 1.5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can no	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10120.2	3500	1.70	NC 23	28.31	120.93	106.37	14.56	78.06	18.65	18.24	1.44
				D31	32.71	132.47	117.379	15.09	84.67	17.82		
2	10212.5	3679.3	1.79	B-1	17.56	111.19	94.15	17.04	76.59	22.25	22.27	1.46
				HC12	18.01	127.43	107.49	19.94	89.48	22.28		
3	10258.3	3688.1	1.79	LB1	37.64	161.358	135.14	26.22	97.50	26.89	26.50	1.42
				G73	33.07	203.81	168.47	35.34	135.40	26.10		
4	10154	3583.8	1.74	3	17.71	160.575	125.8	34.78	108.09	32.17	31.21	1.33
				LC 22	17.05	189.28	149.29	39.99	132.24	30.24		
											1.38	
										From plot OMC = 23		
										MDD = 1.51g/cm^3		



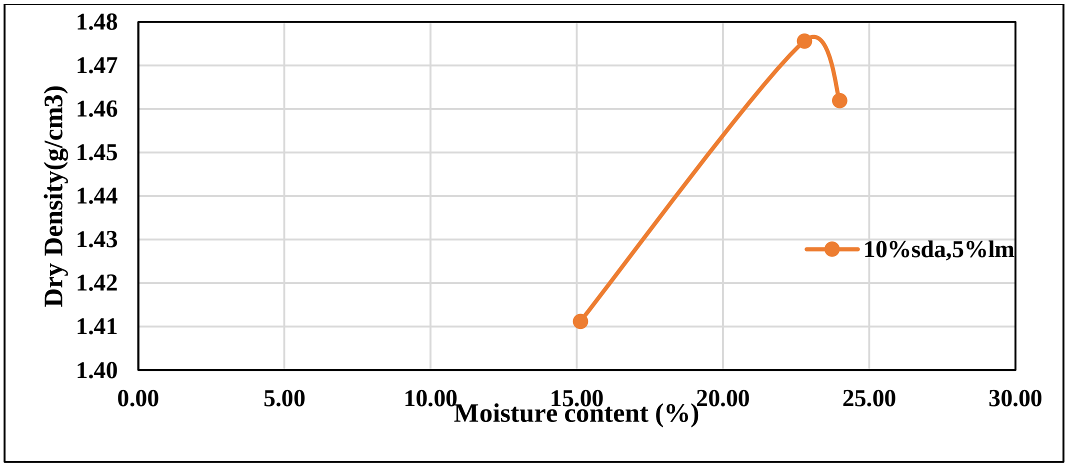
C. SDA5% and lime 2.5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10320.2	3742.95	1.82	NC 23	29.2	142.08	121.155	20.93	91.96	22.76	22.84	1.48
				D31	18.39	115.73	97.58	18.15	79.19	22.92		
2	10413.7	3880.45	1.88	B-1	35.41	129.01	109.21	19.80	73.80	26.83	24.38	1.51
				HC12	27.13	134.85	115.47	19.38	88.34	21.94		
3	10384.6	3851.4	1.87	LB1	35.63	157.92	133.31	24.61	97.68	25.19	24.93	1.50
				G73	27.64	113.45	96.475	16.98	68.84	24.66		
										From plot OMC = 24.5 %		
										MDD = 1.52 g/cm^3		



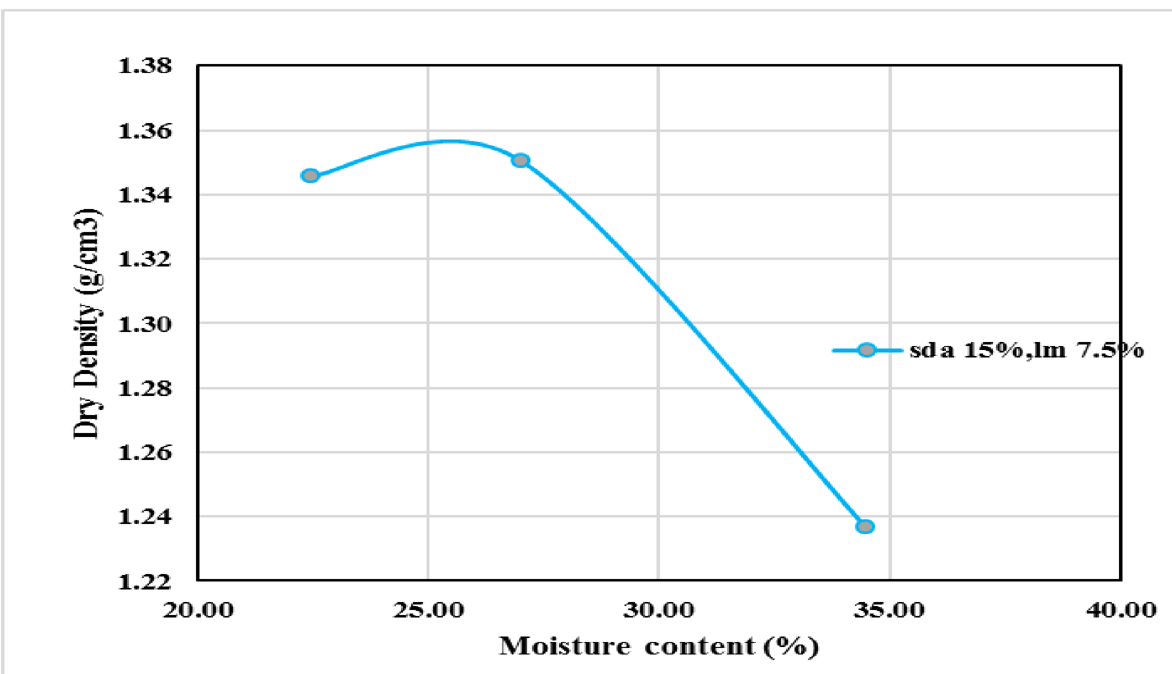
D. SDA10% and lime 5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can no	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10180.5	3347.3	1.62	NC 23	17.608	127.98	110.11	17.87	92.50	19.32	15.13	1.41
				D31	18.55	123	112.7	10.30	94.15	10.94		
2	10466.2	3733	1.81	B-1	37.69	141.58	120.35	21.23	82.66	25.68	22.79	1.48
				HC12	37.44	122.38	108.28	14.10	70.84	19.90		
3	10467.7	3734.5	1.81	LB1	32.9	111.8	96.4	15.40	63.50	24.25	23.99	1.46
				G73	36.6	143.2	122.75	20.45	86.15	23.74		
4	10336.4	3603.2	1.75	3	36.42	151.31	124.48	26.83	88.06	30.47	31.00	1.34
				LC 22	34.64	159.1	129.26	29.84	94.62	31.54		
										From plot OMC 25 %		
										MDD = 1.47g/cm^3		



E. SDA15% and lime 7.5%

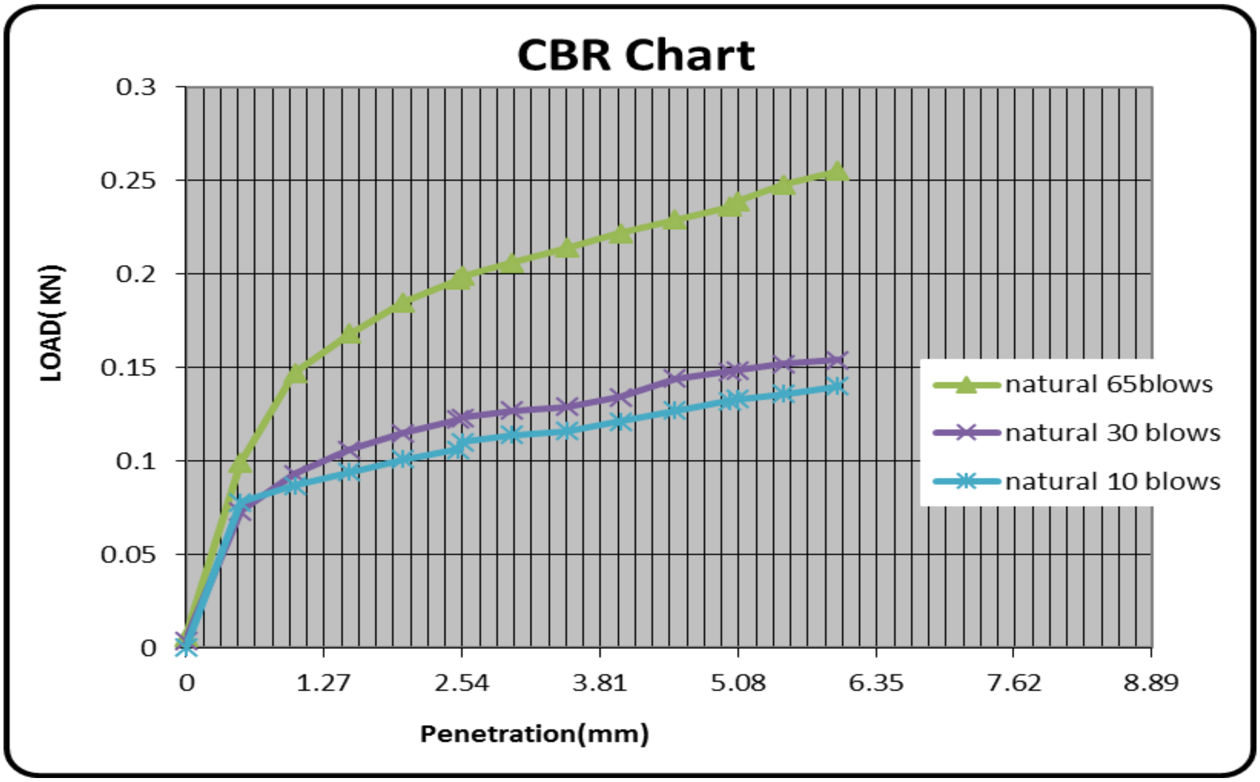
Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%	Average Moisture content,%	Dry density (g/cm^3)
1	10000.2	3399.7	1.65	ZE	33.07	150.26	128.97	21.29	95.90	22.20	22.45	1.35
				A-IC	49.69	173.69	150.75	22.94	101.06	22.70		
2	10073.7	3538.5	1.72	2-Feb	28.74	128.51	107.46	21.05	78.72	26.74	27.00	1.35
				SG-1	26.74	151.28	124.6	26.68	97.86	27.26		
3	9966.2	3431	1.66	G1	32.86	188.65	149.075	39.58	116.22	34.05	34.48	1.24
				RG	37.51	210.23	165.54	44.69	128.03	34.91		
										OMC=24%		
										MDD= 1.345g/cm^3		



2.4 CBR Curves with varying percentage of SDA and lime

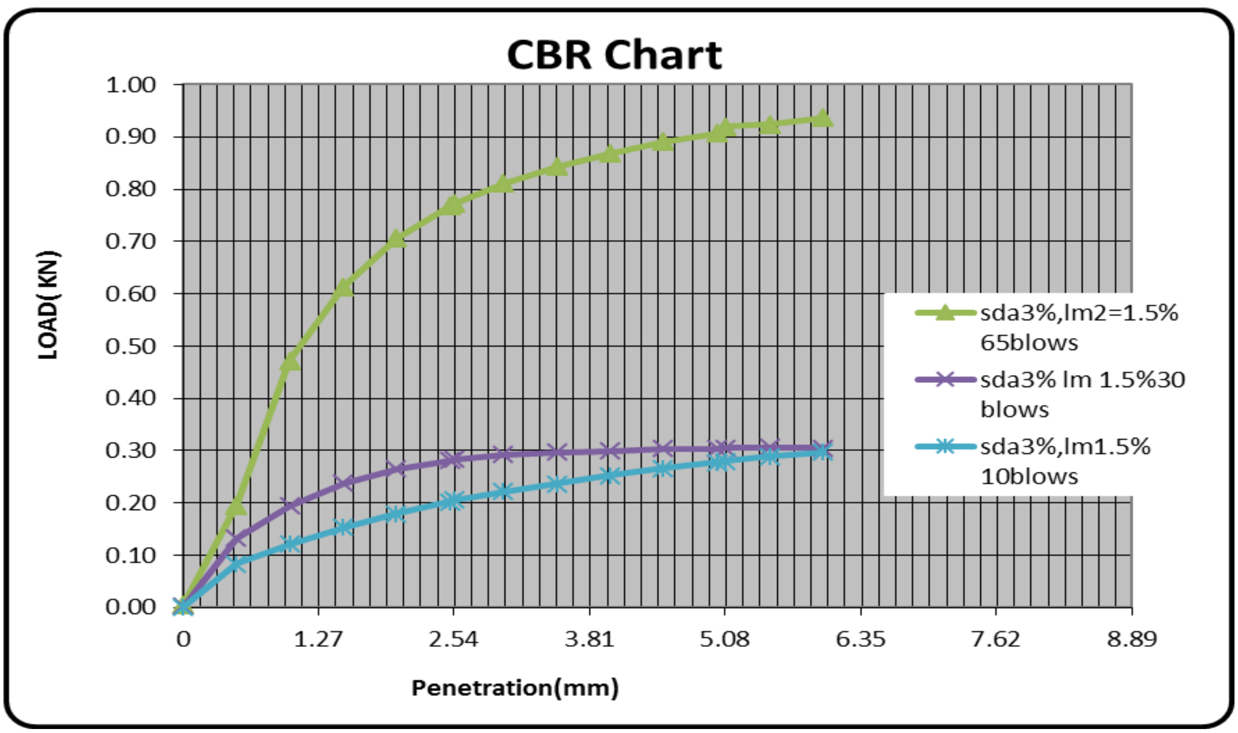
A. Natural

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load,KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.006		0.00	0.004		0.00	0.00	
0.50	0.099		0.50	0.073		0.50	0.08	
1.00	0.147		1.00	0.093		1.00	0.09	
1.50	0.168		1.50	0.106		1.50	0.09	
2.00	0.185		2.00	0.115		2.00	0.10	
2.50	0.197		2.50	0.122		2.50	0.11	
2.54	0.20	1.49	2.54	0.12	0.92	2.54	0.11	0.83
3.00	0.206		3.00	0.127		3.00	0.114	
3.50	0.214		3.50	0.129		3.50	0.116	
4.00	0.222		4.00	0.134		4.00	0.121	
4.50	0.229		4.50	0.144		4.50	0.127	
5.00	0.236		5.00	0.148		5.00	0.132	
5.08	0.24	1.20	5.08	0.15	0.74	5.08	0.13	0.67
5.50	0.25		5.50	0.152		5.50	0.14	
6.00	0.26		6.00	0.154		6.00	0.14	



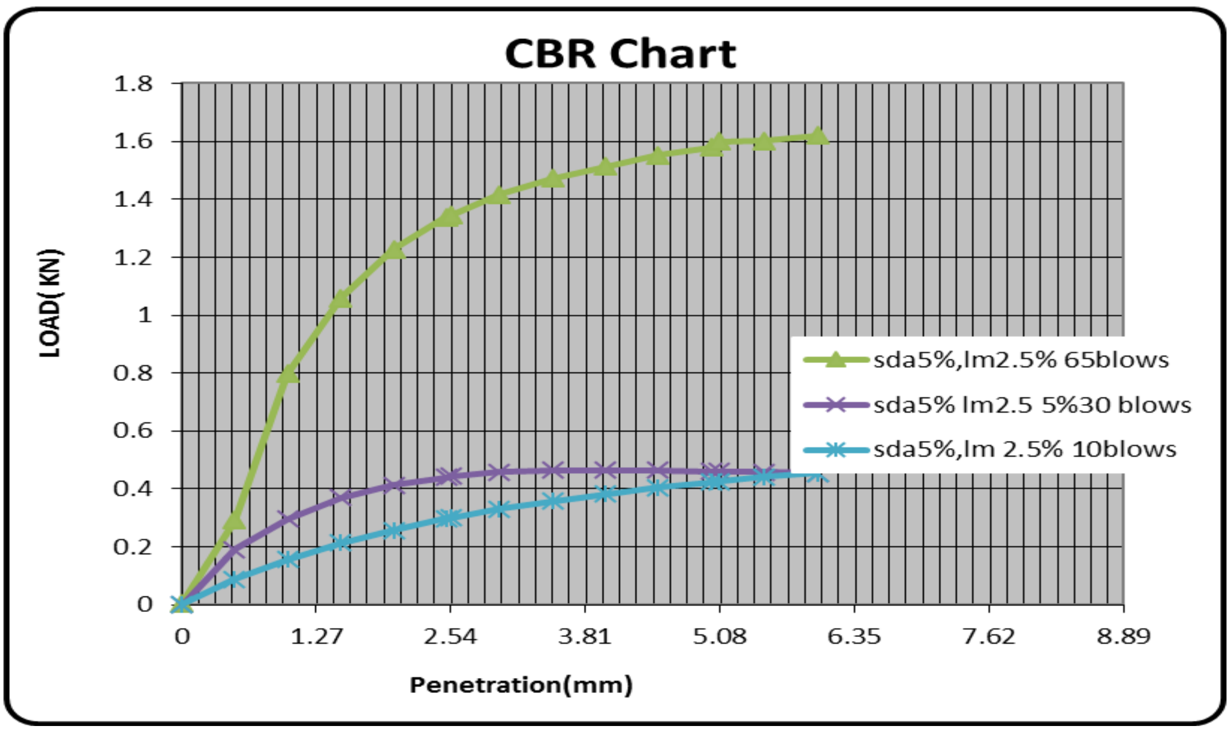
B. 3% SDA and 1.5% lime

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.01		0.00	0.00		0.00	0.00	
0.50	0.10		0.50	0.15		0.50	0.11	
1.00	0.18		1.00	0.18		1.00	0.18	
1.50	0.21		1.50	0.20		1.50		
2.00	0.23		2.00	0.24		2.00		
2.50	0.24		2.50	0.25		2.50	0.23	
2.54	0.25	1.88	2.54	0.27	2.02	2.54	0.27	2.00
3.00	0.26		3.00	0.28		3.00		
3.50	0.27		3.50	0.29		3.50		
4.00	0.28		4.00	0.31		4.00		
4.50	0.29		4.50	0.32		4.50		
5.00	0.30		5.00	0.33		5.00		
5.08	0.31	1.53	5.08	0.35	1.75	5.08	0.34	1.71
5.50	0.32		5.50	0.36		5.50		
6.00	0.34		6.00	0.36		6.00	0.37	



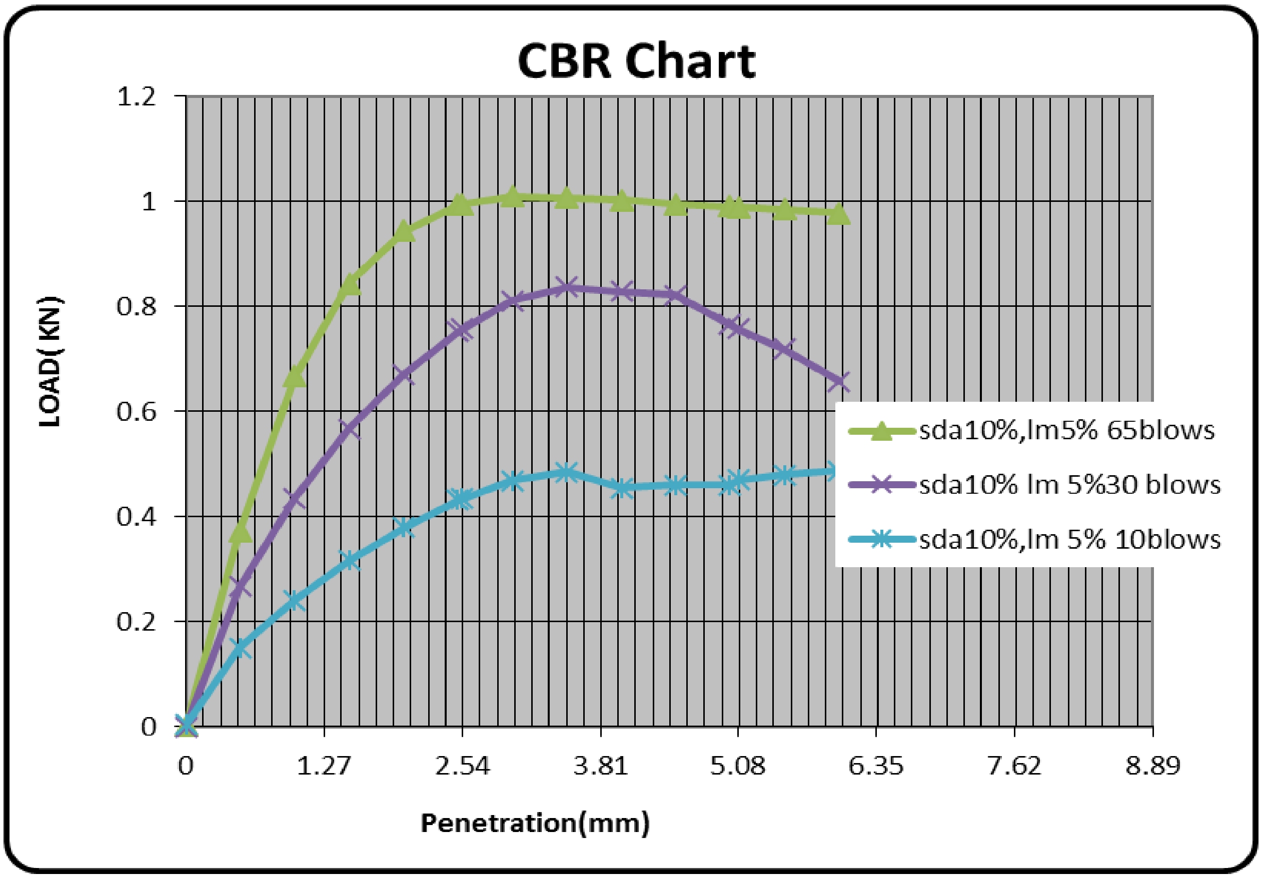
C. SDA 5% and lime 2.5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.005		0.00	0		0.00	0.002	
0.50	0.291		0.50	0.191		0.50	0.089	
1.00	0.797		1.00	0.295		1.00	0.156	
1.50	1.058		1.50	0.369		1.50	0.213	
2.00	1.227		2.00	0.414		2.00	0.257	
2.50	1.339		2.50	0.44		2.50	0.297	
2.54	1.35	10.08	2.54	0.44	3.32	2.54	0.30	2.25
3.00	1.416		3.00	0.458		3.00	0.33	
3.50	1.471		3.50	0.464		3.50	0.357	
4.00	1.514		4.00	0.464		4.00	0.383	
4.50	1.553		4.50	0.464		4.50	0.405	
5.00	1.578		5.00	0.46		5.00	0.424	
5.08	1.60	8.00	5.08	0.46	2.31	5.08	0.43	2.13
5.50	1.601		5.50	0.459		5.50	0.44	
6.00	1.619		6.00	0.455		6.00	0.45	



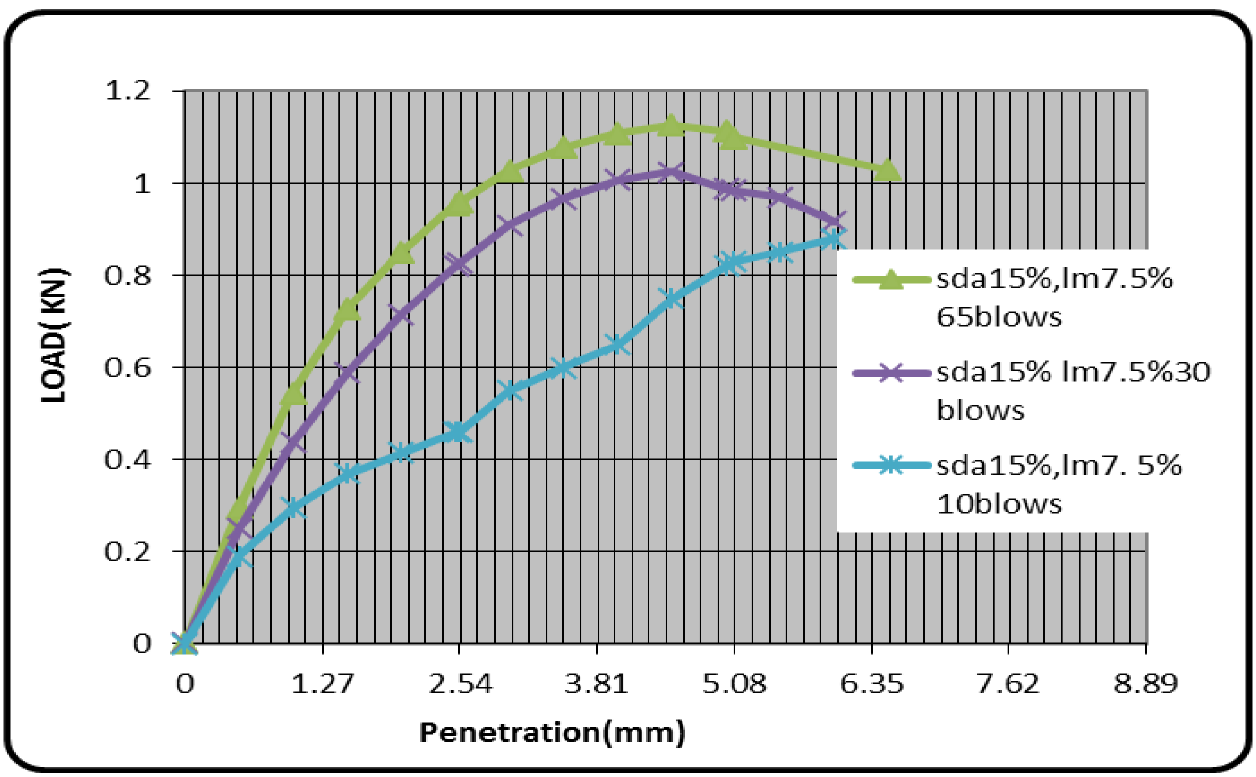
D. SDA 10% and 5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.001		0.00	0		0.00	0.004	
0.50	0.373		0.50	0.267		0.50	0.15	
1.00	0.667		1.00	0.436		1.00	0.241	
1.50	0.844		1.50	0.568		1.50	0.316	
2.00	0.944		2.00	0.672		2.00	0.38	
2.50	0.994		2.50	0.753		2.50	0.431	
2.54	1.00	7.46	2.54	0.76	5.68	2.54	0.43	3.25
3.00	1.01		3.00	0.811		3.00	0.468	
3.50	1.007		3.50	0.837		3.50	0.485	
4.00	1.003		4.00	0.829		4.00	0.46	
4.50	0.995		4.50	0.822		4.50	0.30	
5.00	0.991		5.00	0.766		5.00	0.32	
5.08	0.99	4.95	5.08	0.76	3.79	5.08	0.32	1.58
5.50	0.986		5.50	0.719		5.50	0.29	
6.00	0.978		6.00	0.658		6.00	0.49	

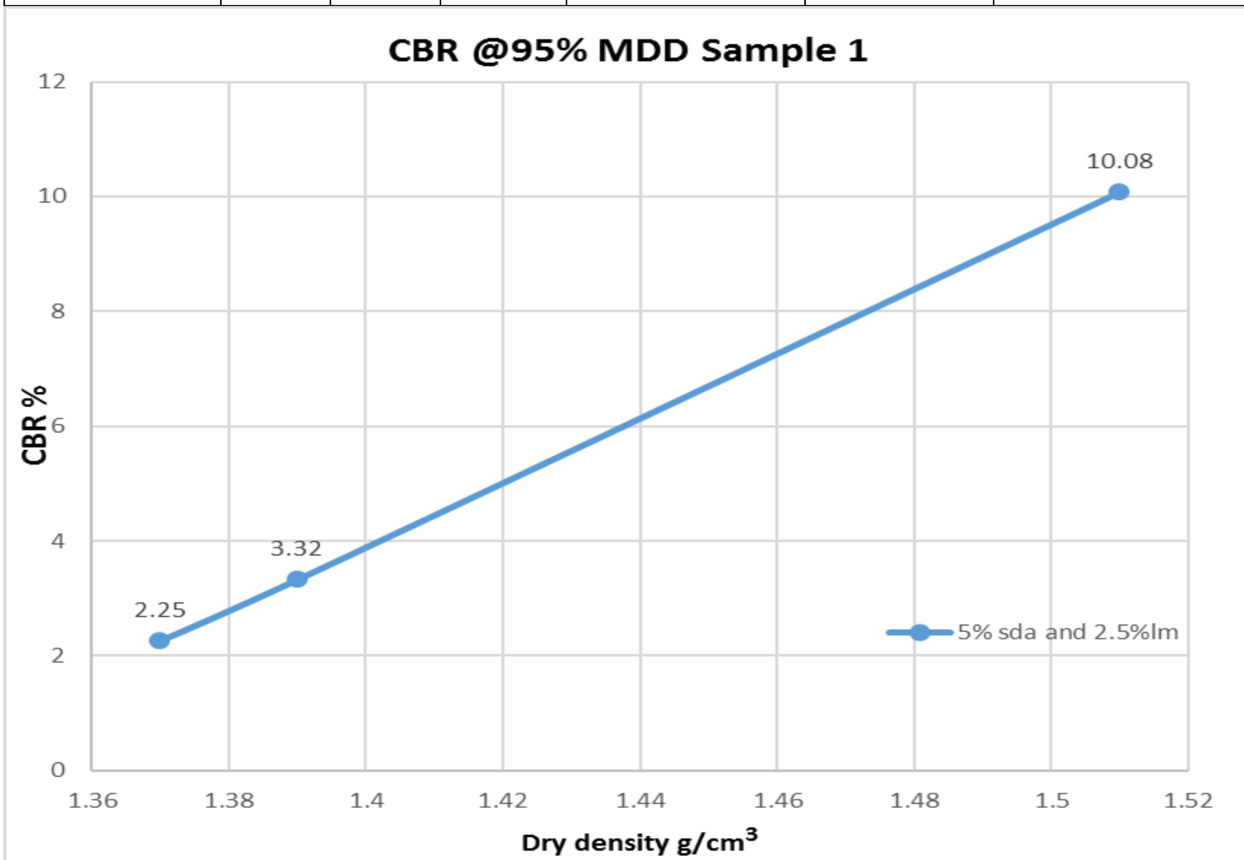


E. SDA 15% and 7.5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.003		0.00	0.003		0.00	0.00	
0.50	0.295		0.50	0.251		0.50	0.19	
1.00	0.544		1.00	0.437		1.00	0.30	
1.50	0.729		1.50	0.59		1.50	0.37	
2.00	0.851		2.00	0.715		2.00	0.41	
2.50	0.953		2.50	0.82		2.50	0.46	
2.54	0.96	7.19	2.54	0.83	6.20	2.54	0.46	3.45
3.00	1.028		3.00	0.908		3.00	0.55	
3.50	1.077		3.50	0.967		3.50	0.60	
4.00	1.109		4.00	1.006		4.00	0.65	
4.50	1.126		4.50	1.024		4.50	0.75	
5.00	1.11		5.00	0.987		5.00	0.82	4.10
5.08	1.10	5.49	5.08	0.98	4.92	5.08	0.83	
6.50	1.029		5.50	0.97		5.50	0.85	
7.00	0.981		6.00	0.917		6.00	0.88	



Number of blows	10	30	65	MDD,g/cm^3	1.5	OMC,%	24.5
Soaked CBR,%	2.25	3.32	10.08	Density required,%	95	Target density,g/cm^3	1.43
Density g/cm^3	1.37	1.39	1.51	CBR,%	6.10%		



APPENDEX 3 Laboratory Test Result Analysis of Sample 2

APPENDIX 3.1 Grain size Analysis

Wet Sieve Analysis

Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage passing
4.75	12.42	0.73295958	0.73	99.27
2	45.59	2.69046916	3.42	96.58
1	12.96	0.76482738	4.19	95.81
0.85	0.79	0.04662142	4.23	95.77
0.425	5.08	0.29979345	4.53	95.47
0.15	7.74	0.45677191	4.99	95.01
0.075	5.17	0.30510475	5.3	94.7

Hydrometer Analysis

Time	Elapsed time t	Actual Hydrom	Eff.depth,L (cm)	Temperature (c0)	K	C_T	Par.diameter D (mm)	Value of 'a' for Gs=2.62	Corrected	% Finer D,P(%)	corrected (Pa)
9:32	1	41	9.4	23	0.02674	0.7	0.040553	0.982484	34.7	68.2	66.17
9:33	2	39.5	9.7	23	0.02674	0.7	0.028985	0.982484	33.2	65.2	63.31
9:37	5	38	9.9	23	0.02674	0.7	0.018622	0.982484	31.7	62.3	60.45
9:47	15	36.5	10.1	23	0.02674	0.7	0.011025	0.982484	30.2	59.3	57.59
4:01	30	34	10.6	23	0.02674	0.7	0.007947	0.982484	27.7	54.4	52.82
4:31	60	31	11.0	23	0.02674	0.7	0.005699	0.982484	24.7	48.5	47.10
5:31	120	30.5	11.1	23	0.02674	0.7	0.004048	0.982484	24.2	47.6	46.15
7:31	240	28	11.5	23	0.02674	0.7	0.002927	0.982484	21.7	42.6	41.38
11:31	480	26	11.9	23	0.02674	0.7	0.002087	0.982484	19.7	38.7	37.57
9:31	1440	24.5	12.1	23	0.02674	0.7	0.00122	0.982484	18.2	35.8	34.71

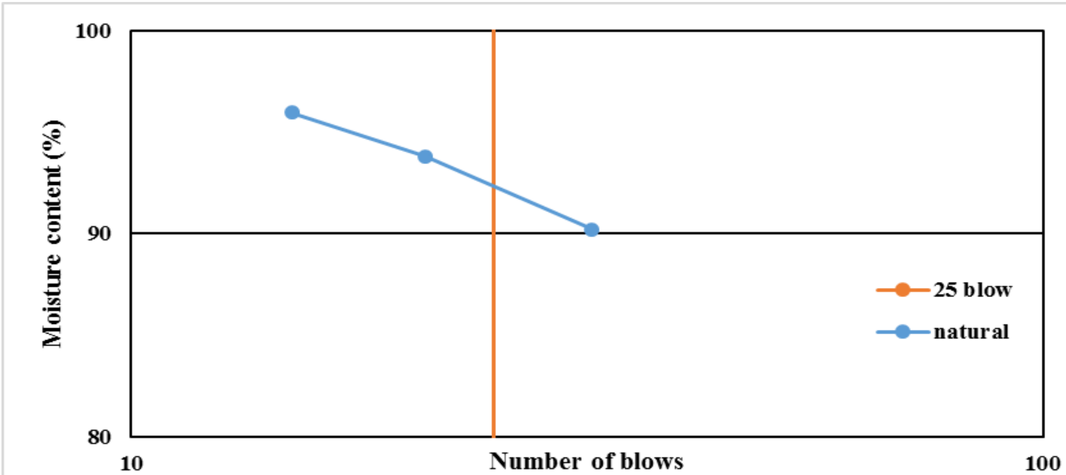
Combined Sieve Analysis

Grain Size (mm)	% passing	Combined % passing
4.75	99.27	99.27
2	96.58	96.58
1	95.81	95.81
0.85	95.76	95.76
0.425	95.46	95.46
0.15	95	95
0.075	94.7	94.7
0.0405532	66.17	66.17
0.0289855	63.31	63.31
0.0186223	60.45	60.45
0.0110252	57.59	57.59
0.0079474	52.82	52.82
0.0056986	47.1	47.1
0.004048	46.15	46.15
0.0029267	41.38	41.38
0.0020874	37.57	37.57
0.0012205	34.71	34.71

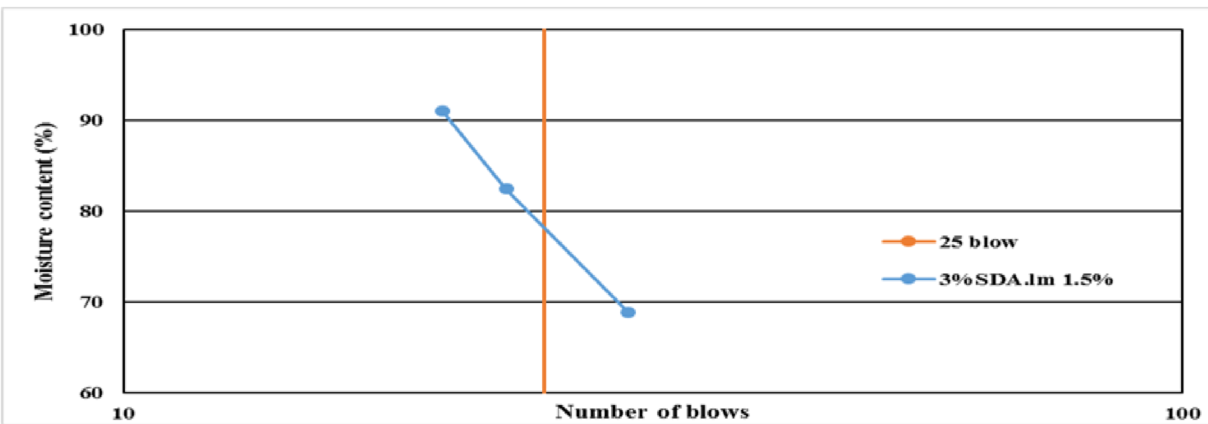
APPENDIX 3.2 Atterberg Limit Test Result

A. Natural

Material location:	Jimma (Shanen Gibe)				
Pit Number	Sample 2(natural)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	32	21	15		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.64	17.58	17.50	17.59	17.91
Wt. of container + wet soil, (g)	31.00	35.00	32.00	26.12	23.72
Wt. of container + dry soil, (g)	24.66	26.57	24.90	23.10	23.08
Wt. of water, (g)	6.34	8.43	7.10	3.03	0.64
Wt. of dry soil, (g)	7.03	8.99	7.40	5.51	5.17
Moisture container, (%)	90.19	93.80	95.95	54.88	12.31
Average moisture contents(%)				33.60	



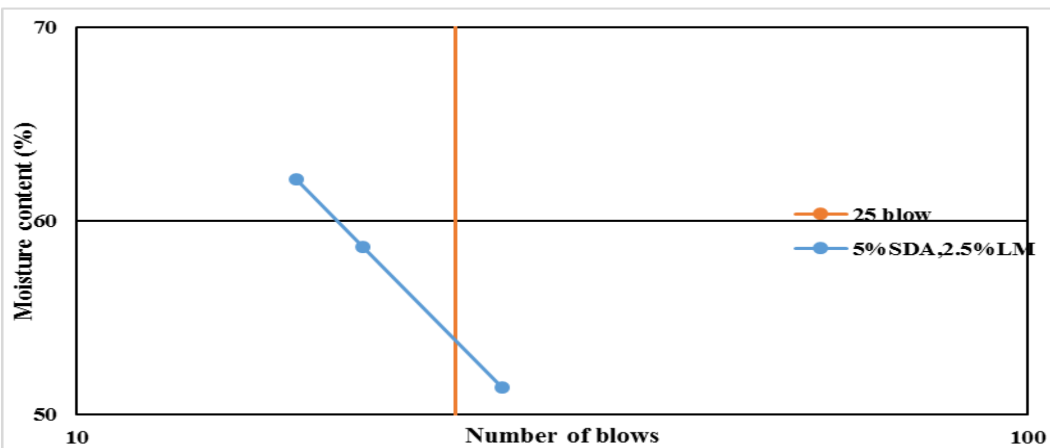
B. SDA 3%, Lime1.5%



Material location:	Jimma (Shanen Gibe)				
Pit Number	Sample 2(sda3%,lm1.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	30	23	20		
Test No	01	02	03	01	02
Wt. of Container, (g)	24.39	5.55	6.22	24.41	7.66
Wt. of container + wet soil, (g)	46.95	31.00	32.91	39.29	23.50
Wt. of container + dry soil, (g)	37.75	19.50	20.19	35.43	19.47
Wt. of water, (g)	9.20	11.50	12.72	3.86	4.03
Wt. of dry soil, (g)	13.36	13.95	13.97	11.02	11.81
Moisture content, (%)	68.83	82.41	91.05	34.99	34.12
Average				34.56	

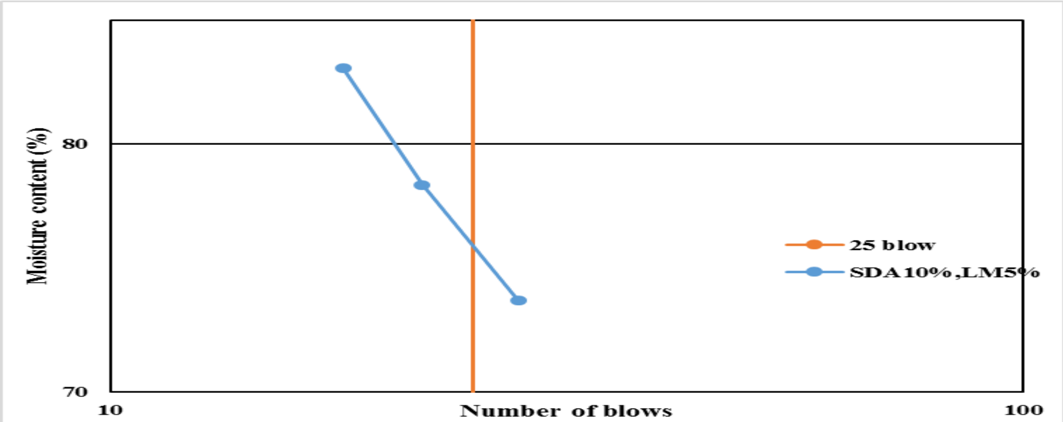
C. SDA 5%, Lime2.5%

Material location:	Jimma(Shanen Gibe)				
Pit Number	Sample 2(sda5%,lm2.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	28	20	17		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.62	20.78	7.65	17.57	28.80
Wt. of container + wet soil, (g)	38.87	43.60	31.92	25.66	36.80
Wt. of container + dry soil, (g)	31.66	35.17	22.62	23.31	35.04
Wt. of water, (g)	7.21	8.44	9.30	2.35	1.76
Wt. of dry soil, (g)	14.04	14.39	14.97	5.74	6.24
Moisture content, (%)	51.39	58.63	62.14	41.01	28.28
Average moisture contents(%)				34.64	



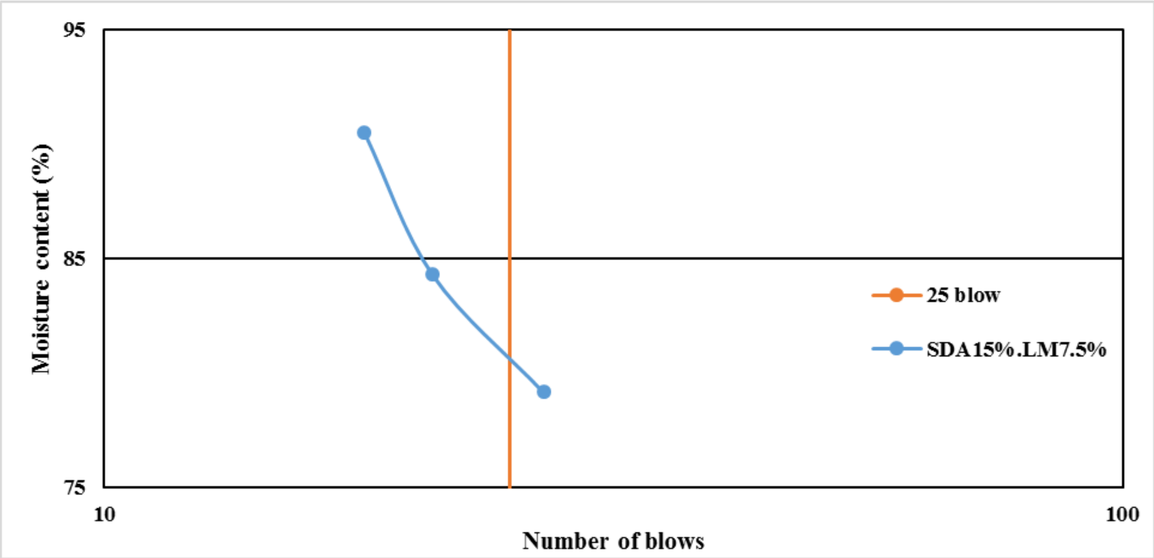
D. SDA 10%, Lime5%

Material location:	Jimma(Shanen Gibe)				
Pit Number	Sample 2(sda10%,lm 5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	28	22	18		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.10	19.50	6.10	17.69	5.46
Wt. of container + wet soil, (g)	41.60	49.10	35.70	26.48	20.80
Wt. of container + dry soil, (g)	31.20	36.10	22.27	24.23	16.78
Wt. of water, (g)	10.40	13.00	13.43	2.24	4.02
Wt. of dry soil, (g)	14.10	16.60	16.17	6.54	11.32
Moisture content, (%)	73.71	78.36	83.07	34.29	35.52
Average moisture contents (%)				34.90	



E.SDA 15%, Lime7.5%

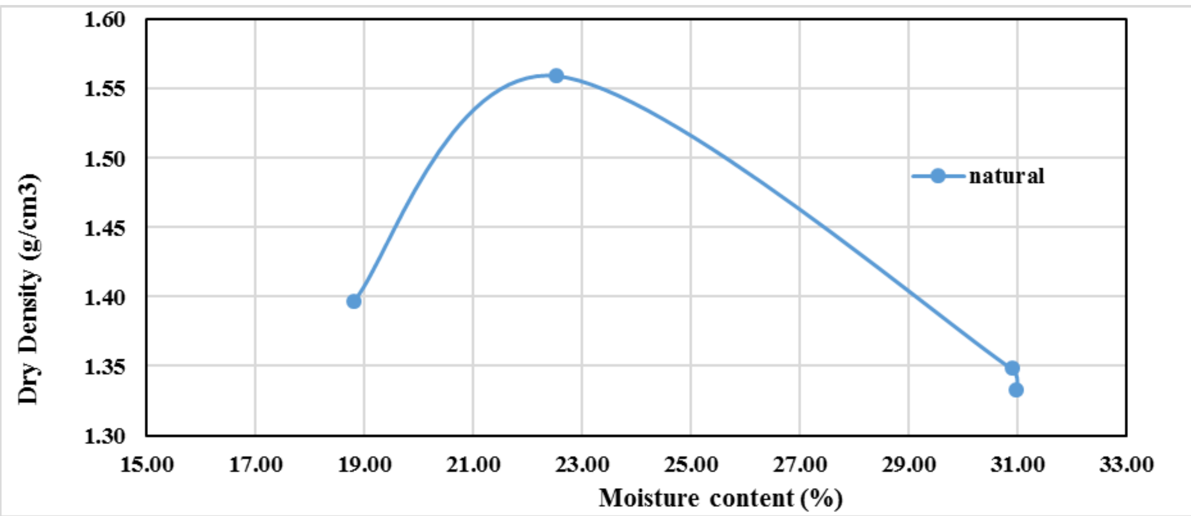
Material location:	Jimma (Shanen Gibe)				
Pit Number	Sample 2(sda5%,lm7.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	27	21	18		
Test No	01	02	03	01	02
Wt. of Container, (g)	25.38	17.95	17.84	17.18	17.41
Wt. of container + wet soil, (g)	39.13	29.99	31.00	25.47	25.97
Wt. of container + dry soil, (g)	33.05	24.48	24.75	23.52	23.79
Wt. of water, (g)	6.08	5.51	6.25	1.95	2.18
Wt. of dry soil, (g)	7.67	6.53	6.91	6.34	6.38
Moisture content, (%)	79.18	84.29	90.48	30.77	34.09
Average moisture contents				32.43	



APPENDIX 3.3 Compaction Test Result

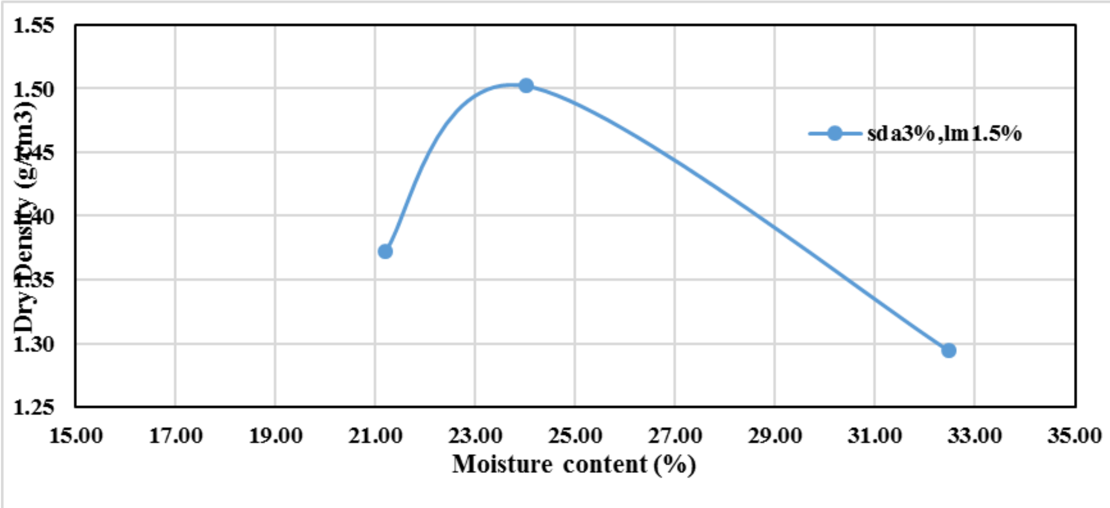
Natural

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10108.9	3418.3	1.66	MM	17.672	120.033	105.335	14.70	87.66	16.77	18.81	1.40
				G3T3	17.558	106.691	91.31	15.38	73.75	20.86		
2	10537.3	3937.1	1.91	205	18.83	88.936	75.809	13.13	56.98	23.04	22.54	1.56
				MK	17.759	105.181	89.388	15.79	71.63	22.05		
3	10239.4	3636	1.76	P66	37.45	150.655	123.756	26.90	86.31	31.17	30.90	1.35
				113	31.947	179.62	144.992	34.63	113.05	30.63		
4	10206.4	3596.2	1.75	P15	33.608	156.334	129.532	26.80	95.92	27.94	30.99	1.33
				P3	25.301	166.75	130.835	35.92	105.53	34.03		
										From plot OMC = 22.5%		
										MDD = 1.560g/cm^3		

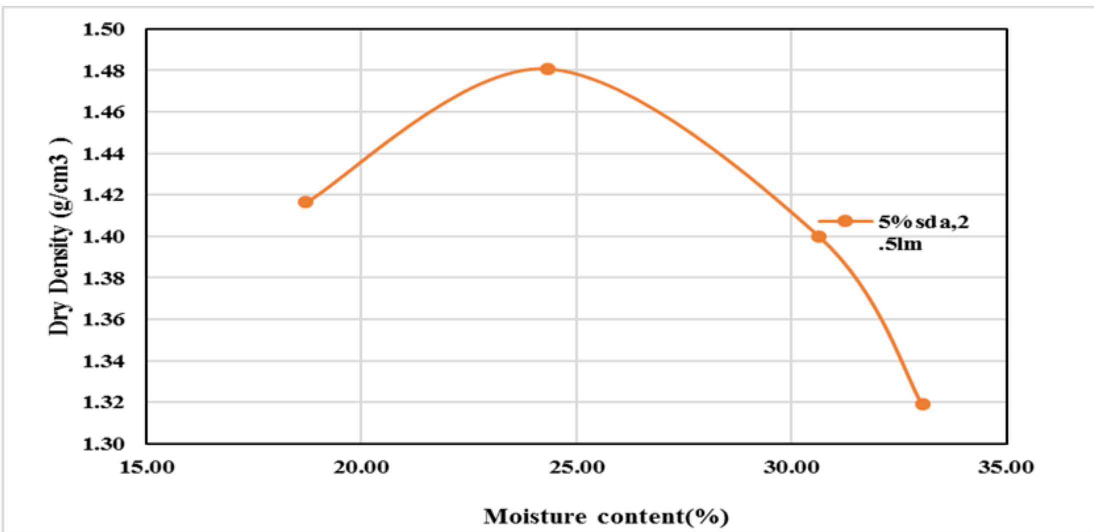


SDA3% and lime 1.5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
2	10067	3426.2	1.66	14	37.528	142.763	125.86	16.90	88.33	19.14	21.20	1.37
				K	17.437	80.343	68.472	11.87	51.04	23.26		
3	10479	3838.7	1.86	G3T3	17.919	119.664	100.545	19.12	82.63	23.14	24.03	1.50
				T10	25.425	183.727	152.157	31.57	126.73	24.91		
4	10155	3532.5	1.71	B3	17.415	100.905	80.67	20.24	63.26	31.99	32.48	1.29
				3-Mar	17.485	86.886	69.681	17.21	52.20	32.96		
											From plot OMC 23.5 %	
											MDD = 1.51g/cm^3	



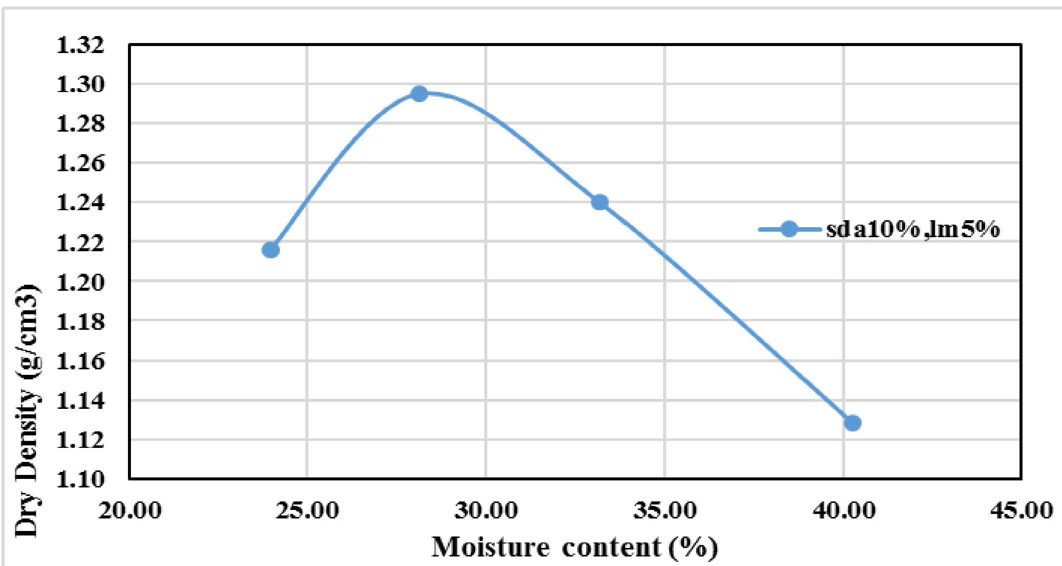
C. SDA5% and lime 2.5%



Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10137.8	3464.2	1.68	J41	32.735	185.127	161.439	23.69	128.70	18.41	18.70	1.42
				HC51	17.659	131.807	113.579	18.23	95.92	19.00		
2	10488.5	3793.2	1.84	HCII	17.652	93.147	78.41	14.74	60.76	24.26	24.33	1.48
				T5C2	18.011	104.756	87.7378	17.02	69.73	24.41		
3	10458.8	3768.5	1.83	13	18.241	103.733	83.748	19.99	65.51	30.51	30.64	1.40
				NB	17.605	91.345	73.99	17.36	56.39	30.78		
4	10289.4	3615.8	1.76	A	7.661	121.13	93.524	27.61	85.86	32.15	33.05	1.32
				T1C1	17.619	117.438	92.141	25.30	74.52	33.95		
										From plot OMC = 24%		
										MDD = 1.480 g/cm^3		

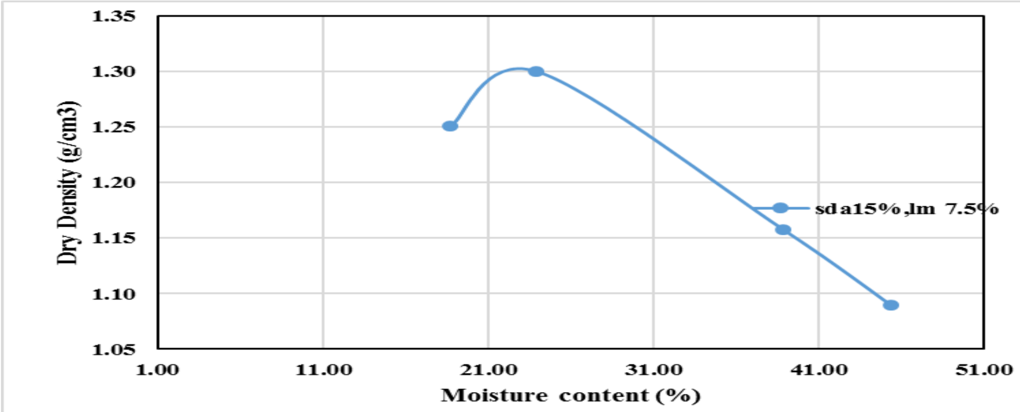
D. SDA10% and lime 5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g		Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	9800.4	3110.1	1.51	TT	17.42	101.12	84.697	16.42	67.28	24.41	23.96	1.22
				`	17.585	74.039	63.296	10.74	45.71	23.50		
2	10045.1	3422.9	1.66	C	32.886	144.816	119.272	25.54	86.39	29.57	28.12	1.29
				G1	17.72	83.169	69.386	13.78	51.67	26.68		
3	10004.8	3407.2	1.65	P2	17.761	138.856	108.848	30.01	91.09	32.94	33.18	1.24
				K	18.156	132.62	103.956	28.66	85.80	33.41		
4	9937	3264.7	1.58	D	17.588	153.282	114.302	38.98	96.71	40.30	40.27	1.13
				36-3	17.192	131.515	98.714	32.80	81.52	40.24		
										OMC=23.5%		
										MDD	1.300g/cm^3	



E. SDA15% and lime 7.5%

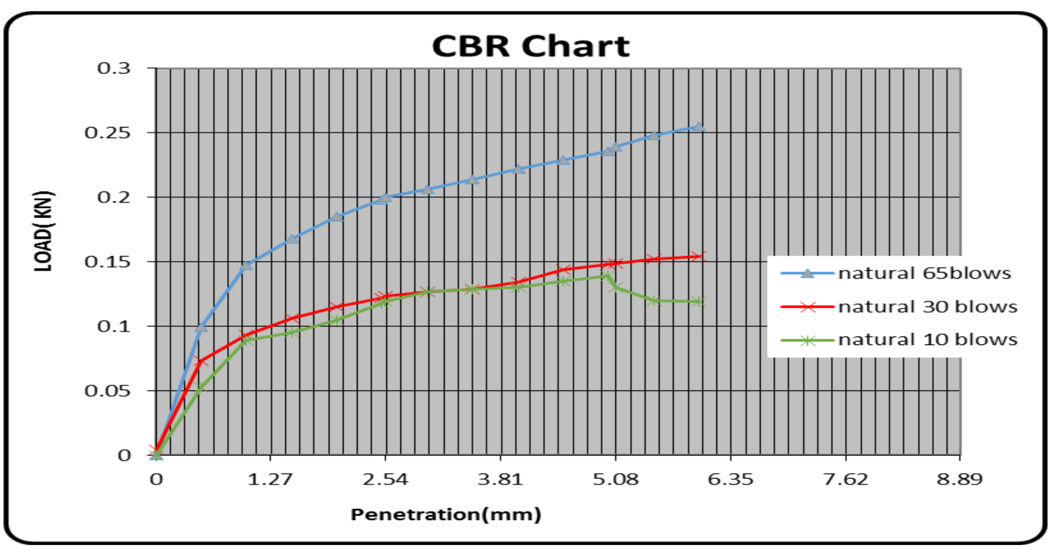
Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	9709.1	3059	1.48	p10	17.64	99.644	86.524	13.12	68.88	19.05	18.73	1.25
				T10	17.15	100.159	87.253	12.91	70.10	18.41		
2	9870	3319.4	1.61	Y	19.622	63.304	56.489	6.82	36.87	18.49	23.93	1.30
				G	18.222	98.172	80.017	18.16	61.80	29.38		
3	9961.9	3311.6	1.61	A7	17.587	64.08	51.136	12.94	33.55	38.58	38.84	1.16
				P15	20.789	84.842	66.836	18.01	46.05	39.10		
4	9814	3263.5	1.58	HPL1	6.172	94.917	67.128	27.79	60.96	45.59	45.34	1.09
				L1	6.43	100.534	71.289	29.25	64.86	45.09		
										From plot OMC =23 %		
										MDD = 1.3g/cm^3		



APPENDIX 3.4 CBR Curves with varying percentage of SDA and lime

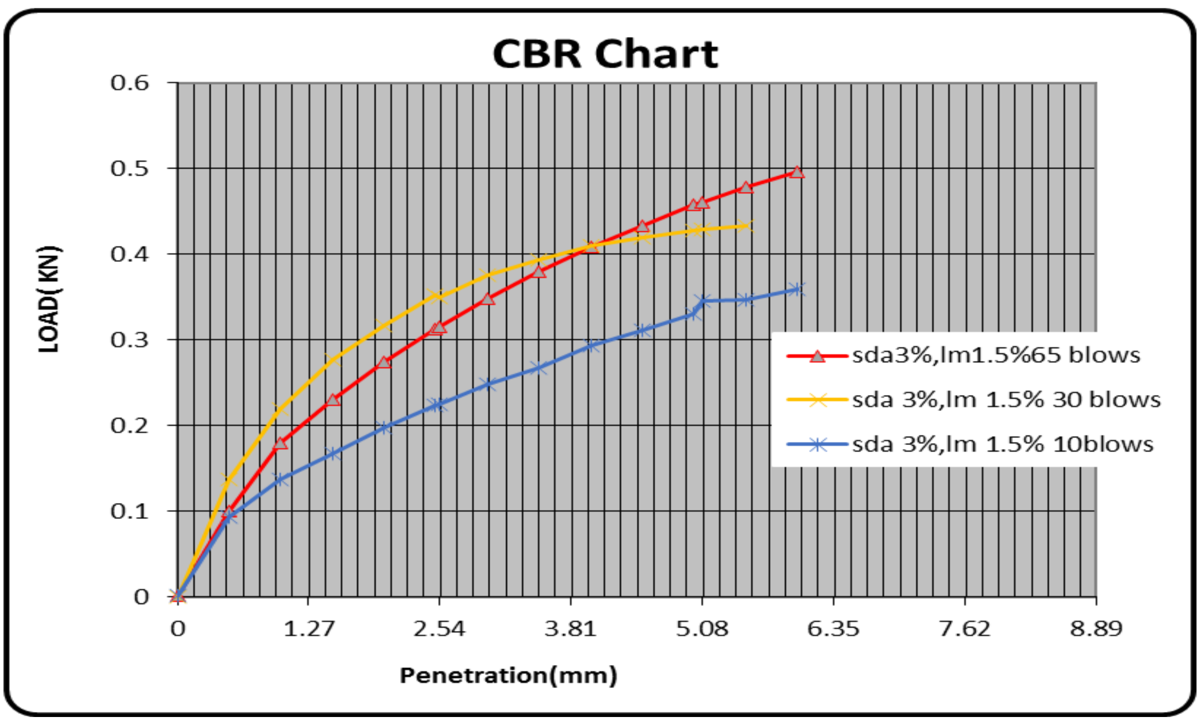
A Natural

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0		0.00	0.004		0.00	0.00	
0.50	0.099		0.50	0.073		0.50	0.08	
1.00	0.147		1.00	0.093		1.00	0.20	
1.50	0.168		1.50	0.106		1.50	0.35	
2.00	0.185		2.00	0.115		2.00	0.49	
2.50	0.187		2.50	0.122		2.50	0.58	
2.54	0.19	1.42	2.54	0.11	0.82	2.54	0.10	0.75
3.00	0.206		3.00	0.127		3.00	0.114	
3.50	0.214		3.50	0.129		3.50	0.116	
4.00	0.222		4.00	0.134		4.00	0.121	
4.50	0.229		4.50	0.144		4.50	0.127	
5.00	0.236		5.00	0.148		5.00	0.132	
5.08	0.24	1.20	5.08	0.15	0.74	5.08	0.13	0.67
5.50	0.25		5.50	0.152		5.50	0.14	
6.00	0.26		6.00	0.154		6.00	0.14	



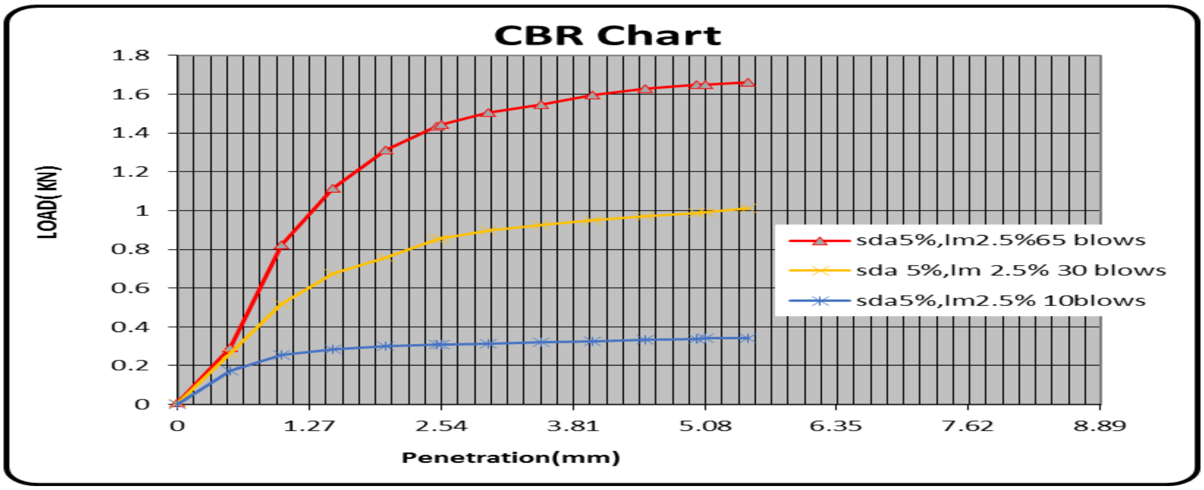
B.SDA 3% Lime1.5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.002		0.00	0		0.00	0.001	
0.50	0.1		0.50	0.137		0.50	0.094	
1.00	0.18		1.00	0.22		1.00	0.137	
1.50	0.23		1.50	0.277		1.50	0.167	
2.00	0.274		2.00	0.317		2.00	0.197	
2.50	0.313		2.50	0.352		2.50	0.224	
2.54	0.32	2.37	2.54	0.35	2.62	2.54	0.23	1.69
3.00	0.348		3.00	0.376		3.00	0.248	
3.50	0.38		3.50	0.394		3.50	0.268	
4.00	0.408		4.00	0.41		4.00	0.293	
4.50	0.433		4.50	0.419		4.50	0.312	
5.00	0.458		5.00	0.428		5.00	0.331	
5.08	0.46	2.31	5.08	0.429	2.15	5.08	0.36	1.78
5.50	0.479		5.50	0.433		5.50	0.347	
6.00	0.496		6.00	1.287		6.00	0.359	



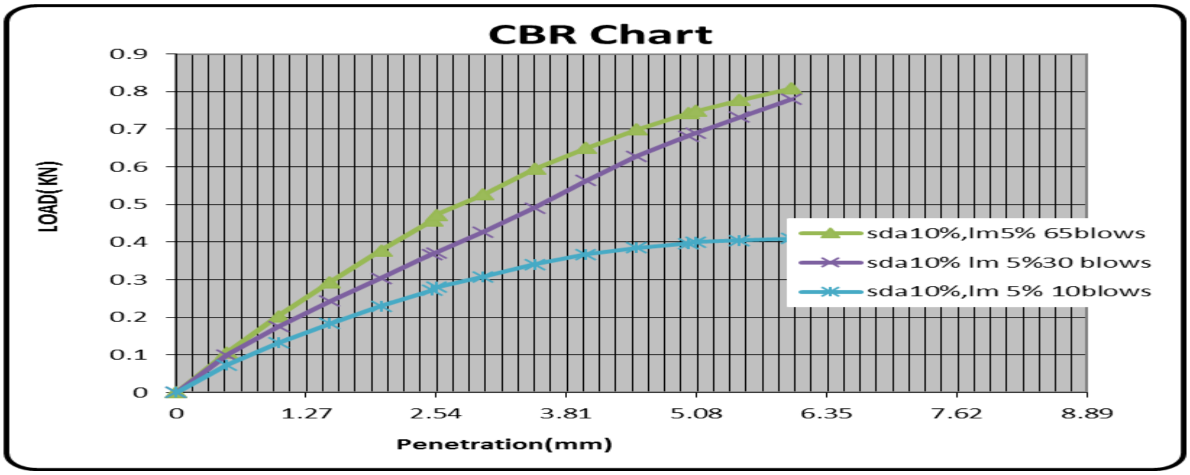
C.SDA 5% Lime2.5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.01		0.00	0.00		0.00	0.00	
0.50	0.29		0.50	0.26		0.50	0.17	
1.00	0.82		1.00	0.52		1.00	0.26	
1.50	1.11		1.50	0.67		1.50	0.29	
2.00	1.31		2.00	0.76		2.00	0.30	
2.50	1.44		2.50	0.85		2.50	0.31	
2.54	1.45	10.84	2.54	0.86	6.41	2.54	0.31	2.39
3.00	1.51		3.00	0.90		3.00	0.32	
3.50	1.55		3.50	0.93		3.50	0.32	
4.00	1.60		4.00	0.95		4.00	0.33	
4.50	1.63		4.50	0.97		4.50	0.33	
5.00	1.65		5.00	0.99		5.00	0.34	
5.08	1.65	8.26	5.08	0.99	4.95	5.08	0.34	1.95
5.50	1.66		5.50	1.01		5.50	0.34	
6.00	1.059		6.00	1.04		6.00	0.34	



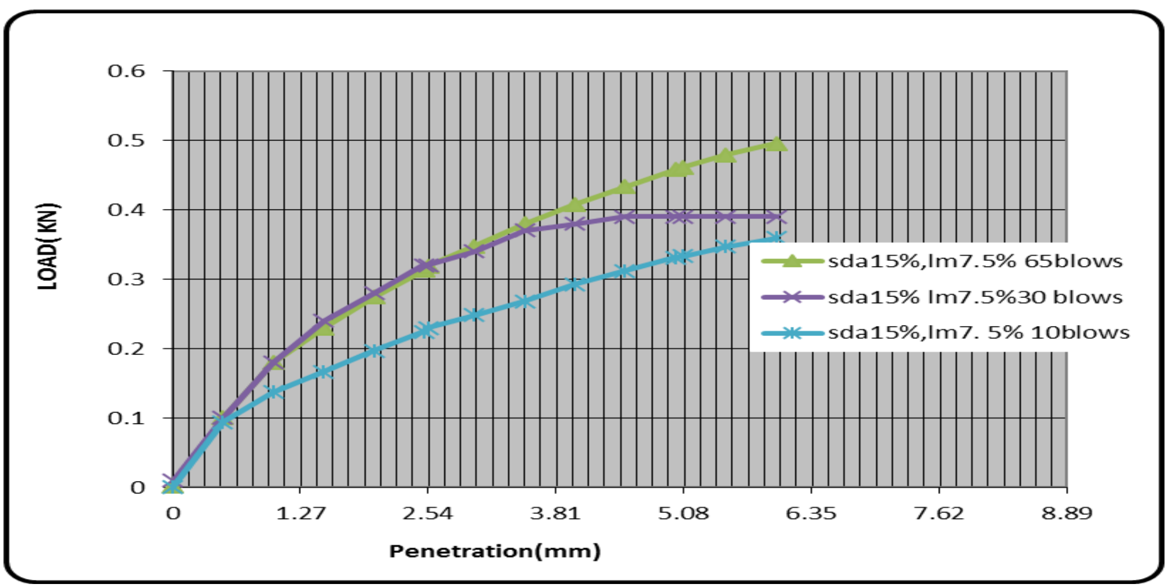
D.SDA 10% Lime5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0		0.00	0		0.00	0	
0.50	0.106		0.50	0.1		0.50	0.073	
1.00	0.203		1.00	0.175		1.00	0.132	
1.50	0.293		1.50	0.243		1.50	0.183	
2.00	0.378		2.00	0.304		2.00	0.23	
2.50	0.457		2.50	0.367		2.50	0.272	
2.54	0.47	3.54	2.54	0.37	2.79	2.54	0.28	2.10
3.00	0.527		3.00	0.427		3.00	0.308	
3.50	0.594		3.50	0.491		3.50	0.341	
4.00	0.65		4.00	0.564		4.00	0.37	
4.50	0.699		4.50	0.628		4.50	0.39	
5.00	0.743		5.00	0.682		5.00	0.40	
5.08	0.75	3.74	5.08	0.69	3.45	5.08	0.40	2.00
5.50	0.778		5.50	0.732		5.50	0.40	
6.00	0.808		6.00	0.78		6.00	0.41	

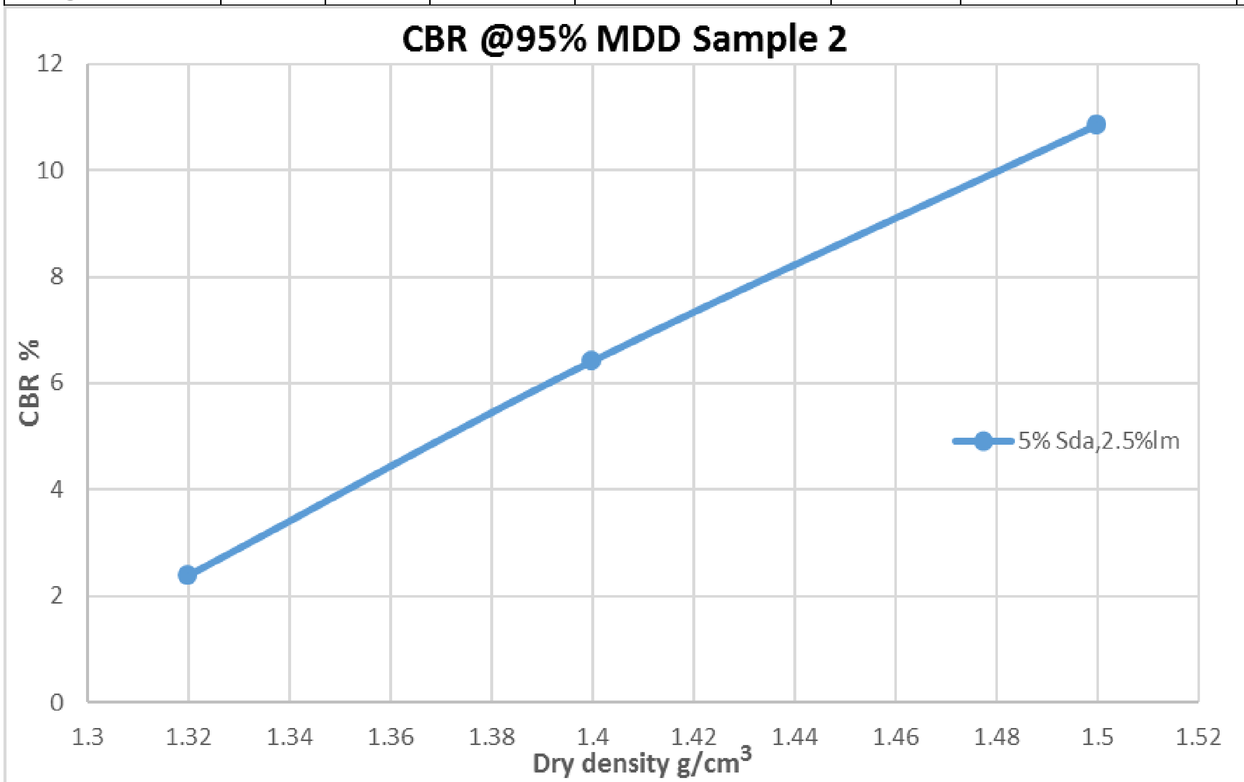


E.SDA 15% Lime7.5%

CBR Penetration Determination								
Penetration after 96 hrs Soaking Period			Surcharge Weight:-4.55 KG					
65 Blows			30 Blows			10 Blows		
Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %	Pen.mm	Load, KN	CBR %
0.00	0.002		0.00	0.01		0.00	0.001	
0.50	0.1		0.50	0.1		0.50	0.094	
1.00	0.18		1.00	0.18		1.00	0.137	
1.50	0.23		1.50	0.24		1.50	0.167	
2.00	0.274		2.00	0.28		2.00	0.197	
2.50	0.313		2.50	0.32		2.50	0.224	
2.54	0.32	2.39	2.54	0.32	2.40	2.54	0.23	2.39
3.00	0.348		3.00	0.34		3.00	0.248	
3.50	0.38		3.50	0.37		3.50	0.268	
4.00	0.408		4.00	0.38		4.00	0.293	
4.50	0.433		4.50	0.39		4.50	0.312	
5.00	0.46		5.00	0.39		5.00	0.331	
5.08	0.46	2.31	5.08	0.39	1.95	5.08	0.33	
5.50	0.479		5.50	0.39		5.50	0.347	1.74
6.00	0.496		6.00	0.39		6.00	0.359	



Number of blows	10	30	65	MDD,g/cm^3	1.48	OMC,%	24
Soaked CBR,%	2.39	6.41	10.84	Density required,%	95	Target density,g/cm^3	1.41
Density g/cm^3	1.32	1.4	1.5	CBR	7%		



APPENDEX 4 Laboratory Test Result Analysis of Sample 3

APPENDIX 4.1Grain size Analysis

Wet Sieve Analysis

Sieve Size(mm)	Mass retained (gm)	Percentage Retained (%)	Percentage Retained (%)	Percentage passing
4.75	7.21	0.66	0.66	99.34
2	25.145	2.29	2.95	97.05
1	9.33	0.85	3.8	96.2
0.85	3.395	0.31	4.11	95.89
0.425	3.69	0.34	4.44	95.56
0.15	8.32	0.76	5.2	94.8
0.075	4.035	0.37	5.57	94.43

Hydrometer Analysis

Time	Elapsed time	Actual Hydr	Eff.depth,	Temperat	K	C_T	Par.diameter D	Value of 'a' for	Corrected hydr	% Finer	corrected (Pass
9:32	1	41.5	9.3	23	0.01337	0.7	0.040553	1.009	35.2	71.0	68.94
9:33	2	40.25	9.5	23	0.01337	0.7	0.028985	1.009	33.95	68.5	66.49
9:37	5	38.5	9.8	23	0.01337	0.7	0.018622	1.009	32.2	65.0	63.06
9:47	15	36.25	10.2	23	0.01337	0.7	0.011025	1.009	29.95	60.4	58.66
4:01	30	34	10.6	23	0.01337	0.7	0.007947	1.009	27.7	55.9	54.25
4:31	60	31.5	11.0	23	0.01337	0.7	0.005699	1.009	25.2	50.9	49.35
5:31	120	30.75	11.1	23	0.01337	0.7	0.004048	1.009	24.45	49.3	47.88
7:31	240	28	11.5	23	0.01337	0.7	0.002927	1.009	21.7	43.8	42.50
11:31	480	26.5	11.8	23	0.01337	0.7	0.002087	1.009	20.2	40.8	39.56
9:31	1440	24.75	12.1	23	0.01337	0.7	0.00122	1.009	18.45	37.2	36.13

Combined sieve analysis

Grain Size (mm)	% passing	Combined % passing
4.75	99.34	99.34
2	97.05	97.05
1	96.2	96.2
0.85	95.89	95.89
0.425	95.55	95.55
0.15	94.79	94.79
0.075	94.43	94.43
0.040553	68.94	68.94
0.028985	66.49	66.49
0.018622	63.06	63.06
0.011025	58.66	58.66
0.007947	54.25	54.25
0.005699	49.35	49.35
0.004048	47.88	47.88
0.002927	42.5	42.5
0.002087	39.56	39.56
0.00122	36.13	36.13

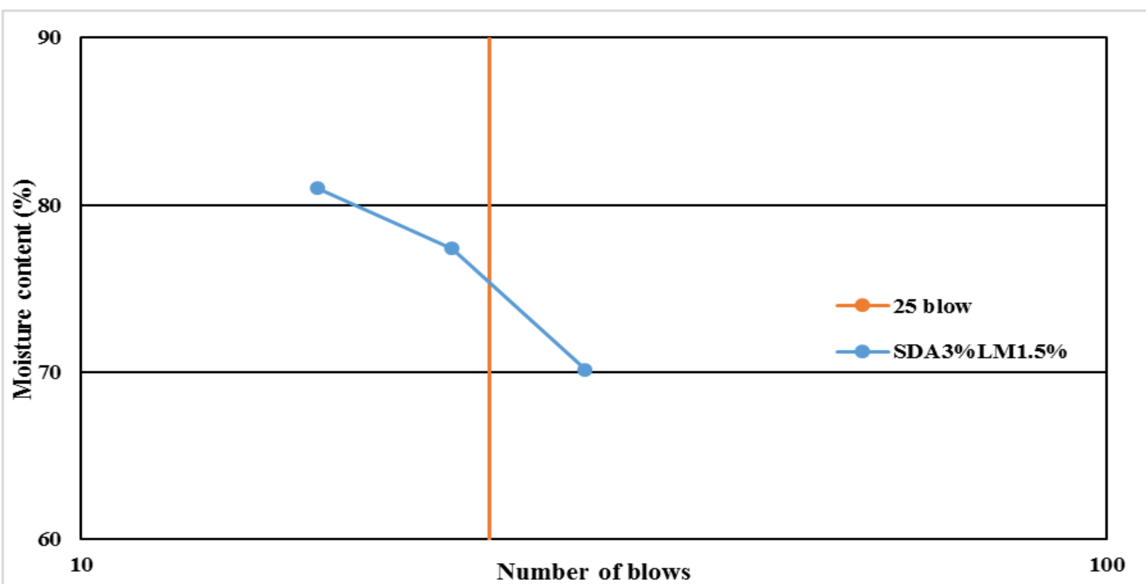
APPENDIX 4.2 Atterberg Limit Test Result

A.Natural

Material location:	Jimma (Technic sefer)				
Pit Number	Sample 3(natural)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	33	24	16		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.64	17.49	22.91	23.59	18.03
Wt. of container + wet soil, (g)	28.58	32.94	38.46	32.25	25.43
Wt. of container + dry soil, (g)	23.40	25.45	30.74	29.66	24.08
Wt. of water, (g)	5.18	7.49	7.72	2.59	1.35
Wt. of dry soil, (g)	5.76	7.96	7.83	6.07	6.05
Moisture container, (%)	89.93	94.10	98.60	42.67	22.31
Average moisture contents(%)				32.49	

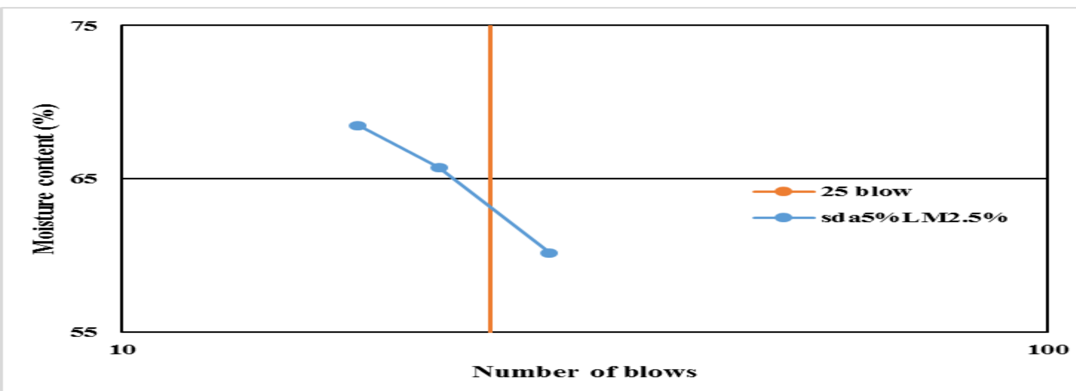
B.SDA 3% and Lime 1.5%

Material location:	Jimma (Technic sefer)				
Pit Number	Sample 3(sda3%,lm1.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	31	23	17		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.49	18.34	17.78	17.81	21.14
Wt. of container + wet soil, (g)	32.09	35.52	34.83	26.74	29.39
Wt. of container + dry soil, (g)	26.07	28.03	27.20	24.25	27.66
Wt. of water, (g)	6.02	7.50	7.63	2.50	1.73
Wt. of dry soil, (g)	8.58	9.69	9.42	6.44	6.53
Moisture content, (%)	70.16	77.39	81.00	38.77	26.44
Average moisture contents(%)				32.60	



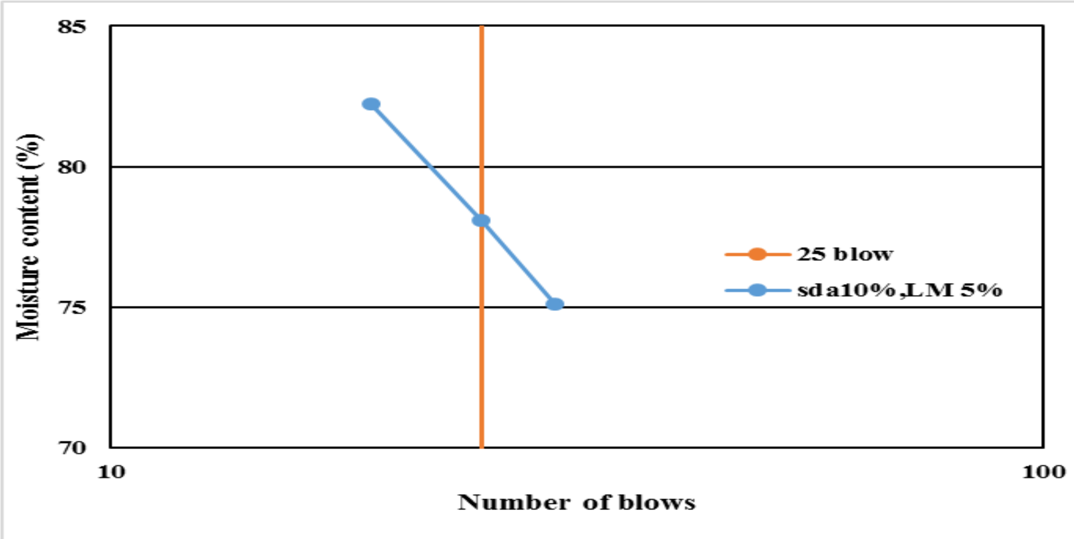
C.SDA 5% and Lime 2.5%

Material location:	Jimma (Technic sefer)				
Pit Number	Sample 3(sda 5%,lm2.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	29	22	18		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.34	19.19	12.65	12.03	24.24
Wt. of container + wet soil, (g)	35.60	38.10	31.20	21.23	33.34
Wt. of container + dry soil, (g)	28.74	30.60	23.66	18.83	31.24
Wt. of water, (g)	6.86	7.50	7.54	2.40	2.10
Wt. of dry soil, (g)	11.40	11.41	11.01	6.80	7.00
Moisture content, (%)	60.18	65.73	68.48	35.29	30.00
Average moisture contents(%)				32.65	



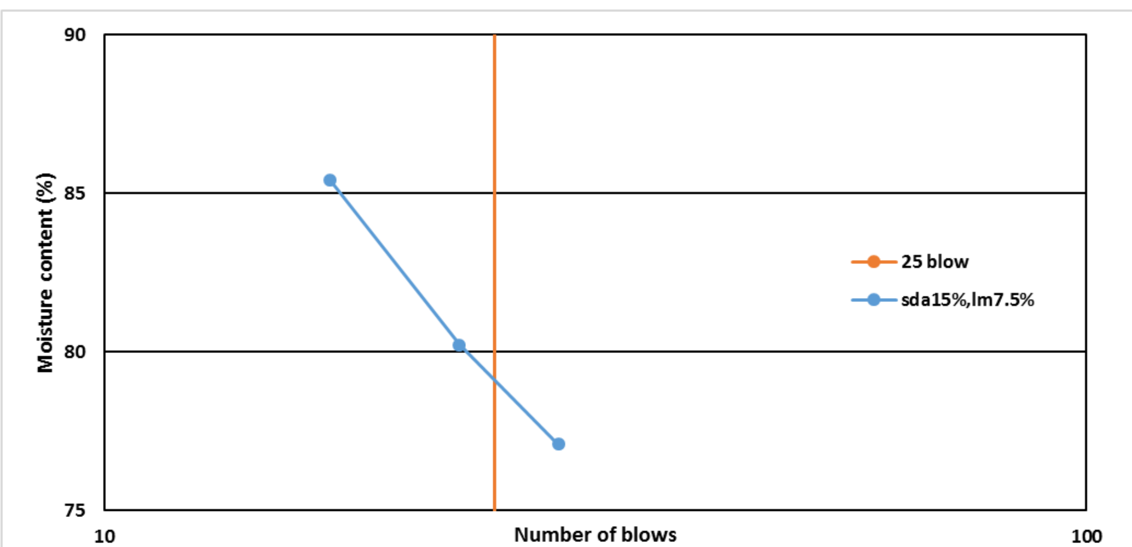
D.SDA 10% and Lime 5%

Material location:	Jimma (Technic sefer)				
Pit Number	Sample 3(sda 10%,lm 5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	30	25	19		
Test No	01	02	03	01	02
Wt. of Container, (g)	17.34	18.60	21.90	25.27	21.68
Wt. of container + wet soil, (g)	38.65	41.02	44.88	34.28	34.16
Wt. of container + dry soil, (g)	29.51	31.19	34.51	32.11	31.06
Wt. of water, (g)	9.14	9.83	10.37	2.17	3.10
Wt. of dry soil, (g)	12.17	12.59	12.61	6.84	9.38
Moisture content, (%)	75.10	78.08	82.24	31.73	33.05
Average moisture contents(%)				32.39	



E.SDA 15% and Lime7.5%

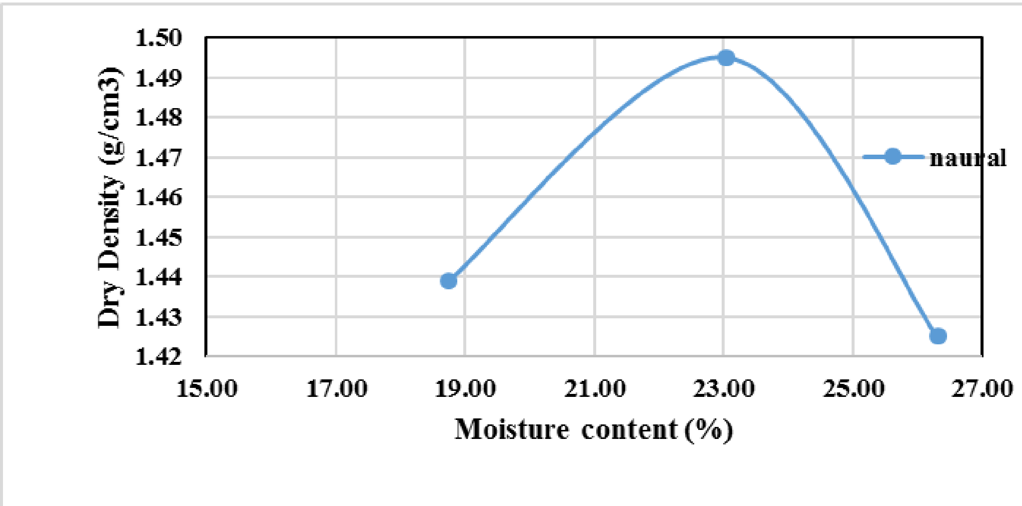
Material location:	Jimma (Technic sefer)				
Pit Number	Sample 3(sda 10%,lm 7.5%)				
Determination	Liquid Limit (D-4318)			Plastic Limit (D-4318)	
Number of blows	29	23	17		
Test No	01	02	03	01	02
Wt. of Container, (g)	15.68	19.08	12.00	17.41	29.20
Wt. of container + wet soil, (g)	31.99	34.11	27.13	24.43	36.86
Wt. of container + dry soil, (g)	24.89	27.42	20.16	22.74	35.01
Wt. of water, (g)	7.10	6.69	6.97	1.69	1.85
Wt. of dry soil, (g)	9.21	8.34	8.16	5.33	5.81
Moisture content, (%)	77.09	80.22	85.42	31.71	31.84
Average moisture contents(%)				31.77	



APPENDIX 4.3 Compaction Test Result of Sample 3

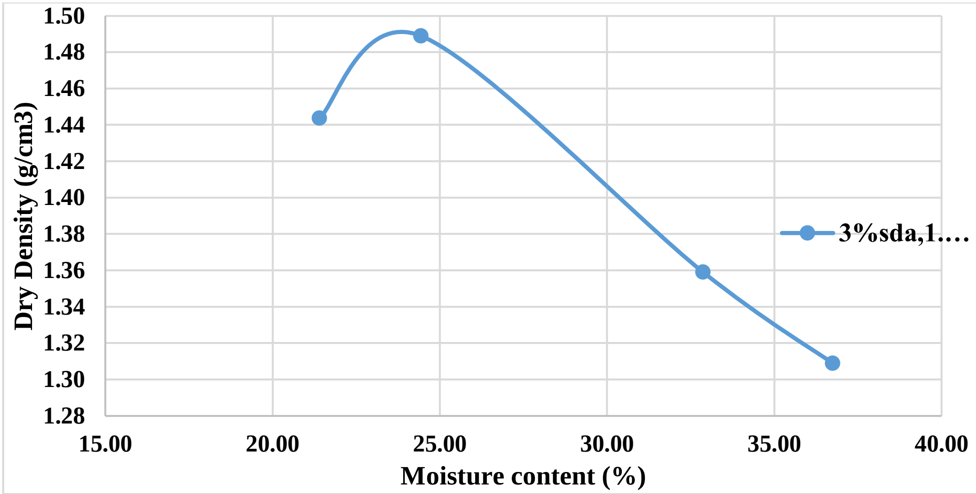
A Natural

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm³)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm³)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10193	3519.88	1.71	14	36.469	129.387	116.035	13.35	79.57	16.78	18.74	1.44
				K	22.2835	104.097	90.071	14.03	67.79	20.69		
2	10440	3789.63	1.84	G3T3	22.983	128.6965	107.071	21.63	84.09	25.72	23.04	1.49
				T10	22.016	114.837	99.134	15.70	77.12	20.36		
3	10382	3708.35	1.80	T2C2	26.7745	138.792	115.328	23.46	88.55	26.50	26.31	1.43
				HB	26.5325	148.589	123.316	25.27	96.78	26.11		
4	10155	3532.5	1.71	B3	17.415	100.905	79.67	21.24	62.26	34.11	33.54	1.28
				3-Mar	17.485	86.886	69.681	17.21	52.20	32.96		
										From plot OMC 23 %		
										MDD = 1.490g/cm^3		



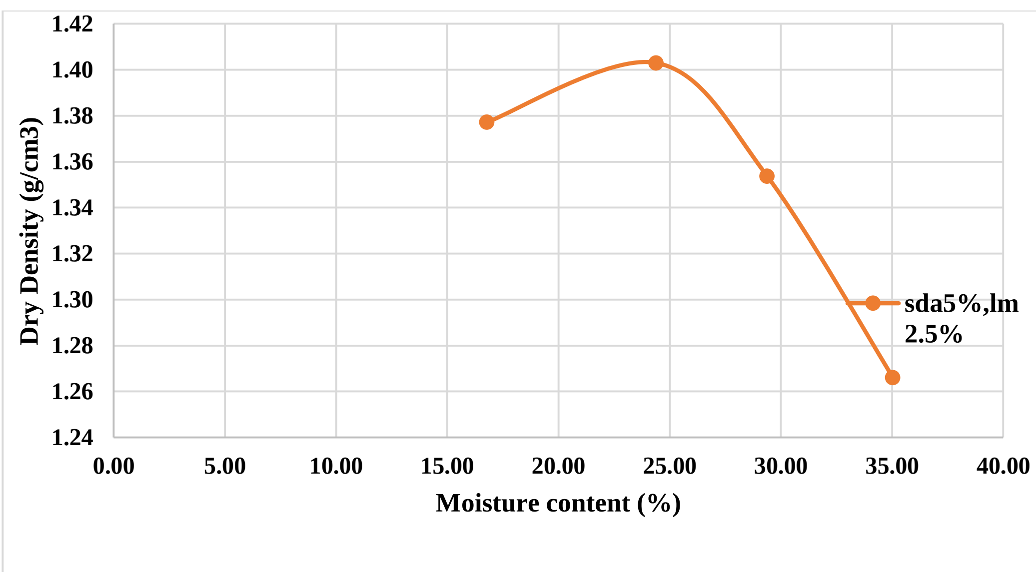
B. SDA 3% and lime 1.5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm³)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm³)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10144.7	3611.3	1.75	NC 23	17.64	126.01	107.22	18.79	89.58	20.98	21.40	1.44
				D31	18.054	120.34	102.01	18.33	83.96	21.83		
2	10450.75	3817.05	1.85	B-1	35.175	130.03	110.08	19.95	74.91	26.63	24.43	1.49
				HC12	34.27	156.01	133.87	22.14	99.60	22.23		
3	10353.55	3720.35	1.81	LB1	35.01	150.82	123.51	27.31	88.50	30.86	32.87	1.36
				G73	29.97	162.93	128.55	34.38	98.58	34.88		
4	10221.4	3687.7	1.79	3	27.76	138.58	99.08	39.50	71.32	55.38	36.75	1.31
				LC 22	27.599	108.78	96.33	12.45	68.73	18.11		
										From plot OMC 24 %		
										MDD = 1.48g/cm^3		



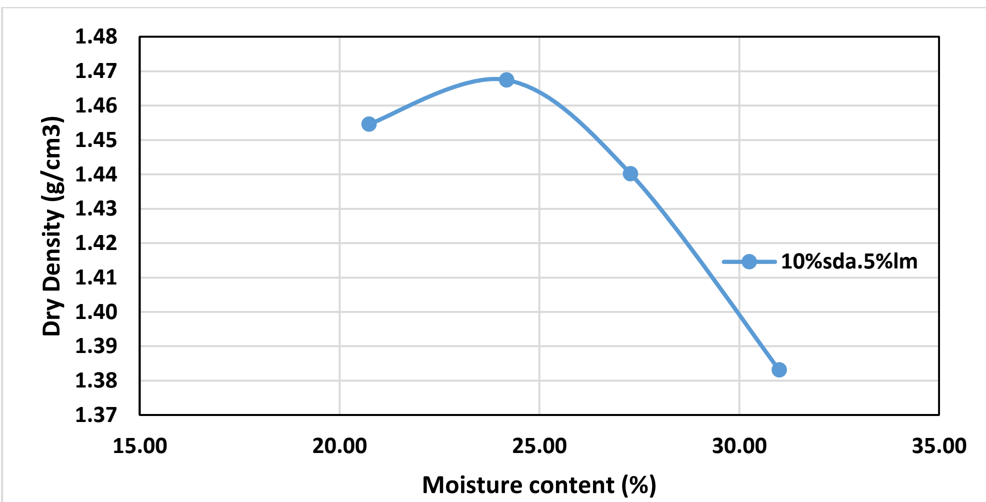
C. SDA 5% and lime 2.5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10108.8	3313.6	1.61	NC 23	22.86	105.53	95.53	10.00	72.67	13.76	16.78	1.38
				D31	25.15	103.25	90.34	12.91	65.19	19.80		
2	10128.8	3595.6	1.75	B-1	25.22	127	106.71	20.29	81.49	24.90	24.39	1.40
				HC12	17.86	105.3	88.44	16.86	70.58	23.89		
3	10141.6	3608.35	1.75	LB1	27.7	150.11	121.99	28.12	94.29	29.82	29.38	1.35
				G73	25.61	168.21	136.21	32.00	110.60	28.93		
4	10055.5	3522.3	1.71	3	17.65	156.93	120.05	36.88	102.40	36.02	35.04	1.27
				LC 22	17.12	160.4	124	36.40	106.88	34.06		
										From plot OMC 24.5%		
										MDD = 1.405g/cm^3		



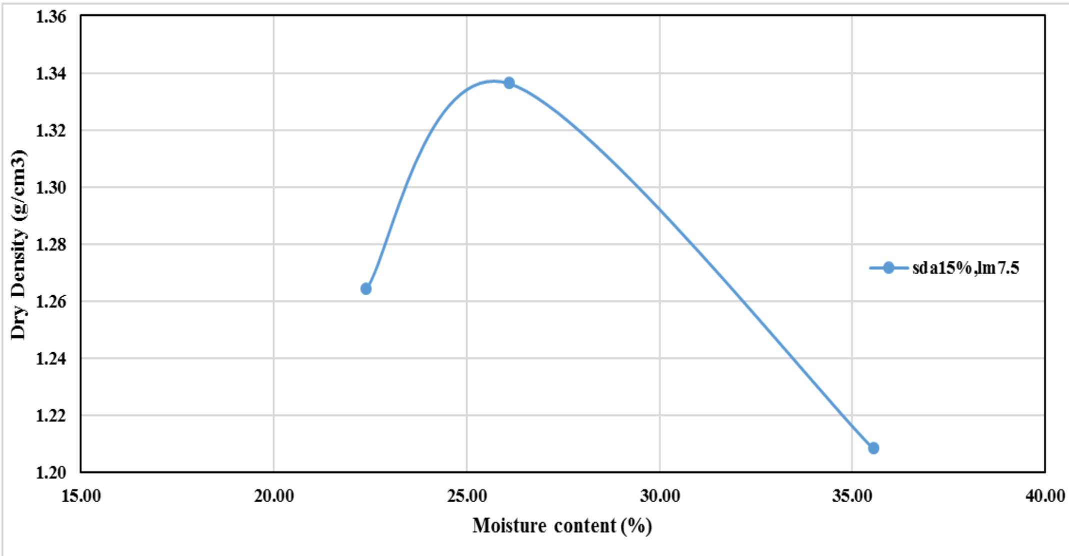
D. SDA 10% and lime 5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	10298.8	3618.4	1.76	NC 23	36.7	169.65	146.82	22.83	110.12	20.73	20.74	1.45
				D31	17.94	114.63	98.02	16.61	80.08	20.74		
2	10424.8	3754.4	1.82	B-1	28.61	121.78	102.88	18.90	74.27	25.45	24.18	1.47
				HC12	17.63	107.92	91.09	16.83	73.46	22.91		
3	10380.2	3776.75	1.83	LB1	25.61	133.7	110.34	23.36	84.73	27.57	27.28	1.44
				G73	17.92	104.63	86.2	18.43	68.28	26.99		
4	10336.4	3733	1.81	3	36.42	151.31	124.48	26.83	88.06	30.47	31.00	1.38
				LC 22	34.64	159.1	129.26	29.84	94.62	31.54		
									From plot OMC 24.5 %			
									MDD = 1.469g/cm^3			



E. SDA 15% and lime 7.5%

Trial No.	Mass of compacted soil + mold, g	Mass of compacted soil, g	Wet density (g/cm^3)	Moisture content Determination							Average Moisture content,%	Dry density (g/cm^3)
				Can No.	Mass of can, g	Mass of wet soil + can, g	Mass of dry soil + can, g	Mass of water,g	Mass of dry soil,g	Moisture content,%		
1	9801.15	3192.65	1.55	ZE	25.36	126.45	107.75	18.70	82.39	22.70	22.40	1.26
				A-IC	33.42	137.92	119	18.92	85.58	22.11		
2	10011.9	3476.65	1.69	2-Feb	24.18	95.91	81.97	13.94	57.79	24.12	26.10	1.34
				SG-1	22.48	124.73	102.31	22.42	79.83	28.08		
3	9914.05	3378.85	1.64	G1	25.22	126.37	100.11	26.26	74.89	35.06	35.54	1.21
				RG	29.15	147.54	116.19	31.35	87.04	36.02		
										OMC=25.5%		
										MDD= 1.34g/cm^3		



APPENDIX 5 Laboratory photos

Figure 1 Excavated test pits

Figure 2 Air drying, crushing and Mixing of soil samples

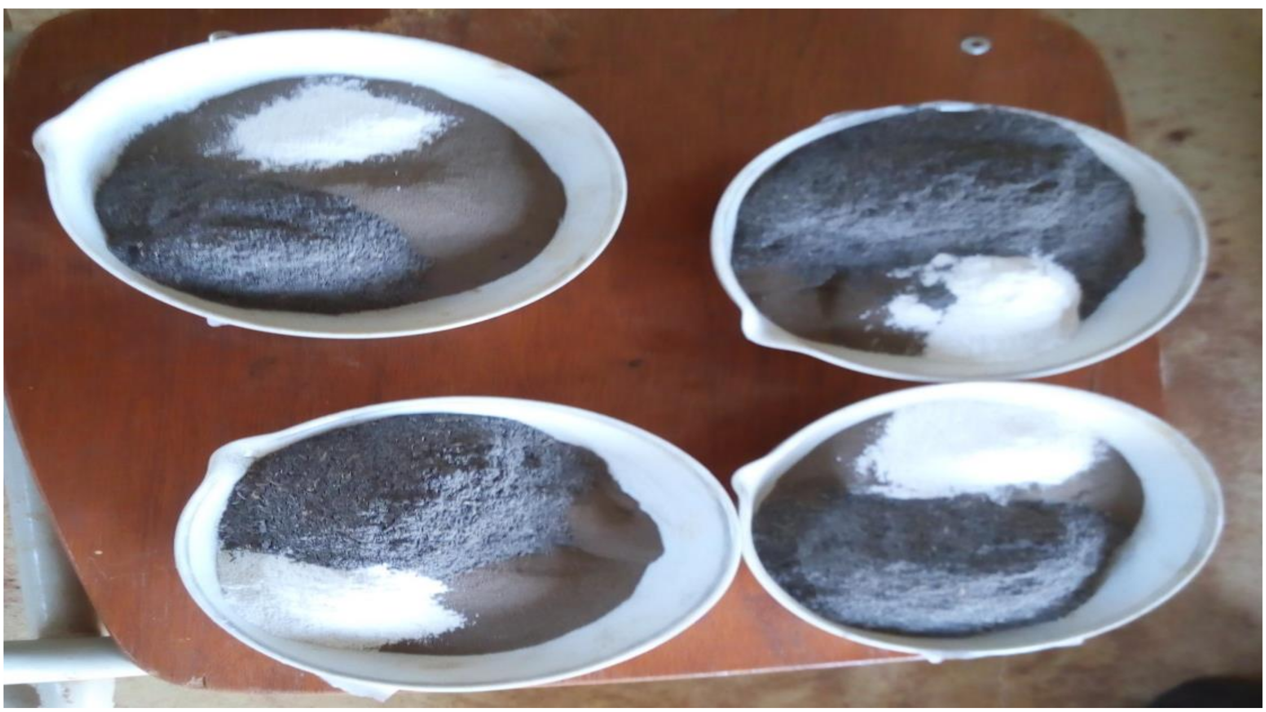


Figure 3 Sample prepared for Atterberg Limits Test

Figure 4 Free swell index test

Figure 5 Sample prepared for Compaction test

Figure 6 compacted sample and soaked sample for CBR test.

Figure 7 UCS Test: sample preparation procedure and specimen with compression device

Figure 8 air dried sample