COMPARISON OF DIFFERENT CEMENT TYPES FOR STABILIZATION OF THE DIFFERENT ROAD SUBGRADE SOILS

By

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DECLARATION

This thesis is my own original work and has not been submitted for examination in any other University.

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DEDICATION

I dedicate this to my Wife, Doreen Ikala and my Children: Anne Mung'ohe and Amy Mghoi who have been a source of inspiration, encouragement and motivation for they accepted my 'absence' during the period of study.

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ABBREVIATIONS

AAOAC	-	Analysis of the Association of Official Analytical Chemists
AASHTO	-	American Association of State Highway and Transport Officials
Al	-	Aluminium
ARM	-	Athi River Mining
AUCBM	-	Arab Union of Cement and Building Materials
BS	-	British Standard
BT	-	Blue Triangle
BSCS	-	British Soil Classification System
BSI	-	British Standards Institution
Ca	-	Calcium
CBR	-	California Bearing Ratio
CCN	-	Cement Chemist Notation
CEC	-	Cation Exchange Capacity
CEN	-	European Committee for Standards

DAZ	-	Diffuse Adsorption Zone
EAPC	-	East Africa Portland Cement
EAS	-	East Africa Standard
EEC	-	European Economic Community
ESA	-	Equivalent Standard Axles
ESP	-	Exchangeable Sodium Percentage
Fe	-	Iron
g	-	Grams
KN	-	Kilo Newton
KS	-	Kenya Standard
LL	-	Liquid Limit
MDD	-	Maximum Dry Density
Mg	-	Magnesium
ml	-	Milliliter
mm	-	Millimeter
N	-	Normal

N/mm^2 - Newton per square millimeter

NEAA - Netherlands Environmental Assessment Agency

NEMA - National Environmental Management Authority

OMC - Optimum Moisture Content

OPC - Ordinary Portland Cement

p - Pressure

PI - Plasticity Index

PL - Plastic Limit

PMC - Present Moisture Content

PPC - Pozzolana Portland Cement

ppm - Parts Per Million

RSC - Residual Sodium Carbonates

SAR - Sodium Adsorption Ratio

SiO_2 - Silicon Dioxide (Silica)

SO_3 - Sulphate

TC - Technical Committee

T - Temperature

t - Time

µg - Microgram

The following abbreviations/notations are used to describe the Cement Chemistry reactions

A = Al_2O_3 Aluminium Oxide (Alumina)

C = CaO Calcium Oxide (Lime)

S = SiO_2 Silicon Oxide (Silica)

C_3S = $3\ CaO*SiO_2$ Tri-calcium Silicate (Alite)

C_2S = $2\ CaO*SiO_2$ Di-calcium Silicate (Belite)

C_3A = $3\ CaO*Al_2O_3$ Tri-calcium Aluminate (Aluminate or Celite)

C_4AF = $4\ CaO*Al_2O_3*Fe_2O_3$ Tetra-calcium Alumino ferrite (Ferrite)

CAH = $CaO*\ Al_2O_3*H_2O$ Calcium Aluminate Hydrate

CH = $CaO*H_2O$ Calcium hydroxide

CSH = $CaO*SiO_2*H_2O$ Calcium Silicate Hydrate

F = Fe_2O_3 Iron Oxide
H = H_2O Water (Hydroxide or Hydrate)
L.S.F = Lime Saturation Factor

M = MgO Magnesium Oxide

ABSTRACT

It is paramount to determine the cement type that is most suitable and cost effective in stabilization of the different soil types prevalent in different parts of Kenya. In this study, seven Cement brands, ‘Power Plus’ 42.5 (CEM I), ‘Power Max’ 42.5 (CEM II/A-L) and ‘Nguvu’ 32.5 (CEM II/B-P); Blue Triangle 42.5 (CEM I) and Blue Triangle 32.5 (CEM IV/A); Rhino 42.5 (CEM I) and Rhino 32.5 (CEM IV/B-P) were obtained from warehouses of the respective companies.

Soil samples used were collected from ongoing projects in different regions of the country, namely Embakasi (Nairobi province), Kiambu (Central province), Machakos (Eastern province), Kilifi (Coast province), Kakamega (Western province) and Bomet (Southern part of Rift Valley province). The chemical compositions of the soil and cement samples were determined with respect to calcium, magnesium, aluminium, iron and silica. Strength of the soil, in terms of the California Bearing Ratio (CBR) of both the neat and treated soils were investigated. CBR is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min to that required for the corresponding penetration of a standard material. Results showed that the CBR of soil treated with cement of strength 42.5 N/mm^2 are higher than those treated with similar quantities of cement of strength 32.5 N/mm^2. For treatment, a series of the various proportions (2, 4 and 6 as percentage) of the different cement types were added to the neat samples and the CBR of the resultant materials determined. The effects of the various proportions of these cements on the strength (CBR) of the soils were thus investigated with a view of determining which cement type could attain the design specifications of the different soil/gravels more cost effectively.

The results showed that the CBR values attained on stabilization using the cements of strength of 42.5 N/mm^{2}are higher than those attained using cements of strength of 32.5 N/mm^2 at the same dosage. This shows that for all the soils tested, cements of strength 42.5 N/mm^2 (Power Plus, Power Max, Blue Triangle 42.5 and Rhino 42.5) are better suited to be used at soil stabilizers than those of strength 32.5 N/mm^2 ('Nguvu', Blue Triangle 32.5 and Rhino 32.5).

Results show that cements of strength 32.5 N/mm^2 can be used to achieve the same CBR as compared to the 42.5 N/mm^2 cements. This can be attained by using larger quantities of the 32.5 N/mm^2 cements as compared to the 42.5 N/mm^2 cements, which would result higher costs (based on current market prices of the two types of cements). For faster economic growth on the limited resources, the use of cement of strength 42.5 N/mm^2 should be encouraged while use of cement of strength 32.5 N/mm^2 should be discouraged.

CHAPTER ONE

1.0 INTRODUCTION

A country's level and rate of development is determined by its infrastructure. Goods and services have to reach the people from areas of production to areas of utilization. In Kenya, goods and services are mainly delivered through road transport. The loads carried by the different roads vary according to traffic classes (Ministry of Works (Kenya) Materials Department, 1986). These classes are as shown in Table 1.1

Table 1.1 Traffic Classes

CLASS	Equivalent Standard Axles (ESA)X 10^6
T5	0.25 – 1
T4	1 – 3
T3	3 – 10
T2	10 – 25
T1	25 – 60

Note: A standard Axle load is equivalent to 80 KN = 8,200kgf

Engineers are expected to design roads to meet the anticipated needs in any given area.

Road design may be divided into three stages, namely feasibility study, preliminary design and final design. One of the major technical aspects of importance is knowledge of the soil upon which a road is to be constructed.

To construct a new road, the vegetation is cleared and the top soil scrubbed to get rid of the roots and the humus which are deleterious to the road. The depth of this scrubbing is dictated by the nature/characteristics of the soil and the anticipated weight to be carried on the road pavement with a minimum of 300 mm. The remaining soil is compacted to give the road subgrade. Compaction helps the soil to be more resistant to soaking up moisture from below. In order to minimize the construction costs, natural materials should be used as much as possible. Every endeavour should be made to use cheap local materials before considering the importation of material from a distance (Ministry of Works (Kenya) Materials Department, 1986). If the material does not meet the design specifications, the traditional method is to excavate the entire unsuitable material, dump it elsewhere and get good material from other sources to fill in. This is then compacted to give the road subgrade. The subgrade is the naturally occurring soil on the construction site reached after scrubbing the top undesired material which is then compacted (Fig.1.1). The figure shows the various pavement layers of a paved road. The subgrade forms the foundation of a road. A foundation is the supporting base of a structure which transmits loads from the structure to the natural ground (Singh A, 1990). The other layers are the subbase, the base course, the binder course and the wearing course. The subbase is a capping placed immediately on the subgrade to receive the stresses from the loading. The base is a capping on the subbase which receives and distributes all the loads. The binder course is sometimes used for bituminous bases before the wearing course, which is the uppermost pavement layer providing the riding surface for vehicles. The thickness of each layer is determined by the class of the anticipated traffic.

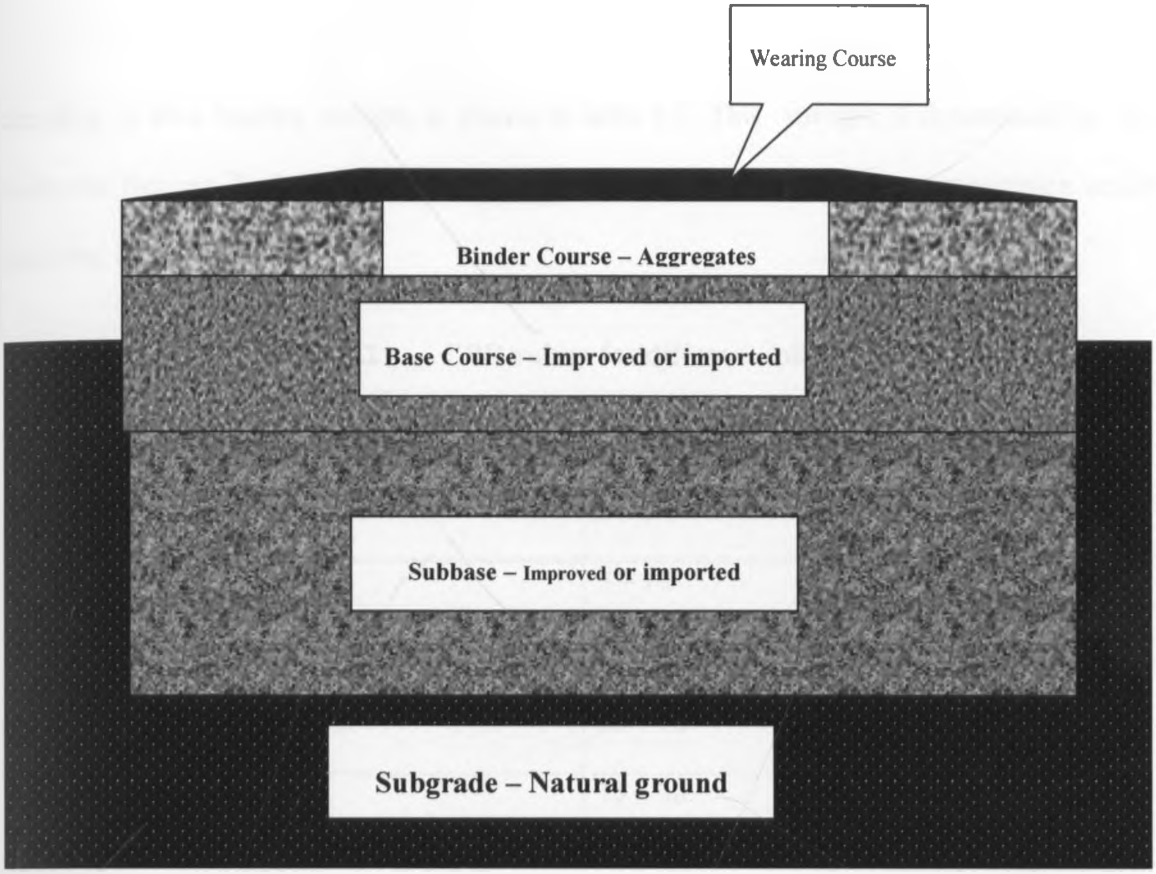

Figure 1.1: **Schematic diagram of the layers of materials in a road cross-section**

Foundations must be safe against bearing capacity and they should not exceed tolerable settlements of the soils.

Thomas G. W. (1977) defined soil as a complex mixture of air, water, organic and inorganic solids. Internationally, soils are classified according to the Airfield classification system, which was devised by Prof. Arthur Casagrade (Murthy V. N. S, 2003). The British Soil Classification System (BSCS) is also based on the same classification as devised by Prof. Casagrade.

A survey of the Kenyan subgrade soils (Ministry of Works (Kenya) Materials Department, 1978; Onduto N. B. et al, 1978) showed that they can generally be subdivided into six (6) major types according to their bearing strength as shown in table 1.2. This strength is determined by the California Bearing Ratio (CBR), which is a measure of soil resistance to penetration under controlled conditions.

Table 1.2 CBR values for different soil types

Soil type	**CBR Range**
S1	2 – 5
S2	5 – 10
S3	7 – 13
S4	10 – 18
S5	15 – 30
S6	>30

The CBR test is a penetration test meant for the evaluation of subgrade strength of roads and pavements. The results obtained by these tests are used with the empirical curves and tables to determine the thickness of the pavement and its component layers. This is the most widely used method for the design of flexible pavement. CBR is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min to that required for the corresponding penetration of a standard material as shown in equation 1.1.1. The reference force to penetrate a standard material is determined by the mould used.

$$\text{CBR} = \left(\frac{\text{test load}}{\text{standard load}}\right) \text{X}100 \qquad \textbf{Eq. 1.1.1}$$

The other common soil suitability test is the Plasticity Index (PI). Plasticity generally means ability to be shaped or formed. The plasticity of clay determines how much it can be stretched. PI is the numerical difference between the Liquid Limit (LL) and Plastic Limit (PL) values. LL is the percent moisture content of soil when soil is liquid (when the soil can't be shaped) and the PL is the percent moisture content when the same soil is plastic (can be rolled to form a threat 3 mm in diameter).When the soil in a construction site does not meet the desired design requirements, the common solution has been to remove the material and replace it with 'good soil' from elsewhere. The alternative method is to alter/ improve the condition of the 'poor soil' (Singh A, 1990). The demand for 'good soil' materials for road building purposes has outstripped the local supply. Good soil for road building purpose is that with the PI and CBR values within the design range. In some cases, this quality of materials could be available but harvesting restricted or prohibited for environmental reasons or could be in areas far away from the site of usage and hence uneconomical to transport. The subgrade strength is governed by the mechanical properties of the soil which are influenced by the chemical composition and moisture content.

Soil is the material that supports foundations and roads and hence the soil chemical and physical characteristics need to be understood to be able to meet the anticipated performance needs. Most saline soils are sodic (the predominant salt is sodium chloride) but they do not have a very high pH nor a poor infiltration rate. Organic matter has properties like large water absorption capacity which are undesirable in engineering. This is why the organic matter content of soils is normally determined. It has been accepted that permeability of soil depends on the properties of both the flowing water and the soil. Factors that have been shown to affect soil water permeability include density and viscosity of water; void ratio, size, shape and arrangement of soil particles; degree of saturation; adsorption complex and clay water interaction; and composition of the soil (Singh A, 1990).

Cement is the fine ground mineral used to bind coarser grained particles in a matrix. It is a hydraulic binder. The current cement standard used within the country has twenty seven (27) types of common cements (Kenya Bureau of Standards, 2001). At the time of beginning this study, comparison of different cement types for stabilization of the different road subgrade soils, Kenya had three (3) local companies namely Bamburi Portland Cement Company, East African Portland Cement Company and Athi River Mining Company which were producing five (5) types of cement products in total.

During construction, contractors are expected to follow the guidelines provided in the Ministry of Works (Kenya) Materials Branch Road Design Manual Part 3.

When roads are constructed in regions with ‘poor’ soils, some of the soils can be improved through stabilization. Soil stabilization may be broadly defined as the alteration or preservation of one or more soil properties to improve engineering characteristics and performance of soil. The purpose of stabilization is to alter the properties of a soil such that the soil is suitable for the relevant layer in a road construction. Stabilization enhances the load bearing capacity, controls or eliminates dust and causes water proofing. Stabilization improves strength, workability, durability and reduces plasticity, permeability, shrinkage and swell.

There are several stabilization methods amongst them use of Cement, lime, Portland blast furnace slag and fly-ash, mechanical, bituminous materials and or a mixture of any of the above. Cement has been found to be used in a wide variety of soils.

In this study, soils were stabilized using different types of cements locally manufactured. The aim was to compare the quantities of cement consumed by the different soils versus the CBR values obtained. Alignment soil was collected from ongoing road construction projects in Embakasi (Nairobi), Ndumberi (Kiambu), Tawa (Machakos), Mariakani (Kilifi), Khumusalaba (Kakamega) and Bomet. Power Plus (CEM I), Power Max (CEM II/A–L) and 'Nguvu' (CEM II/B-P) were sampled in Bamburi Portland Cement Company warehouse, Blue Triangle (CEM I and CEM IV/A) from East African Portland Cement Company warehouse and Rhino (CEM I and CEM IV/B-P) from Athi River Mining Company warehouse.

The chemical properties (calcium oxide, aluminium oxide, iron oxide and silicon dioxide) of the soils and the cement were analyzed according to standard methods (Official methods of analysis of the Association of Analytical Chemists, 1995). CBR of the neat and stabilized soils using 2, 4 and 6 percent of each of the cements were also determined using standard methods (British Standards Institution, 1990).

The rate of change of CBR on addition of the cement to the different soils was compared with a view of determining the cement type that would yield a higher CBR on addition of a smaller quantity of cement.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil

The word 'soil' has different meaning to different people (McFarland, M. J, 2001). The geotechnical/civil engineer normally considers soil to be earth material that supports foundations and roads. From this perspective, soil is all material that covers the bedrock of the earth crust. On the other hand, the traditional meaning of soil is that it is the natural medium for the growth of land plants. The soil Science Glossary from the Soil Science Society of America defines soil as the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. Alternatively, soil is defined as the unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of climate (including water and temperature effects) and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics.

From the second edition of Soil Taxonomy, soil is defined as a natural body comprised of solids (minerals and organic matter), liquid and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment. Knowledge of environmental soil chemistry is paramount to predicting the fate, mobility and potential toxicity of contaminants in the environment. In any given soil, a myriad of chemical reactions can occur which may change the physico chemical characteristics. These reactions could include adsorption/desorption, precipitation, polymerization, dissolution, complexation and oxidation/reduction. Understanding these processes enables better prediction of the fate and toxicity of contaminants, ultimately providing the knowledge to develop sound and cost-effective remediation strategies. It also helps develop ways of improving the soil so that one does not have to move soil around during construction.

Soil chemistry has developed into an important and complex scientific discipline over the past two centuries. Studies on ion exchange, soil acidity/alkalinity, retention of ions by soils, clay mineralogy and chemistry of oxides and hydrous oxides have become the focal points of soil chemists' research for decades (Thomas, G. W, 1977). Up to the late 1960's soil chemistry dealt mostly with understanding chemical reactions to improve crop productivity. Most of the present research focus is directed predominantly towards environmental sustenance. Soil research will improve the ability to make accurate predictions regarding their transport and availability in the environment. To understand the nature of soil, it can be looked at as a mineral and studied. Mineralogy is the study of chemistry, crystal structure, and physical properties of minerals. Specific studies within mineralogy include the processes of mineral origin and formation, classification , geographical distribution, composition as well as their utilization. Thus, there is physical and chemical mineralogy (Ramdell L. S, 1963).

2.1.1 Physical mineralogy

In Physical mineralogy, specific focus is on physical attributes of minerals. The description of physical attributes is the simplest way to identify, classify and categorize minerals.

2.1.2 Chemical mineralogy

According to L. S. Ramsdell (Ramsdell L. S, 1963), Chemical Mineralogy focuses on the chemical composition of minerals in order to identify, classify and categorize them, as well as a means to find beneficial uses from them. There are a few minerals which are classified as whole elements. These include sulfur, copper, silver and gold. A vast majority of minerals are chemical compounds, some more complex than others. In terms of major chemical divisions of minerals, most are placed within the isomorphous groups, which are based on analogous chemical composition and similar crystal forms. A good example of isomorphism classification would be the calcite group, containing the minerals calcite, magnesite, siderite, rhodochrosite, and smithsonite. Weathering depletes the soil's cation exchange; the cation concentration in a soil solution can be quite low and is largely determined by the weathering rate. The weathering rate is dependent on things such as mineralogy, surface area soil moisture, pH and concentration of base cations such as calcium, magnesium, potassium as well as aluminium. There exists no simple relation between soil solution concentration of calcium; magnesium and potassium; and reasonable pH-values. Base cations are cations of strong bases, and strong bases are fully dissociated at the pH-ranges occurring in most natural waters. Soils rich in easily weatherable minerals tend to have both a higher pH and higher soil solution cation concentration. Deposition of sulphate, nitrate and ammonia, decreases the pH of soil without affecting the cation concentrations whereas deposition of sea salt increases the calcium, magnesium and potassium concentrations without affecting the soil pH. pH levels affect the complex interactions among soil chemicals. For example phosphorus mobility requires a pH value of between 6.0 and 7.5 and becomes chemically immobile outside this range by forming insoluble compounds with iron and aluminium in acid soils and with calcium in calcareous soils

In soil science, cation exchange capacity (CEC) is the capacity of a soil for ion exchange of cations between the soil and the soil solution (Brinkman R, 1988; Turner, R. C. and Clark, J. S., 1966). CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination. The quantity of cations that a clay mineral or similar material can accommodate on its negatively charged surface is expressed as milli-ion equivalent per 100 g or more commonly as milliequivalent (meq) per 100 g or cmol/kg. Clays are aluminosilicates in which some of the aluminium and silicon ions have been replaced by elements with different valence, or charge. For example, aluminium (Al^{3+}) may be replaced by iron (Fe^{2+}) or magnesium (Mg^{2+}) leading to a net negative charge. This charge attracts cations when the clay is immersed in an electrolyte such as salty water and causes an electrical double layer. The CEC is often expressed in terms of its contribution per unit pore volume, Q_v. For agricultural soils, CEC is ideally between 10 and 30 meq/100g. Base saturation (the fraction of exchangeable cations that are base cations [Ca, Mg, K and Na]) is closely related to cation exchange capacity (Brinkman R, 1988). The higher the amount of exchangeable base cations, the more acidic it becomes in a short time perspective. Thus, a site with high cation exchange capacity takes a longer time to acidify (as well as to recover from an acidified status) than a site with a low CEC. Alkaline clay soils have a high pH greater than 9, a poor soil structure and a low infiltration capacity. Often they have a hard calcareous layer at 0.5 to 1 meter depth. Such soils owe their unfavorable physico-chemical properties mainly to the dominating presence of sodium carbonate which causes the soil to swell. They derive their name from the alkali metal group of elements which can induce basicity. Sometimes these soils are also referred to as sodic soils. The low infiltration capacity causes water stagnation. The presence of carbonates is either as a result of natural weathering of the soil particles or brought in by irrigation and/or flood water. The sodium carbonate, when dissolved in water, dissociates into two sodium cations and a carbonate anion. The sodium carbonate when reacted with water produces carbon gas and sodium hydroxide giving pH values greater than 9 (Brinkman R, 1988).

The reaction between sodium carbonate (Na_2CO_3) and water (H_2O) can be represented by equations2.1.1 and 2.1.2

$$2Na^+ + CO_3^{-2} + 2H^+ + 2OH^- \longrightarrow 2Na^+ + 2OH^- + H_2CO_3$$ **Eq. 2.1.1**

$$H_2CO_3 \longrightarrow H_2O + CO_2$$ **Eq. 2.1.2**

The carbonic acid (H_2CO_3) is unstable and produces H_2O (water) and CO_2 (carbon dioxide gas).Not all sodium carbonate follows the above chemical reaction. The remaining carbonate in the presence of the calcium ions (Ca^{2+})precipitates as calcium carbonate (slightly soluble) as represented in equation 2.1.3

$$2Na^+ + CO_3^{2-} + Ca^{2+} \longrightarrow 2Na^+ + CaCO_3 \text{ (solid)}$$ **Eq. 2.1.3**

The presence of abundant Na^+in the soil solution and the precipitation of Ca^{2+}causes the negatively charged clay particles to adsorb more Na^+ in the diffuse adsorption zone (DAZ), also called diffuse double layer and in exchange, release Ca^{2+}, by which their exchangeable sodium percentage (ESP) is increased(Bolt G.H. (ed.), 1981).The thickness of the DAZ increases with increasing Na^+ since the Na^+ is more mobile and has a smaller electron charge compared to Ca^{2+}. The thickness is also influenced by the total concentration of ions in the soil moisture in the sense that higher concentrations cause the DAZ zone to shrink. When clay particles with considerable ESP (> 16)are in contact with non-saline soil moisture, the DAZ expands and the soil swells (dispersion). This results in deterioration of the structure reducing the soil's infiltration capacity and water availability as well as increasing the surface-water-logging or runoff. Saline soils do not have unfavourable physical properties since the many ions in the soil solution counteract the swelling. Alkaline soils, in principle, are not saline since the alkalinity problem is worse as the salinity is less. Alkalinity problems are more pronounced in clay soils than in loamy, silty or sandy soils. The clay soils containing montmorillonite or smectite (swelling clays) are more subject to alkalinity problems than illite or kaolinite clay soils. The reason is that the former types of clay have larger specific surface areas and higher CEC. Bentonite, a clay mineral with almost 100% ESP is used in civil engineering as an impermeable curtain in the soil, e.g. below dams, to prevent seepage of water. Alkaline soils with solid $CaCO_3$ can be reclaimed with grass cultures, ensuring the incorporation of much acidifying organic material into the soil, and leaching of the excess sodium (Chhabra, R, 1996). Deep plowing and incorporating the calcareous subsoil into the top soil also helps. It is also possible to reclaim alkaline soils by adding acidifying minerals like pyrite.Alternatively, gypsum (calcium sulfate) can also be applied as a source of $Ca^{2+}$to replace the sodium at the exchange complex. Organic matter has properties like large water absorption capacity which are undesirable in engineering.

This is why the organic matter content of soils is normally determined. It has been accepted that permeability of soil depends on the properties of both the flowing water and the soil. Factors that have been shown to affect soil water permeability include density and viscosity of water; void ratio; size, shape and arrangement of soil particles; degree of saturation; adsorption complex and clay water interaction; and composition of the soil (Singh A, 1990).

2.2 Cement

Cement is a building material made by grinding calcined limestone and clay to a fine powder, which can be mixed with water and poured to set as a solid mass or used as an ingredient in making mortar or concrete. The term cement is also commonly used to refer more specifically to powdered materials which develop strong adhesive qualities when combined with water. There are several hydraulic cements used in construction. These include Portland cement, gypsum plaster, lime and pozzolana. The term cement is used in geology to refer to the fine-grained minerals which bind the coarser-grained matrix in sedimentary rocks. Such cements are typically composed of calcite, quartz or clay minerals. In the Longman Dictionary (2003), cement is defined as a grey powder made from lime and clay that becomes hard when it is mixed with water and allowed to dry and is used in building. All these definitions show that cement is widely appreciated and used and the purpose is the same.

The origin of the word "cement" is traced to the Romans, who used the term opus caementicium to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick additives that were added to the burnt lime to obtain a hydraulic binder were later referred to as cementum, cimentum, cäment and cement.

Cement used in construction is characterized as either hydraulic or non-hydraulic. Hydraulic cements (e.g. Portland cement) harden because of hydration chemical reactions that occur independently of the admixture's water content; they can harden even underwater or when constantly exposed to wet weather. The chemical reaction that results when the anhydrous cement powder is mixed with water produces hydrates that are not water-soluble. Non-hydraulic cements (e.g. lime and gypsum plaster) must be kept dry in order to retain the strength. The most important use of cement is the production of mortar and concrete—the bonding of natural or artificial aggregates to form a strong building material that is durable in the face of normal environmental effects. As a construction material, cement can be added to other material and can become a structural (load bearing) element once hardened. Upon the addition of water and/or additives the cement mixture is referred to as concrete, especially if aggregates have been added. The EconomicExpert.com states that hydraulic cement was first invented by the Egyptians and later reinvented by the Greeks and Babylonians who made their mortar out of lime much harder than the Roman mortars. The Romans later produced good cement from ash. Many excellent examples of structures made from these concretes (natural pozzolana) are still standing, notably the huge monolithic dome of the Pantheon in Rome and the massive Baths of Caracalla built around 212 AD. The vast system of Roman aqueducts also made extensive use of hydraulic cement. Modern hydraulic cements began to be developed from the start of the Industrial Revolution (around 1800) driven by three main needs. These were the need to make hydraulic render (stucco) for finishing brick buildings in wet climate, the need to make hydraulic mortars for masonry construction of harbor works which were in contact with sea water and the need to develop strong concretes.

2.2.1 Types of Cement

There are many cement types and blends, often available as inter-ground mixtures from cement manufacturers, but similar formulations are often also mixed from the ground components at the concrete mixing plant (Kenya Bureau of Standards, 2001). Amongst these are Portland blast furnace cement, Portland fly ash cement, Portland pozzolana cement, Portland silica fume cement, masonry cements, expansive cements, white blended cements, colored cements and very finely ground cements.

The preparation of a standard for cement was initiated by the European Economic Community (EEC) in 1969 (ENV 197-1, 1992). The work was given to the European Committee for Standards (CEN) in 1973 and a Technical Committee (TC) was entrusted with the task of preparing a cement standard for the countries of Western Europe. The TC then identified nearly twenty (20) different types of cement. A further fifty (50) different kinds of cement had been identified by 1990. The main difference was due to the different types of raw materials, different climatic conditions and social- cultural attitudes and different building techniques in different regions of Europe. In view of the large number of different kinds of cement, it was decided to consider only those of which hardening mainly depends on the hydration of calcium silicates and which are provided for common use, hence referred to as 'Common cements'. The current Cement Standard with twenty seven (27) common cement products is based on the same. A high degree of uniformity in all cement properties is obtained through continuous homogenization processes. According to the summary by Eng. Mamoun Obeidat (Arab Union for Cement and Building Materials, 2000), a mixture of natural minerals is transformed into an intimate mixture of synthetic minerals having the required hydraulic properties during clinker burning as represented in equation 2.2.1.

$$\text{Natural minerals} \xrightarrow[\text{Time (t), Pressure (p)}]{\text{Temperature (T)}} \text{Synthetic hydraulic minerals} \qquad \textbf{Eq. 2.2.1}$$

Important chemical – physical processes occur during the heating up. All these processes are significantly affected not only by chemical factors but also by mineralogical and physical factors. During the process, the several chemical reactions may be classified according to their type; namely structural change, decomposition and combination. The structural changes take place both during the formation and cooling of the clinker.

Decomposition reactions take place during clinker formation. An example is dehydroxylation of clay minerals, i.e. the removal of structural water from clay minerals as represented in equation 2.2.2.

$$2SiO_2.Al_2O_3H_2O \xrightarrow[500\text{ - }600^0C]{} 2SiO_2.Al_2O_3 + H_2O \qquad \textbf{Eq. 2.2.2}$$

Other decomposition reactions include the decarbonization of simple carbonate minerals and compound carbonate minerals as represented in equation 2.2.3

$$\underset{\text{Solid}}{MCO_3} \longrightarrow \underset{\text{Solid}}{MO} + \underset{\text{Gas}}{CO_2} \qquad \textbf{Eq. 2.2.3}$$

where M can either be calcium (Ca) for calcite, magnesium (Mg) for magnesite, or calcium and magnesium for dolomite. The decomposition of spurrite proceeds as represented in the equation 2.2.4

$$\underset{\text{(Spurrite)}}{2CaO_2\,(SiO_4).CaCO_3} \xrightarrow{\qquad} \underset{\text{(Belite)}}{2\,CaO_2(SiO_4)} + \underset{\text{Free lime}}{CaO} + \underset{\text{Gas}}{CO_2} \qquad \textbf{Eq. 2.2.4}$$

The reaction mechanism of the setting of cement when mixed with water is not completely known. The different constituents slowly hydrate and crystallize while the interlocking of their crystals gives to cement its strength. Carbon dioxide is slowly absorbed to convert the portlandite ($Ca(OH)_2$) into insoluble carbonate. The term hydration applies to all reactions of cement with water. It is these reactions that determine the properties of the products. It has been proposed that the strength is due to the reaction of alite (C_3S) and aluminate (C_3A). The reaction of calcium silicates with water produces a gel like calcium silicate hydrate and calcium hydroxide. Cement continuously gains strength as long as hydration proceeds. Alite is the mineral in Portland cement responsible for setting and development of "early strength due to the higher calcium content and presence of oxide in the lattice".

$$\text{Calcium Silicates + water} \xrightarrow{\qquad\qquad} \text{Calcium Silicate hydrates + Calcium hydroxide}$$

The reaction is represented by equation2.2.5

$$2(3CaO.SiO_2) + 6\,H_2O \xrightarrow{\qquad} 3\,CaO.2SiO_2.3H_2O + 3\,Ca\,(OH)_2 \qquad \textbf{Eq. 2.2.5}$$

In Cement Chemist Notation (CCN), this reaction is denoted as shown in equation 2.2.6

$$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3CH \qquad \textbf{Eq. 2.2.6}$$

The belite reaction contributes to the late strength due to its lower reactivity and is represented by equation2.2.7.

$$2\,(2CaO.SiO_2) + 4\,H_2O \longrightarrow 3\,CaO.2SiO_2.3H_2O + Ca(OH)_2 \qquad \textbf{Eq. 2.2.7}$$

In CCN, it can be denoted as equation 2.2.8

$$2\,C_2S + 4\,H \longrightarrow C_3S_2H_3 + CH \qquad \textbf{Eq. 2.2.8}$$

The 3 $CaO.2SiO_2.3H_2O$ ($C_3S_2H_3$ – calcium silicate hydrates) grows as a mass of interlocking needles that provide the strength.

Combination reactions are those of formation of the calcium silicates, alite and belite, and formation of aluminate and ferrite.

Belite formation is as represented in the reaction in equation 2.2.9

$$2\,CaCO_3 + SiO_2 \longrightarrow 2\,CaO\,(SiO_2) + 2\,CO_2 \qquad \textbf{Eq. 2.2.9}$$

Alite formation is as shown in the reaction in equation 2.2.10

$$2CaO.(SiO_2) + CaO \longrightarrow 3CaO.SiO_2 \qquad \textbf{Eq. 2.2.10}$$

There are other hydration reactions other than the calcium silicate which include the aluminate and ferrite components. The aluminate hydration reactions are heavily influenced by the presence of gypsum (Calcium sulphate). In the absence of gypsum, the hydration leads to rapid formation of unstable calcium aluminate hydrates as represented in equation 2.2.11

$$3CaO.Al_2O_3 + 6\ H_2O \longrightarrow 3\ CaO.Al_2O_3.\ 6H_2O \qquad \textbf{Eq. 2.2.11}$$

And denoted as shown in equation 2.2.12

$$C_3A + 6\ H \longrightarrow C_3A.H_6 \qquad \textbf{Eq2.2.12}$$

Gypsum reacts with the C_3A to form calcium trisulphate aluminate hydrate (ettringite) as represented in equation 2.2.13.

$$3CaO.Al_2O_3 + 3\ CaSO_4 + 32\ H_2O \longrightarrow 3CaO.Al_2O_3.3\ CaSO_4.32\ .H_2O \qquad \textbf{Eq. 2.2.13}$$

Denoted as equation 2.2.14

$$C_3A + 3CS + 32\ H \longrightarrow C_3A.3CS.H_{32} \qquad \textbf{Eq. 2.2.14}$$

When the entire gypsum is depleted, the ettringite is converted to the monosulphate as shown in equation 2.2.15

$$3CaO.Al_2O_3.3\ CaSO_4.32\ .H_2O + 2(3CaO.Al_2O_3) + 4\ H_2O \longrightarrow 3(3CaO.Al_2O_3.CaSO_4.12H_2O) \qquad \textbf{Eq. 2.2.15}$$

This can be denoted as in equation 2.2.16

$$C_3A.3CS.H_{32} + 2C_3A + 4H \longrightarrow 3(C_3A.CSH_{12}) \qquad \textbf{Eq. 2.2.16}$$

The hydration of calcium aluminate ferrite, C_3AF, is similar to that of C_3A though the process is much slower. The phenomena of swelling, shrinking, creeping and self-healing of cracks are all due to formation of these gelatinous masses holding together. It is also because of these reactions and formation of such 'bonds' with particles of other components that make cement such a versatile binder. In stabilization of road construction materials, cement is used to bind smaller soil particles together to form a more rigid stable mass which can carry a load without breaking off or be carried away by water. This is because the natural soil has several of these components (alite, belite, aluminate and ferrite) depending on its geology. Their presence makes the soils to develop cementitious properties.

The use, hence demand of cement is increasing worldwide. According to the Netherlands Environmental Assessment Agency (NEAA) report published on 19th June 2007, it was estimated that China manufactured 1.235 billion metric tons of cement, which was 44 % of the world total cement production. This means that approximately 2.81 billion metric tons of cement was produced in the world in 2006. The same document states that there is an average annual production growth rate of 5.4 %, which implies that approximately 3.12 billion metric tons was to be produced 2007.

The increased use of cement is attributed to construction of concrete roads and use of cement to stabilize the existing material that does not meet the design parameters expected. Because of the complexities in which cement is used, there exist special cements which are made to meet the different situations of usage (Arab Union for Cement and Building Materials, 2000).

The mentioned cements are:

(i) High early strength cement -

This type is also referred to as rapid hardening cement. In comparison to the others, it contains more alite, aluminate and gypsum, all of which could have been added to increase the rate of hardening. Such cements are used in situations where a rapid strength development is desired. For example when the formwork has to be removed after a short time for re-use or where sufficient strength is required for further construction.

(ii) Regulated set cement -

The active component is calcium fluoroaluminate and is characterized by adding admixtures to retard hardening. This is achieved because strength development occurs in two somewhat independent stages. It is useful for lightweight roof-decks, where it is desirable to apply the roofing soon after the placing of the cement, where it permits easy stripping and re- use of forms.

(iii) Sulphate resisting cement -

The cement is characterized by a low C_3A content with low heat properties and is not attacked by sulphates under normal concentrations in fully compacted concrete.

(iv) Low heat cement -

Their use is recommended for mass concrete construction or large structural sections because they release little heat of hydration, reducing the rate of strength increase.

(v) Low alkali cement -

This type is recommended for use with aggregates which react with alkalis in cement causing concrete deterioration. They are very expensive and production is limited to where it is extremely necessary.

(vi) Expansive cement -

Since concrete paste shrinks due to evaporation of excess water causing cracks in fixtures, such expansive cement compensates by formation of ettringite, a hexacalcium aluminate trisulfate hydrate as a result of the reaction of calcium aluminate with calcium sulfate. They can be used for slabs, highway and airport paving, parking decks and water holding structures.

(vii) High alumina cement -

This cement produces a concrete which has an exceptionally fast rate of hardening and is resistant to attacks by most sulphate solutions. It has higher resistance to acidic solutions though it cannot resist caustic alkali attacks. It is worth noting that this rapid hardening is not accompanied by rapid setting.

(viii) Oil well cement -

These were developed to seal oil and gas wells and are designed to set and cure at high temperatures and pressures. They produce a low viscosity, slow setting slurry and are used with a retarder as well as a friction reducing additive. They can remain fluid for hours but then harden very rapidly.

(ix) Hydroscopic cement -

It is like the ordinary Portland cement though a small amount of water repellant agent is added which forms a protective coating around each cement particle. The coating retards hydration until the cement is mixed with water. These can be used for soil stabilization and where concrete mixes are to be pumped.

(x) Waterproof cement -

It is like the ordinary Portland cement though a small amount a waterproofing agent is added. It is used for concrete construction that is subject to hydrostatic pressure like the basement walls and storage tanks for liquids.

(xi) White cement -

It is manufactured like the ordinary Portland cement though by a special process and is for architectural works and requires suitable light coloured aggregate.

2.3 Roads

Modern roads are normally smoothed, paved or otherwise prepared to allow easy travel although historically many roads were simply recognizable routes without any formal construction or maintenance. The history of roads has been related to the centralizing of populations in powerful cities, which the roads have served for military purposes and for trade, the collection of supplies and tribute. Scientists have found evidence of a network of roads dating back to perhaps 3000 B.C.in Northern Mesopotamia (Hindley G, 1972). In Persia, between 500 and 400 B.C., all the provinces were connected with the capital, Susa, by roads, one of them 1,500 miles (2,400 km) long. The ancient Greeks, cherishing the independence of their city-states and opposing centralization did relatively little road making. Roads were the ancient system of highways linking Rome with its most distant provinces. The roads often ran in a straight line regardless of obstacles and were efficiently constructed. In Italy and in every region that the Romans conquered, they built roads so durable that parts of them yet remain serviceable. Surfaces were made of large stone rested on a bed of smaller stones and cement about 90 cm thick. From the fall of the Roman Empire until the 19th century, the roads were generally neglected and hard to travel. People usually walked, rode horses or were carried in sedan chairs. Goods were transported by pack animals. In France, Louis XIV and Napoleon built good roads for military purposes. Elsewhere on the Continent, roads were not much improved before the middle of the 19th century. Great Britain had two Scottish engineers, Thomas Tedford and John McAdam who greatly improved road building in England and Scotland by introducing the use of a base of large stones surfaced with compacted layers of small stones and they were responsible for the development of the 'macadam'. The invention of macadam road construction provided a quick and durable method for building roads, and asphalt and concrete also began to be used. Motorized traffic in the 20th century led to the limited-access highway, the first of which was a Parkway in New York City built in 1925 (Lay, M, 1986). Super highways also appeared in Italy and Germany in the 1930s. In the 1950s, the United States of America interstate highway system was inaugurated to link the country's major cities.

The planning and building of road arteries, notably the Road Highway in the United States of America was in the early 19th century. At the time of its construction, the National Road was the most ambitious road-building project ever undertaken in the United States. The invention and mass production of the automobile made the road become paramount again. Hard-surfaced highways were stretched across the entire land in a relatively few years. The building of roads became a major branch of engineering surmounting the most difficult obstacles. Roads have helped greatly to equalize and unify large heterogeneous nations. In the United States the Interstate Highway System consists of 68,869 km of roads (all but a few miles of which are completed) connecting every major city. Other well-known road networks which serve to unify large areas include Germany's Autobahn, the Trans-Canada Highway and the Pan-American Highway which is the longest world's motorable road according to the Guinness World Records. In Africa, we have the Great North Road, linking Cape Town to Cairo. This road enters Kenya from Tanzania at Namanga, goes through Nairobi, Nyeri, Isiolo and exits through Moyale to Ethiopia. There is the Northern Corridor, which links Mombasa to West Africa via Nairobi, Nakuru, Eldoret and exits through Malaba to Uganda. The Southern Corridor links Mozambique and Angola. The corridors link the East African coast (Indian Ocean) to the West African coast (Atlantic Ocean). All these road networks in the various regions are developed with the main aim being to improve the movement of people and goods to spur economic growth of the entire region.

As envisaged in the Kenya Vision 2030, it is improvement in the infrastructure that will make the region develop. In a recent conference on development of infrastructure in Kenya, held on 2nd and 3rd November 2010 in Nairobi, Kenya, it was reported that roads are a key area that needs to be invested in to achieve the Vision 2030. According to the presidential speech, during the opening of the conference, it was stated that over 94% of freight transport and over 80% of passengers in Kenya rely on road transport (Ministry of Roads (Kenya), 2010). With an improved road infrastructure, development is attained because of the reduced time lost on transportation and less consumption of fuel. Most countries which import petroleum lose a lot of foreign currency through this importation. Similarly, individuals spend a lot of money to purchase the imported fuel. Bad road infrastructure consumes most of this fuel on traffic jams, money that could have been used/invested in other areas of the economy. This goes further by importation of motor vehicle spare parts to replace the broken and worn out ones. The high costs of fuel affect the cost of farm inputs and farming, which then pushes the cost of living higher.

2. 4 Road Construction

For any road construction to take place there are various stages the process goes through. Engineers are expected to design roads to meet the anticipated needs in any given area in respect to the weight of the load and the durability as well as the available funds. Road design is divided into three stages namely feasibility, preliminary design and final design. It is important to have some knowledge of the particular soil. The basis for a road /highway pavement is the provision of a uniform skid-resistant running surface with adequate life and requiring minimum maintenance. The designer must develop the most economical combination of layers that will guarantee adequate dispersion of the incident wheel stresses so that each layer in the pavement does not become over stressed during the design life of the highway (Martin, R, 2003).

The major variables and the design of a highway pavement include the thickness of each layer in the pavement, the material contained within each layer of the pavement, the type of vehicle in the traffic stream, the volume of traffic predicted on the highway over its design life and the strength of the underlying subgrade soil. Since the subgrade soil is rarely rock, it's normally necessary to superimpose additional layers of materials in order to reduce the stresses incident on it due to traffic loading. The shear strength and stiffness modulus are accepted indicators of the supper susceptibility of soil to permanent deformation. Both these are reduced by increase in moisture content. The California Bearing Ratio (CBR) is often used as an index test though it is not a direct measure of either the stiffness modulus or the shear strength, but is an indicator due to knowledge and experience developed by practitioners.

Road construction contract documents are composed of various sections. There is a Technical Specification section which gives the special specifications of that particular contract. This section of the contract gives details on the location and extent of the construction site; the extent of the contract; the programme of execution of the works; and environment and safety.

2.4.1 Location and extent of construction site

For ease of locating or referring to the place where a road is under construction for monitoring and evaluation/assessment purposes, the place names of the start and end of the construction are mentioned including the distance. For example, during the rehabilitation of the Machakos turnoff – Sultan Hamud section of the Nairobi – Mombasa Road, the location and extent of the site was given as *"The works are located along the Nairobi – Mombasa Road. The road commences at the turn off to Machakos town at the Yomba trading centre and runs in a Southeasterly direction to end about eight (8) kilometers before Sultan Hamud. The site of the works shall be the area within the road reserve and any other places as may be designated in the contract. The total length of the project is approximately fifty five point two five (55.25) kilometer"* (Ministry of Roads and Public works (Kenya), 2006). This description makes it easy for many people to identify the area where the road construction is taking place.

2.4.2 The extent of the contract

The subsection describing the extent of the contract awarded gives details of the works for the particular contract like site clearance and top soil stripping. For example, to construct a new road, the vegetation is cleared and the top soil scrubbed to get rid of the roots and the humus which are deleterious to the road. The depth of this scrubbing is dictated by the nature/characteristics of the soil – all of which should have been done in the preliminary study; and the anticipated weight to be carried on the pavement. The extent of the depth and compaction are under the earthworks and pavement construction. Issues related to soil chemistry are taken care of by the recognition of the effect of drainage and protection of works. The detailed characteristics/parameters to be tested in the soil and the respective acceptable higher limits are normally indicated in the special specifications.

2.4.3 Environment and safety

Under this subsection of the technical specifications, the employer instructs the contractor on the expected aspects of environmental protection. For example, the contractor is instructed to ensure that as far as is reasonably applicable and to the satisfaction of the employer, the impact of the construction on the environment be kept to a minimum and to ensure that appropriate measures are taken to mitigate any adverse effects during the construction.

2.4.4 Materials

Section 2 of the Standard Specification (Ministry of Works (Kenya) Materials Branch, 1986) gives details of all the materials to be used on the construction and how they should be tested for compliance. Section 3 of the Standard Specifications sets the tolerances necessitated because of the anticipated variation in the test results. The materials discussed for the subgrade are those found on the site. The subbase material is obtained by improving the existing material or by importing better material whereas the base is normally imported since the material is expected to meet much higher characteristics. Every endeavor should be made to use the cheap local materials before considering the importation of material. Importation should only be done if the existing material cannot meet the specification even on improvement. The earthworks subsection of the materials section is meant to specify the characteristics that make materials to be unsuitable, this is so because a material considered unsuitable for a construction site A might be considered suitable for another site or project B.As an example, some of the material considered unsuitable on the Machakos turn off – Sultan Hamud project (Ministry of Roads and Public Work (Kenya), 2006) includes material containing more than 5 % by weight of organic matter (such as topsoil and humus), materials from swamps, mud, log stumps and perishable material; material with a swell of more than 3 %; clay with a liquid limit exceeding 50 %; and material having moisture content greater than 105 % of optimum moisture content (standard compaction) in its naturally occurring state. The first part of material importation involves excavation and haulage of the unsuitable material from the construction site to a suitable dumpsite. The second part involves the sighting of a suitable material source, excavation and haulage of the same to the construction site. contractor is expected to meet the entire cost of removing and replacing the unsuitable material. It is appreciated that the materials are not homogeneous and hence a subsection on cement treated materials is included in the document so that for soils that do not meet the requirements, the material can be improved by use of cement.

2. 5 Soil Stabilization

Greater attention is now being paid to the use of locally available material. It is unfortunate that roads pass through regions with poor soils. Such poor soil materials can be used if improved to meet the requirements as stipulated in the Road Design Manuals and Specifications, mostly through stabilization. There are three main purposes for soil stabilization (Singh A, 1990). The first is strength improvement of the existing soil to enhance its load - bearing capacity. The second is dust control to eliminate or alleviate dust generated in dry weather. The third is soil waterproofing which is done to preserve the natural or constructed strength of a soil by preventing the entry of surface water. Thus the purpose of stabilization is to alter the properties of a soil such that the soil is suitable for the relevant layer in a road construction. Stabilization improves strength, workability, durability and reduces plasticity, permeability, shrinkage and swell.

There are several methods of stabilization (Singh A, 1990), among them are Cement stabilization, lime stabilization, Portland blast furnace slag and fly-ash, mechanical stabilization, bituminous stabilization or a mixture of any of the above. The use of cementitious materials allows enhancement of standard and substandard in-situ soils to levels consistent with the design requirements of a given application. Soil stabilization may be broadly defined as the alteration or preservation of one or more soil properties to improve engineering characteristics and performance of soil. The effectiveness of stabilization depends on the ability to obtain uniformity in blending the various materials. The decision as to which method of stabilization to use is primarily financial, but this is also influenced by the characteristics of the materials not meeting the specifications, skills and materials available, resources and equipment available and any previous/existing experience (O'Flaherty, C. A. et al, 2002).

Chemical characteristics of cement make it particularly suited to solidification and stabilization of materials. Solidification increases the compression strength, decreasing permeability and encapsulates toxic elements whereas stabilization changes the chemical properties of the soil fixing the hazardous elements into less soluble and mobile toxic forms. Cement is suited for these since it is multifaceted in the way it reacts with other materials (Leo. J. R., et al, 1979). The main active components of cement are the tri-calcium silicate (C_3S), di-calcium silicate (C_2S), tri-calcium aluminate (C_3A) and tetra-calcium alumino-ferrite (C_3AF) (Kenya Bureau of Standards, 2001). When these components are mixed with water, the hydration reactions start and hydrated gels are formed. Cement in contact with water produces calcium silicate hydrate and calcium alumino hydrates. The C_3A hydrates rapidly, whereas the C_3S and C_2S hydrated gels crystallize more slowly to form a bonded crystal matrix. The C_3AF hydrates slower than the other three components. The properties of soil change on addition of cement, the cementation process providing increased strength. The calcium silicate hydrate and calcium alumino hydrates form irreversible cementation products with soil. The strength and quantity of these products depend on several factors including the type of the soil and cement, the quantity of cement added and the moisture content and the compaction of the soil.

Cement - stabilized materials generally fall into two classes namely; soil - cement and cement modified soil. Soil - cement is a mixture of pulverized soil material and/or aggregates, measured amounts of Portland cement, and water that is compacted to a high density. Enough cement is added to produce a hardened material with the strength and durability necessary to serve as the primary structural base layer in a flexible pavement or as a subbase for rigid pavements. Cement - treated aggregate base and recycled flexible pavements are considered soil - cement products. Cement - modified soil is a soil that has been treated with a relatively small proportion of Portland cement (less cement than is required to produce hardened soil-cement), with the objective of altering undesirable properties of soil to become suitable for use in construction. Cement-modified soil is typically used to improve subgrade soils Alternative terms include cement - treated or cement-stabilized soil or subgrade (Leo, J. R et al, 1979). The cement stabilized materials can be used as subgrade and base materials as specified (Ministry of Works (Kenya), 1986). Records show that the British Transport and Road Research Laboratory (TRRL) has for a long time been doing research into the behavior of soil – cement and the implications for its use in pavement layers (Bofinger, H. E, 1978). In another research, it was seen that the improvement of the one day strength of cement was associated with reactivity of metakaolin (Cassagnabere, F. et al, 2009) and that the general increase of compressive strength in cement reactions is attributed to the formation of ettringite (Katsioli, M. et al, 2009). This meant that cement reactions depend on available cations. Similarly, it was reported that the viability of roads consisting of lateritic soils is proven to be dependent on the chemical and mineralogical composition (Millogo, Y. et al, 2008).

The main reference documents in road construction are the 'Ministry of Works, Materials Branch Road Design Manual Part III: Materials and Pavement Design for New Roads' and the 'Standard Specification for Road and Bridge Construction'. A large percentage of the information used to draft these documents was based on the data available up to 1978. There were only two varieties of cements available in Kenya (Ministry of Works (Kenya), 1986). Currently there are twenty seven cement types (Kenya Bureau of Standards, 2001). Of these cement types, those locally manufactured are CEM I 42.5 (produced by Bamburi, East Africa Portland Cement and Athi River Mining), CEM II/A-L 42.5 (Bamburi), CEM IV/B-P 32.5 (Bamburi), CEM II/B-P 32.5 (ARM) and CEM IV/A 32.5 (EAPC). The cement types are classified differently because of the different quantities of raw materials used in the manufacturing process. They thus have different quantities of the various constituents and hence their effects on any given soil will depend on the quantity of these available constituents. Since addition of cement does alter the chemical nature and improves the soil to meet the desired design characteristics, one needs to know which cement amongst those available is best suited for a particular soil for cost effectiveness. Theoretically, comparing the composition of the same cement type produced by the different companies should not yield a significant difference.

Previous field and laboratory trials have shown that by treating the soils with cement, the CBR is expected to increase and the PI expected to decrease depending on the amount of cement added. The general behaviour can be represented as shown in figure2.1.

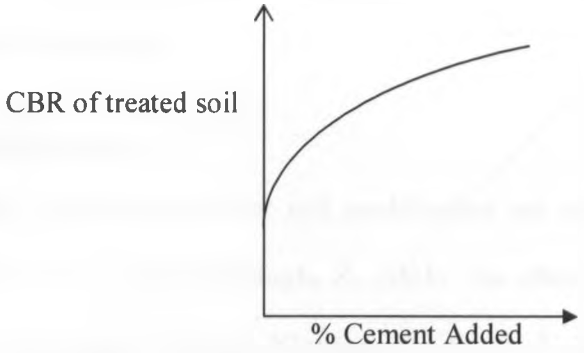

Figure 2.1 - Graph of CBR against % Cement added

The silica – alumina and silica– sesquioxides ratios are used as a method of expressing the nature of clays. A high ratio indicates the presence of siliceous clay whereas a low ratio indicates sesquioxidic clay. Many soil properties depend on whether the clays are siliceous or sesquioxidic. The colloidal properties are more developed in siliceous clays whereas in sesquioxidic clays, anion exchange is more pronounced. The changes in silica- alumina and silica – sesquioxide ratios assist in explaining the development of a soil survey profile (Little, D. N et al, 2003). Research has shown that in cement, the reactive part responsible for early setting is the C_3A, which is a determined by the proportion of contents of the alumina and sesquioxides as represented in equation 2.5.1.

$$C_3A = 2.65\,(Al_2O_3) - 1.69\,(Fe_2O_3) \qquad \textbf{Eq. 2.5.1}$$

Results from further research by use of X-ray diffraction and scanning electron microscopy studies showed that the hydrated iron and aluminum oxides coat the clayey constituents of the soil and bind them into coarser micro aggregations. Analyses of grain size indicated that the remolding phenomenon disaggregates the micro-aggregations into finer clayey clusters (Townsend, F. C. et al, 1971). The findings implied that addition of iron and aluminium affects the binding of clayey constituents.

2.5.1 Cost of Stabilization

The most commonly used additives for soil modification are cement, lime, fly Ash or lime together with cement or fly ash (Nalbantaglu, Z., 2004). The effectiveness of fly ash and cement stabilized subgrade has been reported (Goktepe, A. B. et al, 2008). Generally, the cost of construction of a given road will be dictated by the material existing in the area of construction, the design and the anticipated load. For example, the rehabilitation of the Machakos Turnoff – Sultan Hamud Section of Nairobi – Mombasa road which is 55.25 km long cost Ksh 3,040,616,512.54, an average of approximately Ksh 55 million per kilometer (Ministry of roads and Public works (Kenya), 2006) whereas the Runda – Whispers Estate and the Flats (Kiambu road junction) – Runda Estate which is 2.6 km long cost Ksh 272,545,292.00 an average of approximately Ksh 105 million per kilometer (Ministry of Roads and Public Works (Kenya), 2007). It is interesting to note that the cost incurred on a 'minor' road, in Runda estate is twice as expensive as that on an international highway. . This shows that the cost of a road is mainly due the locality of the road and the quality of materials to be used, mainly to meet the design parameters of the pavement. It was believed by some that using cement for stabilization is the most cost effective way to gain strength and stiffness in construction (O'Grady, J, 2008).

This study of comparison of different cements types for stabilization of different road subgrade soils has investigated rate of change in the CBR of different materials on addition of different cement types. The samples of soils used were chosen on alignment materials from different locations within Kenya based on the ongoing construction works. Selection was also based on the fact that the majority of the soil materials in the chosen areas were known to be different. An exception is the black cotton soil which is predominantly found in the Embakasi area of Nairobi. In the central province, the sample (red coffee soil) was collected in Kiambu. The other materials of interest were the quartzitic gravels that were found predominantly in the Machakos area of Eastern province, calcrete gravels mainly in the Coast province (Kaloleni area) and Lateritic gravels in Khumusalaba region of Kakamega (Western province).

2.6 Problem Statement

Addition of the specified quantities of some of the five (5) different types of cement products produced locally does not yield the expected strength of subgrade soils. The products based on the current Cement Standard are CEM I, CEM II/A-L, CEM II/ B-P, CEM IV/A and CEM IV/B-P. The Road Design Manual Part III and the Standard Specification for Road and Bridge Construction refer to the obsolete Kenya Standard KS 02 -21. Roads are constructed in regions with various types of subgrade soils. There are also various types of subgrade soils in the regions where roads are being constructed. There is need to determine the most suitable cement type to be used for soil stabilization for road subgrade based on the current cement specifications.

2.7 Justification

Cement has been found to be effective in stabilizing a wide variety of soils, including granular materials used in road construction (Little, D. N. et al, 2003). Most contractors use cement to stabilize soils they find not meeting the specified requirements. In regards to the quantity of cement required, they refer to the ‘Special Specifications for Road and Bridge Construction’ which does not indicate the recommended type to use. Use of some of the types makes road construction very expensive since bigger quantities are used. With the current trend and development in the cement industry and specifications, most cement types are being manufactured to meet certain specific uses. It is therefore paramount that the contractors be informed of the types of cements to use in particular locations to make cement stabilization viable. Environmental protection and preservation has also taken centre stage in construction projects making the availability of alternative sources of materials with required characteristics very limited. Every endeavour must be made to utilize the material on site as much as possible

2.8 Objectives

2.8.1 General Objective

To determine the cement type that is most suitable and cost effective in stabilization of the different soil types prevalent in different parts of the country to meet the subgrade design parameters.

2.8.2 Specific Objectives

1. To analyze the chemical properties of cement for the reactive constituents.
2. To analyze the soils for the chemical reactive constituents as in cement.
3. To compare the California Bearing Ratio of the neat versus the stabilized soils at different proportions.
4. To determine how addition of each cement type comparatively affects the strength of the soils during road construction.
5. Recommend the cement type that is cost effective for the different soil types.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Samples of the locally manufactured cement types and subgrade soils from some ongoing construction and rehabilitation projects were collected and their chemical composition determined using standard elemental laboratory procedures (Association of Official Analytical Chemists, 1995). The California Bearing Ratios of the neat soils and the stabilized soils (treated by adding varying quantities of cement) was determined using the standard test methods (American Association of State Highway and Transport Officials, 2010; British Standards Institution, 1990; American Society for Testing and Materials, 1990). The effect of adding different types of cement to the soils was graphically compared.

3.1 Materials used

3.1.1 Apparatus, reagents and Instruments

A set of 20 mm, 5 mm and 425μm test sieves (complying with British Standard 410), 500 ml conical flasks, 50 ml burettes, a set of 10, 20, 25 and 50 ml pipettes, 100 ml graduated measuring cylinder, 150 ml, 250 ml and 600 ml Pyrex beakers, filter funnels, 50 ml, 100 ml and 250 ml volumetric flasks, weigh crucibles, pellet crucibles, moisture tins, drying pans and basins were sourced. The reagents 1N potassium dichromate, 1N ferrous sulphate, concentrated sulphuric acid, concentrated hydrochloric acid, concentrated ortho-phosphoric acid, diphenyl amine indicator, stock solutions each of 1000ppm of iron, calcium, magnesium and aluminium, starch, wax, buffer solutions of pH 4 and 9.2, Whatman filter paper No. 1 and No. 542 both of diameter

150 mm were purchased. Equipment used were the oven (Gallenkamp 180 model), hot plate (Gallenkamp model), pH meter with electrode (EDT DR 359 TX model), analytical balance (Sartorius 1213 MP model), weigh balance (Avery 3303 COB model), pulverizer (Herzog HSM 100 model),the Atomic Absorption Spectrophotometer (Varian AA 10 model) and the X- Ray Fluorescence Spectrophotometer (PAL 3from Phillips). A set of Compression (California Bearing Ratio) equipment complete with the accessories including a dial gauge, set of proctor (model 1500 KN) and CBR moulds, three metal plugs 150 mm in diameter and 50 mm thick and cylindrical metal plunger, vacuum desiccators, sample divider (ELE), a tape measure, shovel, mallet to break the larger soil molds, sample bags and bottles were also sourced. Deionised water was prepared in the Chemistry laboratory of the department using the water deionizer (Ionimizer Mk 8).

3.1.2 Soils

The soil materials were sampled from ongoing road constructions projects in the following areas: Nairobi Province (in Embakasi along the Eastern bypass between City Cabanas and Ruiru), Central Province (along the Ndumberi – Limuru road in Kiambu), Eastern Province (along the Tawa – Kikima – Makutuno road in Machakos), Coast Province (along the Mariakani – Kilifi road in Kilifi), Western Province (along the Stand Kisa - Khumusalaba road in Kakamega) and Rift Valley Province (along the Bomet - Litein road in Bomet)

3.1.3 Cement

The cement types used for the investigation were the brands: 'Power Plus' 42.5 (CEM I), 'Power Max' 42.5(CEM II/A-L) and 'Nguvu' 32.5 (CEM IV/B-P) all manufactured by Bamburi Portland Cement Company; Blue Triangle 42.5(CEM I) and 32.5 (CEM IV/A), both manufactured by East African Portland Cement Company; and Rhino 42.5 (CEM I) and 32.5 (CEM II/B-P) both manufactured by Athi River Mining Company.

3.2 Sampling

3.2.1 Soil

In each of the mentioned sites, Nairobi (between 7 and 8 kilometers from City Cabanas along the Eastern bypass from City Cabanas to Ruiru), Central (between 3 and 4 kilometers from Ndumberi along the Ndumberi – Limuru road in Kiambu), Eastern (between 1 and 2 kilometers from Tawa along the Tawa – Kikima – Makutuno road in Machakos), Coast (between 2 and 3 kilometers from Mariakani along the Mariakani – Kilifi road in Kilifi), Western (between 15 and 16 kilometers from Stand Kisa along the Stand Kisa - Khumusalaba road in Kakamega) and Bomet (between 0 and 1 kilometers from Bomet along the Bomet - Litein road in Bomet), alignment soil materials on the project was collected. Using a shovel, soil material was taken at three sites at 500 meter intervals (at 0 m, 500m and 1000 m) along the selected length of road under construction. The samples were taken up to a depth of six inches of the alignment layer by taking a vertical slice of material on a 1 meter square area at each site. All the materials from the three sites were placed in labeled sample bags and transported to the laboratory for drying.

3.2.2 Cement

Two bags of each cement type were collected from stock piles in the Cement plants. The cement plants included Bamburi Portland Cement (for Power Max, Power Plus and 'Nguvu') in Athi River, East African Portland Cement (for Blue Triangle) in Athi River and Athi River Mining (for Rhino) in Kaloleni, Kilifi. From each bag, approximately 1,000 g of the cement was scooped and kept in a labeled air tight sample bottle.

3.3 Laboratory tests

3.3.1 Instrumentation

The Atomic Absorption Spectrophotometer (Spectra AA 10) was set to the conditions as directed in the equipment's method and operation manual. The wavelength and slit width were set for the respective hollow cathode lamp starting with calcium and the equipment optimized. Prepared standards were aspirated to calibrate and the samples also aspirated to determine their corresponding absorbance. The same procedure was used for the analysis of magnesium, aluminium and iron. The X-Ray Fluorescence spectrophotometer (The Mini Pal 3) was set at 13 KV, 12 µA and 100 seconds as indicated in the instruction and operation manual and used to analyze for the silicon dioxide. The pH meter (EDT DR 539 TX) was calibrated at 24°C using buffer solutions of pH = 4 and pH = 9.2 and then used to determine the pH of the soil samples. Analytical Balance (Sartorius 1213 MP) was tarred and used to measure weights of the pulverized soil for chemical analysis to the fourth decimal point of a gram. Weigh balance (Avery 3303 COB) was tarred and used to weigh samples for both proctor and CBR determination. Weights were recorded to the nearest 1 g.

The pulverizer (Herzog HSM 100) was cleaned and used to crush the soil material passing through sieve of aperture size 425 μm to fine powder. Riffler (Wykehem Farrance)was used to riffle and get a representative portion of both the material passing through the sieve of aperture size 20 mm and retained on the sieve of aperture size 5 mm. Deionizer (Ionimiser Mk 8) was used to deionize tap water to obtain deionized water used for the analysis. A compression equipment(Ele 122 -3- 699) complete with a dial gauge, moulds, metal plugs and the proctor and mould apparatus (Controls 1500 KN, C34A2) were used to make the moulds and determine the penetration after soaking of the moulds.

3.3.2 Chemical composition tests

3.3.2.1 Sample preparation

For each site, material from the three points of the construction was thoroughly mixed while air drying to obtain a representative sample for the location under investigation. Bigger molds of soil were broken using a mallet. The dry material was sieved through the 5 mm sieve and again though the 425 μm to collect approximately 500 g, which was kept in polythene sample bags to be used for chemical composition. Approximately 100 g of the soil passing sieve425 μm was oven dried at 105^0C, allowed to cool then pulverized to give a fine powder. The pulverized material was again oven dried, cooled and placed in air tight sample bottles. Approximately 10.0 g of each soil sample was accurately weighed using the analytical weigh balance and transferred into labeled 600 ml beakers. Similarly, approximately 1.0 g of each of the cement samples from the air tight sample bottles was accurately weighed on the analytical balance and transferred into labeled 600 ml beakers.

3.3.2.2 Sample digestion

The soil and cement samples in the beakers were acid digested (Official Methods of Analysis of the Association of Official Analytical Chemists, 1995). To each beaker, 25 ml of 10 % hydrochloric acid (2.5 ml concentrated acid + 22.5 ml deionized water) was added. The reaction was allowed to proceed until violent production of gases ceased. The contents of each beaker were stirred with a stirring rod, placed on a hot plate and allowed to boil. The beakers were removed from hot plate and allowed to cool. The contents were filtered through the Whatman filter paper No. 1and the filtrate collected in labeled 250 ml beakers. The residue in the filter paper was washed 4 times with 50 ml hot deionized water and the washings collected in the 250 ml beakers and then allowed to completely cool. For each sample, the solution in the 250 ml beaker was transferred into a correspondingly labeled 250 ml volumetric flask. The beakers were rinsed and volume of the solution in the 250 ml volumetric flasks made to the mark with deionized water.

3.3.2.3 Standard solutions

Calcium

From the 1,000 ppm Ca stock solution, 10 ml was pipetted into a 100 ml volumetric flask and volume adjusted to the mark (100 ml) with deionized water to give a solution of concentration 100 ppm Ca. With the 100 ppm working solution, 0, 0.5 ml, 1.0 ml, 1.5 ml, 2.0 ml and 2.5 ml were pipetted into labeled 100 ml flasks and the solution adjusted to 100 ml with deionized water to give standard solutions of 0 ppm, 0.5 ppm, 1.0 ppm, 1.5 ppm, 2.0 ppm and 2.5 ppm Ca respectively.

Magnesium

From the 1,000 ppm Mg stock solution, 10 ml was pipetted into a 100 ml volumetric flask and volume adjusted to the mark (100 ml) with deionized water to give a solution of concentration 100 ppm Mg. With the 100 ppm working solution, 0, 0.5 ml, 1.0 ml, 1.5 ml, 2.0 ml and 2.5 ml were pipetted into labeled 100 ml flasks and the solution adjusted to 100 ml with deionized water to give standard solutions of 0 ppm, 0.5 ppm, 1.0 ppm, 1.5 ppm, 2.0 ppm and 2.5 ppm Mg respectively.

Aluminium

From the 1,000 ppm Al stock solution being used as the working solution, 0, 3.0 ml, 6.0 ml, 9.0 ml, 12.0 ml and 15.0 ml were pipetted into labeled 100 ml flasks and the solution adjusted to 100 ml with deionized water to give standard solutions of 0 ppm, 30 ppm, 60 ppm, 90 ppm, 120 ppm and 150 ppm Al respectively.

Iron

From the 1,000 ppm Fe stock solution, 10 ml was pipetted into a 100 ml volumetric flask and volume adjusted to the mark (100 ml) with deionized water to give a solution of concentration 100 ppm Fe. With the 100 ppm working solution, 0, 2.0 ml, 4.0 ml, 6.0 ml, 8.0 ml and 10.0 ml were pipetted into labeled 100 ml flasks and the solution adjusted to 100 ml with deionized water to give standard solutions of 0 ppm, 2 ppm, 4 ppm, 6 ppm, 8 ppm and 10 ppm Fe respectively.

3.3.2.4 Calibration

Calcium

From the 250 ml volumetric flasks prepared in Section 3.3.2.2, 1 ml of each of the samples was pipetted into a clean labeled 100 ml volumetric flask and volume made to the mark using the deionized water and thoroughly mixed. The prepared calcium standards were aspirated on the optimized AAS and a calibration graph of absorbance versus concentration of calcium drawn. The samples were also aspirated and their corresponding absorbance recorded. All the soil samples gave readings out of range and were diluted twice (50 ml diluted to 100 ml) to give readings within the linear range.

The cement samples gave readings out of range and were diluted ten (10) times by taking 10 ml and diluting to 100 ml before aspirating. The results of the concentration and absorbance of standards were plotted on the calibration graph and the concentration of each sample for the calcium content calculated (Appendices B-1, C-1 and D-1). The calcium content for the soil and cement samples were obtained from equations 3.3.2.1 and 3.3.2.2 respectively.

$$\%\ \text{Calcium as Ca} = \frac{\text{GraphReading} \times 2.5 \times 2}{\text{Mass}} \qquad \textbf{Eq. 3.3.2.1}$$

$$\%\ \text{Calcium as Ca} = \frac{\text{GraphReading} \times 2.5 \times 10}{\text{Mass}} \qquad \textbf{Eq.3.3.2.2}$$

The same concentration of calcium can be expressed as calcium oxide by equation 3.3.2.3

$$\%\ \text{Calcium as CaO} = 1.4 \times \%\ \text{Calcium as Ca} \qquad \textbf{Eq.3.3.2.3}$$

Note:

1.4 is the conversion factor from Ca to CaO (dividing formula masses, 56 by 40).

Magnesium

From the 250 ml volumetric flasks prepared in section 3.3.2.2, 1 ml of the sample was diluted to 100 ml in a volumetric flask. The soil samples were further diluted 20 times (5 ml diluted to 100 ml) whereas the cement samples were not diluted further. The results of the concentration and absorbance of standards were plotted on the calibration graph and the concentration of each sample for the calcium content calculated (Appendix B-2, C-2 and D-2). The magnesium content for the soil and cement samples were obtained from equations 3.3.2.4 and 3.3.2.5 respectively.

$$\%\ \text{Magnesium as Mg} = \frac{\text{Graph Reading x 2.5 x 20}}{\text{Mass}} \qquad \textbf{Eq. 3.3.2.4}$$

$$\%\ \text{Magnesium as Mg} = \frac{\text{Graph Reading x 2.5}}{\text{Mass}} \qquad \textbf{Eq. 3.3.2.5}$$

Equation 3.3.2.6 shows the expression for the oxide.

$$\%\ \text{Magnesium as MgO} = 1.67 \text{ x } \%\ \text{Magnesium as Mg} \qquad \textbf{Eq. 2.3.3.6}$$

Note:

1.67 is the conversion factor from Mg to MgO, which is given by dividing the formula mass of magnesium oxide (40) and that of magnesium (24).

Aluminium

From the 250 ml volumetric flasks prepared in section 3.3.2.2, 1 ml of the sample was diluted to 100 ml in a volumetric flask. The soil samples were further diluted 10 times (10 ml diluted to 100 ml) whereas the cement samples were read as prepared. The results of the concentration and absorbance of the standards were, plotted on the calibration graph and the concentration of each sample for the aluminium content calculated (Appendix B-3, C-3 and D-3). The aluminium content for the soil and cement samples were obtained from equations 3.3.2.7 and 3.3.2.8 respectively.

$$\%\ \text{Aluminium as Al} = \frac{\text{Graph Reading x 2.5}}{\text{Mass}}$$ **Eq. 3.3.2.7**

$$\%\ \text{Aluminium as Al} = \frac{\text{Graph Reading x 2.5}}{\text{Mass x 10}}$$ **Eq. 3.3.2.8**

Equation 3.3.2.9 shows the expression for the aluminium as the oxide.

$$\%\ \text{Aluminium as Al2O3} = 1.89\ \text{X}\ \%\ \text{Aluminium as Al}$$ **Eq. 3.3.2.9**

Note:

1.89 is the conversion factor from Al to Al_2O_3, which is given by dividing the formula mass of aluminium oxide (102) and twice that of aluminium (27).

Iron

From the 250 ml volumetric flasks prepared in section 3.3.2.2, 1 ml of the sample was diluted to 100 ml in a volumetric flask. The soil samples were diluted 10 times (10 ml diluted to 100 ml) whereas the cement samples were not diluted further. The results of concentration and absorbance of the standards were plotted on the calibration graph and the concentration of each sample for the iron content calculated (Appendix B-4, C-4and D-4). The iron content for the soil and cement samples were obtained from equations 3.3.2.10 and 3.3.2.11 respectively.

$$\%\ \text{Iron as Fe} = \frac{\text{Graph Reading x 2.5 x 10}}{\text{Mass}}$$ **Eq. 3.3.2.10**

$\% \text{ Iron as Fe} = \frac{\text{Graph Reading x 2.5}}{\text{Mass}}$ **Eq. 3.3.2.11**

The expression for the iron as the oxide is as shown in equation 3.3.2.12

$\% \text{ Iron as Fe2O3} = 1.43 \text{ X } \% \text{ Iron as Fe}$ **Eq. 3.3.2.12**

Note:

1.43 is the conversion factor from Fe to Fe_2O_3, which is given by dividing the formula mass of iron oxide (160) and twice that of iron (56).

3.3.2.5 Silicon

Approximately 10.00 g of the pulverized sample (soil or cement) was accurately weighed into a mortar. 5.00g of starch (used as binder) was added and the material thoroughly mixed. The mixture was placed into a pellet crucible and pressed to make a pellet. The pellet was analyzed with the X-Ray Fluorescent spectrophotometer. Results obtained were given as percent composition (Appendix C-5, C-6, D-5).

3.3.2.6 pH

30 g of each of the dried soil samples passing through the 425 μm sieve were weighed into a clean 150 ml beaker and 75 ml deionized water added, a ratio of water to soil = 5 : 2 (British Standards Institution, 1990). A buffer tablet of pH 4 was dissolved into a clean 150 ml beaker with 100 ml of deionized water. Using a pH electrode, the pH meter was calibrated to read pH = 4. Similarly, a buffer tablet of the pH = 9.2 was dissolved in 100 ml deionized water in a 150 ml beaker and the solution (buffer) used to calibrate the meter to read pH = 9.2.The pH electrode

was severally rinsed with the deionized water, placed in the supernatant liquid from the sample and the pH of the sample determined and recorded.

The pH measurements were repeated and recorded for all samples (Appendix C-7, D-6).

3.3.2.7 Organic Matter

Approximately 0.20 g of the pulverized material was accurately weighed into a sample crucible. The sample was then transferred to a 500 ml conical flask with a stopper. 20 ml of concentrated sulphuric acid were added slowly to the flask, which was then stoppered and shaken vigorously. The stopper was removed and 10 ml of 1 N potassium dichromate added to the solution by use of a pipette and contents of the flask shaken. The flask was kept in an area free from direct light (dark area). The flask was removed from the dark area, 200 ml of deionized water added and flask vigorously shaken. 100 ml of orthophosphoric acid was added and contents again shaken to mix completely. 5ml of the diphenylamine indicator was added to the solution, shaken and the flask contents titrated using 1 N ferrous sulphate to a blue colour. An excess of 0.5 ml of the dichromate was added to this mixture to revert to the original green colour. The titration using ferrous sulphate was continued more accurately until the first permanent blue colour reappeared. The total volume of ferrous sulphate used per sample (X) was recorded.

The same process was repeated without using a sample (a blank starting with addition of concentrated sulphuric acid) and volume of ferrous sulphate used (Y) recorded.

The percent organic matter content was obtained by the formula in equations 3.3.2.13 and 3.3.2.14 (Appendix C-8, D-7)

$$V = 10.5\,x\,(1 - {}^{X}/_{Y})$$ **Eq. 3.3.2.13**

$$\%\ \text{organic Content} = \frac{0.67 \times V}{\text{Mass of sample (g)}}$$ **Eq. 3.3.2.14**

Where

10.5 = Volume of dichromate added (10.5 ml)

X = Volume of 1 N ferrous sulphate used by sample

Y = Volume of 1 N ferrous sulphate used by blank

V = Volume of 1 N dichromate that has reacted with the organic matter

3.3.3 California Bearing Ratio test

The air dried material passing through the 20 mm BS test sieve and retained on the 5 mm BS test sieve was used to determine the California Bearing Ratio (British Standards Institution, 1990). All the material retained on the 5 mm sieve was riffled to give smaller portions to be used.

3.3.3.1 CBR of neat soil

Several parameters of the soil were used to determine the CBR. These include the Maximum Dry Density (MDD), Present Moisture Content (PMC) and the Optimum Moisture Content (OMC).

3.3.3.2 Present Moisture Content

A moisture tin with lid was weighed on an analytical balance and the weight (w_1) recorded. A small quantity of the sieved material was put into the moisture tin, covered with the lid, placed on an analytical balance and the weight (w_2) recorded. The tin was uncovered and together with its contents placed in an oven at 105^0C for four (4) hours, removed, allowed to cool, covered and reweighed to obtain weight (w_3)

Weights w_1, w_2 and w_3 were used to determine the Present Moisture Content (PMC), by the formula in equation 3.3.3.1

$$\text{Present Moisture Content} = 100\,x\,\left(\frac{w2 - w3}{w2 - w1}\right).$$ **Eq. 3.3.3.1**

Where: w_1 = weight of empty moisture tin with lid

w_2 = weight of moisture tin with lid and air dried sample

w_3 = weight of moisture tin with lid and oven dried sample

3.3.3.3 Maximum Dry Density

A clean proctor mould with a base plate was placed on the Avery weighing balance and its weight (m_1) recorded. The mould was placed on a laboratory table. A dry clean basin was placed on the balance, tarred and 2500 g of the sieved material was placed in the basin. 250 ml of water (10 % by weight of the mass of sample used), was measured using the measuring cylinder, added to the basin and the material thoroughly mixed. The material was subdivided into three portions. One of the portions was placed into a proctor mould with a collar and compacted with a 2.5 kg rammer with twenty seven (27) blows. The second and third portions were added into the mould and similarly compacted successively. The collar was removed and the straight edge used to level the material to the brim of the mould. The mould with base plate and contents was placed onto theAvery weighing balance and the weight (m_2) of the mould and contents recorded. By use of the weight difference, the bulk density of the material was obtained as represented in equation 3.3.3.2

$$\text{Bulk density} = (m_2 - m_1)/1000/0.001 = (m_2 - m_1)\ \text{kgm}^{-3}$$ **Eq. 3.3.3.2**

The compacted material was removed from the mould and a small quantity of the compacted material used to determine the moisture content of the compacted material, as in Section 3.3.3.2 by the formula in equation 3.3.3.3

Moisture Content of compacted material $= 100\,x\,(\frac{w2-w3}{w2-w1}).\%$ **Eq. 3.3.3.3**

The calculated density and moisture content of each test were recorded. The process was repeated using 150 ml. 200 ml, 300 ml and 350 ml of water.

Note:

> *Process is repeated until addition of more water starts giving a lower density of the bulk material*

A graph of density (on the Y- Axis) derived from equation 3.3.2.2 versus the percent moisture content (on the X- Axis) derived from equation 3.3.3.3 was drawn. The Maximum Dry Density is the density corresponding to the peak of the graph and the Optimum Moisture Content is the percent moisture content corresponding to the peak of the graph. (Appendix A-1)

The mass of the wet material to be used at OMC per mould at 100 % MDD for T99 was obtained by the formula in equation 3.3.3.4.

Mass (m) $= 23.05x\,(100 + OMC)x\,\frac{MDD}{100}$ **Eq. 3.3.3.4**

The actual total wet mass of the sample required per mould was m + 500 g.

Thus, the dry mass is calculated as given in equation 3.3.3.5 below.

$$\text{Dry mass per mould} = \text{total wet mass requiredx } \frac{100}{(100+\text{PMC})} \qquad \textbf{Eq. 3.3.3.5}$$

And the amount of water to be added was given by equation 3.3.3.6.

$$\text{Amount of water} = \text{total wet mass x } \frac{(\text{OMC}-\text{PMC})}{100} \qquad \textbf{Eq. 3.3.3.6}$$

The amount of sample as calculated by the dry mass per mould was placed into a mixing basin, the calculated amount of water measured by a measuring cylinder added and material thoroughly mixed. The material was subdivided into three equal portions. A filter paper No. 1 was place on the base plate of the CBR mould. Like for the proctor, one of the portions of the mixed material was placed into a CBR mould, a spacer placed on top of the material and compacted with a 2.5 kg rammer with twenty (20) blows. The spacer was removed, a second portion of material added into the mould, the spacer placed on it and again compacted with 20 blows by the rammer. The spacer was removed, the remaining third portion of material placed into the mould, and the spacer fitted and similarly compacted. The mould with the material was placed onto a compressor and pressed to a force of 50 KN. The spacer was removed, a filter paper placed on the sample in the mould and spacer returned. Together with the base plate and spacer, the sample in the mould was immersed and soaked in water for four days.

3.3.3.4 CBR Test

The mould with the sample was removed from the water, tilted to allow excess water drain and then placed on the CBR machine. The penetration from the prove ring was read. The dial readings from the prove ring were recorded every after a penetration of 0.25 mm into the material and the readings recorded (Appendix A-2). After attaining the maximum value, the mould with material was removed and placed upside down and again penetrated. Readings from this side were similarly recorded. The readings were plotted on the form (See Appendix A2) and the CBR calculated using equation 3.3.3.7. The highest of the four CBR values was recorded as the CBR of the material. The test was done in triplicate and the mean of the three readings was taken to be the CBR of the material. Readings were recorded to the nearest whole number (Appendix E)

$$\text{CBR} = \text{Penetration} \times \text{ring factor} \qquad \textbf{Eq. 3.3.3.7}$$

3.3.3.5 CBR of treated Soil

A similar procedure is followed for the determination of CBR of a treated (stabilized) material. After determining the dry mass per mould to be used, the amount of cement (stabilizer) to be added was calculated using equation 3.3.3.8

$$\text{Mass of cement} = \%\ \text{cement} \times \text{dry mass} \qquad \textbf{Eq. 3.3.3.8}$$

The measured amount of cement was added to the sample in the mixing basin and thoroughly mixed. Thus, the total dry mass used is the sum of the sample dry mass and mass of cement. Hence the quantity of water to be added was calculated based on the total dry mass as in equation 3.3.3.9

$$\text{Amount of water} = \text{total dry mass} \times \frac{(\text{OMC}-\text{PMC})}{100} \qquad \textbf{Eq. 3.3.3.9}$$

After adding this amount of water, the sample and water were thoroughly mixed and subdivided into three equal portions. A No. 1 filter paper was placed on the base plate in the mould and the portions compacted and pressed as in Section 3.3.3.4. After placing the filter paper on the surface, a thin layer of melted wax was applied on both sides of the mould and material in the mould allowed to cure for seven (7) days. The base plate, the spacer and wax were removed and the mould with the cured material immersed and soaked in water for seven (7) days. After seven (7) days, the mould with the sample was removed from the water, tilted to allow excess water drain and penetrated on both sides on the CBR machine to determine the CBR as described in section 3.3.3.4

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Chemical composition

The results obtained from the chemical composition determination for the soils and cements are contained in Appendices B, C and D, and can be summarized as shown in the tables below.

Table 4.1: Composition of Oxides in Soil

	Composition as % m/m						
Material Source	**CaO**	**MgO**	**Al_2O_3**	**Fe_2O_3**	**SiO_2**	**Organic Matter**	**pH**
Nairobi Soil	1.84	1.00	12.59	6.71	56.80	3.48	6.92
Kiambu soil	0.19	0.42	34.88	10.39	28.60	1.07	5.27
Machakos Soil	0.11	0.17	31.68	6.11	49.00	1.17	5.30
Kilifi Soil	0.77	0.75	13.29	3.14	74.00	0.73	7.41
Kakamega Soil	1.19	0.50	24.58	12.68	41.00	2.46	6.31
Bomet Soil	0.26	0.33	26.48	11.68	41.50	1.34	5.74

Table 4.1 shows that the abundant component of the soil is silicon dioxide, commonly referred to as silica (SiO_2), which ranges from the lowest of approximately 28.60 % in the soil from Kiambu, to as high as 74 % for the soil from Kilifi. The other components were aluminium oxide, commonly referred to as alumina (Al_2O_3) giving values ranging from 12.59 % for Nairobi to 34.88 % for Kiambu, and iron oxide (Fe_2O_3) with values generally less than half that of aluminium oxide. Calcium oxide levels were very low, on average below 1 % other than in

samples from Nairobi which had a high of 1.84 % and Kakamega 1.19 %.Magnesium oxide levels were also low. Lowest was 0.17 % for Machakos and the highest was1.00 % for Nairobi. The pH values of the soils are within a small range. The lowest pH was 5.27 and the highest 7.41. The quantities of the organic matter are low, the highest being 3.48 %, in the Nairobi soil and the lowest 0.73 % in the Kilifi soil. Organic matter in soil is known for being a pH buffer and a binder for soil particles and heavy metals and it also influences the water holding capacity and aeration. All these factors are positive for agricultural uses but negative for engineering uses of the soil. The allowed levels for organic matter vary from region to region.

Table 4.2: Composition of Oxides in Cement

Cement type	**Percent Composition of oxides, % m/m**					**Reactive Minerals**		
	CaO	**MgO**	**Al_2O_3**	**Fe_2O_3**	**SiO_2**	**C_3A**	**C_2S**	**C_3S**
Power Plus 42.5	62.78	0.88	5.99	2.74	21.60	11.24	26.35	47.12
Power Max 42.5	60.19	0.63	5.78	2.31	21.68	11.41	33.46	38.00
Blue Triangle 42.5	63.43	0.67	7.41	4.57	17.97	11.91	2.32	65.18
Rhino 42.5	63.41	1.81	6.27	3.24	19.91	11.14	11.85	59.93
'Nguvu' 32.5	44.10	0.77	3.99	2.47	18.65	6.40	47.90	7.36
Blue Triangle 32.5	50.10	1.62	3.69	1.76	20.43	6.80	42.50	21.29
Rhino 32.5	52.75	0.75	4.24	2.56	23.13	6.91	61.24	6.71

Note: $C_3A = 2.65\ Al_2O_3 - 1.69\ Fe_2O_3$

$C_2S = 8.6\ SiO_2 + 5.07\ Al_2O_3 + 1.08\ Fe_2O_3 - 3.07\ CaO$

$C_3S = 4.07\ CaO - 7.6\ SiO_2 - 6.73\ Al_2O_3 - 1.43\ Fe_2O_3$

The results in Table 4.2 show that the most predominant constituent in all cement samples was calcium oxide, ranging from 44.10 % for 'Nguvu' to 63.43 % for Blue Triangle 42.5. The second highest constituent is silicon dioxide varying from 17.97 % in Blue Triangle 42.5to 23.13 % in Rhino 32.5. The least constituent of the five tested oxides is magnesium oxide varying from 0.63 % for Power Max to 1.81 % for Rhino 42.5. The aluminium oxide content is nearly double the iron oxide content in all samples. Tri-calcium aluminate (C_3A) hydrates rapidly, whereas the tri-calcium silicate (C_3S) and di-calcium silicate (C_2S) hydrated gels crystallize more slowly to form a bonded crystal matrix as mentioned in Section 2.5.1.Cements with higher CaO percentages have higher C_3A values (Table 4.2), though the CaO content is not part of the formula for C_3A. This implies that the higher the CaO, the higher the C_3A.

Cements classified as of strength 42.5N/mm^2 have an average CaO value of 62.45 % and C_3A value of 11.52 while those classified as of strength 32.5 N/mm^2 have an average CaO of 48.98 % and C_3A of 6.70.

4.2 California Bearing Ratio (CBR)

The results obtained from the California Bearing Ratios for the different neat materials and with their respective stabilized materials are contained in Appendices E and F.

4.2.1 Sampling Sites

CBR of the neat soil from the different sampling sites gave the values graphically shown in Figure 4.1. Nairobi 2 %, Kiambu 3 %, Machakos 14 %, Kilifi 5 % , Kakamega 15 % and Bomet 10 %. These CBR values were expected to increase on addition of cement.

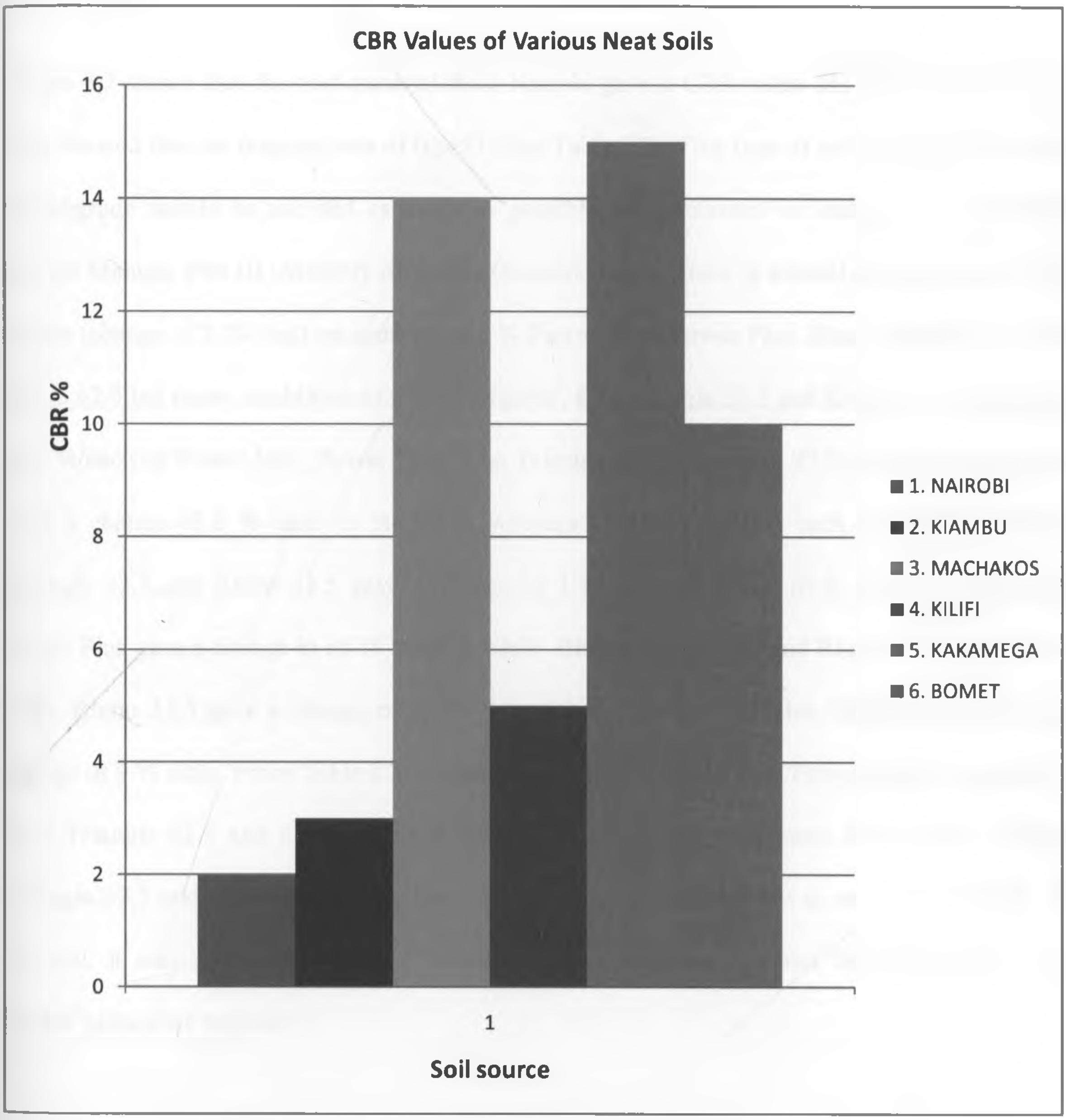

Figure 4.1 CBR of various Neat Soils

Nairobi Soil

Figure 4.2 shows that the neat material from Nairobi gave a CBR value of2 % (Appendix E1). This showed that the material was of typeS1 (See Table 1.2). This type of soil is poor and its use as subgrade should be avoided as much as possible, as mentioned in Section 6.1.2 of Road Design Manual, Part III (Ministry of Works (Kenya), 1986). There is a small change in the CBR values (change of 1 % unit) on addition of 2 % Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5 but none on addition of 2 % of 'Nguvu', Blue triangle 32.5 and Rhino 32.5. Addition of 4 % each of Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5 to the neat material gave a change of 6 % units in the CBR, whereas addition of 4 % each of 'Nguvu', 'Blue Triangle 32.5 and Rhino 32.5 gave a change of 3 % units. Addition of 6 % Power Max and Power Plus gave a change in of 18 % units while, Blue Triangle 42.5 and Rhino 42.5 gave 15 % units. Rhino 32.5 gave a change of 10 % units while 'Nguvu' and Blue Triangle 32.5 gave a change of 9 % units. From Table 4.2, cements with a high C_3A (namely Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5) increase the CBR of the soils more than 'Nguvu', Blue Triangle 32.5 and Rhino 32.5. Since the purpose of adding cement was to increase the CBR of the soil, it was seen that the 42.5 N/mm^2 cements achieved the aim better than the 32.5 N/mm^2hencewere superior.

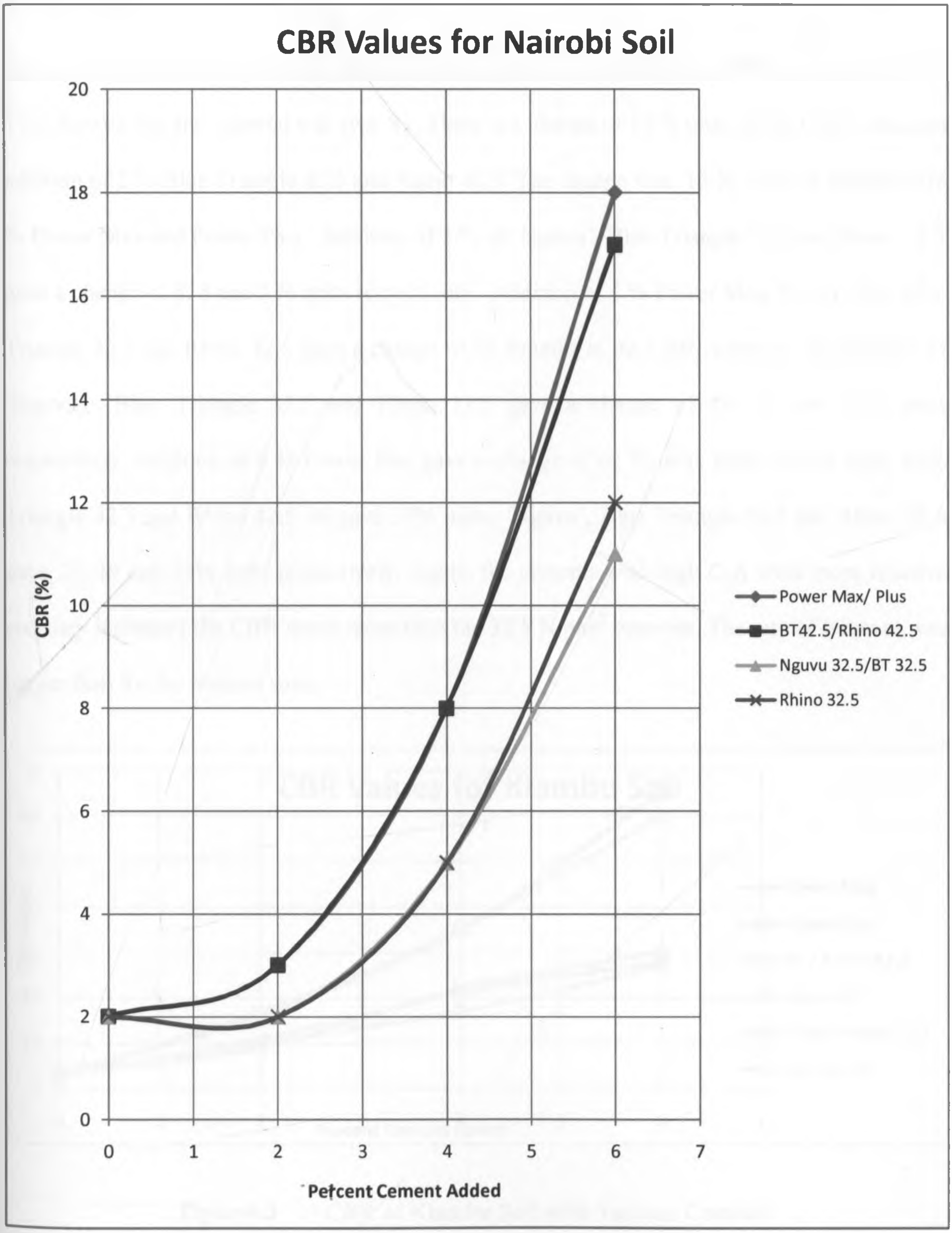

Figure 4.2 CBR of Nairobi Soil with Various Cements

Kiambu Soil

Figure 4.3shows that the neat material from Kiambu gave a CBR value of3 % (Appendix E2). This showed that the material was type S1. There is a change of 14 % units in the CBR values on addition of 2 % Blue Triangle 42.5 and Rhino 42.5. The change was 13 % units on addition of2 % Power Max and Power Plus. Addition of 2 % of 'Nguvu', Blue Triangle 32.5 and Rhino 32.5 gave a change of 6, 8 and 7 % units respectively. Addition of 4 % Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5 gave a change of 32 % units in the CBR, whereas the addition of 'Nguvu', 'Blue Triangle 32.5 and Rhino 32.5 gave a change of 19, 18 and 14% units respectively. Addition of 6 % Power Plus gave a change of 62 % units while Power Max, Blue Triangle 42.5 and Rhino 42.5 all gave 57% units. 'Nguvu', Blue Triangle 32.5 and Rhino 32.5 gave 27, 25 and 24% units respectively. Again, the cements with high C_3A were more reactive and they increased the CBR much more than the 32.5 N/mm^2 cements. The rate of increase was bigger than for the Nairobi soils.

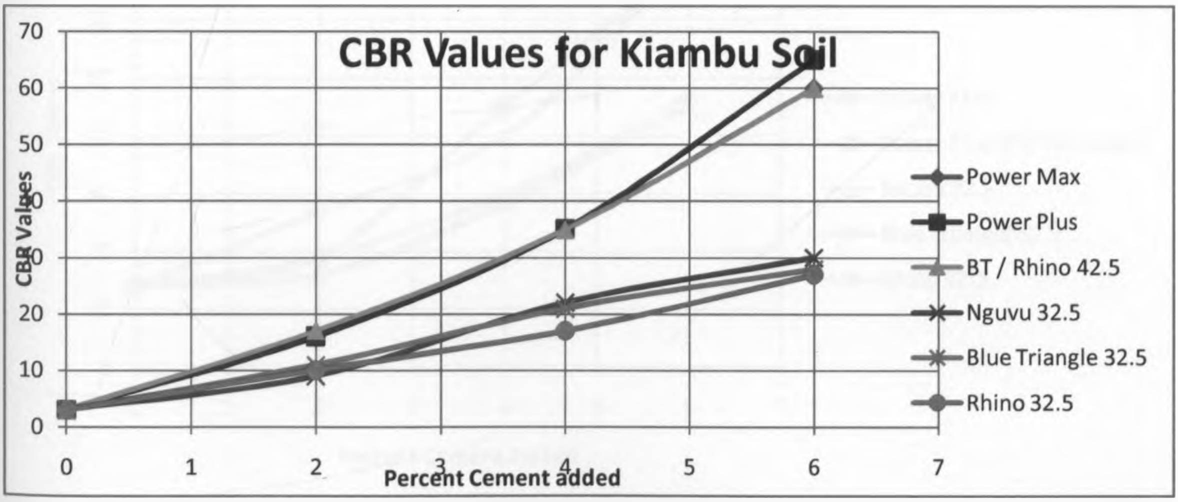

Figure4.3 CBR of Kiambu Soil with Various Cements

Machakos Soil

Figure 4.4 shows that the neat material from Machakos gave a CBR value of14 % (Appendix E3). This shows that the material was of type 4 (Table 1.2). There was a change of 5 % units in the CBR values on addition of 2 % Power Plus, Blue Triangle 42.5 and both Rhino 42.5 and 32.5 , 13 % units on addition of 2 % Power Max and 2 units on addition of 2 % Blue Triangle 32.5.There was a change of 2 % units on addition of 2 % of 'Nguvu'. Addition of 4 % Power Plus, Blue triangle 42.5 , Rhino 42.5 and 'Nguvu' gave a CBR value of 45 % units whereas the addition of 4 % Power Max gave a CBR of 40 units. Blue Triangle 32.5 and Rhino 32.5 gave a change of 14 and 16% units respectively. Addition of 6 % Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5 all gave a change of 56 % units while 'Nguvu', Blue Triangle 32.5 and Rhino 32.5 all gave a change of 31 % units. Thus, on addition of 6 % of any of the 42.5 N/mm^2 cements gave a uniform reading of 70 % whereas the same amount of the 32.5 N/mm^2 cements gave a reading of 45 %.

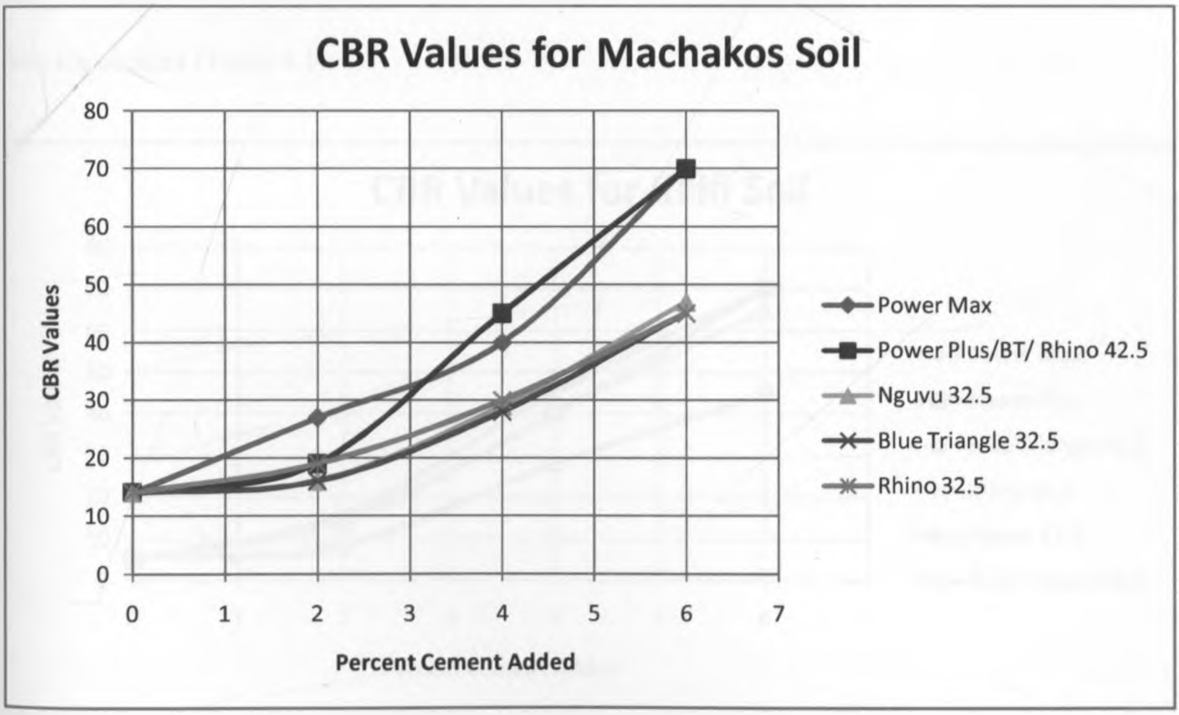

Figure 4.4 CBR of Machakos Soil with Various Cements

Kilifi Soil

Figure 4.5 shows that the neat material from Kilifi gave a CBR value of 5 % (Appendix E4). This shows that the material was either typeS1 or S2. There was a change of approximately 10 % units in the CBR values on addition of 2 % of the 42.5 N/mm^2 cements (Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5) and an average of 4 % units on addition of 'Nguvu', Blue Triangle 32.5 and Rhino 32.5. Addition of 4 % Power Max, Power Plus and Blue Triangle 42.5 caused a change of 35 % units, Rhino 42.5 gave a change of 40% units whereas the addition of the same percentage of 'Nguvu', 'Blue Triangle 32.5 and Rhino 32.5 gave a change of 23 %units. Addition of 6 % Power Plus, Power Max and Rhino 42.5 gave a change of 65 % units; Blue Triangle 42.5 gave a change of 60 % units while addition of the same quantity of 'Nguvu', Blue Triangle 32.5 and Rhino 32.5 gave a change of 40 % units. Kilifi soil had very high silicon dioxide content (Table 4.1).

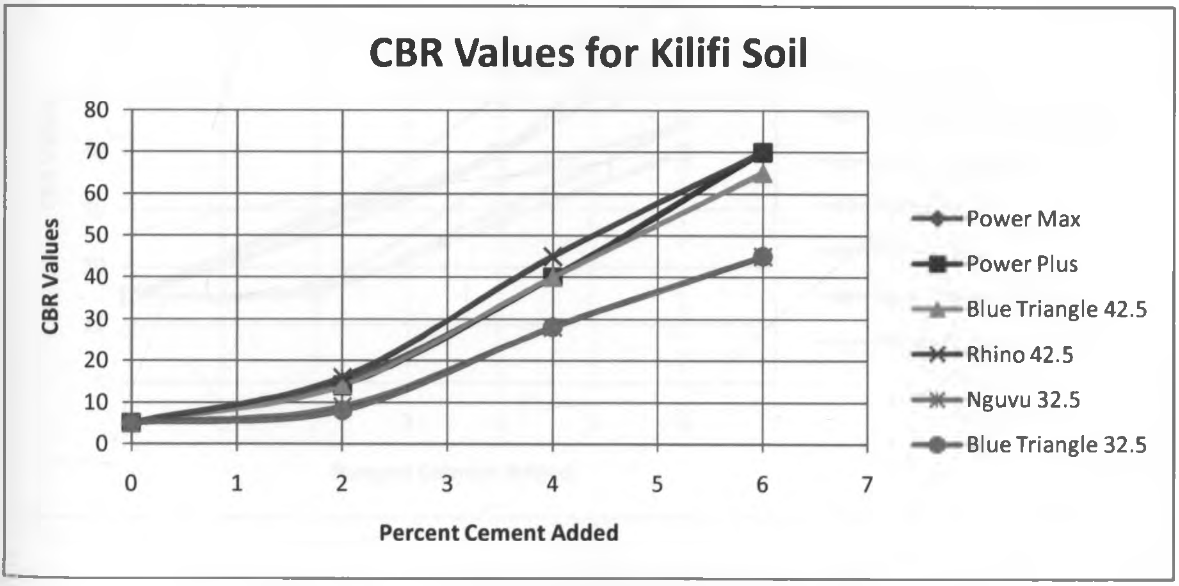

Figure 4.5 CBR of Kilifi Soil with Various Cements

Kakamega Soil

Figure 4.6 shows that the neat material from Kakamega gave a CBR value of 15 % (Appendix E5). This showed that the material was either of type S4 or S5 (Table 1.2). There was a change of approximately 13% units in the CBR values on addition of 2 % of the 42.5 N/mm^2 cements (Power Max, Power Plus Blue Triangle 42.5 and Rhino 42.5) and an average of 1 % unit on addition of 'Nguvu', Blue Triangle 32.5 and Rhino 32.5. Addition of 4 % Power Max, Power Plus and Rhino 42.5 caused a change of 25 % units, Blue Triangle 42.5 gave a change of 30 % units in the CBR, whereas addition of the same quantity of 'Nguvu', 'Blue Triangle 32.5 and Rhino 32.5 gave a change of 15, 13 and 19 % units respectively. Addition of 6 % Power Plus, Blue Triangle 42.5 and Rhino 42.5 gave a change of 55 % units; Power Max gave 45 %units while 'Nguvu', Blue Triangle 32.5 and Rhino 32.5 gave a change of 30, 25 and 30 % units respectively

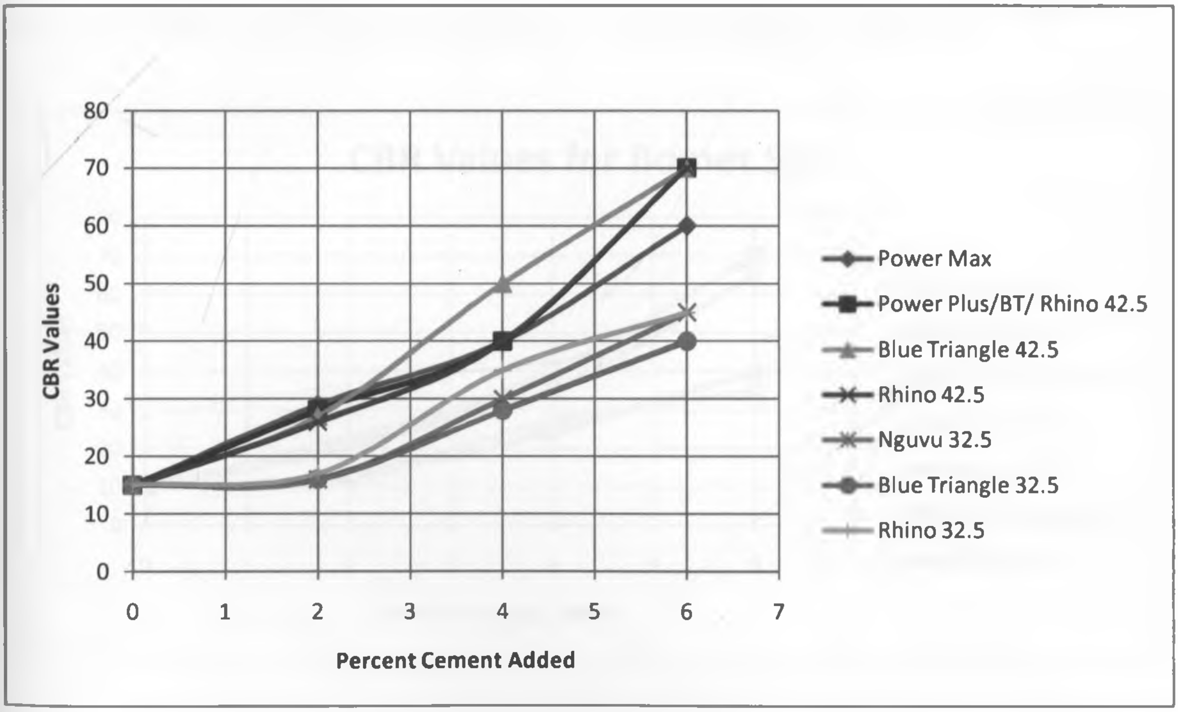

Figure 4.6 CBR of Kakamega Soil with Various Cements

Bomet Soil

Figure 4.7shows that the neat material from Bomet gave a CBR value of 10 % (Appendix E6). This showed that the material was either of typeS2, S3 or S4 (Table 1.2). There was a change of approximately 11 % units in the CBR values on addition of 2 % of the 42.5 N/mm^2 cements (Power Max, Power Plus, Blue Triangle 42.5 and Rhino 42.5) and an average of 3 % units on addition of 'Nguvu', Blue Triangle 32.5 and Rhino 32.5. Addition of 4 % Power Max, Power Plus and Blue Triangle 42.5 caused a change of 30% units, Rhino 42.5 gave a change of 25 %units whereas the addition of 'Nguvu', 'Blue Triangle 32.5 and Rhino 32.5 gave a change of 17, 14 and 15% units respectively. Addition of 6 % Power Max, Power Plus and Blue Triangle 42.5 gave a change of 60% units while Rhino 42.5gave 50 % units. Addition of 'Nguvu', Blue Triangle 32.5 and Rhino 32.5gave a change of 25, 30 and 30 % units respectively.

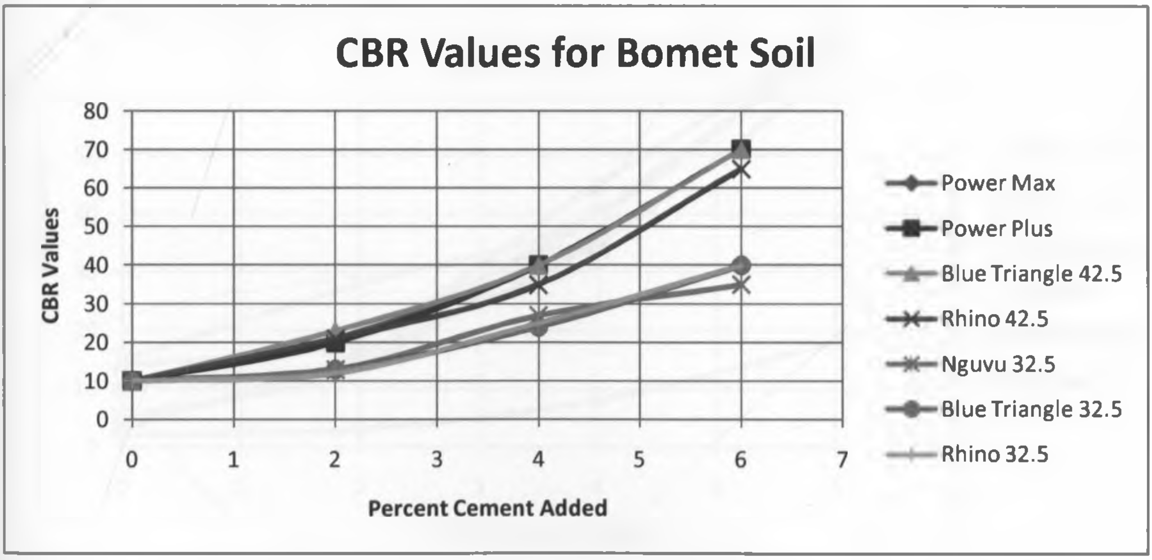

Figure 4.7 CBR of Bomet Soil with Various Cements

4.2.2 Cement Types

Power Plus 42.5

Figure 4.8 shows the CBR values of neat soil as 2, 3, 5, 10, 14 and 15 % for Nairobi, Kiambu, Kilifi, Bomet, Machakos and Kakamega in that order. There was an increase in the CBR values as cement was added. The rate of change increased with increasing cement content. Using the Kilifi soil as an example, the neat soil had a CBR of 5 %. The value rose to 14 % on addition of 2 % Power plus (a change of 9 % units).Addition of a further 2% gave a CBR of 40 % (change of 26 % units) and a further increase of another 2 % (total of 6 %) gives a CBR of 70 % (a change of 30 %). The trend is similar for all the soils. The final change in the CBR values depends on the soil type. The biggest change on 6 % addition of cement was in Kilifi soil (65 %) and the smallest in Nairobi soil (16 %). This showed that the Kilifi soil is ideal for stabilization whereas the Nairobi soil is not suitable.

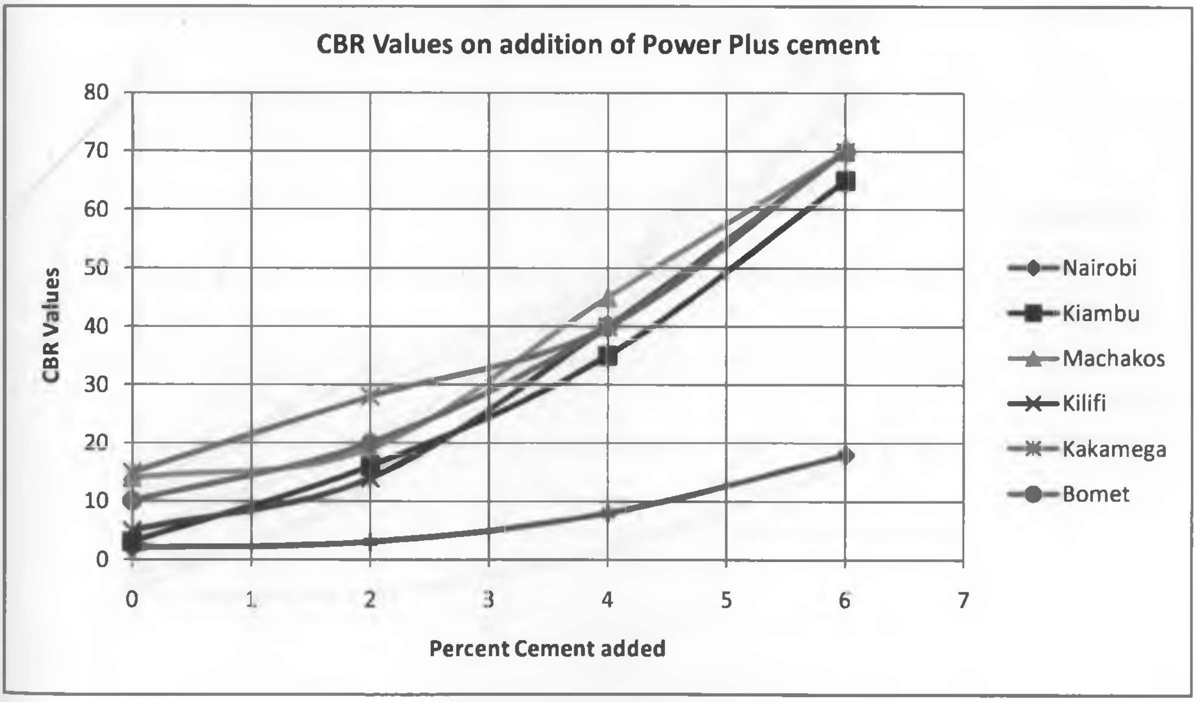

Figure 4.8 CBR of Power Plus Cement with Various Soils

Power Max 42.5

Figure 4.9 shows that there was an appreciable increase in the CBR of soil with addition of cement though the rate of change was not uniform. The biggest increase was for the Kilifi soil at 65 %while the Nairobi soil had the least at 16 %. At 4 % addition of the cement, the CBR values of the stabilized soils from Machakos, Kilifi, Kakamega and Bomet were all equal, at 40 %. The soil from Kakamega though having the highest CBR of the neat material had a lower CBR after addition of 6 % cement compared to the soils from Kilifi and Bomet.

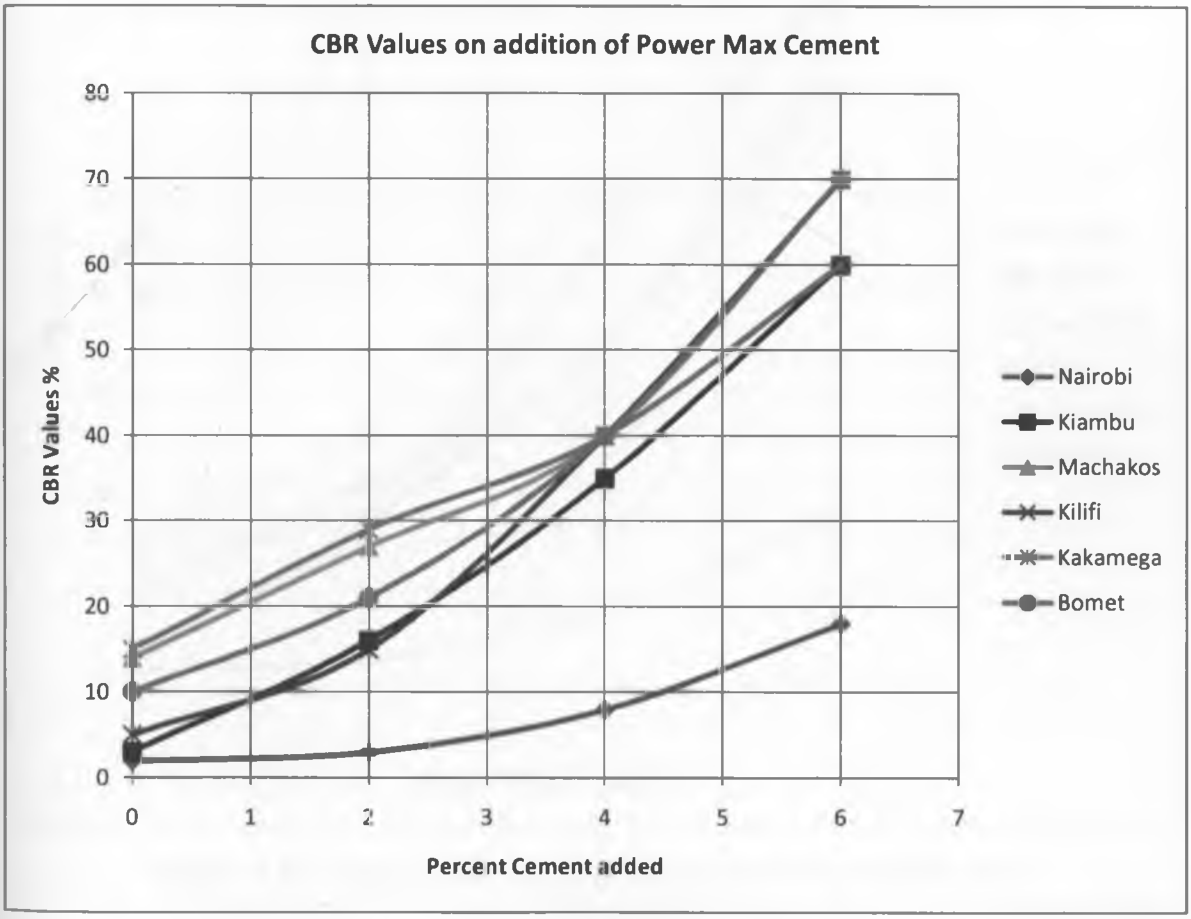

Figure 4.9 CBR of Power Max Cement with Various Soils

Blue Triangle 42.5

This cement had the same trend as that of Power Plus and Power Max as shown in Figure 4.10. The CBR of the stabilized soils rose sharply except for the Nairobi soil. The CBR for Kakamega, Machakos and Kilifi soils rose to a maximum of 70 % at 6 % cement addition.

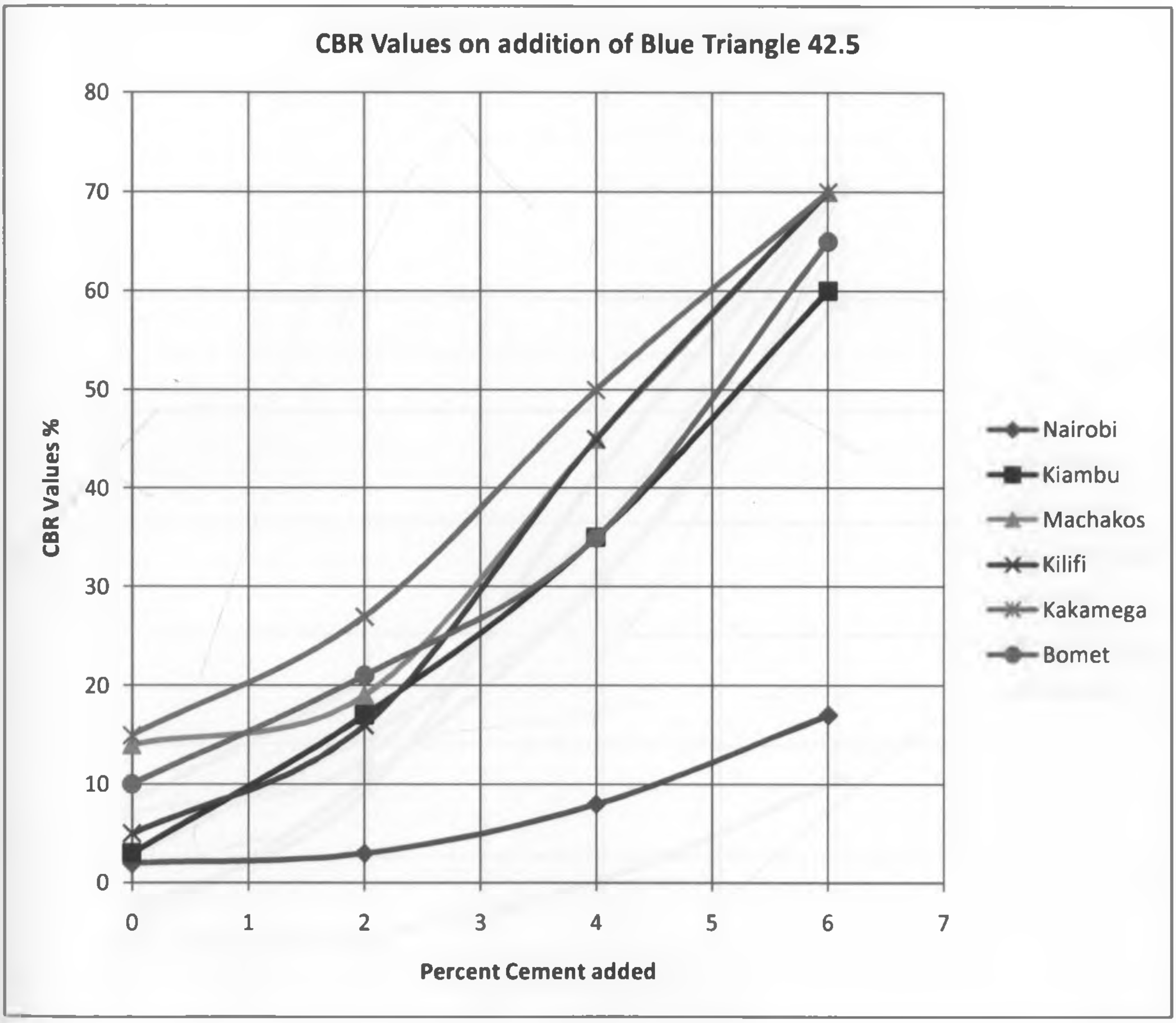

Figure 4.10 CBR of Blue Triangle 42.5 Cement with Various Soils

Rhino 42.5

The cement had same trend as that of Power Plus, Power Max and Blue Triangle 42.5as shown in Figure 4.11. The CBR of the Kakamega, Machakos and Kilifi soils rose to a maximum of 70 % while that of Bomet and Kiambu reached a maximum of 65 % and 60 % respectively.

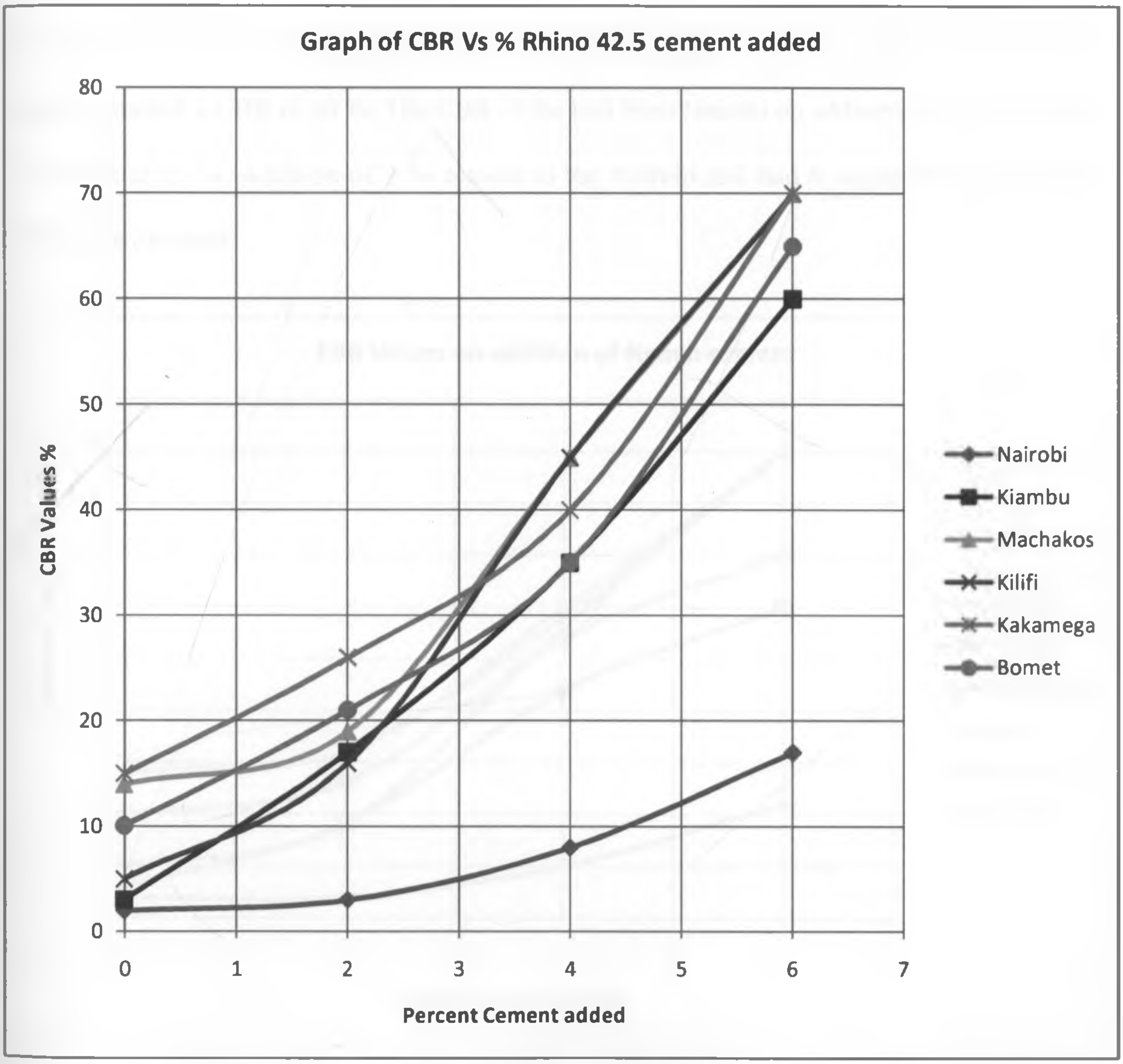

Figure 4.11 CBR of Rhino 42.5 Cement with Various Soils

'Nguvu' 32.5

There was a general increase of CBR values with increasing amount of 'Nguvu' as is shown in Figure 4.12 though with lower values compared to those of equivalent quantities obtained for Power Plus, Power Max, Blue Triangle 42.5 and Rhino 42.5. The highest CBR obtained were for the Machakos, Kilifi and Kakamega soils all at 45 %.

The CBR of the soil from Bomet on addition of 6 % cement is 35 %, whereas the soil from Kiambu attained a CBR of 30 %. The CBR of the soil from Nairobi on addition of 6 % cement is the lowest at 11 %. Addition of 2 % cement to the Nairobi soil had a negligible effect on the CBR value obtained.

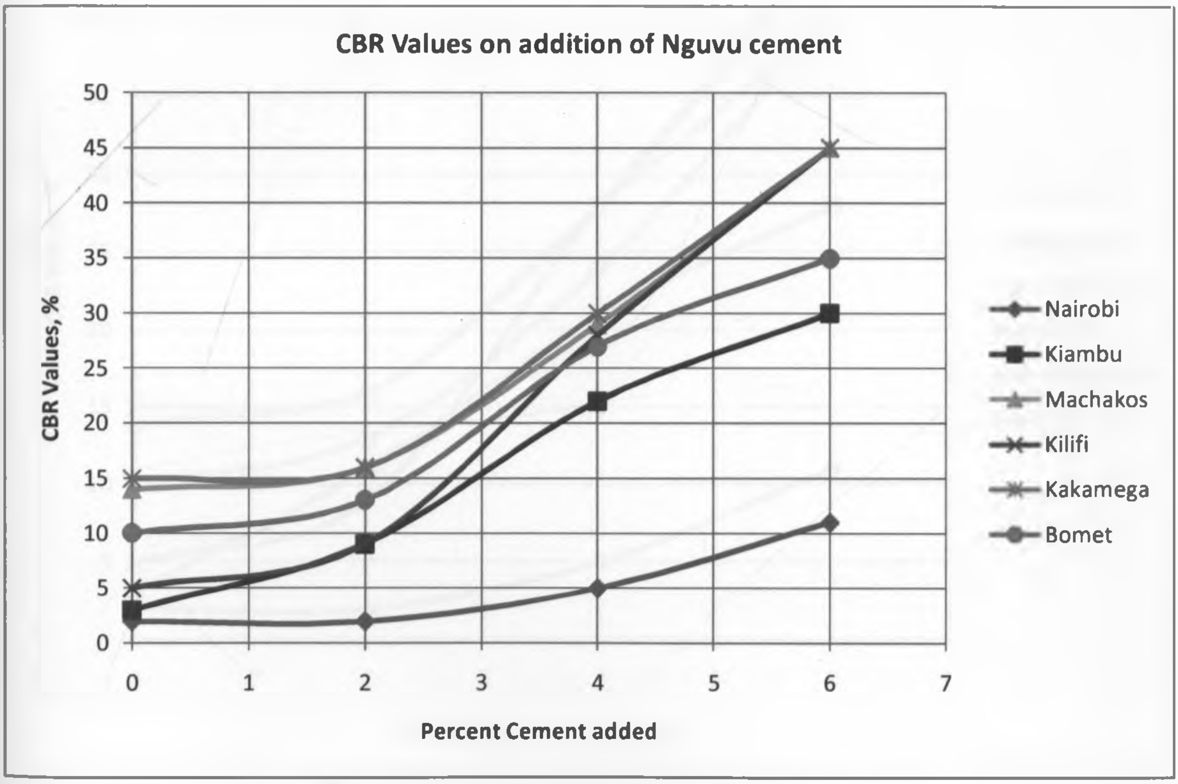

Figure 4.12 CBR of 'Nguvu' Cement with Various Soils

Blue Triangle 32.5

Figure 4.13 shows that the effect of adding Blue Triangle 32.5 is similar to that of adding 'Nguvu'. The CBR of the soil from Kakamega and Bomet at 6 % cement added was 40 % whereas those for the Nairobi soil at 6 % cement addition was 11 %. Addition of Blue Triangle 32.5 had a minimal effect on CBR of Nairobi soil.

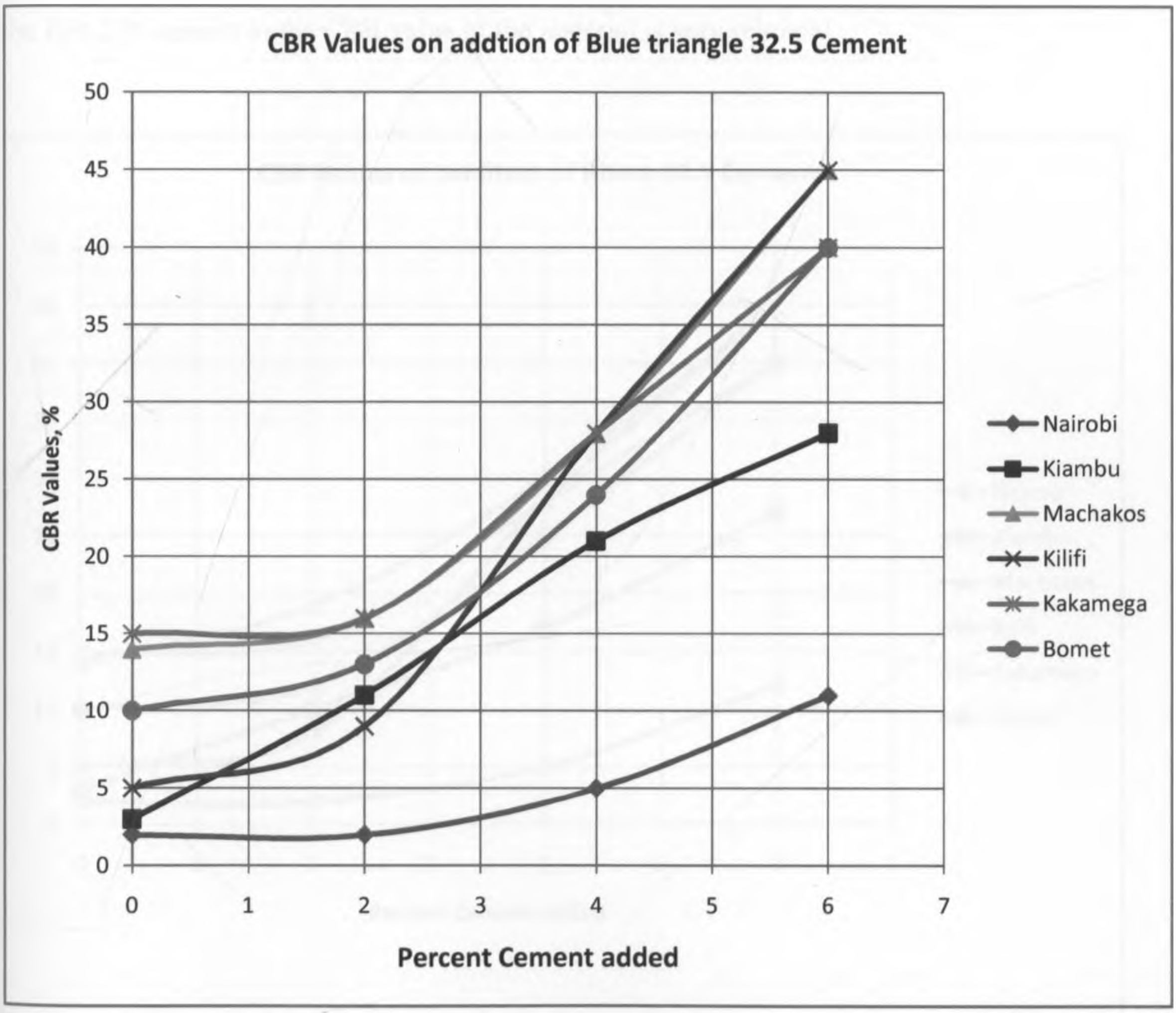

Figure 4.13 CBR of Blue Triangle 32.5 Cement with Various Soils

Rhino 32.5

Figure 4.14 shows that the behavior of Rhino 32.5is same as that of 'Nguvu' or Blue Triangle 32.5. The CBR of the soil from Kakamega and Bomet at 6 % cement addition was 40 %, whereas the soil from Kiambu attained a CBR of 27 %. The CBR of the soil from Nairobi on addition of 6 % cement is the lowest at 11 %. This also shows that cement does not alter the behaviour of the soil much. Like for the 'Nguvu' and Blue Triangle cements, the effect of adding the first 2 % cement to the CBR value of the material is very minimal

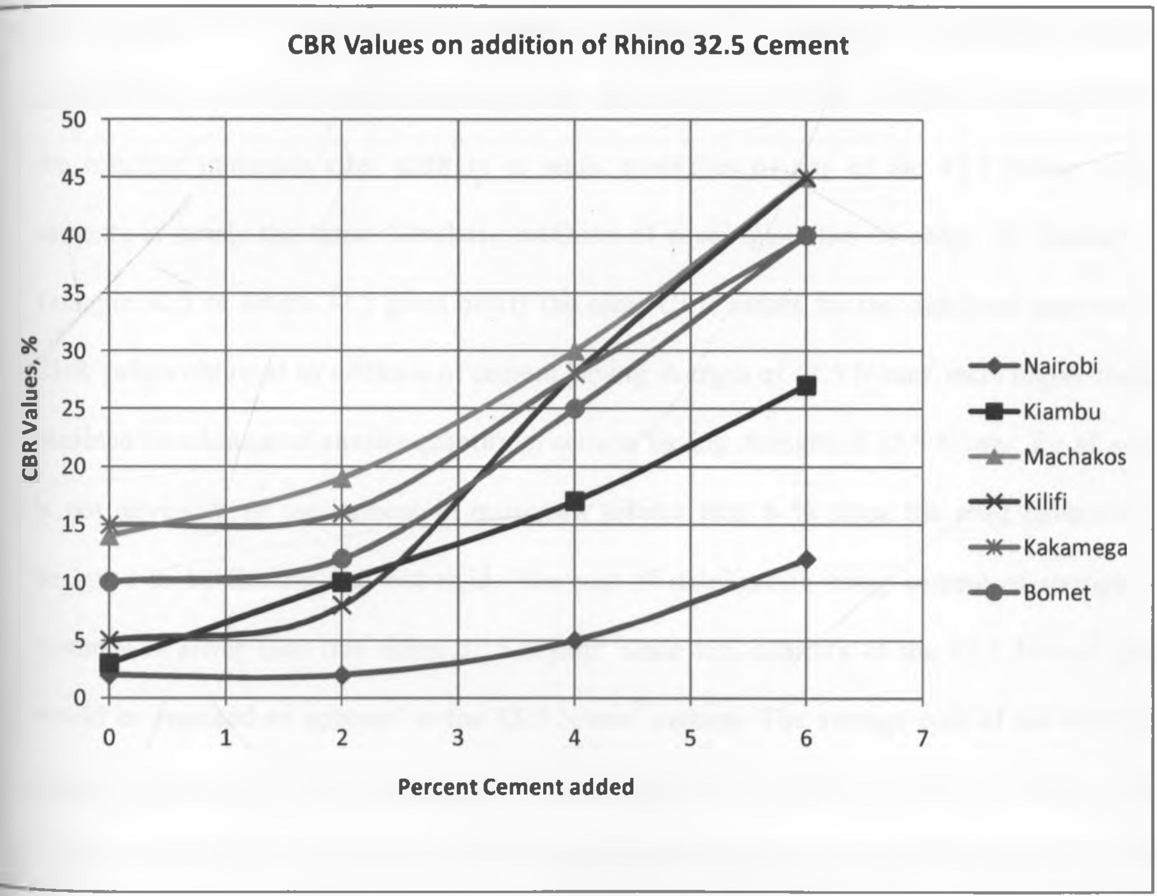

Figure 4.14 CBR of Rhino 32.5 Cement with Various Soils

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The most abundant constituent in soil is silicon dioxide (Silica – SiO_2) whereas the most abundant constituent of cement is calcium oxide (lime – CaO). From the results, cements with strength 42.5 N/mm^2 (Power Plus, Power max, Blue Triangle 42.5 and Rhino 42.5) have high calcium oxide levels and hence a high value of the tri- calcium aluminate (C_3A), whereas those with strength 32.5 N/mm^{2}have lower calcium oxide and C_3A values. This means that the percent composition of calcium oxide determines the value of the C_3A.The California Bearing Ratios of the resultant materials after addition of equal quantities of any of the 42.5 N/mm^2 strength cements is nearly the same. Similarly, addition of equal quantities of either of 'Nguvu', Blue Triangle 32.5 or Rhino 32.5 gives nearly the same CBR values for the stabilized materials. The CBR values obtained by addition of cement having strength of 42.5 N/mm^2 were higher than that obtained on addition of similar quantity of cement having strength of 32.5 N/mm^2 for all soils. It is not advisable to use cement in quantities greater than 6 % since the road pavements are designed to be flexible and not rigid. The cost of stabilization using cement of strength 42.5 N/mm^{2}was lower than that using 32.5 N/mm^2 since less quantity of the 42.5 N/mm^2 cement would be required as opposed to the 32.5 N/mm^2 cement. The average cost of the 42.5N/mm^2 cement was Ksh 4/= more expensive per kilogram than that of the 32.5 N/mm^2 as of June 2011. High organic matter content in the Nairobi soil could be one of the interferences in the soil that made the value of CBR remain low despite addition of cement as a stabilizer.

Lastly, the cost of construction of a road is depended on the site of construction as opposed to the anticipated volume and weight of traffic or class of road.

5.2 Recommendation

1. Clause 207 and Table 2-3 of Section 2 on Materials and Testing of Materials, in the Standard Specification for Road and Bridge Construction should be reviewed to capture the current and correct standard for cement products.

2. It should be specified in road construction contract documents that the type of cement to be used in stabilization of soils and gravels is cement of strength 42.5 N/mm^2.

3. Contractors should be instructed to use the materials on the construction site as much as practically possible through stabilization to limit the destruction of the environment in search of what they consider 'suitable materials'.

4. More research needs to be done to investigate the effect of the various types of cements to the Atterberg limits of soils.

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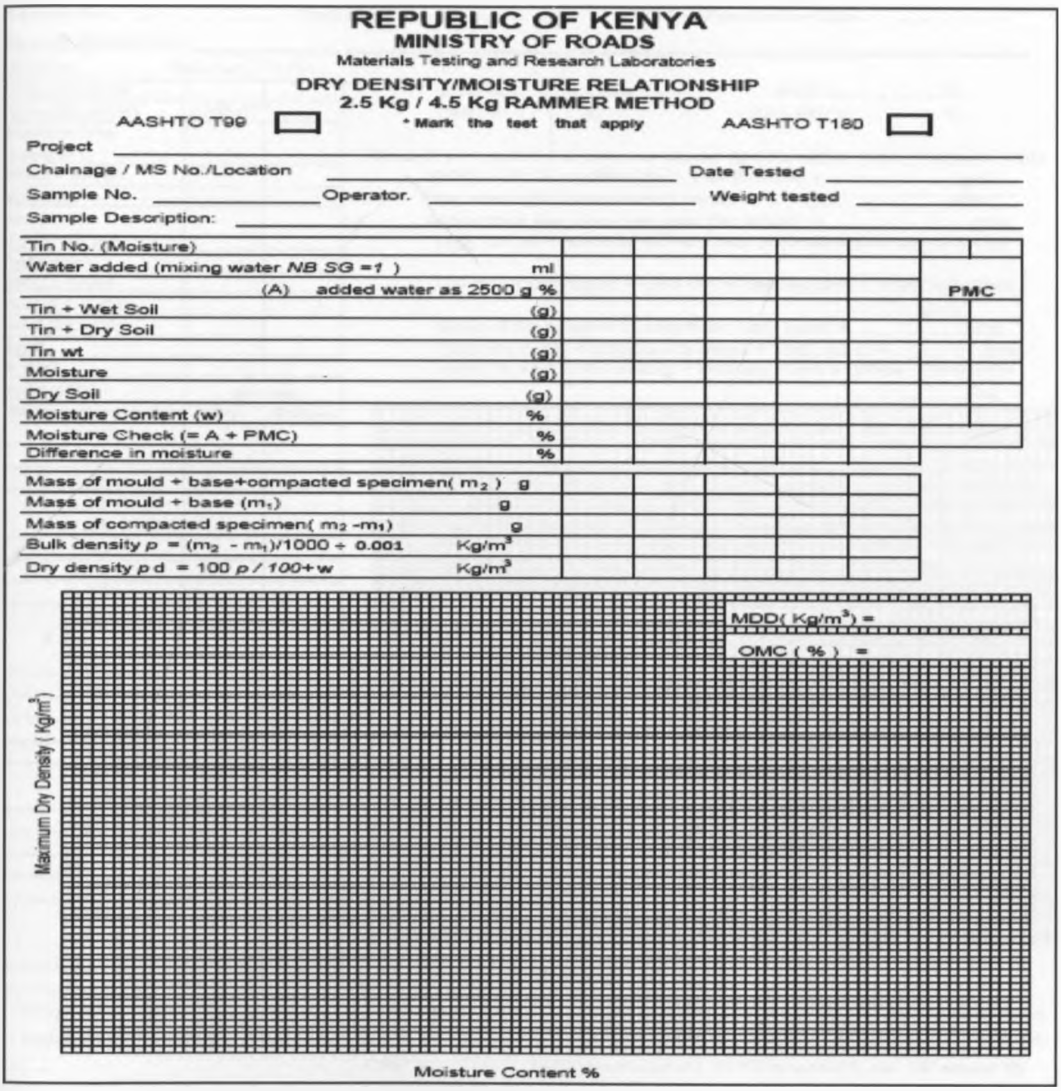
APPENDICES

A-1

Dry Density/ Moisture Relation Form



REPUBLIC OF KENYA
MINISTRY OF ROADS
Materials Testing and Research Laboratories
DRY DENSITY/MOISTURE RELATIONSHIP
2.5 Kg / 4.5 Kg RAMMER METHOD

AASHTO T99 ☐ * Mark the test that apply AASHTO T180 ☐

Project ____________________

Chainage / MS No./Location ____________________ Date Tested ____________________

Sample No. ____________________ Operator. ____________________ Weight tested ____________________

Sample Description: ____________________

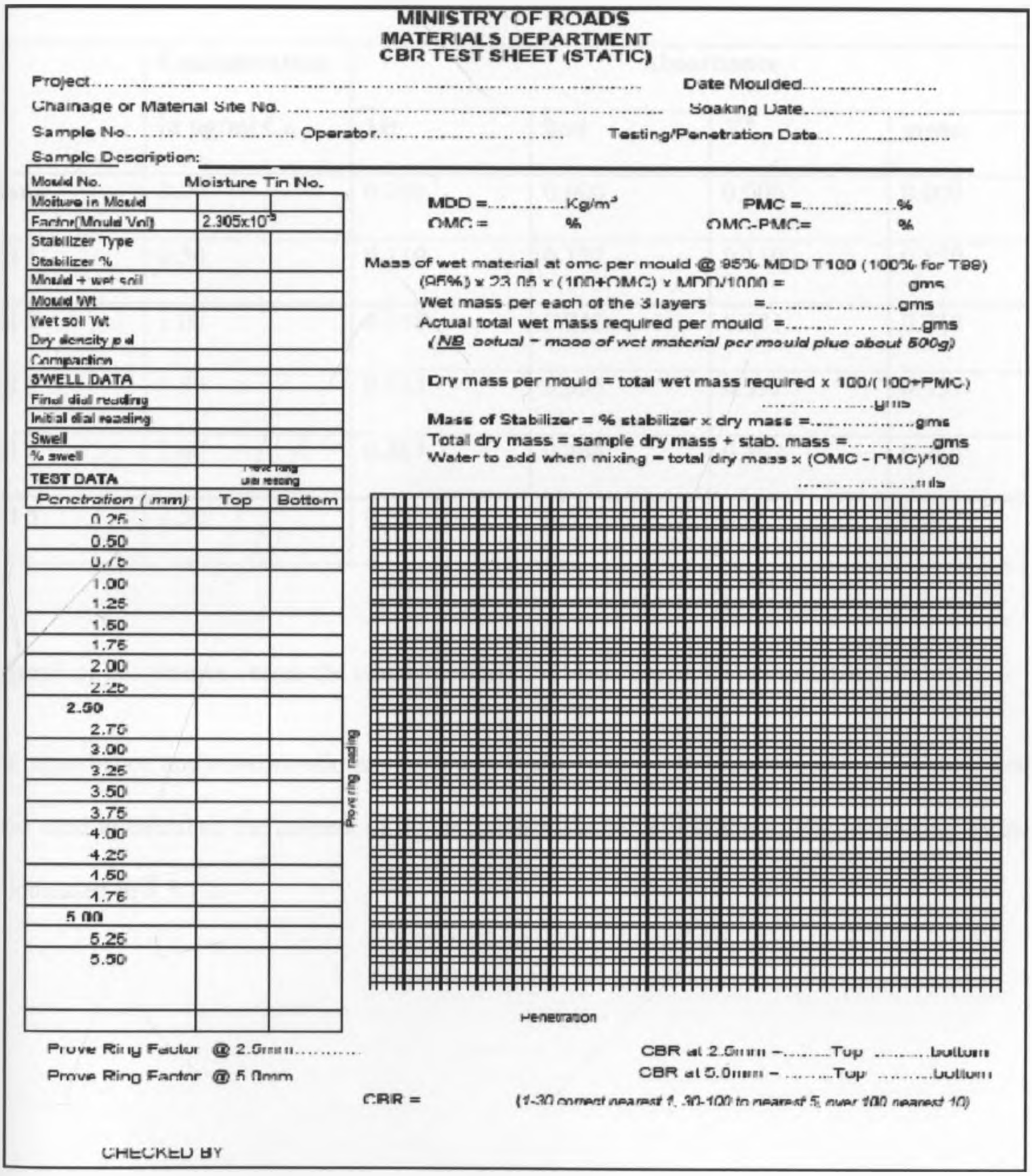
Tin No. (Moisture)							
Water added (mixing water *NB SG =1*)	ml						
(A) added water as 2500 g	%						PMC
Tin + Wet Soil	(g)						
Tin + Dry Soil	(g)						
Tin wt	(g)						
Moisture	(g)						
Dry Soil	(g)						
Moisture Content (w)	%						
Moisture Check (= A + PMC)	%						
Difference in moisture	%						

Mass of mould + base+compacted specimen(m_2)	g					
Mass of mould + base (m_1)	g					
Mass of compacted specimen($m_2 - m_1$)	g					
Bulk density $p = (m_2 - m_1)/1000 \div 0.001$	Kg/m³					
Dry density $pd = 100\, p / 100 + w$	Kg/m³					

MDD(Kg/m³) =

OMC (%) =

CBR Form



MINISTRY OF ROADS
MATERIALS DEPARTMENT
CBR TEST SHEET (STATIC)

Project…………………………………………………………………………… Date Moulded……………………
Chainage or Material Site No. ……………………………………………………… Soaking Date……………………
Sample No…………………… Operator…………………………… Testing/Penetration Date……………………
Sample Description:

Mould No.	Moisture Tin No.	
Moiture in Mould		
Factor(Mould Vol)	2.305×10^{-3}	
Stabilizer Type Stabilizer %		
Mould + wet soil		
Mould Wt		
Wet soil Wt Dry density ρ d		
Compaction		
SWELL DATA		
Final dial reading		
Initial dial reading		
Swell		
% swell		
TEST DATA	Prove ring dial reading	
Penetration (mm)	Top	Bottom
0.25		
0.50		
0.75		
1.00 1.25		
1.50		
1.75		
2.00		
2.25		
2.50 2.75		
3.00		
3.25		
3.50		
3.75		
4.00 4.25		
4.50		
4.75		
5.00		
5.25		
5.50		

MDD =…………….Kg/m³ PMC =…………….%
OMC = % OMC-PMC= %

Mass of wet material at omc per mould @ 95% MDD T100 (100% for T99)
(95%) x 23.05 x (100+OMC) x MDD/1000 = gms
Wet mass per each of the 3 layers =…………………gms
Actual total wet mass required per mould =…………………gms
(NB actual – mass of wet material per mould plus about 500g)

Dry mass per mould = total wet mass required x 100/(100+PMC)
…………………gms
Mass of Stabilizer = % stabilizer x dry mass =…………………gms
Total dry mass = sample dry mass + stab. mass =……………gms
Water to add when mixing = total dry mass x (OMC - PMC)/100
…………………mls

Prove ring reading

Penetration

Prove Ring Factor @ 2.5mm…………
Prove Ring Factor @ 5.0mm

CBR at 2.5mm –………Top ………bottom
CBR at 5.0mm – ………Top ………bottom

CBR = *(1-30 correct nearest 1, 30-100 to nearest 5, over 100 nearest 10)*

CHECKED BY

B-1

Calibration Table for Calcium

	Concentration in µg/ml Ca	Absorbance			
		1st	2nd	3rd	mean
Blank	0.00	0.001	0.000	0.000	0.000
Std 1	0.50	0.119	0.122	0.119	0.120
Std 2	1.00	0.238	0.241	0.241	0.240
Std 3	1.50	0.353	0.355	0.357	0.355
Std 4	2.00	0.467	0.464	0.462	0.464
Std 5	2.50	0.580	0.572	0.565	0.572

A graph of absorbance versus the concentration (C-1) was drawn from this table.

The absorbance and concentrations of calcium in the samples as read from the calibration graph were used to calculate the content of the calcium oxide percent in the soil/cement using formula as indicated in 3.3.1.1.

B-2

Calibration Table for Magnesium

	Concentration in µg/ml Al	Absorbance			
		1st	2nd	3rd	Mean
Blank	0.00	0.001	0.000	0.000	0.000
Std 1	0.10	0.151	0.153	0.152	0.152
Std 2	0.20	0.300	0.302	0.303	0.302
Std 3	0.30	0.444	0.446	0.445	0.445
Std 4	0.40	0.587	0.584	0.584	0.585
Std 5	0.50	0.724	0.720	0.717	0.720

A graph of absorbance versus the concentration (C-2) was drawn from this table.

The absorbance and concentrations of magnesium in the samples as read from the calibration graph were used to calculate the content of the magnesium oxide percent in the soil/cement using formula as indicated in 3.3.1.2

B-3

Calibration Table for Aluminium

	Concentration in μg/ml Al	**Absorbance**			
		1st	**2nd**	**3^{rd}**	**Mean**
Blank	0.00	0.001	0.000	0.000	0.000
Std 1	30.0	0.150	0.152	0.153	0.152
Std 2	60.0	0.302	0.304	0.305	0.304
Std 3	90.0	0.448	0.450	0.452	0.450
Std 4	120.0	0.587	0.590	0.592	0.590
Std 5	150.0	0.734	0.732	0.732	0.733

A graph of absorbance versus the concentration (C-3) was drawn from this table. The concentrations of aluminium in the samples from the calibration graph were used to calculate the aluminium oxide percent composition using formula as indicated in 3.3.1.3.

B-4

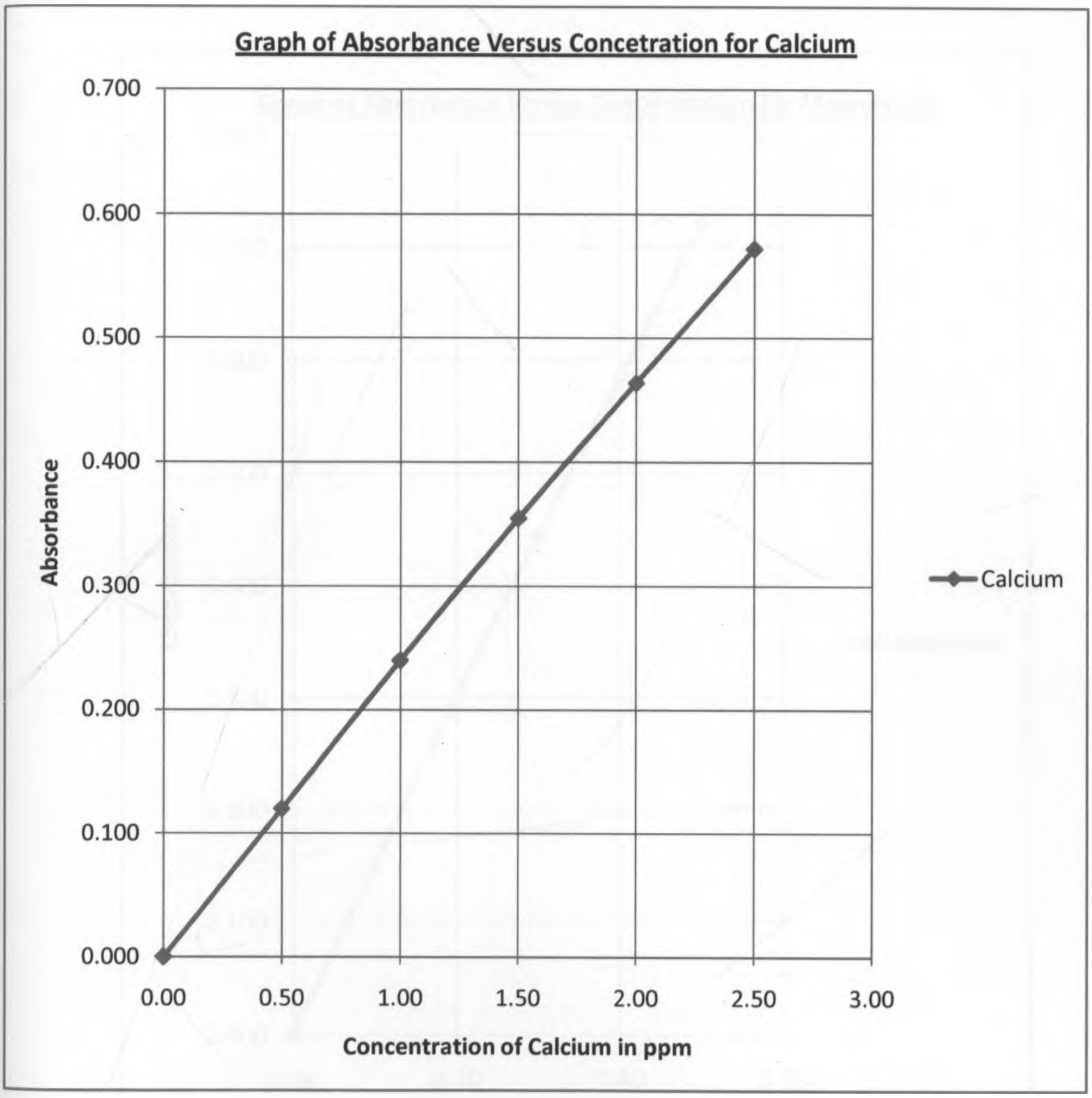
Calibration Table for Iron

	Concentration in µg/ml Fe	**Absorbance**			
		1st	**2nd**	**3rd**	**Mean**
Blank	0.00	0.001	0.000	0.000	0.000
Std 1	2.00	0.120	0.122	0.123	0.122
Std 2	4.00	0.242	0.243	0.243	0.243
Std 3	6.00	0.364	0.363	0.363	0.363
Std 4	8.00	0.481	0.480	0.482	0.481
Std 5	10.00	0.600	0.599	0.597	0.598

A graph of absorbance versus the concentration (C-4) was drawn from this table. The concentrations of iron in the samples from the calibration graph were used to calculate the iron oxide percent composition using formula as indicated in 3.3.1.4

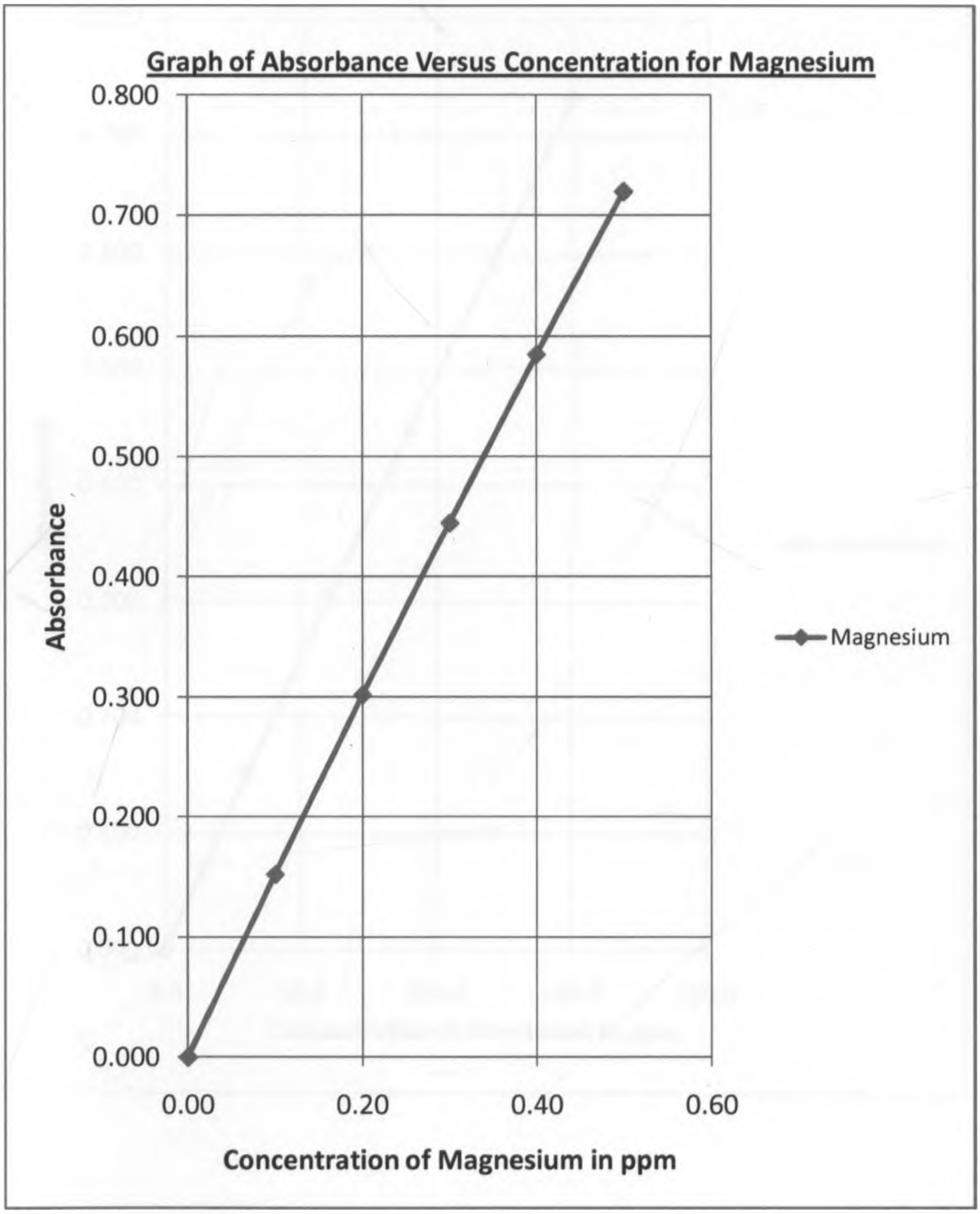
C-1

Calibration Graph for Calcium



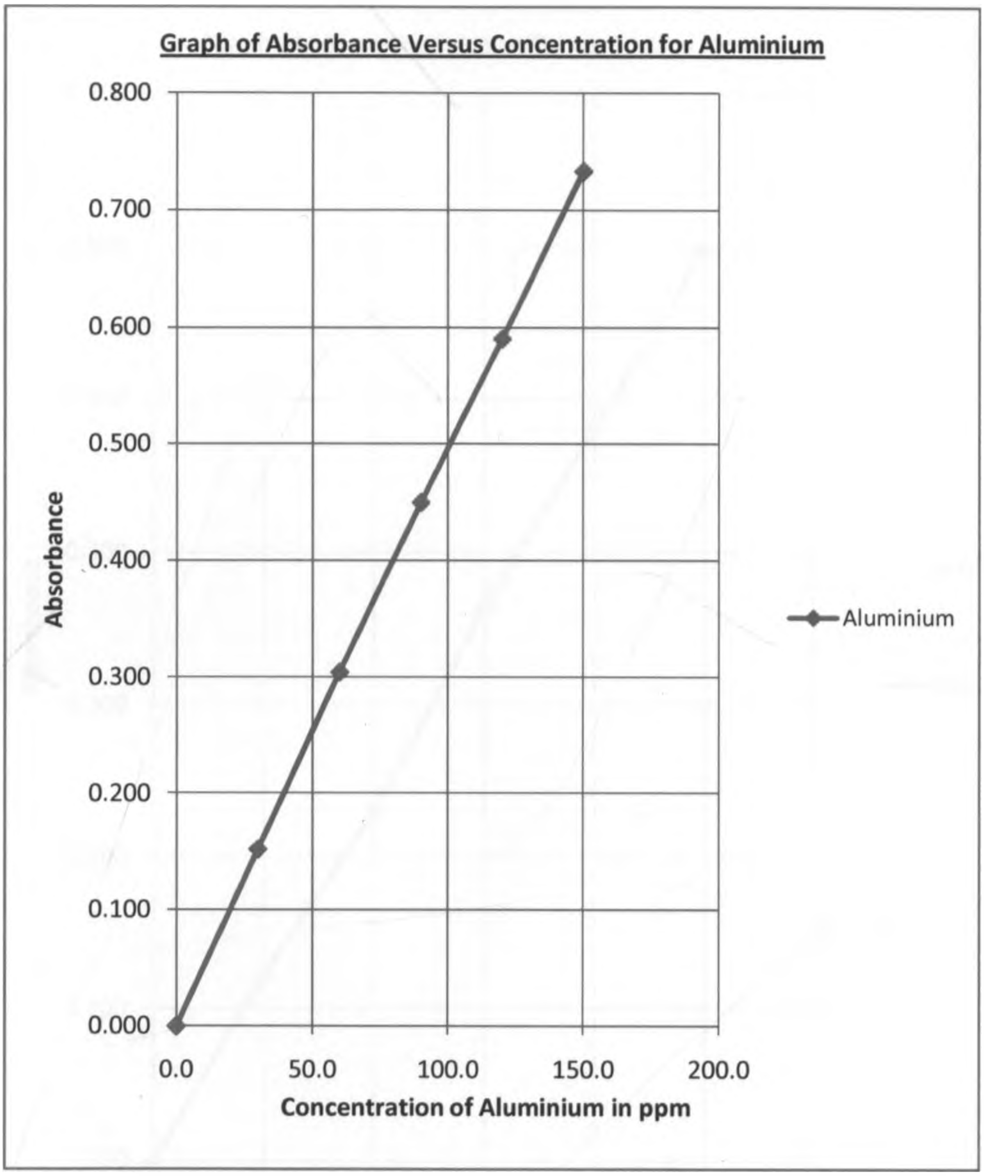
C-2

Calibration Graph for Magnesium



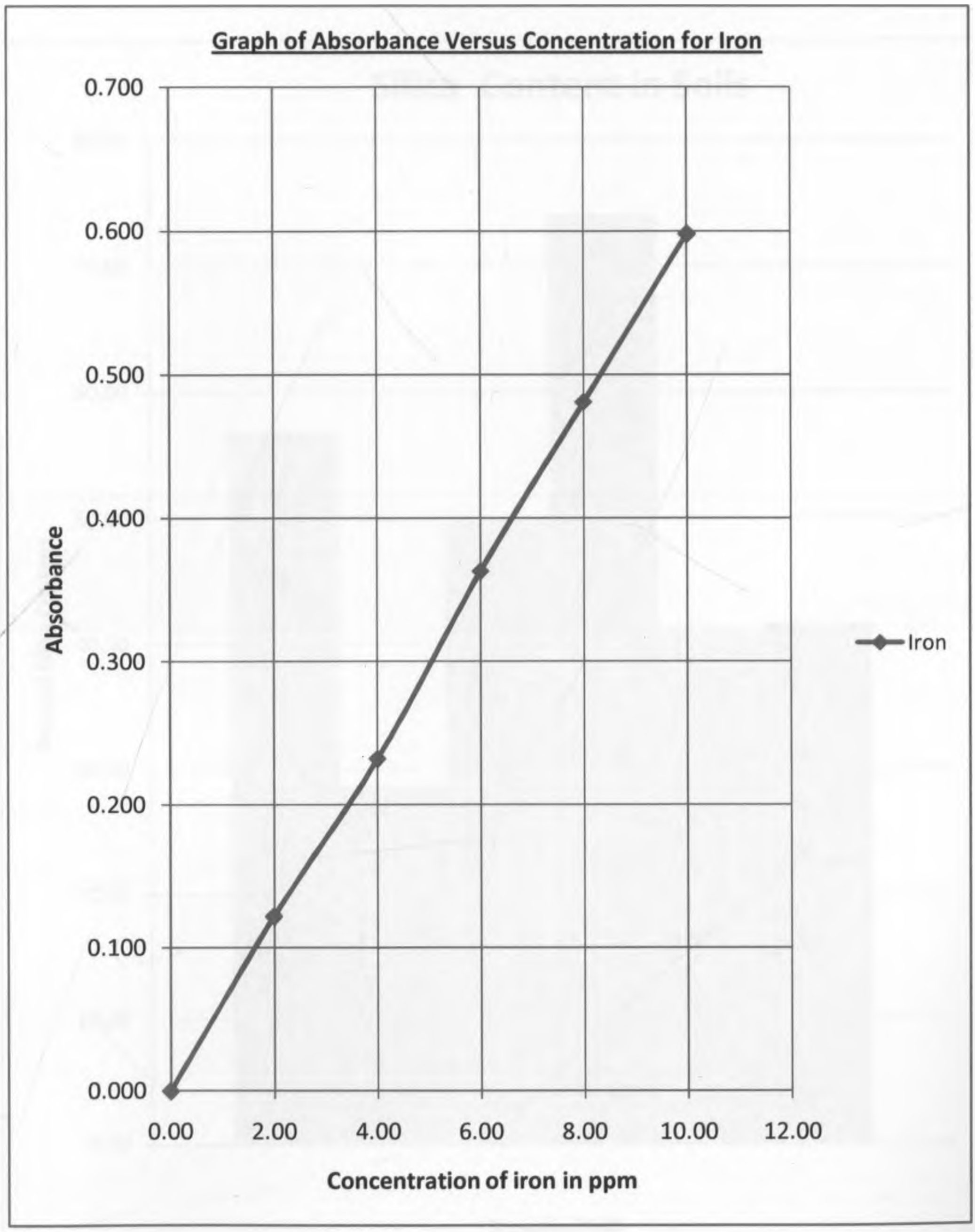
C-3

Calibration Graph for Aluminium



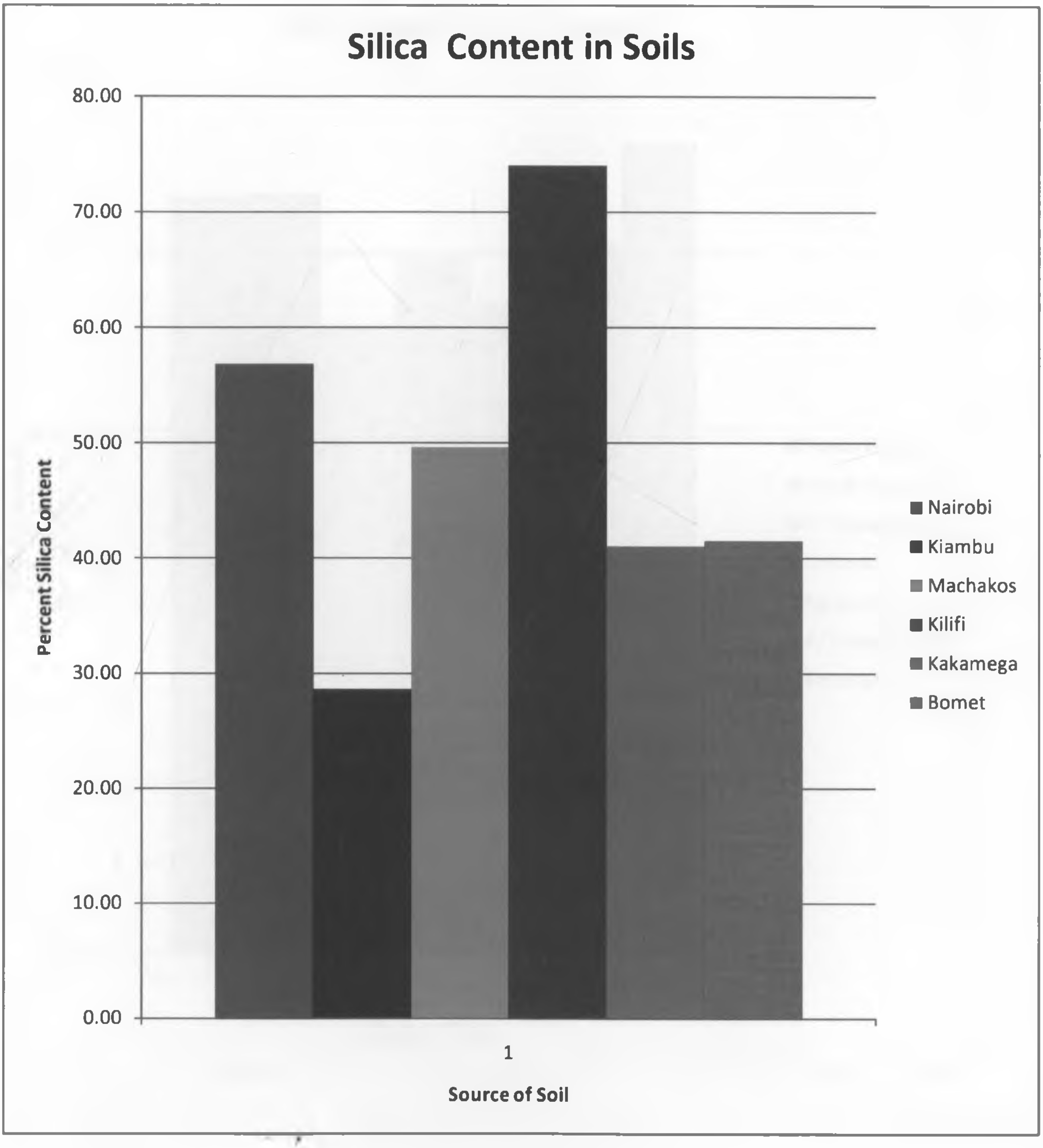
C-4

Calibration Graph for Iron



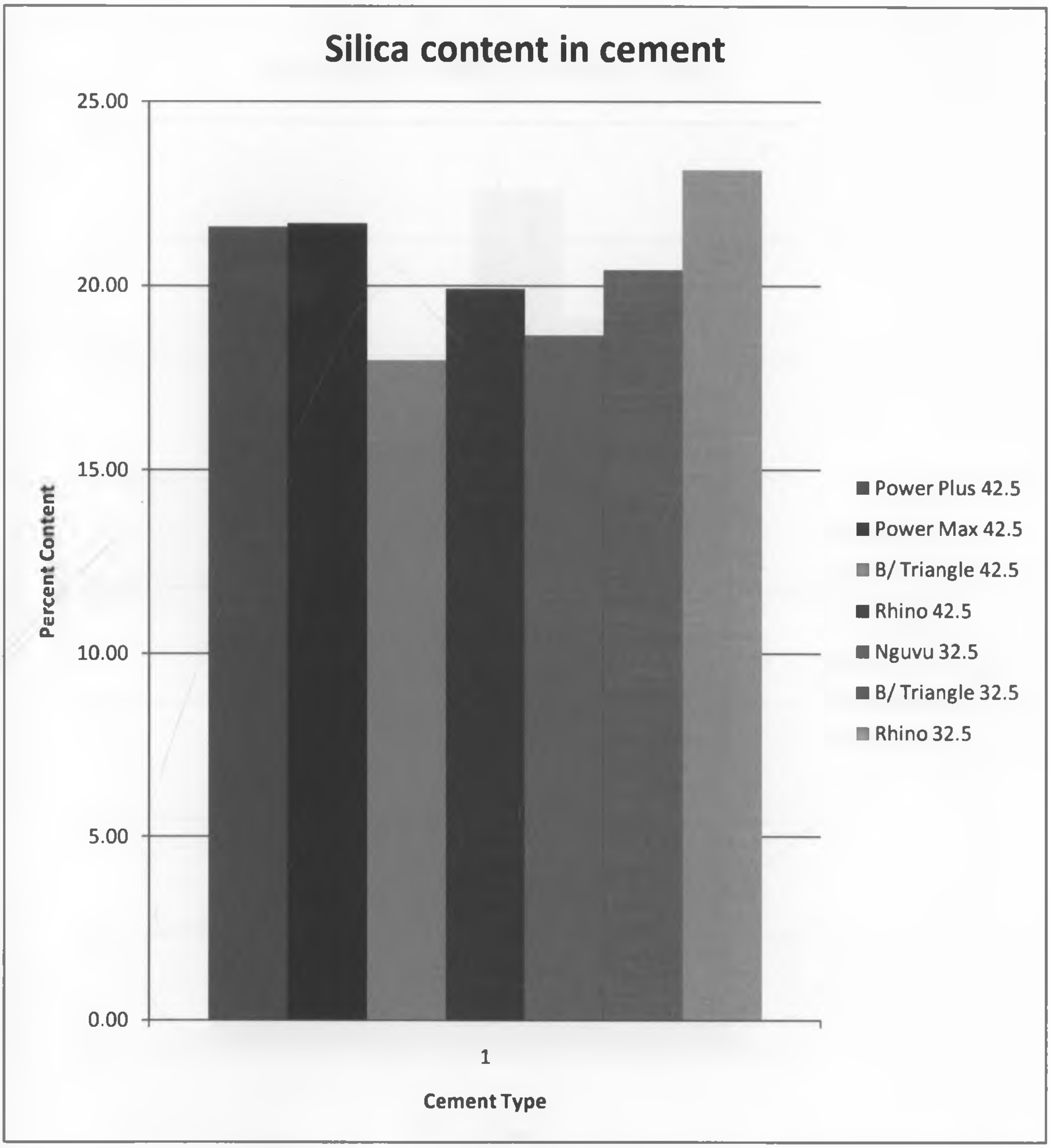
C-5

Graph of Silica Content in Soil



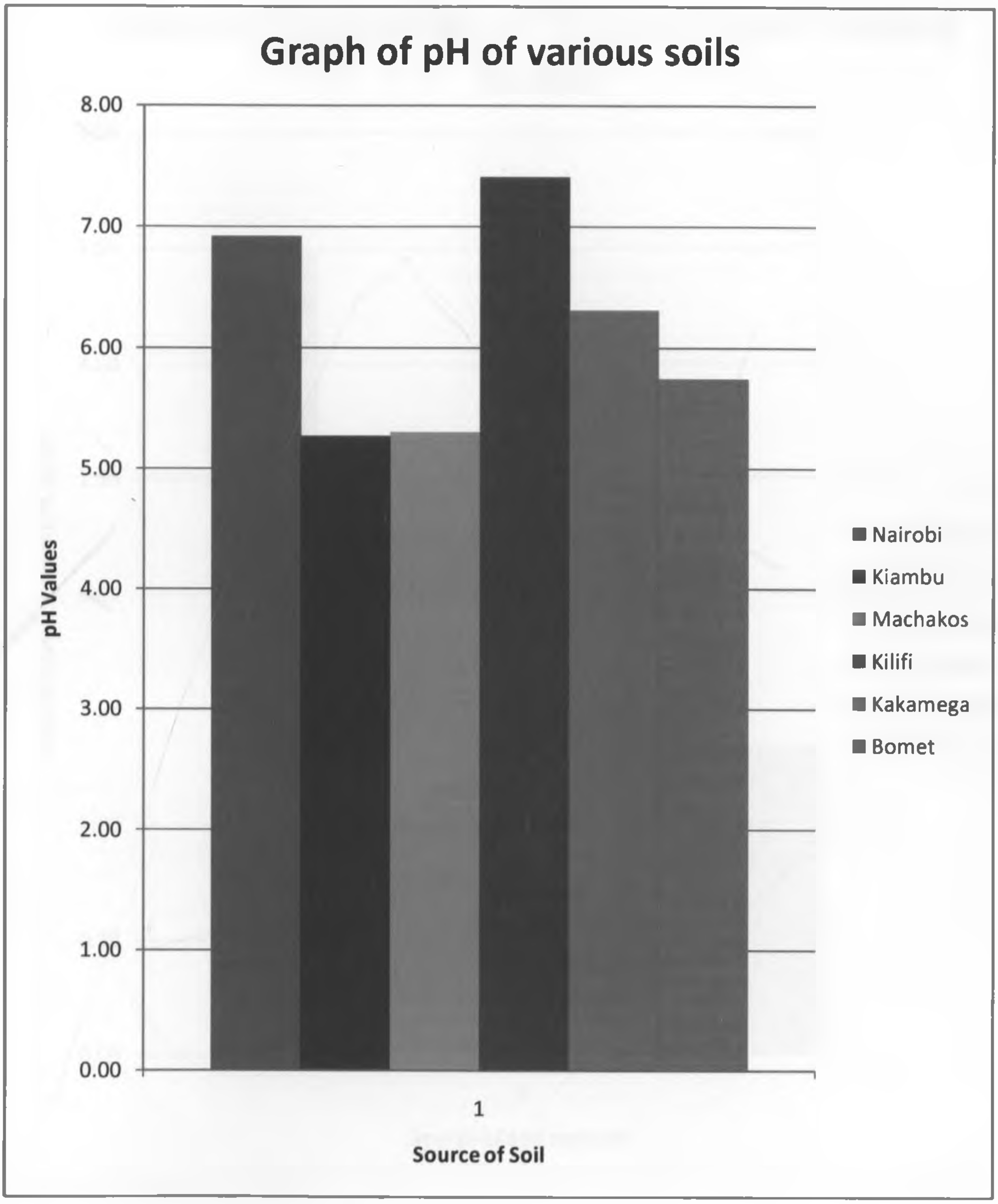
C-6

Graph of Silica Content in Cement



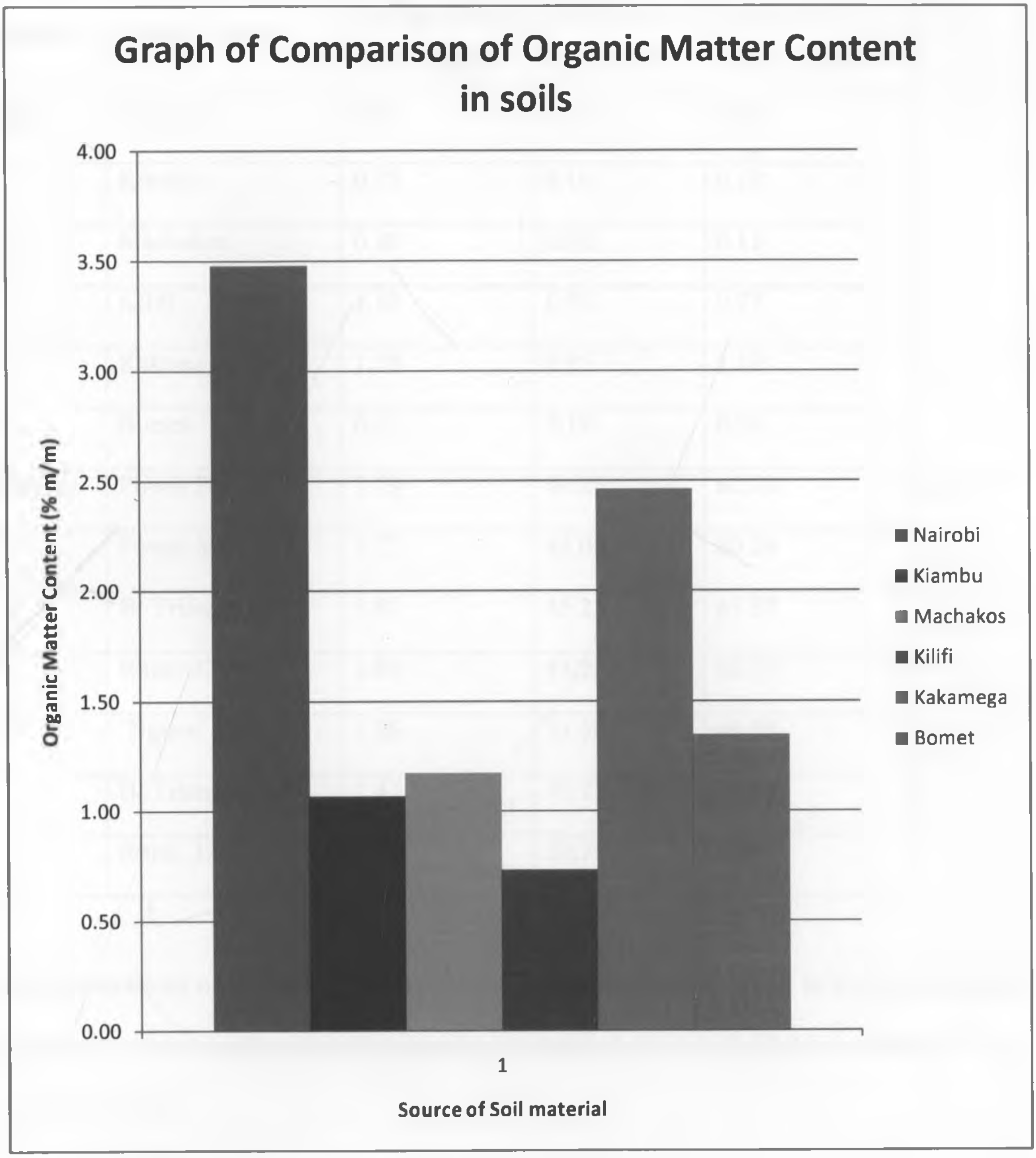
C-7

Graph of pH of Soil



C-8

Graph of Organic Matter Content in Soil



D-1

Calcium Content in Samples

Material	Source/ Type	Concentration From Graph	Calcium as Ca, % m/m	Calcium as CaO, % m/m
Soil	Nairobi	2.63	1.32	1.84
	Kiambu	0.27	0.14	0.19
	Machakos	0.16	0.08	0.11
	Kilifi	1.10	0.55	0.77
	Kakamega	1.70	0.85	1.19
	Bomet	0.37	0.19	0.26
Cement	Power Plus 42.5	1.79	44.85	62.79
	Power Max 42.5	1.72	43.00	60.20
	B/ Triangle 42.5	1.81	45.25	63.35
	Rhino 42.5	1.81	45.25	63.35
	'Nguvu' 32.5	1.26	31.50	44.10
	B/ Triangle 32.5	1.43	35.75	50.05
	Rhino 32.5	1.51	37.75	52.85

The concentrations of calcium in the samples from the calibration graph in C-1 were used to calculate the calcium oxide percent composition using formula as indicated in equations 3.3.2.1, 3.3.2.2 and 3.3.2.3

D-2

Magnesium Content in Samples

Material	**Source/ Type**	**Concentration From Graph**	**Magnesium as Mg, % m/m**	**Magnesium as MgO, % m/m**
Soil	Nairobi	0.12	0.60	1.00
	Kiambu	0.05	0.25	0.42
	Machakos	0.02	0.10	0.17
	Kilifi	0.09	0.45	0.75
	Kakamega	0.06	0.30	0.50
	Bomet	0.04	0.20	0.33
Cement	Power Plus 42.5	0.21	0.53	0.88
	Power Max 42.5	0.15	0.38	0.63
	B/ Triangle 42.5	0.16	0.40	0.67
	Rhino 42.5	0.43	1.08	1.80
	'Nguvu' 32.5	0.42	1.06	1.77
	B/ Triangle 32.5	0.38	0.96	1.60
	Rhino 32.5	0.18	0.45	0.75

The concentrations of magnesium in the samples from the calibration graph in C-2 were used to calculate the magnesium oxide percent composition using formula as indicated in equations 3.3.2.1, 3.3.2.5 and 3.3.2.6

D - 3

Aluminium Content in Samples

Material	Source/ Type	Concentration From Graph	Aluminium as Al, % m/m	Aluminium as Al_2O_3, % m/m
Soil	Nairobi	26.67	6.67	12.59
	Kiambu	73.86	18.47	34.88
	Machakos	67.09	16.77	31.68
	Kilifi	28.15	7.04	13.29
	Kakamega	52.06	13.02	24.58
	Bomet	56.08	14.02	26.48
Cement	Power Plus 42.5	12.68	3.17	5.99
	Power Max 42.5	12.23	3.06	5.78
	B/ Triangle 42.5	15.68	3.92	7.40
	Rhino 42.5	13.27	3.32	6.27
	'Nguvu' 32.5	8.44	2.11	3.99
	B/ Triangle 32.5	7.81	1.95	3.69
	Rhino 32.5	8.97	2.24	4.24

The concentrations of aluminium in the samples from the calibration graph in C-3 were used to calculate the aluminium oxide percent composition using formula as indicated in equations 3.3.2.7, 3.3.2.8 and 3.3.2.9

D-4

Iron Content in Samples

Material	Source/ Type	Concentration From Graph	Iron as Fe, % m/m	Iron as Fe_2O_3, % m/m
Soil	**Nairobi**	1.88	4.70	6.71
	Kiambu	2.91	7.28	10.39
	Machakos	1.71	4.28	6.11
	Kilifi	0.88	2.20	3.14
	Kakamega	3.55	8.88	12.68
	Bomet	3.27	8.18	11.68
Cement	**Power Plus 42.5**	0.77	1.93	2.75
	Power Max 42.5	0.65	1.63	2.32
	B/ Triangle 42.5	1.28	3.20	4.57
	Rhino 42.5	0.91	2.28	3.25
	‘Nguvu’ 32.5	0.69	1.73	2.46
	B/ Triangle 32.5	0.49	1.23	1.75
	Rhino 32.5	0.72	1.80	2.57

The concentrations of iron in the samples from the calibration graph in C-4 were used to calculate the iron oxide percent composition using formula as indicated in equations 3.3.2.10, 3.3.2.11 and 3.3.2.12

D-5

Silica Content in Samples

Material	**Source/ Type**	**Silicon Content as SiO_2, % m/m**		
		A	**B**	**Average**
Soil	Nairobi	56.50	57.32	56.91
	Kiambu	33.25	32.99	33.12
	Machakos	58.46	57.92	58.19
	Kilifi	81.01	79.07	80.04
	Kakamega	51.00	49.18	50.09
	Bomet	63.05	63.75	63.40
Cement	Power Plus 42.5	18.58	18.62	18.60
	Power Max 42.5	15.70	15.66	15.68
	B/ Triangle 42.5	19.99	19.95	19.97
	Rhino 42.5	22.94	22.88	22.91
	'Nguvu' 32.5	35.68	35.62	35.65
	B/ Triangle 32.5	34.42	34.44	34.43
	Rhino 32.5	27.11	27.15	27.13

D-6

Soil pH

The pH values obtained in the analysis are as tabulated below.

Material Source	pH Values			
	First Reading	second Reading	Third Reading	Average Reading
Nairobi	6.96	6.88	6.91	6.92
Kiambu	5.26	5.30	5.24	5.27
Machakos	5.30	5.28	5.33	5.30
Kilifi	7.40	7.40	7.43	7.41
Kakamega	6.35	6.26	6.32	6.31
Bomet	5.80	5.68	5.74	5.74

D-7

Soil Organic Matter Content

The formula used to calculate the organic matter content in the soil is as below:

$$\% \text{ organic Content} = \frac{0.67 \times V}{\text{Mass of sample (g)}}$$

Where $\mathbf{V = 10.5 \times (1 - {}^{X}/_{Y})}$, and **Y = 10.6 ml**

Source of Soil	**Mass of sample**	**Volume of FeSO$_4$ (X ml)**	**X/Y**	**V**	**% Organic matter**	
						Average
Nairobi	0.2119	9.50	0.90	1.10	3.48	3.48
	0.2499	9.30	0.88	1.30	3.49	
	0.2314	9.40	0.89	1.20	3.47	
Kilifi	0.1853	10.40	0.98	0.20	0.72	0.73
	0.2791	10.30	0.97	0.30	0.72	
	0.2699	10.30	0.97	0.30	0.74	
Kiambu	0.2499	10.20	0.96	0.40	1.07	1.07
	0.1901	10.30	0.97	0.30	1.06	
	0.2512	10.20	0.96	0.40	1.07	
Machakos	0.2292	10.20	0.96	0.40	1.17	1.17
	0.1701	10.30	0.97	0.30	1.18	
	0.2299	10.20	0.96	0.40	1.17	
Kakamega	0.1892	9.90	0.93	0.70	2.48	2.46
	0.2182	9.80	0.92	0.80	2.46	
	0.2186	9.80	0.92	0.80	2.45	
Bomet	0.2012	10.20	0.96	0.40	1.33	1.34
	0.2459	10.10	0.95	0.50	1.36	
	0.2001	10.20	0.96	0.40	1.34	

E-1

CBR values of Nairobi Soil

CEMENT TYPE	SET	% Cement Added			
		0	2	4	6
Power Max 42.5	1	2	3	9	17
	2	2	2	7	18
	3	2	3	8	18
	Average	2	3	8	18
Power Plus 42.5	1	2	3	7	16
	2	2	3	9	18
	3	2	3	7	18
	Average	2	3	8	18
Blue Triangle 42.5	1	2	3	8	16
	2	2	3	8	17
	3	2	3	7	18
	Average	2	3	8	17
Rhino 42.5	1	2	3	8	16
	2	2	3	8	18
	3	2	3	7	17
	Average	2	3	8	17
'Nguvu' 32.5	1	2	2	6	11
	2	2	2	5	13
	3	2	2	4	10
	Average	2	2	5	11
Blue Triangle 32.5	1	2	2	5	10
	2	2	2	5	12
	3	2	2	5	11
	Average	2	2	5	11
Rhino 32.5	1	2	2	6	13
	2	2	2	4	12
	3	2	2	5	10
	Average	2	2	5	12

E-2

CBR values of Kiambu Soil

CEMENT TYPE	SET	% Cement Added			
		0	2	4	6
POWER MAX 42.5	1	3	17	34	60
	2	3	17	37	65
	3	3	15	35	60
	Average	3	16	35	60
POWER PLUS 42.5	1	3	17	35	70
	2	3	15	35	65
	3	3	16	37	60
	Average	3	16	35	65
BLUE TRIANGLE 42.5	1	3	16	35	60
	2	3	19	40	65
	3	3	17	35	60
	Average	3	17	35	60
RHINO 42.5	1	3	20	45	65
	2	3	14	35	60
	3	3	17	30	55
	Average	3	17	35	60
‘NGUVU’ 32.5	1	3	4	20	30
	2	3	14	25	35
	3	3	10	22	30
	Average	3	9	22	30
BLUE TRIANGLE 32.5	1	3	12	22	30
	2	3	12	21	30
	3	3	9	20	25
	Average	3	11	21	28
RHINO 32.5	1	3	14	20	28
	2	3	10	18	29
	3	3	7	13	25
	Average	3	10	17	27

E-3

CBR values of Machakos Soil

CEMENT TYPE	SET	% Cement Added			
		0	2	4	6
POWER MAX 42.5	1	14	25	40	70
	2	14	28	40	70
	3	14	27	45	75
	Average	14	27	40	70
POWER PLUS 42.5	1	14	18	45	70
	2	14	21	40	70
	3	14	19	45	65
	Average	14	19	45	70
BLUE TRIANGLE 42.5	1	14	17	40	65
	2	14	21	50	70
	3	14	19	45	70
	Average	14	19	45	70
RHINO 42.5	1	14	23	45	65
	2	14	17	40	70
	3	14	17	45	70
	Average	14	19	45	70
'NGUVU' 32.5	1	14	16	30	50
	2	14	19	28	45
	3	14	15	30	45
	Average	14	16	29	45
BLUE TRIANGLE 32.5	1	14	18	30	45
	2	14	15	25	50
	3	14	15	28	40
	Average	14	16	28	45
RHINO 32.5	1	14	25	40	45
	2	14	14	24	45
	3	14	19	25	40
	Average	14	19	30	45

E-4

CBR values of Kilifi Soil

CEMENT TYPE	SET	% Cement Added			
		0	2	4	6
POWER MAX	1	5	16	45	70
	2	5	17	40	70
	3	5	12	35	65
	Average	5	15	40	70
POWER PLUS 42.5	1	5	15	35	75
	2	5	12	35	65
	3	5	15	45	70
	Average	5	14	40	70
BLUE TRIANGLE 42.5	1	5	12	35	60
	2	5	16	40	70
	3	5	14	40	65
	Average	5	14	40	65
RHINO 42.5	1	5	16	45	65
	2	5	15	45	75
	3	5	16	40	70
	Average	5	16	45	70
‘NGUVU’ 32.5	1	5	10	28	45
	2	5	9	30	45
	3	5	7	26	40
	Average	5	9	28	45
BLUE TRIANGLE 32.5	1	5	6	25	40
	2	5	10	31	50
	3	5	8	28	45
	Average	5	8	28	45
RHINO 32.5	1	5	12	32	55
	2	5	7	25	40
	3	5	7	28	40
	Average	5	9	28	45

E-5
CBR values of Kakamega Soil

CEMENT TYPE	SET	% Cement Added			
		0	2	4	6
POWER MAX 42.5	1	15	30	45	60
	2	15	28	30	55
	3	15	28	40	70
	Average	15	29	40	60
POWER PLUS 42.5	1	15	32	45	75
	2	15	25	35	70
	3	15	27	40	70
	Average	15	28	40	70
BLUE TRIANGLE 42.5	1	15	21	45	65
	2	15	30	55	80
	3	15	30	50	70
	Average	15	27	50	70
RHINO 42.5	1	15	26	40	70
	2	15	22	40	65
	3	15	30	45	75
	Average	15	26	40	70
‘NGUVU’ 32.5	1	15	15	32	45
	2	15	15	29	40
	3	15	17	30	45
	Average	15	16	30	45
BLUE TRIANGLE 32.5	1	15	13	30	40
	2	15	19	26	40
	3	15	16	28	45
	Average	15	16	28	40
RHINO 32.5	1	15	17	33	35
	2	15	15	35	45
	3	15	18	35	50
	Average	15	17	34	45

E-6

CBR values of Bomet Soil

CEMENT TYPE	SET	% Cement Added			
		0	2	4	6
POWER MAX 42.5	1	10	22	35	65
	2	10	19	38	65
	3	10	21	45	75
	Average	10	21	40	70
POWER PLUS 42.5	1	10	20	45	70
	2	10	17	30	60
	3	10	24	50	75
	Average	10	20	40	70
BLUE TRIANGLE 42.5	1	10	22	40	65
	2	10	30	45	80
	3	10	17	35	60
	Average	10	23	40	70
RHINO 42.5	1	10	22	40	70
	2	10	20	38	70
	3	10	20	34	60
	Average	10	21	35	65
'NGUVU' 32.5	1	10	12	27	35
	2	10	15	29	40
	3	10	11	24	32
	Average	10	13	27	35
BLUE TRIANGLE 32.5	1	10	15	18	40
	2	10	13	35	50
	3	10	10	18	35
	Average	10	13	24	40
RHINO 32.5	1	10	10	29	40
	2	10	12	24	40
	3	10	14	23	35
	Average	10	12	25	40

E-7

SUMMARY OF RESULTS FOR VARIOUS CEMENTS ON EACH SOIL

		X - AXIS	0	2	4	6
NAIROBI	Power Max/ Plus	Y - AXIS	2	3	8	18
	Power Plus		2	3	8	18
	BT42.5/Rhino 42.5		2	3	8	17
	Rhino 42.5		2	3	8	17
	'Nguvu' 32.5/BT 32.5		2	2	5	11
	Blue Triangle 32.5		2	2	5	11
	Rhino 32.5		2	2	5	12
KIAMBU	Power Max		3	16	35	60
	Power Plus		3	16	35	65
	BT / Rhino 42.5		3	17	35	60
	Rhino 42.5		3	17	35	60
	'Nguvu' 32.5		3	9	22	30
	Blue Triangle 32.5		3	11	21	28
	Rhino 32.5		3	10	17	27
MACHAKOS	Power Max		14	27	40	70
	Power Plus/BT/ Rhino 42.5		14	19	45	70
	'Nguvu' 32.5		14	16	29	47
	Blue Triangle 32.5		14	16	28	45
	Rhino 32.5		14	19	30	45
KILIFI	Power Max		5	15	40	70
	Power Plus		5	14	40	70
	Blue Triangle 42.5		5	14	40	65
	Rhino 42.5		5	16	45	70
	'Nguvu'/Rhino 32.5		5	9	28	45
	Blue Triangle 32.5		5	8	28	45

KAKAMEGA	Power Max		15	29	40	60
	Power Plus		15	28	40	70
	Blue Triangle 42.5		15	27	50	70
	Rhino 42.5		15	26	40	70
	'Nguvu' 32.5		15	16	30	45
	Blue Triangle 32.5		15	16	28	40
	Rhino 32.5		15	17	35	45
BOMET	Power Max		10	21	40	70
	Power Plus		10	20	40	70
	Blue Triangle 42.5		10	23	40	70
	Rhino 42.5		10	21	35	65
	'Nguvu' 32.5		10	13	27	35
	Blue Triangle 32.5		10	13	24	40
	Rhino 32.5		10	12	25	40

E-8

SUMMARY OF RESULTS ON VARIOUS SOILS BY EACH CEMENT

		X - AXIS	0	2	4	6
POWER PLUS 42.5	Nairobi	Y- axis	2	3	8	18
	Kiambu		3	16	35	65
	Machakos		14	19	45	70
	Kilifi		5	14	40	70
	Kakamega		15	28	40	70
	Bomet		10	20	40	70
POWER MAX 42.5	Nairobi		2	3	8	18
	Kiambu		3	16	35	60
	Machakos		14	27	40	70
	Kilifi		5	15	40	70
	Kakamega		15	29	40	60
	Bomet		10	21	40	70
BLUE TRIANGLE 42.5	Nairobi		2	3	8	17
	Kiambu		3	17	35	60
	Machakos		14	19	45	70
	Kilifi		5	14	40	65
	Kakamega		15	27	50	70
	Bomet		10	23	40	70
RHINO 42.5	Nairobi		2	3	8	17
	Kiambu		3	17	35	60
	Machakos		14	19	45	70
	Kilifi		5	16	45	70
	Kakamega		15	26	40	70
	Bomet		10	21	35	65

‘NGUVU’ 32.5	Nairobi		2	2	5	11
	Kiambu		3	9	22	30
	Machakos		14	16	29	45
	Kilifi		5	9	28	45
	Kakamega		15	16	30	45
	Bomet		10	13	27	35
BLUE TRIANGLE 32.5	Nairobi		2	2	5	11
	Kiambu		3	11	21	28
	Machakos		14	16	28	45
	Kilifi		5	9	28	45
	Kakamega		15	16	28	40
	Bomet		10	13	24	40
RHINO 32.5	Nairobi		2	2	5	12
	Kiambu		3	10	17	27
	Machakos		14	19	30	45
	Kilifi		5	8	28	45
	Kakamega		15	16	28	40
	Bomet		10	12	25	40