TECHNICAL AND ECONOMIC EVALUATION OF SOIL STABILIZATION USING RICE HUSK ASH (RHA) AND NATURAL LIME (NL) AS AN ALTERNATIVE TO CUTTING AND FILLING IN ROAD CONSTRUCTION

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Technical and Economic Evaluation of Soil Stabilization using Rice Husk Ash (RHA) and Natural Lime (NL) as an Alternative to Cutting and Filling in Road Construction

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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

I dedicate this work with much love and appreciation to my family. I owe gratitude to God.

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LIST OF ABBREVIATIONS

NL – Natural Lime

RHA – Rice Husk Ash

JKUAT – Jomo Kenyatta University of Agriculture and Technology

CBR – California Bearing Ratio

UCS – Unconfined Compressive Strength

MDD – Maximum Dry Density

OMC – Optimum Moisture Content

BS 1377 – British Standards Institution 1377

SL – Shrinkage Limit

CM – Cubic Meter

Km – Kilometer

PL – Plastic Limit

LL – Liquid Limit

PI – Plasticity index

SL – Shrinkage Limit

CEC – Cation Exchange Capacity

CSH – Calcium Silicate Hydrates

CAH – Calcium Aluminates Hydrates

CASH – Calcium Aluminum Silicate Hydrates

GBFS – Granulated Blast Furnace Slag

CBPD – Cement By-Pass Dust

XRD – X-ray diffraction

VA – Volcanic Ash

PVD – Prefabricated Vertical Drains

ISS – Ionic Soil Stabilizer

NCC – Nairobi City County

KURA – Kenya Urban Roads Authority

KeRRA – Kenya Rural Roads Authority

KeNHA – Kenya National Roads Authority

RAR – Rural Access Roads Program

MRP – Minor Roads Program

ABSTRACT

Pavement construction in areas where expansive clay forms the bulk of alignment soil is expensive. The common practice in Kenya is to remove the undesirable material, and fill the space with more stable materials, the cost for such construction methods are unnecessarily very high. The present study has evaluated the technical and economic viability of stabilization of problematic expansive clays soils using Rice Husk Ash (RHA) and Natural Lime (NL) through experimentation designs and cost benefit analysis for subgrade class S2 pavement construction. The aim of this study was to assess the technical and economic viability of using RHA and NL to stabilize expansive clay soil under Kenyan conditions. Expansive soil specimens from Kitengela, Kajiado County, were stabilized by adding varying quantities of RHA and NL. Chemical and geotechnical tests were performed on untreated and stabilized samples to assess the effect of RHA and NL on the properties of expansive clays. The bearing strength of the clay soil increased significantly from a California Bearing Ratio (CBR) value of 2% to 9% with addition of 20% RHA and 2% Lime. A CBR of 9% met the minimum requirement for a road subgrade layer. Increasing RHA content in expansive clay soils resulted in increased Cation Exchange Capacity. With the addition of stabilizers, free swell dropped from 2% for untreated material to as low as 0.6% which is within specified limits of below 1%. With the addition of 20% RHA and 2% NL the soil Plasticity Index (PI) reduced from 56% to 8%, compared to a maximum allowable PI of 50%. This study demonstrates that: a minimum of 20% RHA and 2% NL will stabilize expansive clay soil for subgrade construction; the cost of Stabilization of Expansive Clay soil (SEC) technology, using RHA and NL, is relatively low compared to Conventional Methods (CM) which involve cutting and filling and the SEC technology can save up to 17% of the cost of earth works in road construction and up to 39% of the cost of sub-grade construction. The study therefore recommends 20% RHA and 2% NL as optimum proportions of stabilizers required to give expansive clay soil the desired engineering properties to support road pavement.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Because expansive clays are characterized by excessive compression, dispersion, collapse, low shear strength, low bearing capacity and high swell potential (Rao & Thyagara, 2007), such soils are unsuitable for road subgrade layer construction. Expansive clays usually experience large volume changes depending on the amount of water contained in the soil voids. Such soils can form deep cracks in drier seasons and expand dramatically when wet. Such instability affects the strength performance of soil as a construction material (Tripathy *et al*., 2002). Volume changes involving shrinkage and swelling cause deformation of the road surface, while increased moisture content in expansive clay soils significantly reduces soil bearing strength. Expansive clays usually develop a sand-like texture when dry (Akbulut & Arasan, 2010), making them susceptible to erosion. The sand-like texture is composed of a very dense clay matrix.

Various methods of dealing with expansive clays have been documented. This including avoidance of expansive clay areas, excavation and replacement of expansive clay, soil stabilization with lime or cement, avoidance of problematic soils along the alignment, and confining expansive clays under improved subgrade by use of at least 300mm capping layer to minimize moisture changes (Kenya Ministry of Transport and Communication, 1987).

Soil stabilization occurs when substances, with inherent binder characteristics to improve the engineering characteristics of unstable soils, are added. In the process of stabilization cementitious material (aggregations) are formed and this has also been associated with increased hydraulic conductivity (Al-Rawas, 2002). Various ashes seem to have the capacity for soil stabilization (Mymrin & Ponte, 2005). Portland cement, hydraulic lime, bitumen, and industrial by-products such as blast furnace slag, fly ash, rice husk ash, and cement kiln dust have been used as soil stabilizers (Akbulut & Arasan, 2010). Lime mortar, which can be produced using a traditional kiln at a low cost, is compatible with stone and ancient brickwork and would likely be a better stabilizer of expansive soils than cement (Rao *et al*., 2011). Addition of these stabilizers also decreases the swelling pressure, resulting in stability. This could be because of the pozzolanic and cationic exchange reactions that take place between the soil and the additives. These reactions could create cementitious components such as calcium silicate hydrates (CSH), calcium aluminate hydrates (CAH), and calcium silicate aluminate hydrates (CSAH). Such products increase the strength, reduce the swelling potential and change the classification of the soils. Other methods of stabilization include use of soma fly ash as well as waste marble dust (Rao *et al.*, 2012). Excavation and replacement of expansive clay is very expensive and unsustainable (Nalbantoglu & Tuncer, 2001). Studies done in Kenya have shown that it is feasible to stabilize soil for stabilized block production (Hebib & Farrell, 2003).

Soils with high organic matter are also unstable. The presence of organic matter could inhibit the hydration process of stabilizers such as cement. A study by Hebib and Farrell (2003) showed that the engineering properties of peat were considerably improved when mixed with some binders. However the degree of improvement was markedly different for the two peats that had similar organic content. Their study showed that formation of the stabilized soil structure within the testing chamber significantly reduced the amount of settlement and accelerated the rate of consolidation (Ronoh *et al*., 2014).

The depth of expansive clays in Nairobi varies from 0.3 – 2.0 m (Kenya Ministry of Transport and Communication, 1987). Underlying the expansive clays is a stratum of Nairobi Phonolite (the bed rock), which is strong enough to form pavement support. During construction of roads, expansive clays are usually excavated and transported to spoil areas, making road construction expensive. Therefore, there is need for cost effective methods of dealing with expansive clays in road construction.

Calcium oxide reacts with silicon dioxide, which is available in rice husk ash, to form calcium silicates which are cementitious (Equation 1.1). High calcium ash has reportedly been responsible for the enhancement of CBR from 2.4% to 120% in high phosphate waste (Hadi, 2008). On hydration, quick lime forms slaked lime or lime water. When water is added to lime it becomes hot and cracks to form a white powder, calcium oxide.

This is referred to as slaking of lime.

$$CaO + SiO_2 \longrightarrow \underset{\text{calcium silicate}}{CaSiO_3}$$ …………..**Equation 1.1**

Alhasan & Olaniyi (2013) showed that organic sulphur and buffered acids, whose chemical characteristics were not presented in their paper, increased the CBR of expansive soil by about 10% with addition of 1ml of the solution (Alhassan & Olaniyi, 2013). Cementitious characteristics have been found in Kenyan RHA. A study conducted in 1993 showed that on the basis of 28day strength of RHA cement mortar, formulations with 23.4% RHA and 76.6% OPC can be used without losing the mortar strength properties of OPC (Kamau *et al*., 1993). However the performance of RHA may be affected by presence of impurities such as carbon, which results from incomplete combustion. RHA should therefore be prepared under controlled conditions in a kiln with adequate oxygen to ensure complete oxidation of carbon.

Rice husks, which are abundant in Kenya's rice producing areas, are usually disposed by burning. The resulting rice husk ash (RHA) is non-biodegradable and therefore a threat to the environment (Nyamai, 2012). Lime deposits are also available in Kenya's coastal area. Production of soil stabilization materials from local resources can significantly reduce the cost of construction.

Road infrastructure is a major capital asset that consumes billions of shillings of tax payers' money and is a key asset for development and hence the need for continued investment to maintain, modernize and expand them (Kulkarni *et al.,* 2004). Since investment resources are limited and that all deserving projects cannot be funded within available resources, there is increasing need for research and innovations to develop low cost construction technologies to help maximize utilization of the resources. This has a great potential to benefit society in terms of reducing demands on natural pavement materials, reducing environmental problems, and conserving energy (Tao *et al.,* 2008). Conversely, professionals in pavement engineering often hesitate to adopt such new technologies mainly due to the lack of cost benefit and performance information. Economic analysis is a critical component of a comprehensive project or program evaluation methodology that would help consider all key quantitative and qualitative impacts of highway investments (Zhao *et al.,* 2013). It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. Expansive clays experience large volume changes as a result of changes in water content, forming deep cracks in drier seasons and expand dramatically when wet. This form of instability affects the performance of soil as a construction material. Strength properties of these soils also change according to the amount of water contained in the soil voids.

Development of infrastructure in developing countries and in particular capital projects quite often encounter constrained budgets which usually present great challenges to project managers, engineers and other project stakeholders in identifying and justifying the use of cost-effective or cost-saving sustainable construction methods. Such developments are vital socio-economic pathways to a better quality of life in urban areas which often can be costly and energy inefficient depending with the construction method applied. Expansive clay soils lack the capacity to support infrastructure such as roads. This problem can be resolved through soil stabilization.

The cost of road construction is dependent on a number of factors including cost of materials, equipment, labour, and the method of construction; the other factors are labour productivity, weather, environmental conditions, standards of quality, intended use of the road and weather conditions (Sawhney *et al.*, 2004; AASHTO, 2003). Selection of construction material, labour and equipment for a given project, in a particular location, from available alternatives will give different costs and therefore the need to carry out cost-benefit analysis. The objective of a cost-benefit analysis is to translate the effects of an investment into monetary terms and to account for the fact that benefits accrue over a long period of time while capital costs are incurred primarily in the initial years (Lad & Samant, 2014).

In a separate study (Karatai *et al*, 2016) it has been determined that addition of 20% RHA and 2% Lime is sufficient to condition expansive clay soil for road construction. However, the economic viability of soil stabilization has not been verified.

Using the case of Enterprise Road in Nairobi County, this study examines the economic viability of using RHA and lime to stabilize clay soil for road construction.

1.2 Problem Statement

Road construction method involving excavations to remove and replace problematic expansive clay soils makes the costs of such construction works unnecessarily high. The cost of cutting and hauling expansive clay soil during road construction in Kenya makes the cost of such construction unnecessarily high. This study evaluated the technical viability of stabilization of problematic expansive clays soils using Rice Husk Ash (RHA) and Natural Lime (NL) through experimentation designs and cost benefit analysis to compare the technology with the current practice of cutting and filling. The effect of rice husk ash and natural lime on the strength, plasticity and swell of expansive clays were investigated and an optimum combination of RHA and NL determined. While considerable work has been done to demonstrate soil stabilization using Rice Husk Ash (RHA) and Natural lime (NL), little efforts have been paid to determining optimum quantities of the additives required to meet existing standard specifications for road construction as well as evaluating the economic viability of using such technologies in road construction.

1.3 Objectives

1.3.1 The Overall Objective

The main objective of this research was to evaluate the technical and economic viability of treating expansive clay soils using Rice Husk Ash (RHA) and Natural Lime (NL) in road construction sites in order to improve workability and eliminate the cost of soil cutting and hauling from construction sites in Kenya.

1.3.2 Specific Objective

The specific objectives were:-

i. To assess the effect of rice husk ash and natural lime on the strength, plasticity, swell and the Cation Exchange Capacity (CEC) of expansive clays.

ii. To evaluate the economics of stabilizing expansive clays with rice husk ash and natural lime.

1.4 Justification

In Kenya, the cost of road construction in areas with expansive clay soils is significantly expensive due to the need to remove the clay soils and replace with more stable material. Stabilization of such soils could avoid expensive cutting and filling. This study provides data to support use of stabilization as an alternative to cutting and filling.

1.5 The Research Questions and Assumptions

The research question in this study was; “Could stabilization of expansive clay soils with RHA and NL offer a viable alternative to the current practice of cutting and filling?” Key assumptions made in this study were:-

i. The properties of the materials used in this study including RHA, NL and Expansive Clay Soils are considered to represent the properties of such materials in the entire Republic of Kenya.

ii. The case study of construction of Enterprise Road used in this study, including prices for materials used in the cost benefit analysis, was assumed to represent the characteristics of road construction works in areas with expansive clay soils.

1.6 The Scope and Limitations of Study

The scope of this work was limited to laboratory testing of expansive clay soil stabilized with varying quantities RHA and NL to assess the effect the stabilizers on the strength, plasticity, swell and the Cation Exchange Capacity (CEC) of as well as cost benefit analysis of Stabilization of Expansive Clay Soil (SEC) technology.

CHAPTER TWO

LITERATURE REVIEW

This chapter has highlighted the various studies that have been conducted in the past on stabilization of expansive clay soils. This review has revealed that little research has been conducted to develop new and sustainable construction materials in developing countries. There is need for research in tropical developing economies to identify alternative construction materials including rice husk ash, which was the subject of this research.

2. 1 Road construction in Kenya

The road network in Kenya at independence was 45,000 km out of which only approximately 2,000 km were paved while the rest was mainly earth roads (Kenya Roads Board Annual Report and Financial Statements, 2013). In order to support the country's development objectives at the time, the government embarked on a program of upgrading roads to bitumen standards and improvement of rural roads to gravel standards. As a result, the paved road network was expanded from 2,000 km in 1963 to 11,189 km in 2009.

In the early 1990’s, the rural access roads improved under the Rural Access Roads Program (RAR) and Minor Roads Program (MRP) in many areas of Kenya as they were of a better standard than the higher class feeder roads (Roads 2000 Strategic Plan 2013 –

2017). As a result the Government of Kenya through the Road Maintenance Initiative (RMI) identified constraints to road maintenance and outlined mitigations measures thereto. One of the recommendations was to utilize the labour based experience to also maintain the higher class feeder roads as well as some paved roads in both rural and urban areas. In the late 1980's and 1990's the emphasis shifted from construction to maintenance as it was becoming evident that Kenya was unable to maintain her roads adequately. The country faced several development challenges on maintenance of roads which form an interconnected transport network and its maintenance does not provide sufficient serviceability. Also there was inadequate coordination of implementing agencies and development partners. In addition to this the private construction sector in Kenya constitutes one of the largest industries in the country and as such is the major executioner of road works. However, as an industry the sector is underdeveloped and poorly represented, especially the hundreds of locally based small-scale contractors. More over local resource based approach is not fully mainstreamed in academic and skills training institutions as well as in research works.

The process of reforms was a collaborative effort between the Government and Development Partners towards establishing an effective and sustainable management and financing of the public road network (Kenya Roads Board Annual Report and Financial Statements for the Year Ended 30th June 2013). The creation of the Road Maintenance Levy Fund (RMLF) in 1994, which has continued to provide a secure and sustainable source of maintenance funds, and the establishment of the Kenya Roads

Board (KRB) in 1999 to manage the fund, have been important milestones. In 1999, the country embarked on a program of upgrading roads to bitumen standards and improvement of rural roads to gravel standards in order to support the country's development objectives. In 2001, the Ministry of Roads, with financing from World Bank, engaged a Consultant to undertake a Road Inventory and Condition Survey (RICS) for the Classified Roads using Geographical Positioning Systems (GPS). The RICS study led to the establishment of a database for classified roads in a Geographical Information System (GIS). Unfortunately, the extent of the unclassified rural and urban roads remained unknown and was estimated to range from 80,000 to 130,000km making it difficult for their effective maintenance and development planning. This led to improvement in the road network condition for the classified roads which is currently estimated at 17% good, 51% fair and 31% in poor condition. On the other hand, majority of the unclassified roads are in un-maintainable condition with only 5% good, 22% fair while 72% is in poor condition.

Kenya has a tradition for Structured Labour Based road works, starting in the 1970's with the Rural Access Roads Program (RAR) that was implemented from 1974 to 1986 and constructed about 8,000 km of farm to market access roads (Roads 2000 Strategic Plan 2013 – 2017). This was followed by the Minor Roads Program (MRP) in the late eighties (1986 to 1996) which improved about 4,500 km of the classified Secondary (D), Minor (E) and Special Purpose roads such as tea, coffee, settlement area and wheat roads in areas of high agricultural potential in the country.

In the early 1990's it was realized that the level of road maintenance was not sufficient to keep the growing number of improved roads in good condition. In order to address the situation, the Government initiated the Road 2000 Strategy which is a method of road development and management that ensures optimum utilization and development of locally available resources where technically and economically feasible. The Road 2000 Strategy was to be rolled out nationwide to cover the entire road network based on the lessons learnt from the two previous labour based programs (RAR and MRP). However, due to various institutional and operational challenges, the strategy was only implemented in 6 districts in Kenya by the year 2000 and its impact was limited.

The Kenya Roads Act, 2007 established three new Road Authorities, namely, the Kenya National Highways Authority, KeNHA, the Kenya Rural Roads Authority, KeRRA and the Kenya Urban Roads Authority, KURA (Kenya Roads Board Annual Report and Financial Statements for the Year Ended 30th June 2013). These Authorities have now been constituted and the new institutional structure is in place. There is also the Materials Research and Testing Department formed through The Kenya Roads Act, 2007 it is in charge of testing of engineering and non-engineering materials for the building and construction industry in the country. The Department also undertakes geotechnical studies for foundations, road pavement studies and carries out research on the performance of various products.

In the KeNHA Strategic Plan for the period 2008 – 2012, the Strategic Model recognizes the promotion of the use of local resources in road construction and maintenance as a key objective. The Authority commits to ensure that locally available materials for road construction are utilized and not imported. As much as possible, local labour would also be used in road construction. To achieve the results, the following strategies and activities would be implemented:-

1. Enhance the use of local resources by:
   i. Promoting research and development in the use of local and recycled materials through linkages with local and international institutions.
   ii. Encouraging the use of locally available labour and materials in road construction and maintenance where appropriate.
2. Build capacity of local human resources in road consulting services, construction and maintenance by:
   i. Establishing mechanisms to encourage foreign consultants and contractors to partner with local firms in projects funded by the Authority to enhance knowledge transfer and capacity building.
   ii. Building capacity of young professional graduates through internship in KeNHA projects;
   iii. Sensitizing/lobbying the public and other key stakeholders on road construction projects and distribution.” (Roads 2000 Strategic Plan 2013 – 2017).

It’s therefore worth noting that construction and upgrading of roads to bitumen standards in Kenya has been an expensive exercise since independence requiring the authorities to invest huge amount of finances. Adoption of cheaper and sustainable technologies such as use of locally available materials would have tremendous impact in lowering the cost of road construction.

2. 2 Challenges of black cotton soil in road construction

Black cotton clay is an expansive soil which swells or shrinks excessively due to changes in moisture content and has an appreciable plasticity in the clay fraction (Hashim *et al*, 2013). It is dark grey to black in color and has a high content of clay usually over 50 percent in which montmorillonite is the principal clay mineral that gives the soil expansive property. These soils are soft and highly compressible, and have unacceptable consistency indices, low strength, and high impermeability. These undesirable properties make them unfit for use in infrastructural development projects hence the need to have them stabilized. The behavior of expansive soils is uncertain when subjected to moisture changes and this present considerable challenge in their utilization for infrastructural development. The strength properties of these soils change according to the amount of water contained in the voids of the soils. The movement of water into and out of the soil voids induces severe swell-shrink behaviour causing stress levels which could result in damages to facilities placed on them.

Due to the seasonal variation in the moisture content of black cotton soil, structures built on the soil experience severe stresses which may eventually lead to failure (Figure 2.1).

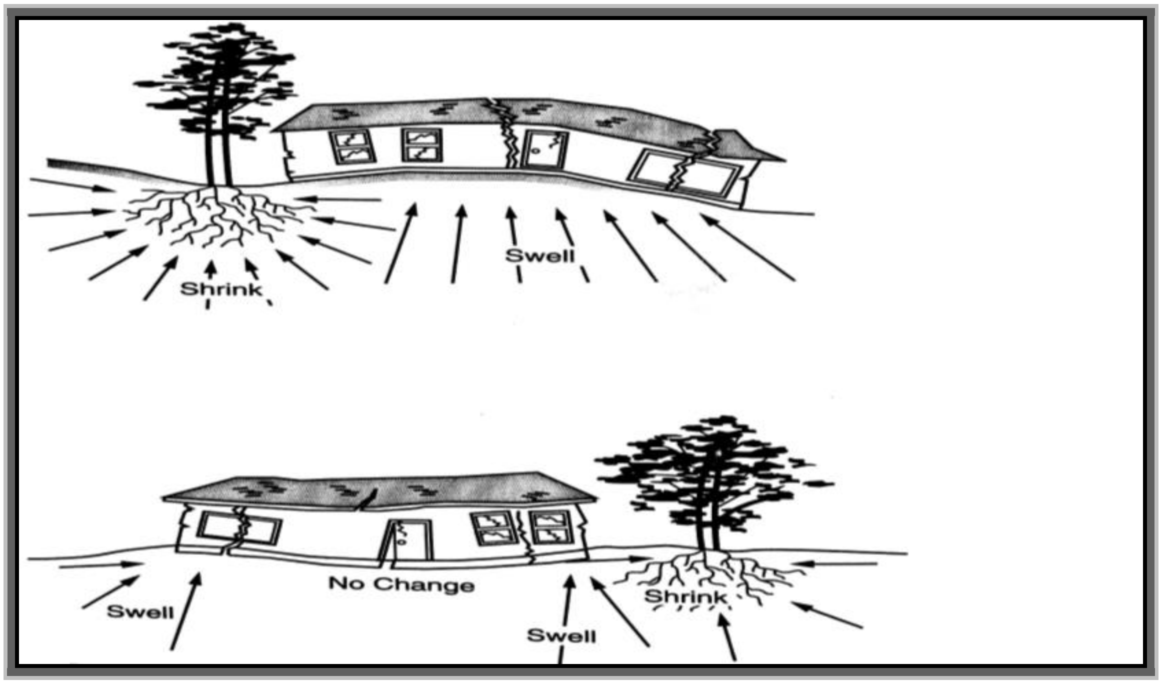

Figure 2.1: Effects of swelling and shrinking behavior of expansive clay soils on structures (Source: Bell and Howell, 1981)

Road construction over an extensive area of black cotton soil generally poses operational, maintenance and construction challenges due to factors such as the high volume changes, severe cracking when dry, low bearing value when wet, lack of drainage and scarcity of suitable construction materials. (Hashim *et al*, 2013). The change in void ratio with a change in water content for an expansive soil such as black cotton soils is as a result of desiccation and water absorption and this provides an understanding of swelling and shrinkage behavior (Tripathy *et al*, 2002).

Expansive soils have the tendency to swell when they come in contact with moisture and to shrink if moisture is removed from them (Hashim *et al*, 2013). These volume changes in swelling soils are the cause of many problems found in structures that come into their contact or constructed out on them. Partially saturated clayey soils with high plasticity are very sensitive to variations in water content and show excessive volume changes (Sarkar *et al,* 2012). This highly plastic soil may create cracks and damage on the pavements, railways, highway embankments, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines and sewer lines. Highly plastic soil exhibits undesirable engineering properties under load. They have low shear strengths and tendency to lose shear strength further upon wetting or other physical disturbances. The plastic soils are highly prone to shear failure due to the constant load over time and considered poor material for foundations.

Expansive soils exhibit significantly high volumetric deformations and hence pose a serious threat to stability of structures and foundations (Hanumantha *et al*, 2014). Clays have always presented problems for lightly loaded structures, including pavements, by consolidating under load and by changing volumetrically along with seasonal moisture variation. Expansive soil behaviour is generally attributed to existence of clay soils, and is characterized by excessive compression, dispersive behavior, collapsing behavior, low shear strength, high swell potential, and frost susceptibility (Petry *et al*, 2002).

There are various options in foundation practices adopted to minimize heave in expansive soils (Kumar *et al*, 2000). One option is avoiding the expansive soil in favor of safer foundation soils; this option is not an economically viable proposition in most situations due to decreasing land available for development. With the development of several modern techniques for effectively combating problems posed by expansive soils, this option is seldom adopted. Another option is stabilization which involves use of mechanical, physical, and chemical alterations. Mechanical alterations include excavation of expansive soil and replacement with non-expansive material, where the depth of the active zone is small and where suitable replacement material is available. Physical alteration involves mixing granular material with expansive clay to minimize heave. The faster ingress of water due to increased permeability is a disadvantage of this method. Chemical alteration involves the addition of chemicals to expansive clay to reduce heave by altering the nature of the clay minerals and of all the chemicals tried, lime has been found to be most effective and economical additive (Kumar *et al*, 2000).

Therefore, expansive clay soils are not fit for use in infrastructural development projects due to their numerous undesirable properties discussed in this section and hence the need to have them stabilized. Stabilization of expansive soils enables modification of the undesirable properties such us excessive compression, dispersive behavior, collapsing behavior, low shear strength, high swell potential, and frost susceptibility.

2. 3 Soil stabilization

Excessive heave, settlement, low shear strength, and internal erosion of some soils cause damage to many civil engineering structures such as spread footings founded on expansive soils; roads, highways, and airport runways constructed on expansive subgrade; and earth dams constructed with dispersive soil (Nalbantoglu & Tuncer, 2001).

Koteswara *et al.* (2012) defined soil stabilization as a procedure where natural or manufactured additives or binders are used to improve the properties of soils. The natural durability and strength of soil can be improved through the process of "soil stabilization" using different types of stabilizers. For many centuries various soil stabilizers have been tried which include natural oils, plant juices and even animal dung. Portland cement, hydraulic lime, bitumen by-products such as blast furnace slag, fly ash, gypsum and cement kiln dust have also been tried as soil stabilizers.

According to Hashim *et al*, (2013), soil stabilization is the alteration of one or more soil properties to create an improved soil material possessing the desired engineering properties. In the study, three purposes for soil stabilization identified include increasing the shear strength of an existing ground condition to enhance its load-bearing capacity, achieve a desired improved permeability and enhance the durability of the soil to resistance to the process of weathering, and traffic usage.

Innovative soil stabilization techniques are necessary to fulfill the increasing needs for roads infrastructure as well as preserve the environment (Hashim *et al*, 2013). This is to ensure adequate subgrade stability, especially for weaker or wetter soils. Soil stabilization methods that are currently being used for improvement of highway sub-grade and sub-base can be grouped into three broad categories which are; mechanical stabilization, use of geo-synthetics for soil stabilization and chemical admixture stabilization. Stabilization makes it possible for soils to support themselves and other imposed loads. Mechanical stabilization is a process of mixing two or more soils with different particle size gradations to produce a new soil with desired engineering characteristics followed by compaction of the mixture to the required density using conventional methods. The particle size distribution and the mineralogical composition are the important factors governing the engineering behavior of a soil and significant changes in the properties can be made by addition or removal of suitable soil fractions. The soils may be mixed at the construction site or at a central plant, or in a borrow area. Adequate mixing and compaction are required for successful mechanical stabilization. Compaction provides a significant effect on soil properties, such as strength and stress-strain characteristics, permeability, compression, swelling and water absorption (Lim *et al*, 2014).

Soil moisture content and the degree of pulverization of expansive soils are two construction factors which affect the quality of chemical stabilization (Petry *et al*, 2002). First, subgrades are rarely pre-wetted but are brought to the required water content during construction; often they are worked dry of optimum, resulting in incomplete chemical reactions due to lack of water. Secondly, the degree of pulverization is often substandard. Addition of inorganic chemical stabilizers like cement and lime has two-fold effect on soil properties namely; acceleration of flocculation and promotion of chemical bonding. Due to flocculation, the clay particles are electrically attracted and aggregated with each other. This results in an increase in the effective size of the clay aggregations. The main advantages of liquid chemical stabilization is that only a small volume of stabilizing agent is generally required and the cost of stabilization is lower than that of other methods of stabilization (Lim *et al*, 2014).

According to studies on stabilization by Lim *et al*, (2014), lime must react intimately with particles to enact the pozzolanic process; the larger the soil particles, the longer that process will take. One of the most useful factors in overcoming sulfate-induced heave is pre-wetting the soil to a moisture content of three to five percentage points above optimum for the treated soils and keeping the moisture at this level until final compaction. The additional moisture maximizes the quantity of sulfates solubilized, making them available to react with calcium from lime and aluminum from clay to form the stable mineral ettringite. This can in some cases significantly reduce the damage caused by sulfate-induced heave by forcing formation of the expansive calcium-aluminate-sulfate-hydrate compounds before compaction and by forcing a more stable sulfate-rich form of the expansive minerals from the outset. It is important to note that in spite of all the concerns over sulfate-induced heave, the vast majority of lime and lime-fly ash-treated clay subgrades and lower plasticity Portland cement treated subgrades never exhibit sulfate-induced heave.

Portland cement can be used to stabilize any soil except highly organic soils. Portland cement increases soil strength, decreases compressibility, reduces swell potential, and increases durability. Cement stabilization creates a hard, bound, impermeable layer. Cement-stabilized materials are rarely used as a surfacing material because they can become brittle and crack under traffic loads; cement-treated soils are most frequently used as a stabilized subgrade or road base. Cement-stabilized subgrade and base materials can be used in roads for very low to high traffic volume applications (Lim *et al*, 2014).

According to Lim *et al*, (2014), fly ash can be used in stabilization when wet soil conditions are present and weather conditions or time constraints prevent the contractor from processing the soil to dry it out. The fly ash lowers the water content and plasticity of the soil and improves workability; this allows for construction of an adequate working platform for construction operations. Fly ash also used to reduce the shrink/swell potential of clay soils. Fly ash stabilization of clay soils can increase CBR values from 2 to 3 (untreated) to 25 to 35 (treated). Unconfined compressive strengths for fly ash-stabilized clay soils can be improved from 700 to 3,500kPa, depending on fly ash source and application rate and the material being stabilized.

Fly ash stabilized soils/aggregates are not used as a surfacing material. Fly ash stabilized subgrade and sub base materials can be used for very low to high traffic volume applications (Lim *et al*, 2014).

Clay additives are naturally occurring soils composed of the mineral montmorillonite. Clay additives are typically used to stabilize non-plastic crushed aggregates; the cohesive properties of the clay additive help to bind the aggregate particles and prevent raveling and wash boarding. The clay additive will also attach to fines in the aggregate mix to reduce fugitive dust. Some dust is still to be expected with clay-stabilized aggregates, so additional dust suppressants are also used in conjunction with the clay additive when dust is an important concern (Lim *et al*, 2014).

When added to clay soils, lime reacts with water in the soil and reduces the soil's water content. The lime also causes ion exchange within the clay, resulting in flocculation of the clay particles. This reaction changes the soil structure and reduces the plasticity of the soil. These changes increase soil workability and can increase the soil strength and stiffness. Lime stabilization is often used as a construction expedient when wet soil conditions are present and weather conditions or time constraints prevent the contractor from processing the soil to dry it out. Lime-stabilized subgrade and sub-base materials can be used for very low to high traffic volume applications. Lime is routinely used as a soil modification agent to improve the performance of sub grade soils with the primary goal of reducing volume change (Lim *et al*, 2014). Lime has been used as an effective additive to improve the soil engineering properties and prevent damage to structures.

Rice husk ash is one of the most cost-effective locally available materials which act as a binding agent like cement which increases some geotechnical properties as well as stabilization of soil as an alternative option of cement and lime. Rice husk ash has high quantity of silica with small quantities of oxide having high specific surface that is very suitable for activating the reaction of soil and act as a binding material like cement (Sarkar *et al,* 2012).

Enzymatic emulsions contain enzymes (protein molecules) that react with soil molecules to form a cementing bond that stabilizes the soil structure and reduces the soil's affinity for water. They bond soil particles together and so reduce dust generation. At higher application rates, enzymatic emulsions can be used to stabilize soils. When applied and compacted properly, the treated soil can be stabilized to form a dense, firm to hard, water-resistant bound layer that can be used as a road surfacing (Lim *et al*, 2014).

There are other methods used for soil stabilization such as commercial soil stabilization methods such as TX-85 liquid soil stabilizer, Termite Saliva (Eko Soil Enzyme), Renolith (a polymer based chemical), which is environmentally friendly and which facilitates the bonding of soil particles, and Perma-Zyme (a proprietary concentrated liquid multi-enzymatic formulation) that alters the properties of earth material to produce superior road base stabilization, Con-Aid is a water soluble anionic compound with surface-active properties designed for stabilizing poor quality soils containing clayey material in order to improve their properties as road construction materials (Lim *et al*, 2014).

The electrical properties of the treated soils can also serve as a good monitoring technique in deep ground chemical stabilization methods. This can be used to determine the degree of soil improvement in terms of its durability, stability and suitability for civil engineering construction designs and applications (Abiodun *et al*, 2014).

The potential benefit of stabilization depends on the type of soil, the amount of stabilizer, stabilizer combinations, and the age of the stabilized soils. Stabilization of soil with admixtures, such as cement, lime, bitumen, fly ash have been successfully investigated and used extensively for road and airport foundations in many countries.

A study was carried out to investigate the increase in unconfined compressive strength (UCS) of peat over time achieved using different binders to form a stabilized soil. It was observed that the 28 days UCS results of fibrous peat soil specimens, stabilized with cement, fly ash, and lime contents, increased from 20 to 670 kPa; and hence conclusion drawn from the tests was that the unconfined compressive strength of a stabilized material formed by mixing peat with the stabilizers was significantly greater than that of the original peat. The study also showed that the engineering properties of the peat were considerably improved when mixed with some binders (Hebib & Farrell, 2003).

Research has been carried out to investigate how compounds of sodium silicate system grout can be used to stabilize organic soil so as to have a better understanding of the engineering behaviour of treated organic soil with sodium silicate mixed with two different activators.

The grout systems are based on reacting a silicate solution to form a colloid which polymerizes further to form a gel that binds soil or sediment particles together and fills voids. These systems consist of sodium silicate and reactor/accelerator (such as aluminium sulfate and calcium chloride) which can be compatible with cement to get strong bonding properties in two-compound system). However, the study does not show the effect of the stabilizer of plasticity and swell potential which are very relevant in construction of engineering structures (Moayedi *et al*, 2012).

Stabilization is also applied in the treatment of municipal solid waste incineration (MSWI) residue to remove organic pollutants. The inorganic pollutants can be stabilized thermally, chemically or by using cement that includes both chemical and mechanical stabilization. Thermal treatment by sintering increases the density, strength and fixation of metals. Treating MSWI residue with clay creates an aggregate that could be applied as construction materials (Jelena *et al*, 2006). Lime stabilization has been successfully used in various projects such as erosion control dam construction, lime column foundations and road foundation treatment (Nalbantoglu & Tuncer, 2001). The studies showed that lime stabilization is a wide spread technique in the field of earthworks that can improve both the workability and the mechanical properties of wet soils.

Rice husk ash has high quantity of silica with small quantities of oxide having high specific surface that is very suitable for activating the reaction of soil and act as a binding material like cement. They can potentially stabilize the expansive soil solely (or) mixed with lime, gypsum.

The utilization of these wastes like RHA, lime and gypsum is an alternative to reduce the construction cost of roads particularly in the rural areas of developing countries (Koteswara *et al*, 2012).

The review has established that cement can be used to stabilize any soil except highly organic soils while fly ash can be used in stabilization when wet soil conditions are present. Clay additives are typically used to stabilize non-plastic crushed aggregates; the cohesive properties of the clay additive help to bind the aggregate particles and prevent raveling and wash boarding. Lime is good for soil modification to improve the performance of sub grade soils in reducing volume change. Rice husk ash is cost-effective locally available materials which act as a binding agent like cement which increases some geotechnical properties and can be used as an alternative option for cement and lime.

2. 4 The economics of road construction

Economic analysis a highway construction project is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. The commonly applied economic analysis methods are based on the estimated mean values of related parameters, such as pavement conditions, construction costs, and user costs.

These methods do not consider the uncertainties of the input parameters and therefore are considered deterministic approaches. An effort was made to establish the relationship between the construction costs and quantities of work in terms of roadway lengths. It is important in the transportation development process that each transportation alternative is properly evaluated for its costs and benefits during its entire life-cycle (Jiang *et al*, 2013).

A cost-benefit analysis is a systematic evaluation of the economic advantages (benefits) and disadvantages (costs) of a set of investment alternatives. The objective of a cost-benefit analysis is to translate the effects of an investment into monetary terms and to account for the fact that benefits generally accrue over a long period of time while capital costs are incurred primarily in the initial years. The primary transportation-related elements that can be monetized are travel time costs, vehicle operating costs, safety costs, ongoing maintenance costs, and remaining capital value. A properly conducted cost-benefit analysis would indicate whether travel time and safety savings exceed the costs of design, construction, and the long-term increased operating costs.

Highway networks are a major capital asset that represents billions of dollars of investment and like any other capital asset, a highway network needs continuing investment to maintain, modernize, and expand.

Maintenance is needed to repair and preserve the original condition of various components of the network that deteriorate over time as a result of continued usage and environmental exposure. System modernization is needed to upgrade the original condition to modern standards, which may be different from those prevalent at the time of the original construction of the network. System expansion is needed to provide new highway facilities that can accommodate and support population and economic growth in the state (Kulkarni *et al*, 2004).

Pressure to use recycled materials in pavement construction is increasing due to a rapid depletion of high-quality natural/ traditional aggregates, skyrocketing materials costs in recent years, and large quantities of waste materials stockpiled around the world. Maximizing the use of recycled materials will bring great benefits, such as reduction of the demand for primary aggregates, and reduction of energy costs associated with natural aggregate extraction and transportation. Stabilization of clay subgrades is a popular alternative for geotechnical engineers considering the economics of construction with expansive clay soils (Mingjiang *et al*, 2008).

Therefore materials management is a distinct system that can contribute to increase the cost effectiveness of a construction project. These results can serve as a benchmark for comparison on future projects of similar size and scope using similar technologies.

The approach of economic analysis has been applied in this study to identify, quantify, and value the economic benefits and costs of stabilization of expansive soils using rice husk ash and natural lime.

2. 5 Quarrying activities for extraction of construction materials

The major environmental and socio-economic problems related to quarrying include landscape alteration, hill cutting affecting local biodiversity, generation of unproductive wastelands, dust pollution, noise pollution, illegal stone extraction, accidents and in some areas lowering of groundwater table. Environmental problems are further aggravated by lack of adequate mitigation measures by the respective quarry operators. This in turn affects the ecological sustainability which is a threat to the overall economic sustainability. With regards to legislation and its enforcement, monitoring, rehabilitation, restoration or post-mining programs for minimization of adverse environmental impacts. Mining activity often leaves villages long-term social, economic and environmental footprints. Social challenges related to the increase in quarrying activities in general include: threats to health and safety, displacement of communities, damage of cultural sites, and the formation of mining villages (Lad & Samant, 2014).

Rice husk ash is an agricultural waste material, if left un-used, may affect the surroundings and also create problem for their disposal. Use of these materials in road construction can alleviate the problem of their disposal to great extent. Studies results indicate that their usage has great impact on the improvement of soil properties and they are very useful for stabilizing clayey soils. The results indicate that unconfined compressive strength of soil and CBR value has increases by using rice husk ash for stabilization of soil (Lim *et al*, 2014). According to the studies, rice milling generates a by-product known as husk which contains about 75% organic volatile matter and the balance 25% of the weight of this husk is converted into ash during the firing process, is known as Rice Husk Ash (RHA). The RHA in turn contains around 85% - 90% amorphous silica which is a great environmental threat causing damage to the land and the surrounding area in which it is dumped since it renders the land idle. However, RHA is the most cost-effective locally available materials act as a binding agent like cement which increases some geotechnical properties as well as stabilization of soil as an alternative option of cement and lime. (Koteswara *et al,* 2012).

Pulverised fuel ash (P.F.A.) which is a waste product of coal burning and only a small proportion of the amount produced is utilized and the majority is dumped in disused clay-pits, gravel pits, and low-lying areas. The construction of roads necessitates the quarrying of natural materials which also involves the dereliction of a large amount of land. Thus, when P.F.A. is used in road construction as a fill material and to a very much lesser extent for sub-base and base construction when stabilized with cement (Mymrin & Ponte, 2005).

A study carried out by Nalbantoglu and Tuncer (2001) has shown that treatment of soils using lime or fly ash can be used effectively in the stabilization of problematic soils. More importantly, it offers an interesting potential for making use of an industrial waste (Nalbantoglu & Tuncer, 2001). There are different methods of altering the nature of the soil to make it fit for construction and stabilization using industrial wastes is one of them (Sabat *et al.*, 2011).

Research carried out by Mymrin and Ponte (2005) in Russia shows the use of a common industrial waste, thermal ash; it reduces the construction cost of road bases, airfields, dams, and foundations of any type of structure in comparison to that of traditional construction materials. Furthermore, the widespread use of the method is expected to produce a major positive impact on the environment because, first of all, a large amount of environment-contaminating industrial waste are chemically bound, and second, the pace of exploitation of natural construction materials in open quarries, which causes the irreversible destruction of ecosystem links, is slowed down (Mymrin & Ponte, 2005).

Therefore, pressure to use recycled materials in pavement construction is increasing due to a rapid depletion of high-quality natural/ traditional aggregates, skyrocketing materials costs in recent years, and large quantities of waste materials stockpiled around the world. Maximizing the use of recycled materials will bring great benefits, such as reduction of the demand for primary aggregates, and reduction of energy costs associated with natural aggregate extraction and transportation.

Therefore, there is increasing need to conserve environment through adoption of affordable and sustainable green technologies and innovative construction practices such as re-use waste material like rice husk ash and coal among other to minimize pollution at the same time reduce construction costs.

2. 6 Cation Exchange Capacity

The Cationic Exchange Capacity is a measure of the soil's ability to hold positively charged ions. These cations are held by the negatively charged clay and organic matter particles in the soil through electrostatic forces (negative soil particles attract the positive cations). Swelling properties of expansive soils are therefore significantly affected by cation exchange capacity of the soil media (Akbulut & Arasan, 2010). Their research found that pozzolatic additives such as lime, fly ash and silica reduced the CEC on treated expansive soils whereas cement slightly increased the CEC. Similar findings were arrived at in a separate study by Nalbantoglu and Tuncer (2001) in which addition of lime and fly ash to expansive clay soil resulted to reduction in CEC and this indicates that the pozzolanic reaction causes the soils to become more granular in nature resulting in higher hydraulic conductivity. From the above two studies, it is noted that RHA having similar chemical properties to those of cement, would result to increase in CEC.

CHAPTER THREE

METHODOLOGY

3.1 Experimental materials

The materials used in the study included expansive clay soil, RHA and natural lime (NL). Expansive clay soil was obtained from Kitengela area, Kajiado County, about 16 km South West of Nairobi City. The soil was collected in polythene bags by open excavation from a depth of 1 m below ground level. Twenty four (24) samples of this soil were treated with different amounts of RHA and NL.

Rice husks were obtained from Mwea Rice Irrigation Scheme located about 100 km North East of Nairobi City. RHA was produced by first collecting and removing impurities from rice husks, then burning the husks on an open clean surface at temperature of 800 deg C. The ash was then allowed to cool and packed in polythene bags. NL was obtained through direct purchase from retail shops in Nairobi.

The physical and chemical characteristics of the materials were tested at the Ministry of Transport and Infrastructure, Material Testing and Research Department Laboratories in Nairobi. Loss on Ignition (LOI) for RHA and NL was obtained by burning them in a kiln at 900 deg C.

3.2 Measurement of soil bearing strength capacity

CBR tests were carried out in accordance with British Standard 1377 Part I (1990) where the pressure required to penetrate a soil sample with a plunger of standard area was determined. The measured pressure was then divided by the pressure required to achieve an equal penetration on a standard crushed rock material, giving CBR as a percentage. A compaction machine with 2.5 Kg rammer and a CBR compression machine were used in the CBR test, which gives a measure of the bearing strength of soils. Twenty four (24) sets of stabilized soil specimens were prepared by adding varying quantities of NL and or RHA. Soil and stabilizers were thoroughly mixed at pre-determined optimum moisture content, and were sealed and stored for 24hrs. The samples were then compacted into the CBR moulds in three layers using the 2.5 Kg rammer and applying 27 blows in each layer. The data obtained was analyzed by plotting the CBR against varying quantities of NL and or RHA.

3.3 Measurement of Soil Cationic Exchange Capacity

The Cationic Exchange Capacity (CEC) was measured using the Bache method (Zawawi & Banfill 2006). Some six (6) samples of expansive clay soil and six (6) samples of mixture of varying quantities of RHA (0% to 40%) and NL (0% to 6%) were subjected to the CEC test. The stabilized soil was dried at 105^0 C and samples weighing 4.5g saturated with sodium acetate ($CH_3COONa.3H_2O$) solution (1 N) at pH of 8.2. When the samples were fully saturated, ethanol (95%) was used to wash out excess salt and the

Na+ cations were replaced with NH_4+ by adding ammonium acetate (CH_3COONH_4) solution (1 N) at pH of 7.0. Subsequently, the amount of sodium in the solution was determined by the atomic adsorption method and the Cation Exchange Capacity, CEC (mequiv/100g), of the samples was calculated using Equation 3.1 (Akbulut & Arasan, 2006).

$$CEC = \frac{10^4}{W * N_f * D}$$ ……………….**Equation 3.1**

Where; N_f is concentration of the ion of interest in the extract, D is density coefficient of ammonium acetate solution (1.073g/cm3) and W is oven-dried sample weight (g).

3.4 Assessment of the swelling characteristics of black cotton soil

The swelling potential of expansive clay soil was assessed in the laboratory by utilizing the conventional odometer apparatus (Kenya Ministry of Roads and Public Works, 1986), in accordance with British Standard 1377 Part I (1990). In determining the swell potential, 10g of stabilized sample was weighed and placed in an odometer filled with water. The material was allowed to settle and the initial level of the submerged soil read and noted as V1. The soil submerged in water was kept for 24 hrs and the final volume of soil read as V2. The swell was computed using the following relationship.

$$SWELL = \left(\frac{V_2 - V_1}{V_1}\right) * 100$$ …………… **Equation 3.2**

3.5 Assessment of Soil Plasticity

Plastic Limit

The Plastic Limit (PL), which is determined by rolling out a thread of the fine portion of soil on a flat, non-porous surface, was measured in accordance with British Standard 1377 Part I (1990). PL is the moisture content at which the thread breaks apart at a diameter of 3.2 mm. The materials used in this study included 24 samples of expansive clay soil and 24 samples of mixture of varying quantities of RHA (0% to 40%) and NL (0% to 6%) and distilled water. The equipment used included one glass plate, moisture content tins, a weighing balance (sensitive to 0.01 g) and a drying oven. The 24 sets of stabilized soil specimens were prepared by adding varying quantities of NL and/or RHA and passing the mixture through 425µm Sieve. Each set of the stabilized soil was subjected to the above procedure and the PL determined.

Liquid limit

The Liquid Limit (LL) is the water content at which a cohesive soil ceases to behave as a semi solid material and reacts as a viscous fluid. The LL was determined using Casagrande apparatus British Standard 1377 Part I (1990). Some 24 samples of expansive clay soil and 24 samples of a mixture of varying quantities of RHA (0% to 40%), and NL (0% to 6%) with distilled water were used in the experiment. The equipment used included Casagrande apparatus, moisture content tins, balance (sensitive to 0.01 g) and drying oven. Twenty four (24) sets of stabilized soil specimens were prepared by adding varying quantities of NL and/or RHA and passing through 425μm Sieve at varying moisture content. The liquid limit was determined as the moisture content of a soil when 25 blows cause 13mm of closure of the groove at the base of the cup British Standard 1377 Part I (1990). Samples were taken at this point for determination of Liquid Limit. Each set of the stabilized soil was subjected to the above procedure and the LL determined.

Plasticity Index (PI) was computed for each set of PL and LL with equal quantities of RHA and NL as the difference between the liquid limit and the plastic limit (PI = LL-PL).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Results are presented here on effect of RHA and NL on the following properties of expansive clay soils: subgrade strength, swell, plasticity and soil Cation Exchange Capacity. The section also presents the cost benefit analysis of using the stabilization technology in road construction. It has been noted that in Africa, road construction costs include the initial investment to construct roads to paved standard; rehabilitation costs that typically entail the reinstatement of roads to the original design standards; and periodic maintenance cost that involve the repair of minor surface defects and a seal or thin overlay, but without structural improvements (African Development Bank , 2014).

4.2 The effect of RHA and NL on Sub-grade strength characteristics

Adding RHA and NL to expansive clay soil tended to enhance its strength. The maximum dry density of expansive clay soil increased linearly with the addition of RHA (Figure 4.1).

One of the factors that can affect the performance of RHA as a pozzolan is its level of purity which is measured in terms of “Loss on Ignition” (LOI). RHA and NL had a LOI of 12.8% and 23.5%, respectively (Table 4.1). RHA was nearly 80% silica and had some cementitious characteristics due to the presence of Calcium oxide (Table 4.1).

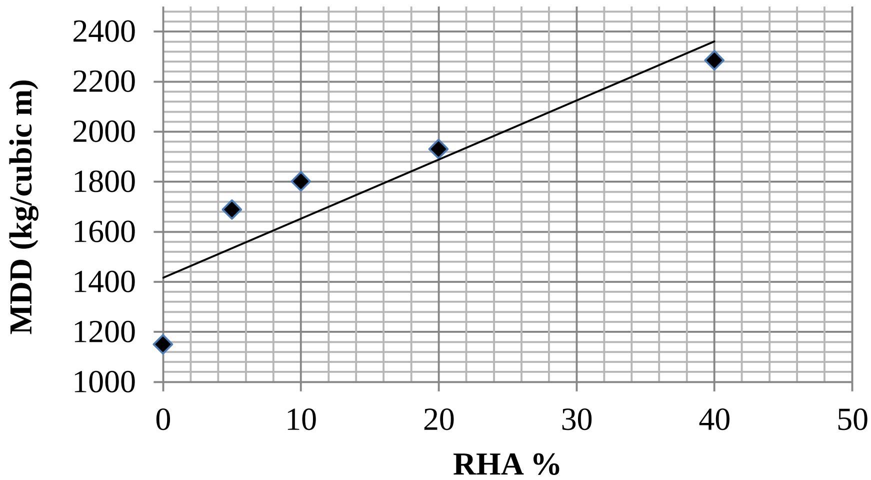

Figure 4.1: Effect of Rice Husk Ash on the density of subgrade material

Table 4.1: Chemical and Physical Properties of RHA and NL

Chemical constituent	**RHA**	**NL**
Silica as SiO_2(%)	78.9	65.8
Calcium as CaO(%)	1.7	0.65
Potassium as K_2O, % m/m	2.8	-
Sodium as Na_2O, % m/m	0.1	-
Phosphorous as P_2O_5, %	1.3	-
Aluminum as Al_2O_3, %	Nil	-
Iron as Fe_2O_3(%)	Nil	3.88
Loss on ignition (%)	12.8	23.5
Bulk densities (Kg/m^3)	512	1162

As can be noted in Figures 4.2 – 4.5, increasing the quantities of RHA and NL resulted to enhanced soil bearing capacity. However, there exists an optimum amount of RHA and NL beyond which CBR does not increase. With 4% lime in the soil, the optimum amount of RHA was 20%; and with 6% NL, the optimum amount of RHA was about 5%. According to Ministry of Roads and Public Works, Kenya (1986), the minimum required CBR for the sub-grade layer of a road pavement is 8% after a 4-day soak on a laboratory mix compacted to a dry density of 100% MDD (AT T99). This standard was achieved by a minimum combination of 2% lime and 20% RHA (Figure 4.3). The enhanced CBR of expansive clay soil when RHA and NL are added may be attributed to the formation of cementations compounds (Rao *et al*., 2012). In a laboratory study, Roy (2014) found that the presence of RHA and cement considerably improved the CBR and the unconfined compressive strength (UCS) of expansive soil. Maximum strength improvement was attained when 5% RHA was mixed with 6% lime (Figure 4.5). Roy (2014) associated the increase in CBR with formation of cementitious compounds in the soil.

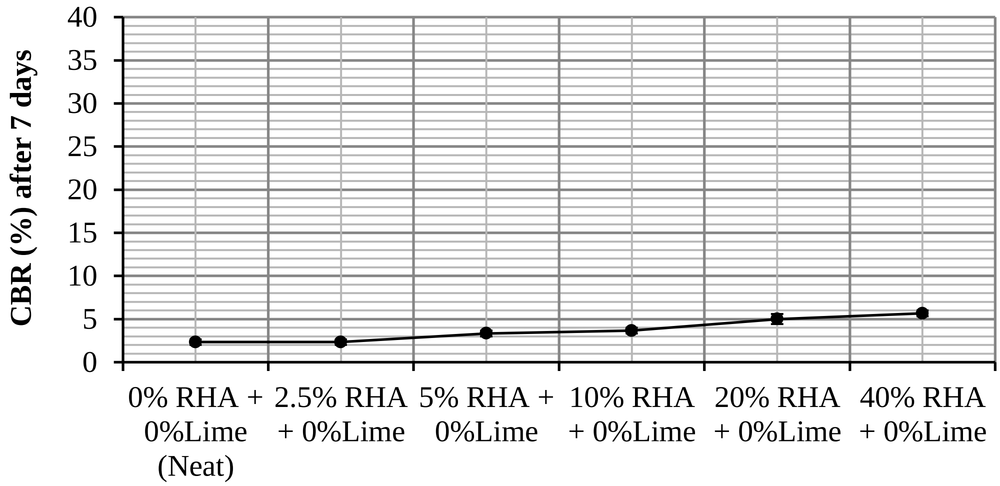

Figure 4.2: Effect of RHA on the bearing capacity of expansive clay soils for 0% lime

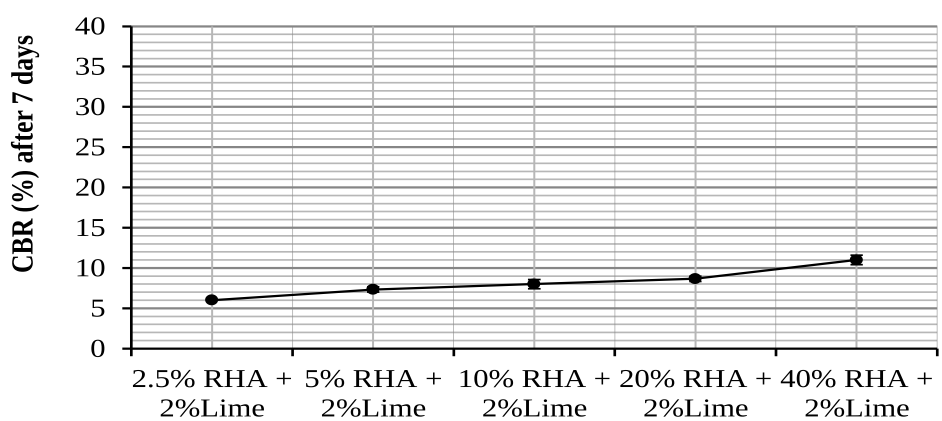

Figure 4.3: Effect of RHA on the bearing capacity of expansive clay soils for 2% NL

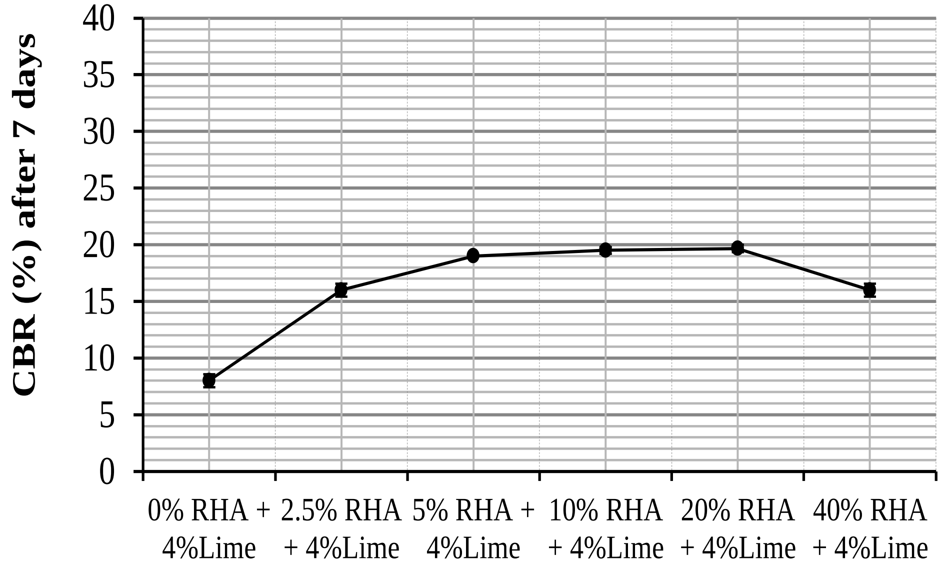

Figure 4-4: Effect of RHA on the bearing capacity of expansive clay soils for 4% NL

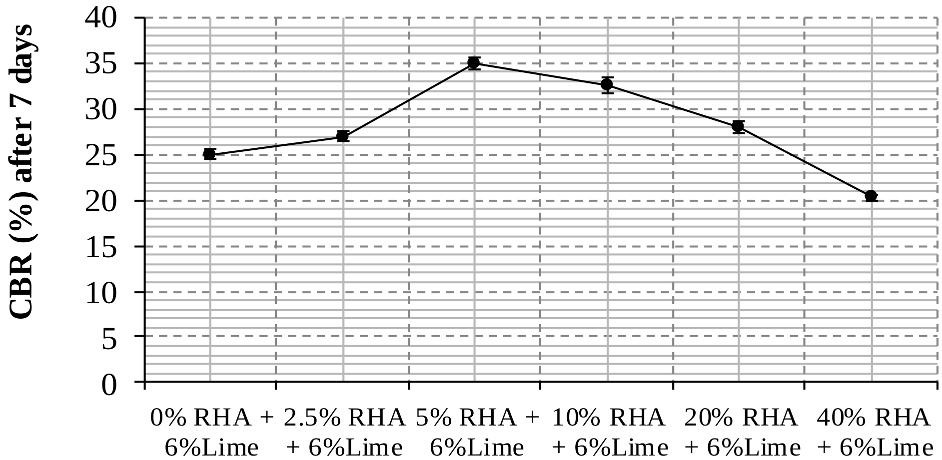

Figure 4.5: Effect of RHA on the bearing capacity of expansive clay soils for 6% NL

Clearly, the pozzolanic substances; silica and calcium oxide are responsible for soil stabilization. In their study, Mymrin and Ponte (2005) found that oil shale fly ash had substantial quantities of Silica and CaO which could stabilize different kinds of loam soils to acceptable limits. This study has shown that an optimum mix of 20% RHA combined with 2% NL will give expansive clay soil the desired strength characteristics (Figure 4.3).

4.3 Effect of Soaking on Expansive Clay Soil strength

Road subgrade refers to all the materials (insitu or fill) in the bottom-most layer of the pavement. Subgrade strength falls under different classes (Table 4.2).

Class S1 and S2 with CBRs median below 8% are unsuitable for placing any pavement.

Therefore, these soils have to be replaced with improved material or treated before pavement is placed on them.

Table 4.2: Strength characteristics of different classes of subgrade (Source: Kenya Ministry of Transport and Communication - Road Design Manual, 1987)

Subgrade class	CBR Range	Median
S1	2-5	3.5
S2	5-10	7.5
S3	7-13	10
S4	10-18	14
S5	15-30	22.5
S6	>30	

Excessive moisture in the subgrade could negatively affect the strength of the subgrade material. This study established that soaking subgrade materials in water for 7 days reduced the strength of soaked material (Figure 4.6). For both soaked and un-soaked samples the CBR increased with increasing quantities of RHA.

From this study it is clear that excess moisture can negatively affect the strength of a road constructed on stabilized subgrade soil (Figure 4.6). Therefore, stabilization of soil can only be useful in semi-arid areas where there is no possibility of excessive wetting. It is concluded that this technology is best used is arid and semi-arid parts of the country.

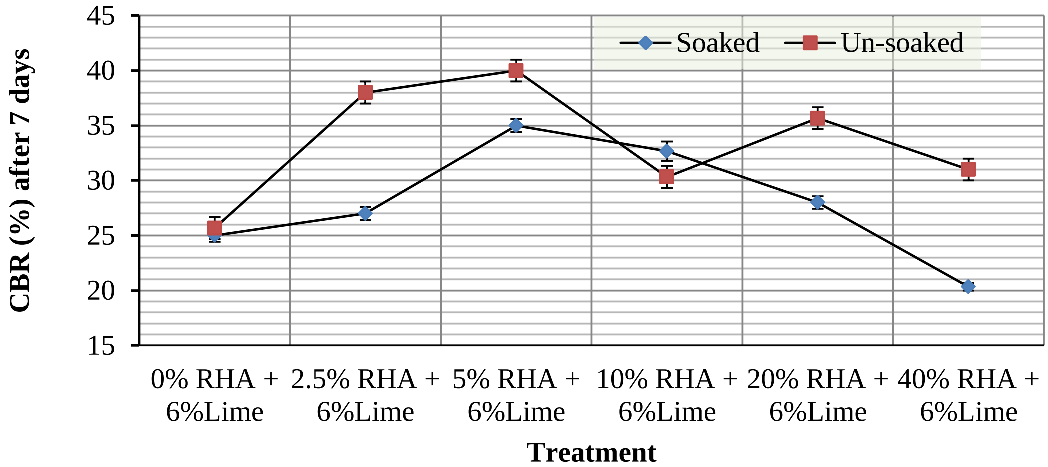

Figure 4.6: Effect of soaking on subbase strength

4.4 The effect RHA and NL on Swell

The swell potential for untreated soil was 2% (Figure 4.7) compared to the required maximum of 1% (Kenya Ministry of Roads and Public Works, 1986). Such high swell potential for untreated soil can be attributed to three major factors; chemical composition, fabric, and mineralogy of the soil (Rao *et al*., 2011). A free swell of less than 1% was obtained with single application of RHA content of 2.5% and above or NL content of 2% and above (Figure 4.7). Calcium and magnesium ions which are present in RHA react with the clay particles through a cation exchange process resulting in the formation of aggregations, hence reducing swell potential (Hadi, 2008).

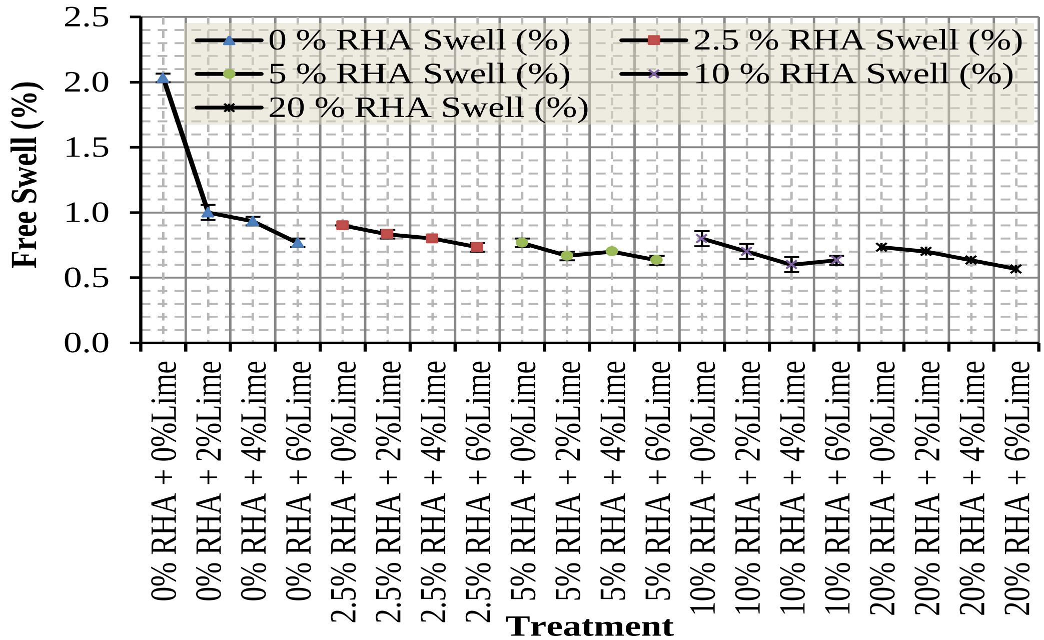

Figure 4.7: Effect fixed percentage of RHA and varying quantities of NL on Free Swell

4.5 The effect of RHA and NL on Plasticity

Plasticity Index decreased with increasing quantities of RHA and NL (Figure 4.8). Similar findings were obtained by Fattah *et al*. (2013). A steady decrease in plasticity index at all soil-RHA-NL combinations is attributed to the fact that the RHA reaction forms compounds possessing cementitious properties. This was similar to the findings of the study by Hensley (2007) on pozzolans such as hydrated lime, fly ash and cement kiln dust (CKD) used to stabilize cohesive soils whereby they were found to be effective in reducing the Atterberg Limits of all soils to a great extent. Addition of 20% RHA and 2% NL reduced the soil Plasticity Index (PI) from 56% to 8%.

According to the Ministry of Roads and Public Works, Kenya (1986), PI for the sub-grade layer of a road pavement should not exceed 50%. To achieve the desired plasticity only small amounts of stabilizers (2.5% RHA or 2% lime) were required (Figure 4.8).

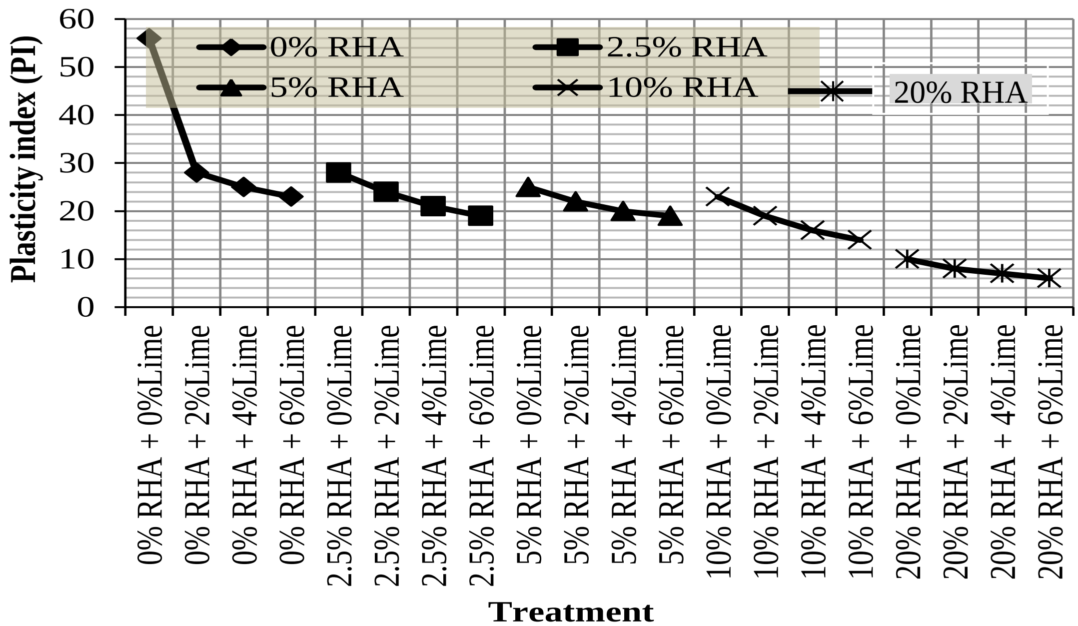

Figure 4.8: Effect of RHA and NL on Plasticity

4.6 The effect RHA and NL on Soil Cation Exchange Capacity

Chemical analysis revealed that the concentration of Ca^{2+} and mg^{2+} in untreated black cotton soil was 3644 ppm and 1648 ppm, respectively; meaning that calcium and magnesium in the soil contributed 39.1 and 17.7 meq/100g towards the CEC of the soil (Table 4.3). The quantities of sodium and potassium in the soil were negligible and hence CEC was calculated as a function of the concentration of Ca^{2+} and Mg^{2+} ions only.

Addition of RHA and NL enhanced the quantities of Ca^{2+} and Mg^{2+}, and hence increased the CEC. The CEC of expansive clay soils increased linearly with increasing quantities of RHA (Figure 4.9). Studies by Hadi (2008) showed that Calcium and Magnesium ions react with the clay particles through a cation exchange process resulting in the formation of aggregations, resulting to reduction in swell potential.

Table 4.3: Properties of Black cotton soil from Kitengela

Specific gravity		1.15
Plasticity index (%)		56
Free swell (%)		2
Exchangeable cations (CEC mequiv/100g))		
	Sodium	1.2
	Potassium	0.3
	Calcium	39.1
	Magnesium	17.7
	Total	58

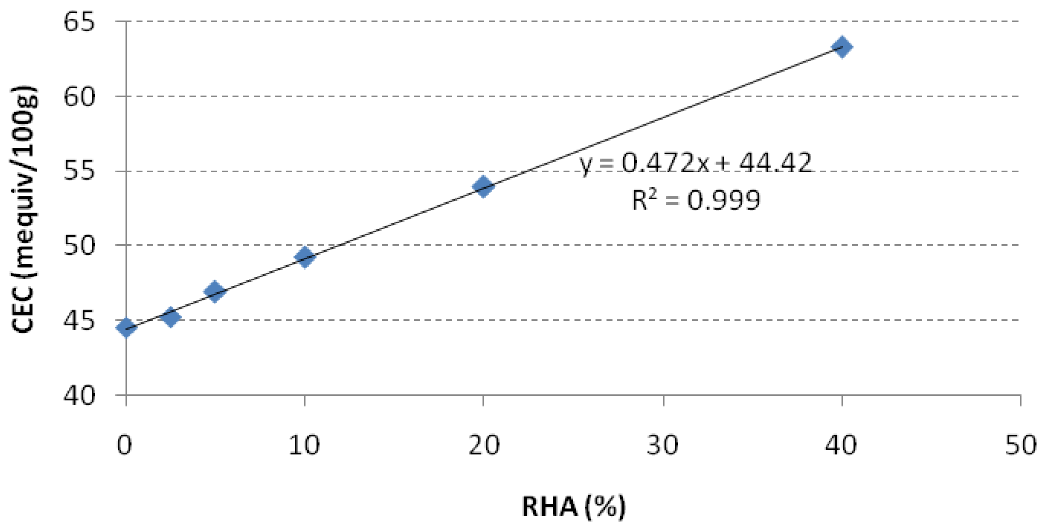

Figure 4.9: Effect of RHA on the Cation Exchange Capacity of Soil Treated 2% NL

4.7 Cost Benefit Analysis of Stabilization of Expansive Clay Soil (SEC) Technology

4.7.1 Rehabilitation of Enterprise road, Nairobi

The road considered for cost benefit analysis was Enterprise Road starting from Mombasa Road, at global position 1°19’47.15" S 36°52'13.59" E (altitudes of 1640m) to Ngong River at a global position of 1° 18'57.79" S 36°51'42.27" E (altitude 1634m) in Nairobi City, Kenya (Figure 4.10). Enterprise Road is the main arterial road in Nairobi’s industrial area having a total length of 6.2 Km.

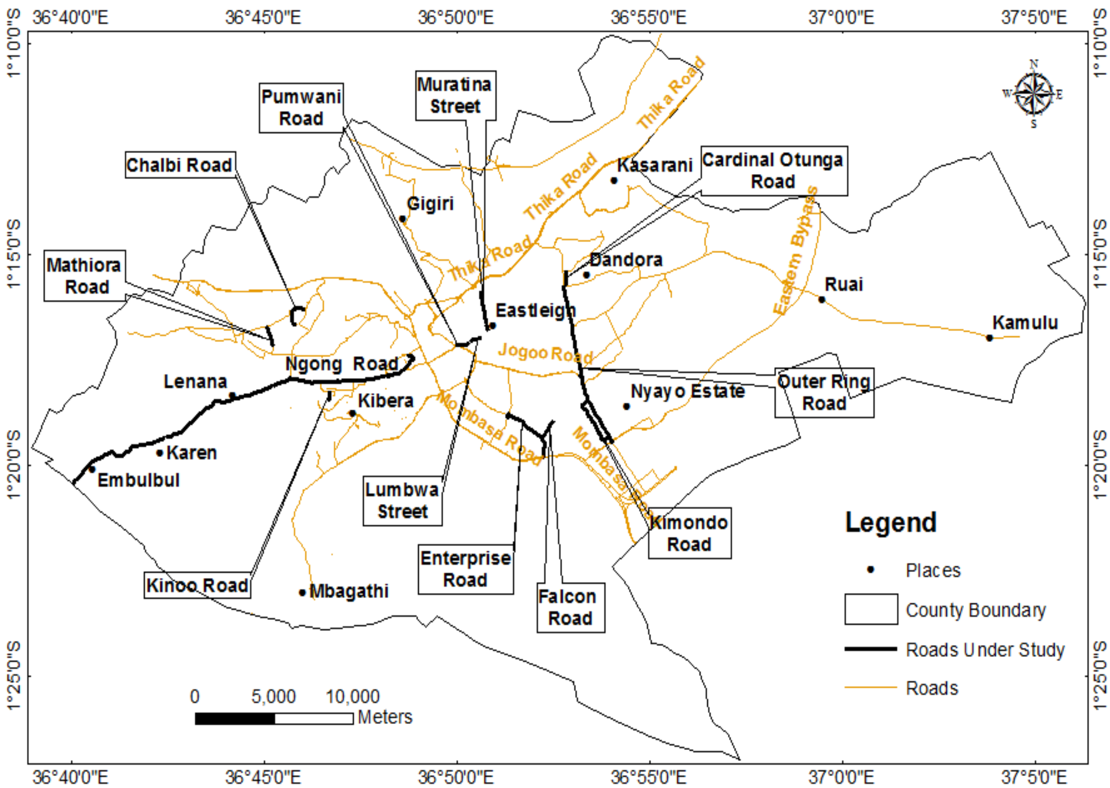

Figure 4.10: Location of Nairobi City County Roads considered in the study

At the beginning of the year 2009, the section of Enterprise Road between Mombasa Road and Ngong River with a total length of 2Km had undergone structural and functional failure with the drains completely silted. The poor state of the road caused heavy traffic congestion. According to the Roads Department of Nairobi City County (NCC), before the rehabilitation program of 2009, the average traffic speed on Enterprise Road was about 8 km/hr compared to recommended 50 km/hr. Construction works to rehabilitate the road involved the conventional methods of cutting to remove expansive clay soils and filling with suitable material.

Alignment soils along Enterprise road and most parts of Nairobi are predominantly expansive clays (black cotton soils) with a poor rating as sub-grade material (Ministry of Transport and Communication, 1987). The depth of expansive clay in Nairobi varies from 0.3 – 2.0 m, and underlying the expansive clays is a stratum of Nairobi Phonolite (the bedrock), which is strong enough to form pavement support. Therefore, 1.2m depth of soil was removed and the area filled with quarry fill (average of 1200mm) as subgrade before the construction of other pavement layers which included a hand-packed base (300mm), asphaltic concrete binder (50mm) and wearing courses (35mm) (Figure 4.11 and 4.12). To ensure that the road was well drained, a rectangular invert Block Drain (IBD) was constructed on both sides of the 10.5m carriageway.

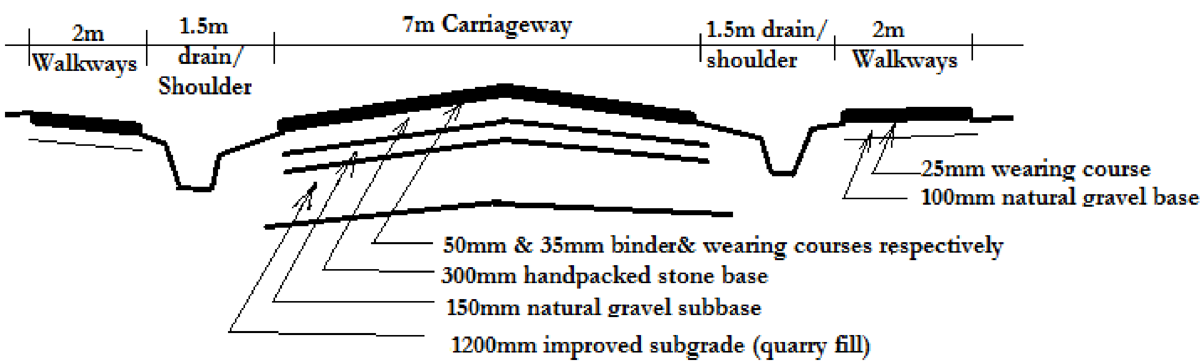

Figure 4.11: Typical road cross section for Enterprise road

Excavation and carting away of expansive soils	Filling with superior material (quarry fill)

Figure 4.12: Cutting and filling activities during construction of Enterprise Road

4.7.2 Cost evaluation of Conventional Construction Methods (CM) and the proposed SEC Technology

Road construction costs include the initial investment and rehabilitation costs that typically entail the reinstatement of roads to the original design standards; and periodic maintenance costs that involve the repair of minor surface defects (African Development Bank (AfDB), 2014). To evaluate the cost of the Conventional Methods (CM) of construction and the proposed SEC Technology, we assumed that the life of a road constructed using either technology would be 10 years.

The estimated capital and maintenance costs were calculated for both CM and the proposed SEC Technology (Table 4.4). The present worth of cost was worked out using the uniform series present worth formula (Equation 4.1). The rate of return was estimated as 12% (African Development Bank, 2014).

In this study, it was assumed that over the 10 year design life time, the annual maintenance cost for CM and SEC Technology would be 6% of the capital costs.

$$PV = \sum_{n=1}^{n} \frac{C}{(1+i)^n} = C\left[\frac{1-(1+i)^{-n}}{i}\right]$$ ....**Equation 4.1**

Where PV= Present Value of costs; n= design life (years) and i= effective annual interest rate or rate of return (source: African Development Bank, 2014).

Using conventional method of cutting and filling on Enterprise Road, earth works involved excavation of averagely 1.2 m of expansive clay soil (16,450 m3 per km) at the cost of US$ 6 per cubic meter. This subgrade layer required an average of 1.2 m (16,450 m3 per km) depth of quarry fill at the cost of US$12 per cubic meter. The sub-base layer covering the subgrade, consisting of 150mm of natural gravel (1,650m3 per km), was constructed at the cost of US$17 per cubic meter. The sub-base was covered with 300mm thick (3,300 m3 per km) hand packed base layer of stones at the cost of US$21 per cubic metre. The wearing and binder course was constructed at the cost of US$ 14.2 per km.

To evaluate the benefits of the proposed SEC Technology relative to CM costs, the case of Enterprise Road was used. It was assumed the sub-base, base and the wearing courses for a road constructed on SEC Technology would be the same as when CM is used. The only difference would be that, when the stabilization option is considered, the 1.2 m in-situ subgrade (Figure 4.11) would be excavated, mixed with the stabilizing agents and then compacted according to standard practices (Ministry of Transport and Communication, 1987). The soil would be thoroughly mixed with the stabilizing agent at an Optimum Moisture Content (OMC) of 35% in accordance with British Standard 1377-Part 2 (1990).

It is estimated that the cost of construction using the proposed SEC Technology would be US$ 889,980 per km compared to the cost of construction using CM, US$ 735,795 per km (Table 4.4).

This study established that the cost of earth works including excavation and construction of the base, sub-base and the subgrade layers would be 44% and 38% of construction cost when using CM and the proposed SEC Technology, respectively (Table 4.4). For both methods of construction, the wearing course was relatively the most expensive item in the pavement construction. The relatively low cost of SEC Technology earthworks makes it an attractive construction method.

According to NCC and Kenya Urban Roads Authority (KURA) the budget for the 2014/15 financial year, most parts (16 km) of 28 km of Arterial and Primary Roads in NCC (Figure 4.9 and Table 4.5) had deteriorated and required reconstruction. Using the SEC Technology, an estimated saving of US$ 2.5 million (17% of the cost of construction by conventional methods) would be made (Table 4.6).

Table 4.4: Estimated capital and maintenance costs (KES) using CM and the SEC Technology: Case study of Enterprise Rd Nairobi (design lifetime 10 years).

CM (cutting and filling) **<u>Capital/Investment costs</u>**					
	Cost Item Units	**Unit cost (US$/ m^3)**	**Quantity** (m^3/km)	**Cost (US$/km)**	**Proportion of *Total Cost* (%)**
Drainage	m / km	19	1,000	19,000	2
Excavation (average 1.2 m depth)	m^3/km	6	16,450	98,700	11
Sub-grade: Quarry fill (1.2 m depth)	m^3/km	12	16,450	197,400	22
Sub-base: Natural Gravel (150mm depth)	m^3/km	17	1,650	28,050	3
Base: Hand packed Stones (300mm depth)	m3/km	21	3,300	69,300	8
Wearing and binder course	m^3/km	243	935	227,205	26
Road Furniture - Kerbs and Channels	m / km	10	2,500	25,000	3
Total Capital Cost (KES)				664,655	
<u>Recurrent (Maintenance) Cost</u>					
Annual routine and periodic maintenance cost	Piecework (6 % of total capital costs)			39,879	
Total present value of annual recurrent costs@12% p.a. rate of return				***225,325***	
TOTAL cost of CM per km				**889,980**	

Table 4.4 Cont. …

SEC (RHA and NL) <u>Capital/Investment costs</u>					
	Cost Item Units	**Unit cost (US$/ m^3)**	**Quantity** (m^3/km)	**Cost (US$/km)**	**Proportion of *Total Cost* (%)**
Drainage	m / km	19	1,000	19,000	3
Excavation (average 1.2 m depth)	m3/km	6	16,450	98,700	13
RHA for on-site soil treatment (1.2 m average)	m3/km	1	16,450	16,450	2
NL for on-site soil treatment (1.2 m average)	m3/km	3	16,450	49,350	7
On-site soil treatment, mixing and compaction	m3/km	1	16,450	16,450	2
Sub-base: Natural Gravel (150mm depth)	m3/km	17	1,650	28,050	4
Base: Hand packed Stones (300mm depth)	m3/km	21	3,300	69,300	9
Wearing and binder course	m3/km	243	935	227,205	31
Road Furniture - Kerbs and Channels	m / km	10	2,500	25,000	3
Total Investment Cost (KES)				**549,505**	
<u>Recurrent (Maintenance) Cost</u>					
Annual routine and periodic maintenance costs	Piecework(6 % of total capital costs)			32,970	
<u>Total present value of annual recurrent costs</u>@12% p.a rate of return				186,290	
TOTAL cost of SEC per km				**735,795**	

Table 4.5: Arterial/Primary roads within Nairobi City County scheduled for rehabilitation and the proportion and equivalent lengths that need to be repaired (Source: Nairobi City County).

Name of Road	**Location**	**Length (km)**	**Soil**	**Condition**	**Estimated Equivalent Repairable length (KM)**	**Construction Cost using CM (KES)**	**Construction Cost using SEC Technology (US$)**	**Source of Funding**
Ngong Rd.	Kilimani / Karen	6.9	Clay	Paved – Fair requiring widening- 10% poor condition.	0.69	614,086	507,699	KURA
Outer ring Rd	East Division Embakasi	6	Clay	Paved - about 30% poor condition, with some sections that have failed;	1.8	1,601,964	1,324,431	KURA
Muratina St.	Eastleigh	1.4	Clay	Paved - about 100% poor condition,	1.4	1,245,972	1,030,113	KURA
Kinoo Rd	Jamuhuri	0.4	Clay	Paved - about 70% poor condition	0.28	249,194	206,023	NCC
Muthiora Rd	Kawangware	3.2	Clay	Unpaved	3.2	2,847,936	2,354,544	NCC
Falcon Rd	ImaraDaima	1.5	Clay	Unpaved - bad condition	1.5	1,334,970	1,103,693	NCC
Lumumba Drive	Roysambu	1	Clay	Unpaved - bad condition	1	889,980	735,795	NCC
Kimondo Rd	KwareEmbakasi	1.4	Clay	Unpaved - bad condition	1.4	1,245,972	1,030,113	NCC
Thiong'o Rd	Kawangware	1.6	Clay	Unpaved - bad condition	1.6	1,423,968	1,177,272	NCC

Table 4.5 Conti….

Name of Road	Location	Length (km)	Soil	Condition	Estimated Equivalent Repairable length (KM)	Construction Cost using CM (KES)	Construction Cost using SEC Technology (US$)	Source of Funding
Chalbi Drive	Lavington	1	Clay	Paved - 60% bad condition	0.6	533,988	441,477	NCC
Cardinal Otunga Rd	Kariobangi	0.7	Clay	Paved - 60% bad condition	0.42	373,792	309,034	NCC
Upendo Rd	Mathare	1.7	Clay	Unpaved - 100% bad condition	1.7	1,512,966	1,250,852	NCC
Pumwani Rd	Gikomba	0.7	Clay	Paved - 50% bad condition	0.35	311,493	257,528	NCC
Lumbwa St	Gikomba	0.4	Clay	Paved - 60% bad condition	0.24	213,595	176,591	NCC
	Total	**27.9**			**16.2**	**14,399,876**	**11,905,163**	

Table 4.6: Cost comparison between CM and SEC and potential savings that could be realized from use of SEC in road rehabilitation in Nairobi City County

Total length of road network to be repaired (Km)	Construction Cost using CM (US$)	Construction Cost using SEC (US$)	Savings (US$)	% saving
16.2	14,399,876	11,905,163	2,494,713	17%

4.7.3 Subgrade layer construction costs

Kenyan standards require that the materials forming the road subgrade should comply with minimum quality requirements including the California Bearing Ratio (CBR) which is an indication of soil bearing strength, swell and plasticity index. The CBR of soil forming subgrade layer should not be less than 8%; the swell should be less than 1% and the plasticity index should not exceed 50% (Table 4.7). Expansive clay soils along Enterprise Road had very low bearing strength (6 to 7%); very high plasticity (PI above 56%) and swelling capacity (swell above 2%).

Following CM, the expansive clays were excavated over a section of 2km and new fill material placed (Figure 4.12). The width of the road was 10.5m while the depth of cut varied from 1.2m to 1.5m. A cost comparison between CM and SEC Technology on construction of subgrade layer consisting expansive clay over a 1 km length of Enterprise Road indicated a saving of US$ 115,150 representing 39% of the total cost (Table 4.10).

The total volume of excavations was computed through end area method from cross sections plotted at 20m intervals as 1,6450m^3 (Table 4.8).

The unit cost for excavation per m^3 during the time of implementation of the contract (2009) was US$ 6; hence the total cost of excavation was US$98,700 per km.

Table 4.7: Minimum Quality of Improved Subgrade (Ministry of Roads and Public Works, Kenya: Standard Specification for Road and Bridge Construction, 1986)

SUB-GRADE QUALITY	MINIMUM SPECIFIED
CBR at 100% MDD Standard Compaction (at T99) and 4 days soak	not less than 8%
Swell at 100% MDD Standard Compaction (at T99) and 4 days soak	less than 1%
Plasticity Index	less than 50%

Table 4.8: Cost of subgrade per km construction using CM

Materials and other Cost Items	Costs Item Units	Unit cost (US$/ m^3)	Quantity (m^3/km)	Amount (US$/km)
Excavation (1.2 m depth average)	m^3/km length	6	16,450	98,700
Sub-grade (Quarry fill/hard core) – 1.2 m depth	m^3/km length	12	16,450	197,400
TOTAL				**296,100**

The total volume of quarry fill required for filling excavated area (1.2m depth) computed through end area method would be 16,450m^3. Assuming a unit cost of US$ 12 per m^3 of quarry fill, the total cost of filling would be US$ 197,400 per km.

Therefore, the total cost for subgrade construction using CM per km section of road would be US$ 296,100.

The total volume of subgrade to be stabilized was computed through end area method from cross sections plotted at 20m intervals as 16,450m^3 (Table 4.9). The unit cost of RHA used in the SEC Technology was estimated to US$ 1 per m^3, the total cost for stabilizing expansive soil would be US$ 16,450 per km. The unit cost per m^3 of NL used in the SEC Technology was estimated at US$ 3. Therefore, the total cost of NL used in the SEC approach was calculated as US$ 49,350. The cost of on-site mixing and compaction was estimated to be US$ 1 per m^3 giving a total cost of mixing and compaction as US$ 16,450 per km. The works would also involve excavation of the 16,450 m^3 at a rate US$ 6, costing US$ 98,700 per km. The total cost of subgrade construction using SEC Technology was found to be US$ 180,950 per km.

Table 4.9: Cost of subgrade construction using SEC

Materials and Other Cost Items	Costs Cost Item Units	Unit cost (US$/ m^3)	Quantity (m^3/km)	Amount (US$/km)
Excavation (average 1.2 m depth)	m^3/km length	6	16,450	98,700
RHA for on-site soil treatment (1.2 m depth average)	m^3/km length	1	16,450	16,450
NL for on-site soil treatment (1.2 m depth average)	m^3/km length	3	16,450	49,350
On-site soil treatment (1.2 m depth average) mixing and compaction	m^3/km length	1	16,450	16,450
TOTAL				**180,950**

Table 4.10: Cost comparison on subgrade construction using CM and SEC (US$/km).

Length of road (km)	Subgrade construction cost using CM (US$)	Subgrade construction cost using SEC (US$)	Savings (US$)	Savings (%)
1	296,100	180,950	115,150	39

In SEC Technology a soil layer, 1.2m deep would be stabilized using RHA and NL. RHA is readily available in the rice producing areas of the country and NL is a common construction material. Therefore there should be minimum constraints against the SEC Technology.

The SEC Technology reduces the cost of subgrade construction by 39% compared to conventional construction methods.

4.7.4 Environmental benefits of the SEC Technology

In addition to the capital and recurrent cost of road construction (Tables 4.4), cost benefit analysis (CBA) should be undertaken to compare conventional methods against the SEC Technology, in terms of the cost of land and environmental costs. Some environmental and economic benefits are realized when waste ashes are used as replacement for cement in soil stabilization which may be necessary for the construction of road bases, dams, and foundations of any type of structure (Mymrin & Ponte, 2005).

In SEC Technology a 1.2m soil layer is stabilized using mostly plant-based ash. This study considered rice husk ash (RHA) for stabilization which is readily available in the rice producing areas of Kenya. Although we have not placed a financial value on the environmental and social benefits of the SEC Technology, its adoption would certainly reduce dumping of unwanted plant material such as rice husks in the environment. Disposing rice husks on farms takes away land from useful utilization (Rao *et al*, 2011). Cutting and dumping of poor quality soil on productive land as a result of construction activities would also be avoided.

Soil quality deterioration and decrease in vegetation abundance are grave consequences of open dumping of material [Ali *et al*, 2013]. Covering of vegetation through dumping of expansive clay contribute immensely towards killing vegetation in the area which provide valuable protection cover against soil erosion.

The SEC Technology eliminates excavations and transportation of excavated material to disposal sites and delivery of fill material from quarries to construction sites. Use of the SEC Technology would set free this land for useful economic activities and avert further conversion of productive land to idle land.

Quarrying for the production of fill material required in road construction is usually done by open cast method using rock drills, explosions of dynamite among other methods (Lad & Samant, 2014).

All these have negative environmental impacts. Continuous quarrying and stone crushing operations are major sources of dust, noise and vibration pollution in the surrounding environment (Lad & Samant, 2014). The adoption of SEC Technology would likely lead to reduced quarrying activities since the demand fill material would be much lower than when conventional pavement construction is practiced. Furthermore, noise and dust would be significantly reduced.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Road pavements must not be affected by low soil bearing capacity, swelling and contraction as a result of soil moisture variation and the base and sub-base should not to suffer distress due to variation in soil moisture. This study established that stabilization of expansive clay with 20% RHA and 2% NL gave expansive clay soil the necessary strength (CBR of 8%) and reduced the soil Plasticity Index (PI) from 56% to 8% acceptable for road construction. Increasing the quantity of lime continuously increased the soil strength. However, because of the cost of lime, the quantity has to be limited to the lowest allowable level to maintain a CBR of 8% at day 7. However, a free swell of less than 1% was obtained for RHA content above 2.5% or NL content above 2%. The CEC of expansive clay soils increased linearly with increasing quantities of RHA and this improved the properties of expansive clay soil by reducing swell potential. It is further concluded that stabilization with rice husk ash is best suited for arid and semiarid condition where there is no possibility of excessive wetting for extended periods.

This study has come up with three conclusions:-

1. Stabilization of expansive clay soils using RHA and NL is technically viable and the optimum quantities of 20% RHA and 2% NL were adequate to modify the properties of the clay soil for road construction.

2. The cost of stabilization of expansive clay soils (SEC) using RHA and NL is relatively low compared to conventional methods (CM) which involve cutting and filling. Soil stabilization of Expansive Clays using RHS and NL can save up to 17 % of the cost of earth works in road construction;
3. The cost comparison between CM and SEC in the construction of the subgrade layer consisting expansive clay soil per km section of Enterprise Road indicated a US$ 115,150 saving, representing 39% of the total cost of sub-grade construction.

5.2 Recommendations

5.2.1 Recommendations

This study recommends 20% RHA and 2% NL as optimum proportions of stabilizers required to give expansive clay soil the desired engineering properties to support road pavement. It is however recommended that the use of these materials be tested in an actual road construction project first on a trial section.

5.2.2 Recommended areas for further research

The present study has developed a method for stabilization of expansive clay soil using a combination of Rice Husk Ash (RHA) and Natural Lime (NL). However, further studies could be conducted on stabilization of expansive clay soil using a combination of RHA with other pozzolanic waste materials such as fly ash. Comparison of construction cost using different combinations will help determine most cost effective stabilization method.

REFERENCES

African Development Bank (2014). Study on Road Infrastructure Costs: Analysis of Unit Costs and Cost Overruns of Road Infrastructure Projects in Africa. Market Study Series.

African Development Fund (2013). *Arusha-Holili/ Taveta-Voi Road Project. Project Appraisal Report.* Nairobi: African Development Fund

African Development Fund (2013). *Nairobi Outer Ring Road Improvement. Project Appraisal Report*. Nairobi: African Development Fund

Akbulut, S. and Arasan, S. (2010). The Variations of Cation Exchange Capacity, pH, and Zeta Potential in Expansive Soils Treated by Additives. *International Journal of Civil and Structural Engineering, 1*(2), 139-154.

Alhassan, H. and Olaniyi, L. (2013). Effect of 'Ionic Soil Stabilizer 2500'on the Properties of Black Cotton Soil. *British Journal of Applied Science and Technology, 3*(3), 406-416.

Ali, S., Pervaiz, A., Afzal, B., Hamid, N. and Yasmin, A. (2013). Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping site of Islamabad city. *Journal of King Saud University- Science*, *26*, 59-65.

Al-Rawas, A. (2002). Microfabric and mineralogical studies on the stabilization of an expansive soil using cement bypass dust and some types of slags. *Canadian Geotechnical Journal, 39*, 1150–1167.

American Association of State Highway and Transportation Officials (AASHTO), (2003).*User Benefit Analysis for Highways*, United States of America: AASHTO.

Fattah, M.Y., Rahil, F.H., Al-Soudany, K. Y. H. (2013). Improvement of clay soil characteristics using rice husk ash. *Journal of Civil Engineering and Urbanism, 3*(1), 12-18.

Hadi, N. A. R. M. A. (2008). Stabilization of the phosphatic waste using high calcium ash in Jordan. *Canadian Journal of Civil Engineering, 35*, 1193-1199.

Hebib, S. and Farrell, E. (2003). Some experiences on the stabilization of Irish peats. *Canadian Geotechnical Journal, 40*, 107-120.

Hensley, T. T. (2007). *Pozzolan stabilized subgrades*. Lincoln, USA: Nebraska Department of Roads.

Zhao, Y. G., Li, S., Guan, B. and Yang, Y. (2013). A model for life-cycle benefit and cost analysis of highway. *Projects, 6*(5), 633-642.

Kamau, G. N., Mbindyo, J. K. N., Z. P., Githinji, R.J.R. Tuts and Kinyua, A.M. (1993). Rice husk ash and its application as cement replacement material in Kenya. *International Journal of Biochemiphysics , 2*(1and2), 138-142).

Karatai, T. R., Kaluli, J. W., Kabubo, C. K. and Thiong'o, G. T. (2016). Soil stabilization using rice husk ash (RHA) and Natural lime (NL) as an alternative to cutting and filling in Road Construction. *Journal of Construction Engineering and Management.*

Kenya Ministry of Roads and Public Works (1986). *Standard specifications for Roads and Bridge Construction,* Nairobi: Government Printer.

Kenya Ministry of Transport and Communication (1987). *Road Design manual Part III*, Nairobi: Kenya Roads Department, Ministry of Transport and Communication.

Kenya Roads Board (2013). Annual Report and Financial Statement for the year ended 30th June 2013. Kenya Roads Board.

Kulkarni, R., Miller, D., Ingram, R., Wong, C. and Lorenz, J. (2004). Need-based project prioritization: alternative to cost-benefit analysis. *Journal of Transportation Engineering,* 150-158.

Lad, R. J. and Samant J. S. (2014). Environmental and Social Impacts of Stone Quarrying, a Case Study of Kolhapur District. *International Journal of Current Research, 6*(63), 5664-5669.

Lim, S. M., Wijeyesekera, D. C., Lim, A. J. M. S. Bakar, I. B. H. (2014). Critical Review of Innovative Soil Road Stabilization Techniques. *International Journal of Engineering and Advanced Technology (IJEAT), 3* (5).

Mymrin, V. A. and Ponte, H.A. (2005). Oil Shale Fly Ash utilization as independent binder of natural clay soil for road and airfield base construction. *Particulate Science and Technology, 23*, 99-107.

Nalbantoglu, Z. and Tuncer, E. (2001). Compressibility and hydraulic conductivity of chemically treated expansive clay. *Canadian Geotechnical Journal, 38,*154-160.

Nyamai, M. (2012). *A comparative assessment of SRI and Conventional Rice Production in Mwea Irrigation Scheme, Kenya.* Unpublished M.Sc thesis, Juja: Thesis, Jomo Kenyatta University of Agriculture and Technology.

Rao, K., Pranav, P. and Anusha, M. (2011). Stabilization of Expansive Soil with Rice Husk Ash, Lime and Gypsum - An Experimental Study. *International Journal of Engineering Science and Technology, 3*(11), 8076-8085.

Rao, K., Rao, G. and Pranav, P. (2012). A Laboratory Study on the effect of Rice Husk Ash and Lime on the Properties of Marine Clay. *International Journal of Engineering Science and Technology*, *2*(1), 345-353.

Rao, S. M. and Thyagara, T. (2007). Swell-Compression behaviour of compacted clays under chemical gradients. *Canadian geotechnical Journal, 44*, 520-532.

Ronoh, V., Too, J. K. and Kaluli, J.W. (2014). Cement effects on the physical properties of expansive clay soil and the compressive strength of compressed interlocking clay blocks. *European International Journal of Science and Technology, 3* (8), 74-82.

Roy, A. (2014). Soil stabilization using rice husk ash and cement. *International Journal of Civil Engineering and Research*, *5*(1), 49-54.

Sawhney, A., Walsh, K. D. and Brown IV, A. (2004). International comparison of cost for the construction sector: towards a Conceptual Model. *Civil Engineering and Environmental Systems, 21*(3), 151-167.

Stehouwer R., Day R. and Macneal E. (2006). Nutrient and trace element leaching following mine reclamation with biosolids. *Journal of Environmental Quality, 35*, 1118–1126.

Tao, M., Zhang, Z. and Wu, Z. (2008). Simple procedure to assess performance and cost benefits of using recycled materials in pavement construction. *Journal of Materials in Civil Engineering,* 718-725.

Tripathy, S., Rao, K. S. S. and Fredlund, D. G. (2002). Water content – void ratio swell–shrink paths of compacted expansive soils. *Canadian Geotechnical Journal, 39*, 938–959.

Zawawi, R. and Banfill, P. (2006). Effect of burning conditions on properties of artificial hydraulic lime mortar obtained from limestone and siliceous waste materials. *Advances in Applied Ceramics, 105*(4), 175-178.