STABILIZATION OF EXPANSIVE CLAY SOIL USING BAGASSE ASH AND LIME

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Stabilization of Expansive Clay Soil Using Bagasse Ash and Lime

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This work is dedicated to my wife Beatrice Obirica Khaoya and my children Lewin, Reevin, Livia, Audry, Eugene and Wendy for their prayers, support and encouragement during my studies and not forgetting my parents Mr. Barasa Musungu (deceased) and Mrs. Ruth Nanjala Barasa.

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God bless you all

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ABBREVIATIONS AND ACRONYMS

PI	Plasticity Index
CBR	California Bearing Ratio
PL	Plastic Limit
PM	Plasticity Modulus
LL	Liquid Limit
MC	Moisture Content
DD	Dry Density
BS	British Standard
RDM	Road Design Manual
MDD	Maximum Dry Density
OMC	Optimum Measure Content
SCBA	Sugar Cane Bagasse Ash
PMC	Present Moisture Content

ABSTRACT

Expansive clay soil is encountered in most parts of Bungoma County and the preliminary investigation shows that it belongs to A-7-5 class of soil in the AASHTO soil classification system and generally has poor engineering properties. Traditional stabilizers like cement, lime and others have been efficient and effective in soil stabilization but their rising cost and negative impact to the environment has led to research into bagasse ash waste to be used as an alternative in soil stabilization. The study investigated the properties of expansive clay soil when stabilized by lime, bagasse ash and combination of lime and ash. The research covered grading test, Plasticity Index (PI) and California Bearing Ratio (CBR). First, particles size distribution was determined from grading test, secondly varying percentages (4%, 5%, and 6%) of lime was used to stabilize clay soil and then PI and CBR were determined. The same procedure was repeated for bagasse ash and finally the varying mix ratios of lime and ash 1:4, 2:3, 3:2 and 4:1 on the sample. The PI results were as follows; lime (26%, 21% and 14%), ash (34%, 33% and 30%) and ratio of lime/ash (32%, 29%, 24% and 20%) respectively. The trend indicated that the PI of the stabilized clay soil decreased with increase in the quantity of lime, ash and ratio lime to ash in all the samples. The addition of lime or bagasse ash also reduced the shrinkage and swelling factor of soil. The CBR was carried out using Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) from graph of dry density against moisture content obtained from proctor test. The CBR results were as follows; lime (38%, 45%, and 50%), ash (6%, 4% and 2%), and ratio of lime/ash (19%, 27%, 30%, and 36%) respectively. The trend indicated that California Bearing Ratio increased with increase in lime quantity added but decreased when bagasse ash was used. The combination of lime and ash gave good results that meet the set standard by road design manual part III of minimum CBR of 20 for sub base road. The results of ash on PI and low CBR values it was concluded that sugarcane bagasse ash alone cannot be used to stabilize expansive clay soil. It was found that both lime and bagasse ash reduced the linear shrinkage, however, the addition of lime

reduced the linear shrinkage to a greater degree than the same percentage of bagasse ash. When lime and bagasse ash are combined at the optimum ratio of 4:1, the stabilization results of California Bearing Ratio of 36, plasticity index 20, Linear shrinkage of 9.0, negligible swelling create a material that can used for construction works. Therefore, this study shows that lime in combination with bagasse ash can be effectively used to improve expansive soils with low soaked CBR value and high plasticity. It's therefore recommended that since bagasse ash can partially replaces lime in clay stabilization to form material with cementitious properties, the use of lime should be minimized to reduce creation of carbon dioxide.

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

Bungoma County has poor road network system and is normally attributed to high cost of construction materials and expansive clay soil which swell with little moisture and shrink in dry season. The solution to this problem is to create a cheaper construction material by improving the geotechnical properties of in-situ materials to reduce the overall cost. Stabilization process has been used to improve the properties of clay soil to attain engineering requirement but traditional stabilizers like lime and cement have became very expensive and their side effect to the environment have minimized their usage. The main focus of the study was on bagasse ash waste, a by-product which has a disposal problem in sugar factories. This research evaluated the effect of partial replacement of lime by sugarcane bagasse ash in stabilization of clay soil.

Bagasse is defined as fibrous residue of sugar cane stalks that remains after extraction of sugar (Rainey, 2009). It is normally deposited as waste and it litters the environment. Most of the bagasse produced, amounting to one-third of all the cane crushed in some cases supplies the fuel for the generation of steam according to Bilba, Arsene, and Ouensanga, (2003) which eventually results in bagasse ash. The resulting ash is deposited in stockpiles which are normally dumped in waste landfills and constitute environmental problem to the society. When bagasse is left in the open, it ferments and decays, this brings about the need for safe disposal of the pollutant, which when inhaled in large quantity can result in respiratory disease known as *bagassiosis* (Laurianne, 2004).

Bagasse ash is a pozzolanic material which is very rich in the oxides of silica and aluminum, and sometimes calcium Guilherme, Romildo, Eduardo, Luis, and Cristiano, (2004). Pozzolans usually require the presence of water in order for silica to combine with calcium hydroxide to form stable calcium silicate, which has cementitious properties.

Lime is calcium oxide (CaO) or hydroxides of calcium and magnesium and is made by calcining limestone into either calcitic lime (high in calcium) or dolomitic lime (high in magnesium). Lime stabilization is the most widely used means of chemically for stabilizing unstable soils into structurally sound construction foundations. The use of lime in stabilization creates a number of important engineering properties in soils, including improved strength, improved resistance to fracture, fatigue, and permanent deformation, improved resilient properties, reduced swelling, and resistance to the damaging effects of moisture.

Expansive clay soils encountered in many construction sites in Bungoma County have poor engineering properties. West (1995) defines expansive soils as those soils that consist of clays which shrink and swell with the primary clay being smectite (montmorillonite). Expansive soils affect the engineering structures because of their tendency to heave during wet season and shrink during dry season as per Mishra, Dhawan, and Rao, (2008). In order to make deficient expansive soils useful and meet geotechnical engineering design requirements, the process of stabilization is applied. Traditionally, the three most commonly used stabilizers are cement, lime and asphalt or bituminous compound; but the high cost of processing has made them expensive, deterring their usage. In order to mitigate this problem especially in developing countries, various possible alternatives to lime are considered along with other benefits that may accrue from these alternatives. Several waste materials such as Rice Husk Ash (RHA), Pulverized Fuel Ash (PFA), lime, Sugarcane Bagasse Ash (SCBA) and volcanic ash, are in use in many countries. There are basically two types of pozzolanas, namely natural and artificial pozzolanas. Natural pozzolanas are essentially volcanic ashes from geologically recent volcanic activity and artificial pozzolanas result from various industrial and agricultural processes, usually as by-products. The most important artificial pozzolanas are burnt clay, pulverized-fuel ash (PFA), ground granulated blast furnace slag (GGBFS) and rice husk ash (RHA). These admixtures (fly ash, cold bottom ash, crushed concrete powder, bagasse ash and blast furnace slag and phosphoric waste have been employed in research works by Osinubi, (1997) during soil stabilization. The aim of the study was to determine the effect of using SCBA to blend with lime to stabilize expansive clay.

1.2 Statement of the Problem

Most parts of Bungoma County are covered with expansive clay soils which have poor engineering properties hence is not used during infrastructure development. Soils with desirable engineering properties must be transported from quarries which are many kilometers away hence raising the cost of construction. However, the transportation of large quantities of building material has negative impact on the environment and is not a sustainable practice. This has made roads in Bungoma County are expensive to construct and maintain. The study used combination of lime and bagasse ash additives which are easily available to economically stabilize clay soils in Bungoma County for use on roads, runways, and other similar applications.

1.3 Justification of the Study

Bungoma County is one of the 47 County governments that were established through the promulgation of the new constitution in the year 2010. The County borders the Republic of Uganda to the West, Teso and Busia districts to the South West, Mumias to the South, Trans-Nzoia, Lugari and Kakamega to the North East. The County has an area of 3,032.2 sq. Km and lies between 1,200 and 1,800 meters above sea level. The population of Bungoma is estimated at 1,630,934 (as projected in 2009) of which female constitute 52% while male are 48%. The major economic activity in the area is farming and business but the road network is in a poor state making it impossible for farmers to access the markets. The cost of improving roads is exorbitant due to clay soil which requires a replacement with imported materials or being stabilized. The traditional stabilizers like lime, cement etc are very expensive hence alternative means of using bagasse ash are sorted. The bagasse ash is ready available and has disposal problem with National environmental management Authority (Nema). A report by Yuko, (2004) on Nzoia Sugar Company indicated that the annual production of bagasse was 234,046 tons from the crushed cane of about 568,098 tons which is 40% of the sugar cane processed. About 85% of this bagasse is burned on site at the factories to generate steam for the evaporative extraction of sugar and some of it is also used to produce electricity for factory operations and sale to the local grid. Nevertheless, 15% of the bagasse is still typically surplus and accumulates in huge stacks close to the factories and is periodically hauled away by tractors and burned in fields. Analysis of bagasse ash indicated that its main constituents are cellulose, hemicelluloses, lignin, ash, and wax (Walford, 2008). The Nema has often accused the Company for environmental pollution.

The new discovery for the use of bagasse ash as clay soil stabilizer has solved disposal problem faced by Sugar Companies and also reduced the cost of improving infrastructure in Bungoma County..

1.4 Objectives

1.4.1 General Objective

To assess the effect of partial replacement of lime by sugar cane bagasse ash in stabilization of expansive clay soil to produce sub-base layer material for road construction

1.4.2 Specific Objectives

1. To determine the chemical composition of the sugar cane bagasse ash
2. To determine physical and mechanical properties of expansive clay soil stabilized with lime only and sugar cane bagasse ash only

3. To determine the amount of sugar cane bagasse ash required for partial replacement of lime for optimum expansive clay soil stabilization.

1.5 Research Questions

1. What is the chemical composition of the sugar cane bagasse ash?
2. What are the physical and mechanical properties of expansive clay soil stabilized with lime only and sugar cane bagasse ash only?
3. What is the amount of sugar cane bagasse ash required for partial replacement of lime for optimum expansive clay soil stabilization?

1.6 Scope of the Study

Reviewing literature pertaining to standardized laboratory procedures for preparing mixtures using traditional stabilizers. The scope included:

1. A classification of the soils by performing the following tests: natural water content, particle size distribution, Atterberg limits, moisture-density relationship using standard Proctor test and mineralogy of the clay soil. Other procedures for mixtures involving nontraditional stabilizers that have been studied previously by other researchers.
2. Developing a laboratory mixture preparation and testing procedure that can be used to evaluate and compare traditional and non-traditional stabilizers including bagasse ash.
3. Identifying the existence and significance of trends among base soil characteristics, and strength characteristics using the laboratory procedure developed. This study provides insight into how bagasse ash as stabilizer is effective for stabilizing clay soils commonly encountered in Bungoma County. This report can be used as a guide to help in developing materials that can be used in road construction to improve the economy in the county. In addition, will

solve a disposal problem for the company and hence reduce a pollution level that endangers the lives of people.

1.7 The Limitations

The main research limitations are;

i. Lack of capital to carry out further research to ascertain some reactions like using more quantity of lime and bagasse ash.
ii. Lack of equipment like combustion chambers where high temperatures of bagasse can achieved.
iii. Lack of grinding machine that could have enabled the comparison between burnt and unburnt bagasse on PI and CBR

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews both theoretical and empirical literature on partial replacement of lime by sugarcane bagasse ash in stabilization of expansive clay for road sub-base. The chapter also establishes the research gaps. In this chapter, a theoretical review linking each variable to theories and objectives of the study will be undertaken, the conceptual framework revealed and empirical review to cover each variable undertaken.

2.2 Theory of Change

Theory of Change (ToC) is a specific type of methodology for planning, participation, and evaluation that is used in the philanthropy, not-for-profit and government sectors to promote social change. Theory of Change defines long-term goals and then maps backward to identify necessary preconditions. Theory of Change explains the process of change by outlining causal linkages in an initiative, i.e., its shorter-term, intermediate, and longer-term outcomes. The identified changes are mapped –as the "outcomes pathway" – showing each outcome in logical relationship to all the others, as well as chronological flow. The links between outcomes are explained by "rationales" or statements of why one outcome is thought to be a prerequisite for another (Clark, & Taplin, 2012).

According to Taplin, Clark, Collins, and Colby, (2013), innovation of Theory of Change lies (1) in making the distinction between desired and actual outcomes, and (2) in requiring stakeholders to model their desired outcomes before they decide on forms of intervention to achieve those outcomes. A common error in describing Theory of Change is the belief that it is simply a methodology for planning and evaluation. Theory of Change is instead a form of critical theory that ensures a transparent distribution of power dynamics. Further, the process is necessarily inclusive of many perspectives and participants in achieving solutions.

Theory of Change can begin at any stage of an initiative, depending on the intended use. A theory developed at the outset is best at informing the planning of an initiative. Having worked out a change model, practitioners can make more informed decisions about strategy and tactics. As monitoring and evaluation data become available, stakeholders can periodically refine the Theory of Change as the evidence indicates. A Theory of Change can be developed retrospectively by reading program documents, talking to stakeholders and analyzing data. This is often done during evaluations reflecting what has worked or not in order to understand the past and plan for the future.

Theory of Change as a concept has strong roots in a number of disciplines, including environmental and organizational psychology, but has also increasingly been connected to sociology and political science. Within industrial-organizational psychology, Austin, and Bartunek (2003) have noted that approaches to organizational development are frequently based on more or less explicit assumptions about 1) the processes through which organizations change, and 2) the interventions needed to effect change. Within evaluation practice, Theory of Change emerged in the 1990s at the Aspen Institute Roundtable on Community Change as a means to model and evaluates comprehensive community initiatives. Notable methodologists, such as Huey Chen, Peter Rossi, Michael Quinn Patton, Heléne Clark, and Carol Weiss, had been thinking about how to apply program theories to evaluation since 1980 (Stachowiak, 2010).

Weiss (1995) popularized the term “Theory of Change” as a way to describe the set of assumptions that explain both the mini-steps that lead to the long-term goal of interest and the connections between program activities and outcomes that occur at each step of the way. She challenged designers of complex community-based initiatives to be specific about the theories of change guiding their work and suggested that doing so would improve their overall evaluation plans and would strengthen their ability to claim credit for outcomes that were predicted in their theory. She called for the use of an approach that, at first glance, seems like common sense: lay out the sequence of outcomes that are expected to occur as the result of an intervention, and plan an evaluation strategy around tracking whether these expected outcomes are actually produced. Her stature in the field, and the apparent promise of this idea, motivated a number of foundations to support the use of this technique later termed "the Theory of Change approach"—in the evaluations of community change initiatives. In the years that followed, a number of evaluations were developed around this approach, fueling more interest in the field about its value and potential application.

The study is related to the theory of change since sugarcane bagasse which is acting as a replacement for lime in stabilization of clay soil is part of the environment. The environment is argued to be part of the disciplines covered under the theory. The study highlights the various stages applied to stabilize clay soil using sugarcane bagasse for the purpose of road sub-base. This is in light of the theory of change which calls for the assumptions that explain both the mini-steps that lead to the long-term goal of interest which according to the study is road sub-base.

2.3 Stabilization Process

Soil stabilization is the treatment of clay soils to improve their index properties and strength characteristics such that they permanently become suitable for construction and meet engineering design standards (Salahudeen & Akiije, 2014). Cementitious materials stabilize soils and modify their properties through cation exchange, flocculation and agglomeration, and pozzolanic reactions. The strength, bearing capacity and durability of soils can be increased by addition of some chemical materials. The two frequently used methods of stabilizing soils are stabilization by compaction or stabilization by chemical additives. Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil. The main methods of mechanical stabilization can be categorized into compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation (Guyer, 2011; Makusa, 2012).

2.3.1 Chemical Stabilization

2.3.1.1 Introduction

The main chemical stabilizing agent for expansive clay is lime which may be calcium oxide (CaO) or calcium hydroxide Ca $(OH)_2$. Laboratory testing indicates that lime reacts with medium, moderately fine and fine-grained soils to produce decreased plasticity, increased workability and increased strength (Little, 1995). Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles. These chemical reactions occur in two phases, with both immediate and long-term benefits.

The first phase of the chemical reaction involves immediate changes in soil texture and soil properties caused by cation exchange. When calcium comes in contact with the pore water, hydration occurs resulting in the formation of calcium hydroxide. Some of this calcium hydroxide is adsorbed onto the soil particles. Ion exchange takes place and the soil is modified into drier and coarser structure due to slaking process and flocculation of the clay particles that take place Boardman, Glendinning, and Rogers, (2001). Free calcium from lime exchanges with the adsorbed cations of the clay mineral, resulting in reduction in size of the diffused water layer surrounding the clay particles. This reduction in the diffused water layer allows the clay particles to come into closer contact with one another, causing flocculation/agglomeration of the clay particles, which transforms the clay into a more silt-like or sand-like material. Overall, the flocculation and agglomeration phase of lime stabilization results in a soil that is more readily mixable, workable and ultimately compactable. According to (Christopher, 2005) practically all fine-grained soils undergo this rapid cation exchange and flocculation/agglomeration reactions when treated with lime in the presence of water.

The second phase of the chemical reaction involves pozzolanic reactions within the lime-soil mixture, resulting in strength gain over time. When lime combines with clay soil, the PH of the mixture increases, and at 12.4, the silica and alumina from the clay become soluble and are released from the clay mineral. The calcium hydroxide not consumed in the first process is free to react with the silica (S) and alumina (A) contained in mineral present in the soil. The reactions result into the formation of Calcium aluminate silicate hydroxide (CASH), Calcium Silicate hydroxide (CSH) and calcium aluminate hydroxide (CAH) which has cementitous properties, that strengthens gradually over several years. As long as there is sufficient calcium from the lime to combine with the soluble silica and alumina, the pozzolanic reaction will continue as long as the pH remains high enough to maintain the solubility of the silica and alumina (Little, 1995). Strength gain also largely depends on the amount of silica and alumina available from the clay itself; thus, it has been found that lime stabilization is more effective for montmorillonitic soils than for kaolinitic soils Lees, Abdelkader, and Hamdani, (1982). Due to limited silica in clay soil, there is always free calcium form lime that is not utilized. Therefore the use of bagasse ash wastes which is rich in silica enhances the pozzolanic reactions.

2.3.1.2 Cation Exchange

Negatively charged clay particles adsorb cations of specific type and amount. The replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valance cations such as the calcium ion (Ca^{++}) easily replace cations of lower valance such as sodium ions (Na^{+}). For ions of the same valance, 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 (Mitchell and Soga, (2005).

Below is an example of the cation exchange equation

$$Ca^{2+} + Na^{+} - Clay \rightarrow Ca^{2+}\ Clay + (Na^{+}) \qquad (2.1)$$

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 (Baser, 2009).

2.3.1.3 Flocculation and Agglomeration

Cation exchange reaction result in the flocculation and agglomeration of the soil particles with consequent reduction in the amount of clay-size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Flocculation and agglomeration change the clay texture from that of a plastic, fine grained material to that of a granular soil (Yazici, 2004).

2.3.1.4 Pozzolanic Reactions

Calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are the two outputs in pozzolanic reactions.

$$Ca^{2+} + 2(OH)^{-} + SiO_2 \text{ (Clay Silica)} \rightarrow CSH \quad (2.2)$$

$$Ca^{2+} + 2(OH)^{-} + Al_2O_3 \text{ (Clay Alumina)} \rightarrow CAH \quad (2.3)$$

Pozzolans are a broad class of siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The quantification of the capacity of a Pozzolans to react with calcium hydroxide and water is given by measuring its pozzolanic activity.

2.4 Empirical Literature

2.4.1 Industrial and Agricultural Waste as a Soil Stabilizing Material

The recent research in the field of geotechnical engineering and construction materials focuses on agricultural and industrial wastes being locally available and has disposal problem. The use of different industrial and agricultural wastes has become a common practice in the construction industry. Fly ash, sugarcane bagasse ash, coconut husk ash and rice husk can be sited as an example. Those by-products are increasingly playing a part in road construction and concrete technology, hence minimizing the problem of resource depletion, environmental degradation and energy consumption. This research focuses on the potential utilization of bagasse ash in soil stabilization, specifically expansive clay. In recent years there has been focus on agricultural and industrial by-product for soil stabilization because of pozzolanic activity of ash materials, including the ash derived from combustion of sugarcane solid wastes Villar-Cocina, and Valencia, (2008).

Yadu, Tripathi, and Singh, (2011) presented the laboratory study of black cotton soil stabilized with fly ash (FA) and rice husk ash (RHA). The soil was stabilized with different percentages of FA (i.e., 5, 8, 10, 12, and 15%) and RHA (i.e., 3, 6, 9 11, 13, and 15%). The Atterberg limits, specific gravity, California bearing ratio (CBR), and unconfined compressive strength (UCS) tests were performed on raw and stabilized soils. Results indicated that addition of FA and RHA reduces the plasticity index (PI) and specific gravity of the soil.

Dayakar, Sree, Prasad and Madhurimanmadha, (2003) conducted laboratory investigation for stabilization of expansive soil using silica fume and tannery sludge with percentage of solid wastes varying from 0, 10, 20,30, 40, 50, 60- 70%. The addition of wastes did not improve the index properties and maximum dry density but there was gain in strength of the expansive soil with both tannery sludge and silica fume up to 15%.

Okagbue (2007) evaluated the potential of wood ash to stabilize clayey soil. Results showed that the geotechnical parameters of clay soil are improved substantially by the addition of wood ash. Plasticity was reduced by 35%, CBR, UCS increased by 23–50% and 49–67%, respectively, depending on the compactive energy used. The highest CBR and strength values were achieved at10% wood ash.

Ramírez, Montes, Martínez, Altamirano and Gochi, (2012) noted that Bagasse ash exhibits satisfactory behavior in blended cementitious materials in concrete and has greater potential for use in other applications. The addition of 10% Bagasse ash increased the compressive strength of cement paste at all ages of hydration. The chemical deterioration of blended cement is also reduced due to the pozzolanic nature of Bagasse ash and the reduced permeability of Bagasse ash-containing mixtures. Replacement of fine aggregate with up to 20% by Bagasse ash resulted in equivalent or higher compressive strength and reduced water permeability and chloride diffusion Chusilp, Likhitsripaiboon, and Jaturapitakkul, (2009).

Cordeiro, Toledo, Tavares and Fairbairn, (2008) reported that the physico-chemical properties of Bagasse ash are appropriate for use as a mineral admixture and that reactivity is mainly dependent on particle size and fineness, concluding that it is possible to produce high-strength concrete by using finely ground Bagasse ash. The study to analyze the use of lime and sugar cane bagasse ash (SCBA) as chemical stabilizers in compacted soil blocks was done. The blocks were tested for flexure and compression in a dry and a saturated state. The tests were performed at 7, 14 and 28days of age in order to evaluate the effects of the addition of lime and SCBA on the mechanical properties of the compacted soil blocks. The results indicate that blocks manufactured with 10% of lime in combination with 10% of SCBA showed better performance than those containing only lime. Nevertheless, the addition of lime improved the strength of the blocks when compared with blocks fabricated with plain soil. According to SEM and DRX analyses, considerable improvement of the matrix was observed due to the formation of strong phases, such as CSH and CAH for the mixtures with additives. It was also concluded that the combination of SCBA and lime as a replacement for cement in the stabilization of compacted soil blocks seems to be a promising alternative when considering issues of energy consumption and pollution.

Kiran and, Kiran (2013) carried out for different percentages (4%, 8% and 12%) of bagasse ash and additive mix proportions. The strength parameters like CBR, UCS were determined. It was observed that blend results of bagasse ash with different percentage of cement for black cotton soil gave change in density, CBR and UCS values. The density values got increased from 15.16 KN/m3 to 16.5 KN/m3 for addition of 8% bagasse ash with 8% cement, Then CBR values got increased from 2.12 to 5.43 for addition of 4% bagasse ash with 8% cement and UCS values got increased to 174.91 KN/m2 from 84.92 KN/m2 for addition of 8% bagasse ash with 8% cement.

Chittaranjan, and Keerthi, (2011) studied the 'Agricultural wastes as soil stabilizers'. In this study Agricultural wastes such as sugar cane bagasse ash, rice husk ash and groundnut shell ash are used to stabilize the weak sub grade soil. The weak sub grade soil is treated with the above three wastes separately at 0%, 3%, 6%, 9%,12%and 15% and CBR test is carried out for each per cent .The results of these tests showed improvement in CBR value with the increase in percentage of waste.

Kharade, Suryavanshi, Gujar, and Deshmukh, (2014) stated that bagasse ash can be used as stabilizing material for expansive soils. Various experiments were conducted on black cotton soil with partial replacement by Bagasse Ash at 3%, 6%, 9% and 12% respectively. It was seen that due to addition of bagasse ash, CBR and Compressive strength increases almost by *40%*, but density showed only significant change. The blend suggested 6% bagasse ash, without any addition of cementing or chemical material would be an economic approach. Furthermore if any cementing material is added in suggested blend, then there will be definitely more improvement in properties of expansive soils.

Osinubi (2006) studied the effect of compactive effort and elapse time on the strength of lime-bagasse ash stabilized expansive clay from Gombe, Nigeria. The experimental study involved unconfined compressive strength. The following conclusions are drawn from the study: The results obtained indicate that UCS values increase with lime and bagasse ash treatment.

Salim (2014) conducted a study in Kenya to investigate the effect of adding 3%, 5%, 8% and 10% Sugarcane bagasse ash on the compressive strength of compressed earth brick. They observed that improvement in its compressive strength by 65% with the addition of 10% Sugarcane Bagasse Ash. This showed that the compressive strength of the Sugarcane Bagasse Ash stabilized Compressed Earth Brick increased with an increase sugarcane bagasse ash. The results could be attributed to the progressive densification of the soil/Sugarcane Bagasse Ash matrix as a result of hydration and pozzolanic reactions (Alavez-Ramirez *et al*., 2012).

2.5 The Research Gap

The bagasse has been used in various ways like replacing cement and lime in soil block making, lateritic soil stabilization, etc. but nothing has been done to check the feasibility of the bagasse ash produced in Kenya to blending lime in expansive clay stabilization. In addition, sugar cane bagasse ash has an effect on the strength of compressed earth brick Salim, Ndambuki, & Adedokun, (2014). Cordeiro *et al.*, (2008) reported that the physico-chemical properties of bagasse ash are appropriate for use as a mineral admixture and that reactivity is mainly dependent on particle size and fineness, concluding that it is possible to produce high-strength concrete by using finely ground bagasse ash. In Kenya, the application of sugarcane bagasse ash to stabilize expansive clay is yet to be explored. The aim of this research was to study the effect of Sugarcane Bagasse Ash stabilization expansive clay for road sub-base as a replacement to lime in Kenya.

CHAPTER THREE
MATERIAL AND METHODS

3.1 Introduction

This chapter presents the materials and methodology used during research study. It covers research design, data collection and data analysis techniques.

3.2Materials

3.2.1 Bagasse Ash

Bagasse is the fibrous residue obtained from sugarcane after the extraction of juice at sugar mill factories and previously was burnt as a means of solid waste disposal. However, as the cost of fuel oil, natural gas and electricity has increased, bagasse has become to be regarded as a fuel rather than refuse in the sugar mills. The fibrous residue used for this purpose leaves behind about 8-10% of bagasse ash, Hailu, (2011). Plate 3.1 shows ash obtained from the incineration of fibrous residue of bagasse.

Plate 3.1 Sugarcane Bagasse ash

3.2.2 Expansive Clay Soil

The soil for the research was collected from Bungoma County at 8º 59’ 38.42’’N and 38º 47’ 13.09’’E in several trial pits as indicated in plate 3.2. The sample was picked along the soil profile at the depth of 1.5m to avoid the inclusion of organic matter. Preliminary checks indicated that the soil was grayish black in colour and highly plastic in nature as shown in plate 3.3

Plate 3-2: Bungoma County marked in red

Plate 3-3: Expansive Clay Soil

3.1.3 Lime

The lime used in this study was purchased from hardware in Bungoma town on the counter. It was found to contain calcium oxide (CaO) commonly known as burnt lime, or quicklime, is a white, caustic and alkaline crystalline solid at room temperature plate 3.4. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of aluminum oxide and iron oxide. Muntohar, and Hantoro, (2000) gave the chemical composition of Lime as shown in Table 3.1.

Table 3-1: Chemical analysis of Lime

Description	**Abbreviation**	**lime (%)**
Silica	SiO_2	0.00
Iron	Fe_2O_3	0.08
Calcium	CaO	95.03
Magnesium	MgO	0.04
Sodium	Na_2O	0.05
Potassium	K_2O	0.03
Loss of Ignition	-	4.33
Alumina	Al_2O_3	0.13
Sulphur trioxide	SO_3	0.02
Manganese	MnO	0.60
Phosphorus	P_2O_5	0.00
Water	H_2O	0.04

Plate 3.4 Lime

3.2 Methodology

3.2.1 Determination of chemical composition of sugar cane bagasse ash

The Sugar Cane bagasse Ash (SCBA) was collected from Nzoia Sugar Company Ltd, situated in Bungoma county Western part of Kenya. The chemical analysis of the Ash was performed on 3rd July 2014 by Atomic Absorption Spectrophotometer (AAS) machine at Ministry of Mining and Geology laboratory. Atomic absorption of characteristic excitation energy method was used to identify elements present. The sample was first grounded to fine particles of 100µm or less and then digested to known weight by using a mixture of acid such as aquareqia, hydrofluoric and boric and then stocked to known volume. Each metal element was analyzed at a time using its known characteristic energy excitation. For refractory method such as aluminium, silicon, titanium etc a flame temperature of 3500^{o}c was used and non-refractory used 2000^{o}c to create ground state from sample solution. The AAS machine is calibrated using certified reference standards whose concentration of the metal analyzed are known. The unknown samples are then analyzed against the calibration obtained for the particular element being analyzed at that time.

3.2.2 Soil Classification

Two methods were used; X- ray analysis method and grading test

i) X-ray analysis method of clay soil

The X- ray XRD 600 Diffractometer machine was used to analyze soil particles to determine its properties. The flow diagram in Figure 3.1 shows the procedure used during the experiment:

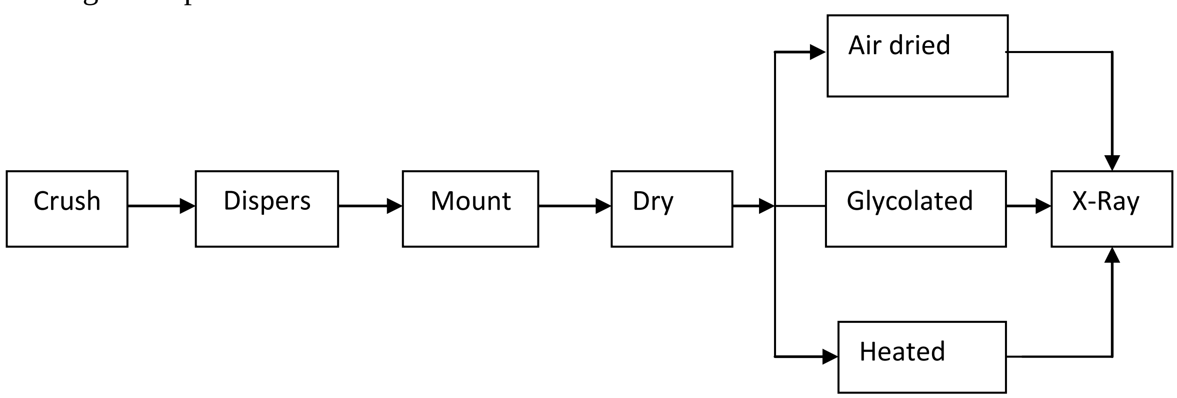

Figure 3.1 Clay Analysis flow chart

1. The sample was crushed and dissolved in distilled water to disperse the particles and then put on glass slide and air dried for about 8 hrs.
2. The reading for air dried was read from the X-ray.
3. Then the same sample was put in a dessicator with10% ethylenegyicol for overnight to enlarge the particles and read in the machine as glycolated.
4. The same sample was put in the furnace at 550^0c for 2 hrs and read in the X-ray machine as heated.
5.

ii) Grading test

Determination of the particle size distribution for the natural soil was conducted accordance to BS 1377 testing procedures. Approximately, 50gm of dry soil passing No. 200 sieve was treated with a dispersing agent for 18 hours. First a sample was washed through a series of sieves with progressively smaller screen sizes to determine the percentage of sand-sized particles in the specimens. Then a hydrometer analysis was then performed to measure the amount of silt and clay size particles. Some of sieves used are shown in Plate 3.5

Plate 3.5 Author is setting up sieve analysis apparatus

3.2.3 Experiment Set Up

The investigation was done according to BS 1377 that involved; air drying of samples and oven drying at 60ºC; breaking up the soil aggregates by rubber covered mallet. Then, sieve analysis as performed and sample was divided into two groups. The first group involved preparation for uniform samples for Atterberg limits and free swell tests. The other group was for compaction and California bearing ratio tests. Soil, lime and bagasse ash was mixed manually to get uniform mix ratio for each test as given in the Tables 3.2 After mixing some tests were performed and other samples were soaked for seven (7) days. The Research done around Bole area indicated that the optimum lime content required to stabilize expansive soil is mostly around 6-8% (Osinubi, 1997). Nigussie, (2011) evaluated the effect of sodium silicate and its combination with cement/lime for soil stabilization collected from Addis Ababa and concluded that 6% lime yielded significant improvement on plasticity and strength properties of clay soil.

Table 3-2: Experiment set up

NO	THE MIXTURE WITH LIME
1	Clay soil + 4% of Lime + water
2	Clay soil + 5% of lime + water
3	Clay soil + 6% of Lime + water
	THE MIXTURE WITH ASH
1	Clay soil + 4% of Ash + water
2	Clay soil + 5% of Ash + water
3	Clay soil + 6% of Ash + water
	THE MIXTURE WITH THE RATIO OF LIME:ASH
1	Clay soil + 1% Lime 4% Ash + water
2	Clay soil + 2% Lime 3% Ash + water
3	Clay soil + 3% Lime 2% Ash + water
4	Clay soil + 4% Lime 1% Ash + water

3.3. Determining the Physical Properties

The research investigated the physical properties of clay which included the following; moisture content, dry density, atterbeg test, specific gravity.

3.3.1. Moisture Content

The test is conducted in accordance with AASHTO T265. Small representative sample of the natural soil and soil-bagasse ash mixture specimen are obtained and oven-dried at 105 ± 5°Cfor at least 12 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.

3.3.2 Specific Gravity

Specific gravity which is the measure of heaviness of the soil particles is determined by using the density bottle method and it was noted from the results that specific gravity of the expansive clay sample was 2.35

3.3.3 Atterberg Limits

The test included the determination of the liquid limits, plastic limits and the plasticity index for the natural soil and the soil-bagasse ash mixtures. The tests are conducted for uncured and 7 days cured stabilized soil samples in accordance with AASHTO T89-90 and T90-96 testing procedures.

3.3.4 Liquid Limit

The soil sample for liquid limit is air dried and 200g of the material passing through No. 40sieve (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 is 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 centre 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, a little quantity of the soil was taken and its moisture content determined. The test is 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 is determined as the moisture content corresponding to 25 blows. The same procedure is also carried out for the treated soil with increment of bagasse ash content.

3.3.5 Plastic Limit

A portion of the natural soil and the soil–bagasse ash mixture used for the liquid limit test is retained for the determination of plastic limit. The ball of the natural soil and the soil– bagasse ash mixture is moulded between the fingers and rolled between the palms of the hand until it dried sufficiently, even though the soil is already relatively drier than the ones used for liquid limit. The sample is then divided into approximately two equal parts. Each of the parts is 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 is reduced to about 3mm. The movement continued until the thread shears both longitudinally and transversely. The crumbled natural soil and soil–bagasse ash mixture is then put in the moisture container and the moisture content determined. The same procedure is also carried out for the treated soil with increment of bagasse ash content.

3.3.6 Plasticity Index

The plasticity index of the samples is the difference between the liquid limits and their corresponding plastic limits. Plate 3.6 show the sample being divided by grooving tool on the Casagrande plate.

$$PI = LL - PL \quad (3.1)$$

Where PI – Plasticity index

LL – Liquid Limit

PL – Plastic Limit

Plate 3-6: Dividing the sample by grooving tool on the Casagrande plate

3.4 Determining the Mechanical Properties

The tests included the determination of the maximum dry density, optimum moisture content and CBR for the natural soil and the soil stabilized by lime and bagasse ash. The tests are conducted for uncured and 7days cured stabilized soil samples in accordance with AASHTO T99-94 testing procedures by the machine.

3.4.1 Maximum Dry Density

The maximum dry density is conducted for both the natural and soil-bagasse ash mixture of about 2.5kg, by varying the moisture content. The sample is then compacted into the 944 cubic centimeters (of mass m1); in three layers of approximately equal mass with each layer receiving 25 blows. The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample leveled off at the top of the mould with a straight edge. The mould containing the leveled sample is then weighed to the nearest 1g. One small representative sample is then taken from the compacted soil for the determination of moisture content. The same procedure is repeated until minimum of five sets of samples are taken for moisture content determination. The values of the dry densities are plotted against their respective moisture contents and MDD is deduced as the maximum point on the resulting curves.

3.4.3 Optimum Moisture Content

The corresponding value of moisture contents at maximum dry densities, which is deduced from the graph of dry density against moisture content, gives the optimum moisture content of expansive clay soil.

3.4.4 California Bearing Ratio

The CBR test is conducted in accordance with AASHTO T193-93 for the natural soils and soil- bagasse ash mixture. For stabilized soil samples tests were conducted for uncured and 7 days cured soil samples. 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.5.0kg of the natural soil and the soil-bagasse ash mixture are mixed at their respective optimum moisture contents in 2124 cubic centimeters mould. The samples are compacted in three layers with 56 blows from the 2.5kg rammer. The CBR test indirectly measures the shearing resistance of a 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 to obtain the same depth of penetration on a standard sample of crushed stone. In equation form, this is:

CBR= (test load on the sample/ standard load on the crushed stone)*100 %

CBR tests were conducted on the compacted specimens at the optimum moisture content using standard compaction test. The compacted soil samples of the CBR mold are soaked for 7 days in a water bath to get the soaked CBR value.

3.5 Determining the Optimum ratio of Sugarcane Bagasse Ash as Partial Replacement of lime in Stabilization of Expensive Clay Soil

The study was carried out by mixing expansive clay soil sample with (4-6) % of varying quantities of lime, bagasse ash, and water. The sample was divided into three parts; one part was stabilized with lime, another part with ash and last part with varying percentage ratio of lime to ash and soaked for seven days Plate 3.7. The samples were tested for plasticity index, and California bearing ratio.

Plate 3-7: Soaked moulds for CBR

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

The results are analyzed and discussed to give the insight of the research in terms of engineering properties of expansive soil in relation to the use. Investigation involved the evaluation of both natural and stabilized soil samples separately by performing the following tests; Atterberg limits, free swell, moisture density relationship (compaction) and California bearing ratio (CBR). Atterberg limits, moisture density relationship (compaction) and CBR are conducted for uncured and 7 days cured soil samples.

4.2 Chemical Analysis of SCBA

The chemical analysis indicated that the ash contained mainly silica, calcium, magnesium and aluminium with other minor elements Table 4.1. The combined percent composition of SiO_2, Al_2CO_3 and Fe_2O_3 of the ash is more than 70% hence exhibits pozzolanicity property according to ASTM C618 – 12 (ASTM 2012) standards for pozzolanic reaction.

Table 4-1: Chemical analysis of Bagasse Ash

Description	Abbreviation	Ash (%)
Silica	SiO_2	66.23
Iron	Fe_2O_3	3.09
Calcium	CaO	2.81
Magnesium	MgO	1.54
Sodium	Na_2O	0.26
Potassium	K_2O	6.44
Loss of Ignition	-	16.36
Alumina	Al_2O_3	1.90
Titanium	TiO_2	0.07
Manganese	MnO	0.60

4.2 Expansive Clay Soil

Results of the study on physical properties on neat sample of clay is given in Table 4.2 and indicated that the sample belonged to expansive clay. Most of the properties required to be improved to meet engineering standard.

Table 4.2 Properties of expansive clay soil

PROPERTY	QUANTITY
Colour	Grayish black
Percentage passing No. 200 sieve, %	99.4
Liquid limit, %	67
Plastic limit, %	32
Plasticity index, %	35
AASHTO soil classification	A-7-5
Free swell, %	0.7
Specific gravity	2.65
Maximum dry density, kg/m^3	1240
Optimum moisture content, %	26.4
Soaked CBR value, %	11

The chemical analysis of expansive clay according to (Ramesh et al., 2003) is shown in Table 4.2. The main components are silica (SiO_2) 52.85% and alumina (Al_2O_3) 12.24%, loss of ignition is 16.18%.

Table 4-3: Chemical analysis of expansive clay

Description	**Abbreviation**	**(%)**
Silica	Sio_2	52.85
Iron	$Fe_{2}o_{3}$	8.04
Calcium	Cao	6.01
Magnesium	Mgo	0.48
Sodium	$Na_{2}0$	0.26
Loss of Ignition	-	16.18
Alumina	$Al_{2}o_{3}$	12.24
Titanium	Tio_2	0.24

4.2.1 X-ray Method of Clay Soil Classification

The software was used to interpret the results which indicated that soil had larger percentage of smectite (montimorilonte) i.e class of clay soil. The smectite group of clays is commonly classified as swelling clays because they demonstrate high peak values in untreated (air dried) and glycolated samples but designate lower values when heated. This indicates that the structure collapses with less/decreasing moisture content. Generally, the peak values of the glycolated samples show values in the range of 12.56-18.92 Å, 13.36-17.46 Å for untreated/air dried samples and values of 9.04-10.22 Å for heated samples, as indicated in the Figure: 4.1

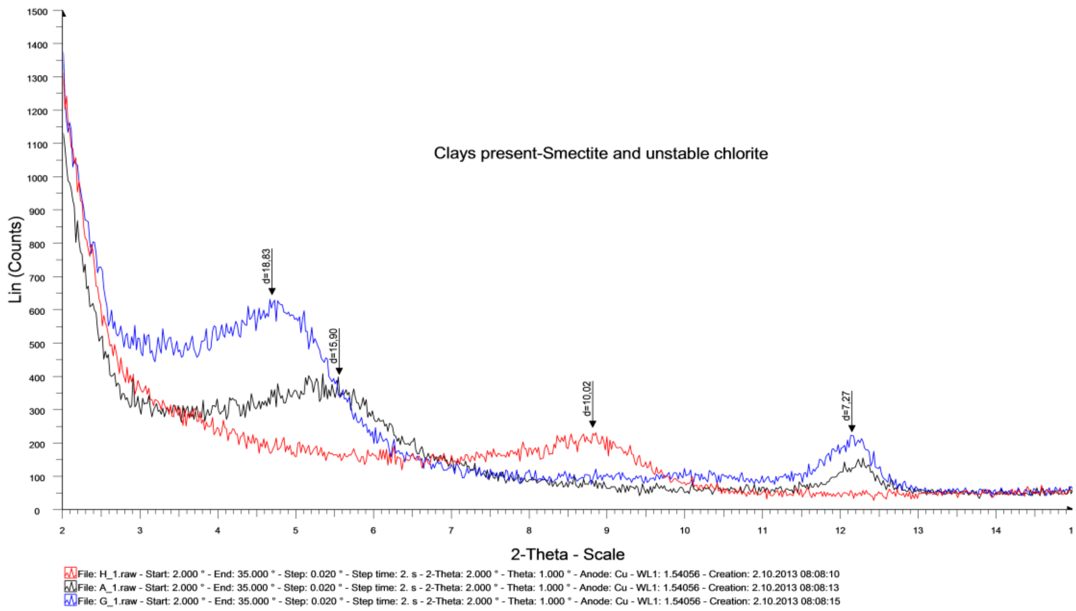

Figure 4-1: Clay present – smectite and unstable chlorite

4.2.2 Grading Test

Results obtained from both wet and dry sieve analysis indicated that the particle size distribution was distributed from the smallest to the largest as given in Figure 4.2. About 99.4% of the soil is passing through No. 200 sieve; it exhibits a liquid limit of 67%, a plastic limit of 32 %, plasticity index of 35 % and swelling of 0.7. The sample had more coarse particles than fine particles as seen from total passing sieve no. 0.425 mm of only 23.3%. The soil has a maximum dry density of 1.24g/cm3, optimum moisture content of 26.2%, and soaked CBR value of 11%. The soil had low bearing capacity when soaked and high plasticity index hence fell below the standard recommendations for most geotechnical construction works especially highway construction. Therefore, the soil requires initial modification and stabilization to improve its workability and engineering property.

Weight of total < 5mm Material Taken = 800g

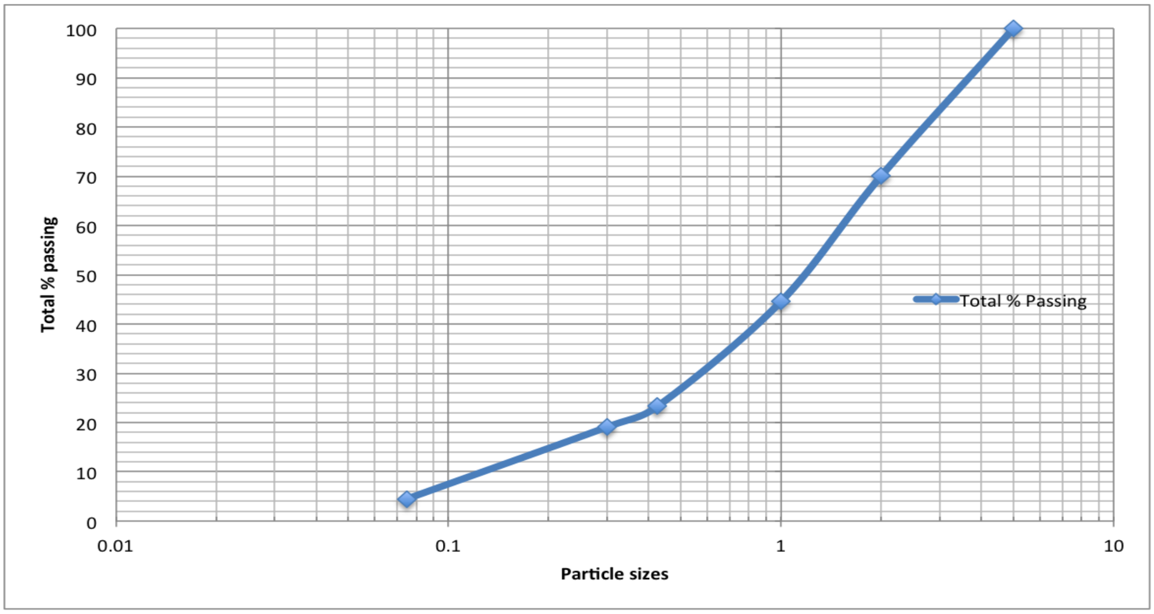

Figure 4-2: Grading curve analysis

4.3 Physical and Mechanical Properties of Expansive Soil Stabilized by Lime and Bagasse Ash

This covered mainly plasticity index and California bearing ratio for the stabilized clay using lime, ash and lime/ash.

4.3.1 Physical Property of Clay Soil Using Lime and Bagasse Ash on Plasticity Index

Liquid limit and plastic limit of clay sample treated by lime and SCBA showed decrease with increase of quantities of lime and ash added. The addition of lime and SCBA has remarkable effect on the plasticity and linear shrinkage of cohesive soils. The effect is due to the partial replacement of high plastic particles of clay with the low plasticity lime and SCBA particles.

Plasticity index generally decreased with increase of lime and bagasse ash content Figure 4-3. As seen from the graph, the addition of the same quantities of lime and bagasse ash decreases the plasticity index of the expansive soil differently. The decreased is observed to be more with bagasse ash than lime.

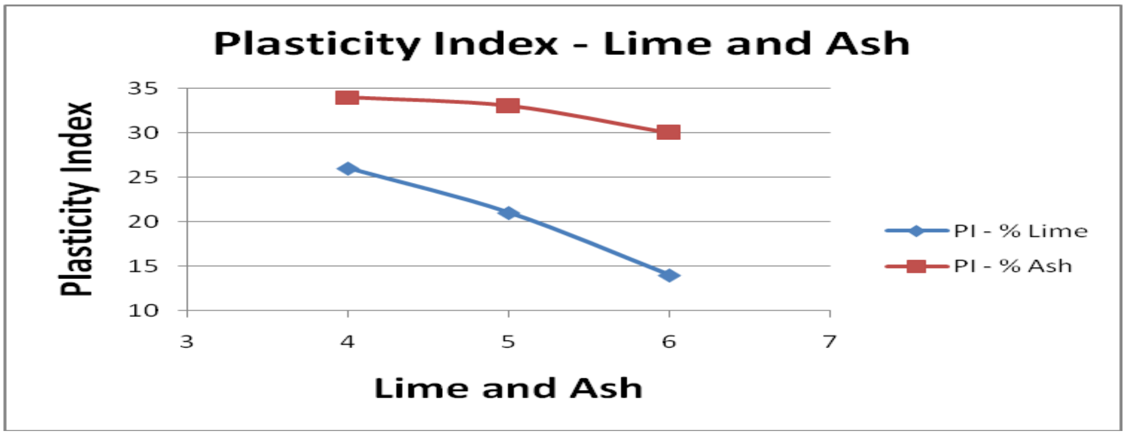

Figure 4-3: Variation of plasticity index with addition of different bagasse ash contents

In general, the plasticity of the soil is decreased by the addition of lime and bagasse ash content. This is clearly shown by the fact that plasticity index of treated soil decreased with increasing additive quantity. These effects are due to the partial replacement of plastic soil particles with lime and bagasse ash which is non plastic material and flocculation and agglomeration of clay particles caused by cation exchange.

4.3.2 Mechanical property of clay soil using Lime and Bagasse Ash on CBR

4.3.2.1 Compaction Characteristics of clay soil

Maximum dry density of neat sample prior to stabilization was 1.24g/cm^3 and Optimum moisture content was 26.4 % as shown in the Figure 4.4

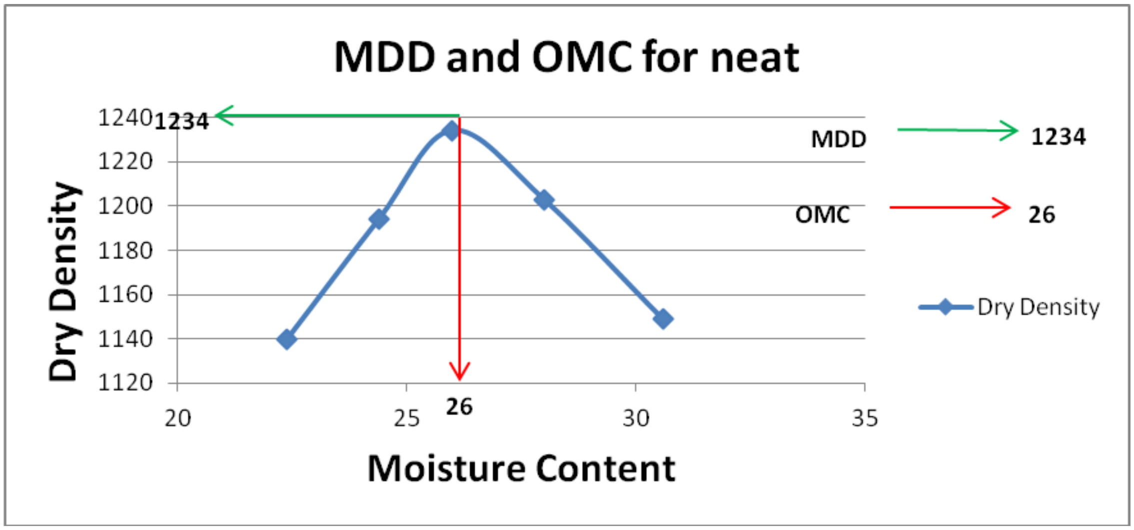

Figure 4.4 Maximum Dry Density and Optimum Moisture Content for neat sample

4.3.2.2 California bearing ratio

Figure 4.5 indicated that the CBR values decreased with increase of bagasse ash, while increased for lime and the ratio of lime to bagasse ash.

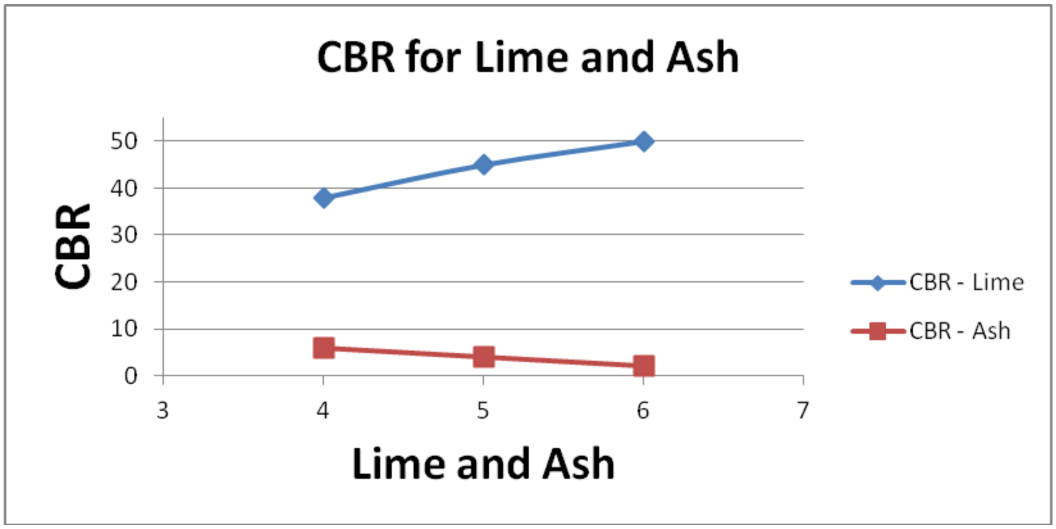

Figure 4-5: CBR of Lime and Bagasse Ash

The increase of CBR for lime is partly because of partial replacement of plastic soil with non-plastic material, flocculation and agglomeration due to cation exchange resulting into increase of soil density. It's also attributed to formation of cementitious properties achieved during the reaction. This also applies to the ratio of lime to ash, main player being Calcium from lime. Reduction of CBR on sample treated with bagasse ash is attributed to lack of acquiring cementitious properties due to minimum amount of Calcium plastic nature of the ash.

4.4 Optimum ratio of sugarcane bagasse ash as partial replacement of lime in stabilization of expansive clay soils

4.4.1 Atterberg Limits

Variations of plasticity index with the addition of (4-6) % lime, and equivalent amount of bagasse ash at a varying ratio of (6- 4) % are presented in Figure 4.6. Plasticity index generally decreased with the addition of additives. The decrease in plasticity index indicates an improvement in the workability of the soil.

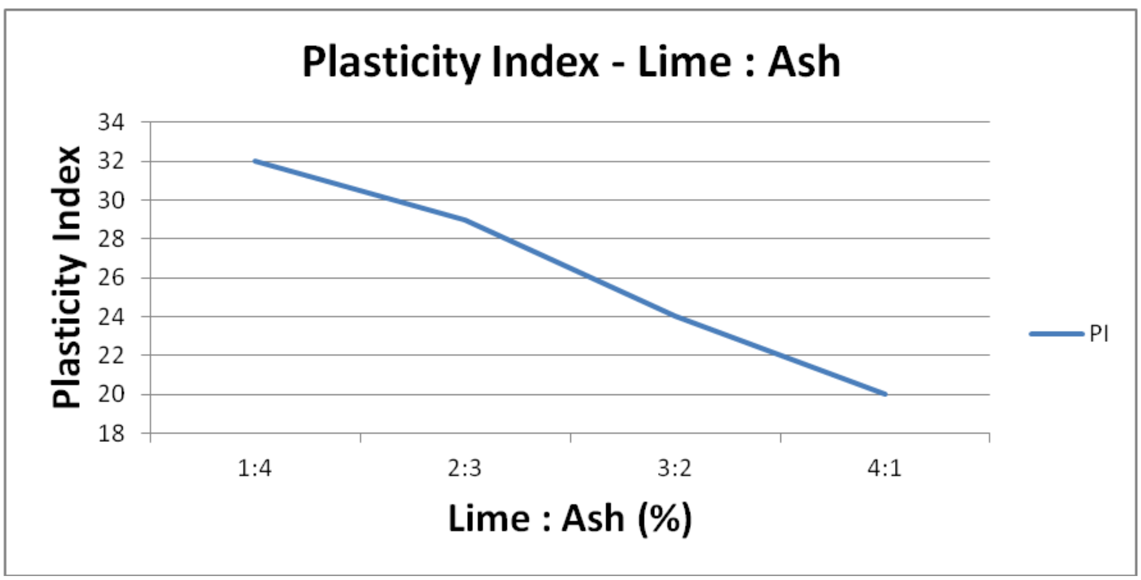

Figure 4-6: Plasticity index; ratio of lime to Ash

Effect of addition of bagasse ash and lime on plasticity index resulted into significant reduction in plasticity. The combination of lime and bagasse ash had more calcium available for cation exchange to take place and also this effect could be attributed to the combined action of partial replacement of plastic soil particles with non-plastic particles of bagasse ash and the ionic exchange of lime clay minerals of the soil. These led to flocculation and agglomeration of the clay particles which in turn reduces the plasticity of the treated soil.

4.4.2 California bearing ratio

Results presented in Figure 4.7 show that generally the CBR of all treated soil increases with addition of lime, lime plus bagasse ash. Results also show that curing enhances the strength development of expansive soil treated with lime and lime plus bagasse ash but curing has an insignificant change when expansive soil is treated with bagasse ash only.

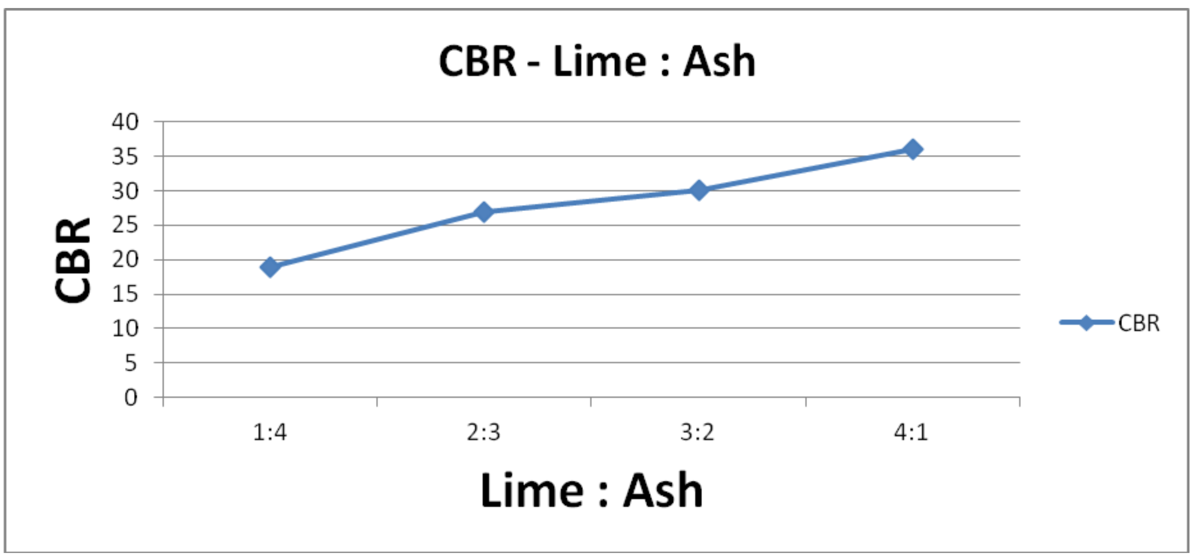

Figure 4-7: CBR for ratio of lime to ash (%)

The addition of lime and bagasse ash together led to a more increase of the CBR value but was lower than when lime was used alone. This shows that the load bearing capacity of the sample increased considerably with bagasse ash and lime treatment and curing has a significant effect on the CBR values. The combination of bagasse ash and lime can strongly improve the strength of expansive soils. The improvements in the CBR values of samples satisfy the minimum requirements that qualify them as road construction materials and showed that the soil sample was effectively stabilized by lime in combination with bagasse ash. This increase was as a result of the formation of cementitious compounds, calcium-silicate-hydrates (CSH) and Calcium- aluminate-hydrates (CAH), by calcium from lime and the readily available silica and alumina from both the soil and bagasse ash. CSH and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of stabilized soil layers. It was also observed that the CBR value increased with curing age for all mixes. This is attributed to the pozzolanic reaction between the lime, soil and bagasse ash resulting in the formation of more cementitious compounds.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The following are conclusions and recommendations that could be drawn based on the results of this research.

The following conclusions can be drawn from the results of the investigation carried out within the scope of the study.

1. The chemical analysis of bagasse ash indicated that the main element were silica (66.23%), potassium (6.44%) iron (3.09%), their combined percent composition is 75.76 % which is above 70 % specified by ASTM C618 – 12 (ASTM 2012) standards for pozzolanic reaction.
2. The plasticity index reduced with increased in content of bagasse ash and lime but the increment for bagasse ash was insignificant compare with the set standard by Road design manual part III. Bagasse ash alone cannot be used for expansive clay soil stabilization.
3. California bearing ratio increased for lime samples but reduced for bagasse ash samples and this was attributed to negligible amount of calcium present in bagasse ash. Similarly bagasse ash has negative impact on the strength of expansive clay soil hence cannot be used as standalone stabilizer.
4. When bagasse ash partially replaced lime, plasticity index reduced and California bearing ratio increased as the ratio varies. At the ratio of 4:1 (lime:ash) the results obtained conformed with the standard set Road design manual part III of CBR 36 %, PI 20% , linear shrinkage of 9.0 and negligible swelling thus can be used for expansive clay stabilization.

5.2 Recommendations

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

1. Sugarcane bagasse ash as investigated in this research work can only be used as a soil stabilizing agent when combined with lime at defined ratio. Therefore sugar industries should impress the new finding regarding the usage of bagasse ash to solve their disposal problem which had put them at logger head with Nema.
2. The sugar factories in collaboration with higher education organizations in the country should work together and establish a research team to further study the use of bagasse ash as a soil stabilizing material on different types of soils.
3. Further study should be done using finely grinded unburnt bagasse and compare with the existing results.
4. The study of bagasse ash as agricultural fertilizer should be investigated

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APPENDICES

Appendix I: Chemical Analysis of Bagasse Ash Results

MINISTRY OF MINING

Telegrams: "MINERALOGY"
Nairobi Telephone: 020-558034
Fax No. 554366:e-mail:cmg@bidii.com
When replying please quote ref No & date

Ref. No. ORIGINAL CERT NO.1843-44/14

MINISTRY OF MINING
MACHAKOS ROAD
P.O. Box 30009-00100 GPO
NAIROBI

Date… 3rd July, 2014

ASSAY CERTIFICATE

SENDER'S NAME : PATRIC BARASA
DATE : 23.05.14
SAMPLE TYPE : ASH/CLAY
SAMPLE NO : 1843-44/14

RESULTS

Lab No.	Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI
1843/14	ASH	66.23	1.90	2.81	1.54	0.26	6.44	0.07	0.60	3.09	16.36
1844/14	CLAY	44.65	14.81	1.69	1.21	0.12	4.92	0.74	0.70	11.1	19.34

Note: The results are expressed in percentage (%), unless otherwise stated.

MINISTRY OF MINING

Telegrams: "MINERALOGY"
Nairobi Telephone: 020-558034
Fax No. 554366:e-mail:cmg@bidii.com
When replying please quote ref No & date

Ref. No. ORIGINAL CERT NO.4927/14

MINISTRY OF MINING
MACHAKOS ROAD
P.O. Box 30009-00100 GPO
NAIROBI

Date... 8th April, 2014

ASSAY CERTIFICATE

SENDER'S NAME : PATRICK BARASA
DATE : 3.10.13
SAMPLE TYPE : ASH
SAMPLE NO : 4927/14

RESULTS

Lab No.	Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI	P_2P_5	SO_4
4927/14	ASH	50.24	1.47	2.72	1.82	0.16	4.56	0.24	0.38	1.03	17.93	0.038	18.98

Note: The results are expressed in percentage (%), unless otherwise stated.

FOR COMMISSIONER OF MINES & GEOLOGY.

R. K. ANGWENYI – SENIOR PRINCIPAL CHEMIST,
FOR: COMMISSIONER OF MINES AND GEOLOGY.

Appendix II: Compaction/Proctor test of Neat

Material weight used gms	2500	2500	2500	2500	2500
Water added % mls	12	14	16	18	20
	300	350	400	450	500
Mould : Number	B1	B1	B1	B1	B1
Factor	1000	1000	1000	1000	1000
Spicemen + mould weight gms	4975	5065	5135	5120	5080
Mould weight gms	3580	3580	3580	3580	3580
Specimen weight gms	1395	1485	1555	1540	1500
Moisture container number	10/12	16/8	22/40	64/84	92/15
MOISTURE CONTENT %	22.4	24.4	26.0	28.0	30.6
DRY DENSITY kg/m^3	1140	1194	1234	1203	1149

Determination PI for Neat using casagrande method

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	D1	D2	D3	D4	D5	D6	D7
Tin + wet soil g	35.6	37.4	39.2	41.8	43.3	24.1	24.3
Tin + dry soil g	30.6	31.8	32.9	34.7	35.1	23.7	23.8
Tin g	22.6	23.0	23.4	24.3	23.4	22.4	22.3
Water g	5.0	5.6	6.3	7.1	8.2	0.4	0.5
Dry soil g	8.0	8.8	9.5	10.4	11.7	1.3	1.5
Moisture content %	62.5	64.0	66.3	68.3	70.1	30.4	33.2

Determination of PI of 4% lime

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	C1	C2	C3	C4	C5	C6	C7
Tin + wet soil g	37.8	39.7	41.9	43.6	45.8	20.1	20.2
Tin + dry soil g	31.5	32.6	34.1	34.9	36.2	19.8	19.9
Tin g	18.9	19.0	19.7	19.5	19.8	18.8	18.8
Water g	6.3	7.1	7.8	8.7	9.6	0.3	0.3
Dry soil g.	12.6	13.6	14.4	15.4	16.4	1.0	1.1
Moisture content %	50.0	52.2	54.0	56.6	58.5	29.6	28.4

DETERMINATION OF PI 5% LIME

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	F1	F2	F3	F4	F5	F6	F7
Tin + wet soil g	54.1	52.5	58.3	58.5	62.8	22.7	23.6
Tin + dry soil g	43.9	42.8	46.9	46.0	49.4	22.1	22.8
Tin g	19.6	20.4	21.8	19.8	22.4	19.6	19.8
Water g	10.2	9.7	11.4	12.5	13.3	0.6	0.8
Dry soil g	24..3	22.4	25.1	26.2	27.0	2.5	3.0
Moisture content %	49.1	43.3	45.5	47.9	49.7	24.2	26.4

DETERMINATION OF PI 6% LIME

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	K1	K2	K3	K4	K5	K6	K7
Tin + wet soil g	57.5	60.6	64.6	67.7	69.3	23.2	23.0
Tin + dry soil g	48.2	50.1	51.9	53.8	54.2	22.5	22.4
Tin g	22.1	21.8	19.9	20.4	22.4	19.8	20.4
Water g	9.3	10.5	12.7	13.9	15.1	0.7	0.6
Dry soil g	26.1	26.3	32.0	33.4	34.8	2.7	2.1
Moisture content %	35.6	37.1	39.6	41.7	43.3	25.4	28.6

DETERMINATION OF PI OF 4% ASH

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	L1	L2	L3	L4	;5	L6	L7
Tin + wet soil g	34.6	36.8	38.5	40.2	42.0	24.2	24.0
Tin + dry soil g	28.4	30.0	31.1	32.2	33.3	23.6	23.5
Tin g	18.8	19.7	20.3	20.8	21.3	21.9	21.9
Water g	6.2	6.8	7.4	8.0	8.7	0.6	0.6
Dry soil g	9.6	10.3	10.8	11.4	12.0	1.7	1.6
Moisture content %	64.6	66.0	68.5	70.2	22.5	35.3	37.5

DETERMINATION OF PI 5% ASH

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	G1	G2	G3	G4	G5	G6	G7
Tin + wet soil g	36.4	38.6	40.3	42.1	44.4	24.6	24.2
Tin + dry soil g	30.7	32.2	33.3	34.4	35.6	23.9	23.8
Tin g	21.4	22.1	22.7	23.0	23.0	21.7	22.7
Water g	5.7	6.4	7.0	7.7	8.8	0.7	0.9
Dry soil g	9.3	10.1	10.6	11.4	12.6	2.2	1.1
Moisture content %	61.6	63.2	65.8	67.8	69.6	31.8	36.4

DETERMINATION OF PI 6% ASH

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	S1	S2	S3	S4	S5	S6	S7
Tin + wet soil g	35.4	37.3	39.6	41.5	43.5	24.3	24.3
Tin + dry soil g	30.3	31.9	33.6	34.9	36.0	23.7	23.7
Tin g	21.7	23.1	24.1	24.9	25.1	22.2	22.0
Water g	5.1	5.4	6.0	6.6	7.5	0.5	0.6
Dry soil g	8.6	8.8	9.5	10.0	10.9	1.5	1.7
Moisture content %	59.6	61.1	63.4	65.7	67.2	33.3	35.3

DETERMINATION OF PI OF THE RATIO 4% ASH TO 1% LIME

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	W1	W2	W3	W4	W5	W6	W7
Tin + wet soil g	32.1	34.2	36.4	38.3	40.2	23.4	23.9
Tin + dry soil g	27.1	29.0	30.8	32.1	33.4	22.8	23.4
Tin g	20.5	20.8	22.2	22.9	23.6	21.1	21.9
Water g	4.4	5.2	5.6	6.2	6.8	0.6	0.6
Dry soil g	7.2	8.2	8.6	9.2	9.8	1.7	1.5
Moisture content %	61.1	63.4	65.1	67.4	69.4	35.3	33.3

DETERMINATION OF PI OF THE RATIO 3% ASH TO 2% LIME

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	M1	M2	M3	M4	M5	M6	M7
Tin + wet soil g	33.2	35.4	37.3	39.1	41.0	29.9	22.3
Tin + dry soil g	28.2	29.9	31.2	32.4	33.6	21.5	22.0
Tin g	19.3	20.5	21.1	21.6	22.1	20.5	21.1
Water g	5.0	5.5	6.1	6.7	7.4	0.4	0.3
Dry soil g	8.9	9.4	10.1	10.8	11.5	1.3	0.9
Moisture content %	56.2	58.5	60.4	62.4	64.3	33.3	33.1

DETERMINATION OF PI OF THE RATIO 2% ASH TO 3% LIME

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	N1	N2	N3	N4	N5	N6	N7
Tin + wet soil g	31.2	33.0	35.0	37.4	39.2	21.1	21.0
Tin + dry soil g	27.2	28.6	30.1	32.2	33.7	20.8	20.8
Tin g	`9.4	20.3	21.2	23.1	24.4	19.9	18.9
Water g	4.0	4.4	4.9	5.2	5.5	0.3	0.5
Dry soil g	7.8	8.3	8.9	9.1	9.3	0.9	1.6
Moisture content %	51.3	53.0	55.1	57.1	59.1	33.3	31.3

DETERMINATION OF PI OF THE RATIO 1% ASH TO 4% LIME

TEST	LL	LL	LL	LL	LL	PL	PL
No. Of blows	50	40	30	20	10		
Tin No.	A1	A2	A3	A4	A5	A6	A7
Tin + wet soil g	36.1	38.1	40.4	42.3	44.6	21.9	22.0
Tin + dry soil g	29.5	31.2	33.0	34.4	36.0	21.6	21.6
Tin g	13.8	25.6	17.0	18.0	18.8	20.5	20.1
Water g	6.6	6.9	7.4	7.9	8.6	0.3	0.4
Dry soil g	15.7	15.6	16.0	16.4	17.2	1.1	1.5
Moisture content %	42.0	44.2	46.3	48.2	50.0	27.3	26.7

Table 8: CBR results for neat

Nil	**Penetration (mm)**	**Prove ring reading**		**CBR (%)**
		Top	Bottom	
-	2.5	11.4	10.3	11
	5.0	10.6	10.1	

Table 9: CBR results for Lime

Lime (%)	**Penetration (mm)**	**Prove ring reading**		**CBR (%)**
		Top	Bottom	
4	2.5	34.6	31.4	38
	5.0	37.7	33.1	
5	2.5	36.2	31.4	45
	5.0	45.4	42.2	
6	2.5	50.7	48.3	50
	5.0	42.2	32.0	

Table10: CBR results for Ash

Ash (%)	**Penetration (mm)**	**Prove ring reading**		**CBR (%)**
		Top	**Bottom**	
4	2.5	5.0	6.2	6
	5.0	6.2	5.8	
5	2.5	3.2	0.7	4
	5.0	4.2	1.3	
6	2.5	1.0	0.8	2
	5.0	1.7	1.0	

Table11: CBR results for the ratio of lime:ash

Ratio Lime: ash %	Penetration (mm)	Prove ring reading		CBR (%)
		Top	Bottom	
1:4	2.5	18.0	15.8	19
	5.0	19.2	18.4	
2:3	2.5	27.4	25.8	27
	5.0	23.9	17.1	
3:2	2.5	28.7	19.5	30
	5.0	30.0	26.1	
4:1	2.5	33.8	36.2	36
	5.0	31.0	24.0	

Table 4-3: Dry sieve analysis – clay soil

B.S sieves mm	Wt. Retained Gms	Wt. Total sample Retained	Total Passing %
5	-	800	100
2	239	561	70.1
1	204	357	44.6
0.425	171	186	23.3
0.3	33	153	19.1
0.075	117	36	4.5

Table 4-5: Plasticity of stabilized clay using lime and ash

S/NO	Materials	Plasticity				
		%	LL	PL	PI	PM
1	LIME	4	55	29	26	1768
		5	46	25	21	1428
		6	41	27	14	952
2	ASH	4	70	36	34	2312
		5	67	34	33	2244
		6	64	34	30	1920
3	LIME/ASH	1-4	66	34	32	2176
		2-3	62	33	29	1972
		3-2	57	33	24	1632
		4-1	47	27	20	1360

Table 4-6: California bearing ratio

S/NO	Materials	CBR			
		%	swelling	Linear shrinkage	CBR values
1	LIME	4	0.5	13	38
		5	0.5	10	45
		6	0.4	6.0	50
2	ASH	4	0.8	16	6
		5	0.9	16	4
		6	0.9	15	2
3	LIME/ASH	1-4	0.6	16	19
		2-3	0.6	13	27
		3-2	0.5	13	30
		4-1	0.5	9.0	36