AN ASSESSMENT OF THE APPLICATION OF USED LUBE-OIL FOR IMPROVEMENT OF ENGINEERING FOUNDATIONS

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An assessment into the application if used lube-oil for improvement of engineering foundations

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DECLARATION

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

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DEDICATION

This thesis is dedicated to my wife Jane Kimali and two sons, Xavier Kioko Kimali and Vincent Mwanzi Kimali for their resilience, positive attitude, encouragement and support throughout my academic life.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	American Standards for Material Testing
BRRI	Building and Road Research Institute
BS	British Standards
CBR	California Bearing Ratio
EMCA	Environmental Management and Coordination Act
ISO	International Organization for Standardization
KNBS	Kenya National Bureau of statistics
LNAPL	Light Non Aqueous Phase Liquid
MDD	Maximum Dry Density
NCCK	National Council of Churches of Kenya
NEMA	National Environment Management Authority
OMC	Optimum Moisture Content
RAP	Reclaimed Asphalt Pavement
UNHCR	United Nations High Commission for Refugees
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WEO	Waste Engine Oil

ABSTRACT

Lube Oil is used to mean Lubricating Oil as used in automobile engines for lubrication of moving parts, cooling, cleaning, corrosion control and is produced in fractional distillation in refinery processes. It is mainly used in the automotive industry but subsequent research with a view to its application for infrastructure development is necessary.

The purpose of this study was to assess the suitability of used lube oil for improvement of engineering foundations as experimented on black cotton and red coffee soils. I was guided by the following specific objectives; to determine the fundamental properties of used engine oil, to explore the effect of used lube oil on the strength and engineering and index properties of the soils and to assess the effect of used lube oil on the permeability of soil.

Soil improvement is the alteration of any property of a soil to improve its engineering performance through for instance; increased shear strength, reduced permeability and reduced compressibility. It results in improved durability of soil by increasing its strength and resistance to water.

The improvement of black cotton soil and red coffee soils were the basis of this study by the application of Used Lube Oil in varying quantities at percentages of 0%, 5%, 10%, 15% and 20% by weight. The soils being highly sensitive to seasonal moisture content variations and are responsible for substantial distress to foundations and the structures that are built over them. When subjected to static and dynamic forces these soils heave and crack due to swelling and shrinkage. Hence, the soils are to be stabilized before construction in order to have efficient and long lasting foundations. The experimental study involved tests on Used Lube Oil using Red Wood Viscometer Test No 1-Universal for viscosity less than 2000 seconds (ASTM D445-06), classification and evaluation of the main index properties of the soil, compaction tests, California bearing ratio tests and permeability tests. The attempt was to investigate the limits within which Used Lube Oil can be used to improve black cotton soil and red coffee soil for engineering foundations and to examine the effect of used lube oil on various geotechnical and engineering properties the methods used being the Red Wood Efflux Viscometer Test No.1-Universal, cone penetrometer test, compaction test, California bearing ratio test and permeability tests.

Key test results were ;800kg/m^3 density of used lube oil and 55mPa.s dynamic viscosity, an increase in the maximum dry densities of black cotton and red coffee soils up to 1655kg/m^3 and 1523kg/m^3 respectively at 10% Used Lube Oil; California bearing ration for black cotton soil and red coffee soil increased from 1 to 8 and 1 to 14 respectively with 10% used lube oil replacement; permeability for black cotton soil and red coffee soil increased to 3.73x10^{-7} and 5.93x10^{-7} ,respectively.

This led to the conclusion that used lube oil increases maximum dry density, increases the California bearing ratio and increases permeability among other properties at 10% used lube oil replacement which is taken as the optimal value.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Soil is generally a very important material in civil engineering where it provides the foundation for all civil engineering structures. Soils exist in many different forms such as clay soils, sandy soils, gravel, organic soils and murram all of which behave differently with regard to strength, susceptibility to cracking, permeability and erosion. These properties can be improved using admixtures such as bitumen, cement, lime, pozollana and used lube oil. As a result of this there is need to improve these weaknesses using an admixture.

Black cotton soils, which form the basis of this thesis, are highly sensitive to seasonal moisture content variations and are responsible for substantial distress to foundations and the structures that are built over them on these soils. Civil Engineering Structures especially foundations in these areas suffer from premature failures attributed to the rich proportions of montimorillonite and kaolinite found in the soil. Stabilizing black cotton soil with chemicals, industrial wastes, geotextiles and so on have been found to be effective in improving their engineering properties, strength characteristics and CBR value.

Black cotton soils are problematic for Civil Engineers, because of their unconventional behaviour. These soils show large volume changes with respect to variation of seasonal moisture content. These soils when subjected to static and dynamic forces heave and crack due to swelling and shrinkage. Hence, the soils are to be stabilized before construction in order to have efficient and long lasting foundations. Considerable research has taken place using different stabilizing materials such as lime, fly ash, cement, rice husk ash, industrial wastes and geosynthetics and proved to be useful improvement of black cotton soils.

Foundation cracks resulting from alternate heave and settlement lead to ultimate failure.

Black cotton soil swells during rainy season and cracks in summer due to shrinkage. These shrinkage cracks are 100 mm to 150 mm wide and 0.5 m to 2 m deep. Swelling creates upwards pressure on the structure and shrinkage creates downward pull. It results into cracks in foundations results, walls and roof, Hence foundation in black cotton soil needs special care.

Used Oil has been a challenge over a long time and efforts to sustainable handling started way back in the 1970s in Pennsylvania. Due to this, interest has been developed into the suitability of Used Oil for soil improvement for engineering foundations.Soil stabilization is the alteration of any property of a soil to improve its engineering performance through for instance; increased shear strength, reduced permeability, and reduced compressibility. It results in improved durability of soil by increasing its strength and resistance to water.

Soil improvement in foundation construction has become very expensive in recent times due to the increased costs on the materials that go into their construction. This research seeks to come up with an appropriate technology that is suitable, sustainable and economically adaptable. Used Lube Oil is thereby investigated to establish its suitability as an improvement material for foundations in Kenya and beyond.

Expansive soils are encountered in arid and semi-arid regions of the world, where annual evaporation exceeds annual precipitation. In India, expansive soils cover about 20% of the total land area (Ranjan & Rao, 2005; Shelke & Murthy, 2010). These soils increase in volume on absorbing water during rainy seasons and decrease in volume when the water evaporates from them (Chen, 1988). The volume increase (swell) if resisted by any structure resting on it; then vertical swelling pressure is exerted by the soil on the structure. This pressure if not controlled, may cause uplifting and distress in the structure (Shelke & Murthy 2010). The strength loss on wetting is another severe problem with such soils. Due to this peculiar behaviour many civil engineering structures constructed on expansive soils get severely distressed. Pavements are in particular, susceptible to damage by expansive soils because they are lightweight and extend over large areas. Dwelling houses transferring light loads to such soils are also subjected to severe distress. Similarly, earth structures such as embankments, canals built with these soils suffer slips and damages (Mishra et al., 2008).

Soil stabilization techniques are widely used for stabilizing expansive soils. Physico-chemical stabilization using lime, cement, fly ash, enzymes, and other chemicals control the swelling in expansive soil (Lopez-Lara et al., 1999). In these techniques, uniform mixing of the stabilizers in soil must be ensured else erratic results may come. Mechanical stabilization of soil (without altering chemical properties) includes controlling compaction (Sridharan and Gurtug, 2004), pre-wetting (Chen, 1988), mixing with sand (Sridharan &Gurtug, 2004; Mishra et al., 2008), using cohesive non-swelling soil (Katti et al., 1983), EPS geofoam (Shelke & Murthy 2010), reinforcing the soil, using geosynthetics (Sharma & Phanikumar, 2005; Ikizler et al., 2009) and by using polypropylene fiber (Muthukumar 2012) are used. Special foundation techniques such as lime under-reamed piles, belled piers and granular pile anchors are also suggested (Phanikumar 1997).

Recently Kumar and Jain (2013) and Kumar (2014) have demonstrated that the concept of granular pile, that is popular in improving the weak marine clays, could be utilized to improve the load carrying capacity of soft expansive black cotton soils too. In the granular pile, also known as stone column, technique about 10 to 35% weak soil is removed and replaced with granular material in the form of piles. Kumar (2014) performed model test in the laboratory on granular piles of sand constructed in soft expansive soil of different UCS values. End bearing granular Piles were casted in the soil and the load test were performed. The test results showed that load carrying capacity of a footing resting on granular pile is significantly more than the corresponding value for the footing placed directly on the soft soil bed. The increase in load carrying capacity is observed for all soil consistencies of the expansive soil. It is concluded from his study that loss in strength and excessive settlement of the expansive soil due to wetting could be minimized to a large extent by installation of granular piles in the soil.

As reported above, besides the strength loss, the swelling and volume instability are the other severe problems with these soils. The present work is an attempt to fill this gap. The size of the sand column and the consistency of the soil play an important role in changing the behaviour of composite ground. Hence these two aspects are varied in the present work and the influence of the sand column diameter and the initial moisture content on the swelling of an expansive black cotton soil has been studied. The details of the experimental program, results of the tests and the conclusions drawn from the study were published.

It has been observed that in Nigerian roads, road construction is mostly done using lateritic soils as base and sub-base materials. If the surfacing material accumulates small surface water due to poor drainages, the water penetrates to the base and sub-base, thereby giving it a bad look. The water percolates the base and sub-base materials and dissolve them thereby causing big damage to the road. The base/sub-base material dissolves because of high percentage of clay soil present or as a result of improper stabilization methods. This depicts the need for special additives in our road pavement material stabilization to ensure improvement in the engineering properties of the soil such as volume stability, strength and stress-strain properties, permeability, and durability.

Much research has been carried out on the stabilization of soil, especially on laterites using several stabilization agents, mostly the use of cement, lime and fly-ash. But meaningful works on the applicability of used engine oil in soil stabilization are wanting. This research is an assessment on the engineering properties of the stabilized soil with used lube oil in varying quantities (0%, 5%, 10%, 15%, and 20%).

Used motor oil contaminations of soil are common wherever motor mechanic workshops are located (Euchun & Braja, 2001).

Oil contaminated soil (OCS) has been defined by Colorado Department of Health and Environment (2003) as any earthen material or artificial fill that has human or natural alteration of its physical, chemical, biological or radiological integrity resulting from the introduction of crude oil, any fraction or derivative thereof (such as gasoline, diesel, or used motor oil) or any oil based product. Oil waste dumping, production, pollution, and spills wreak havoc on the surrounding wildlife and habitat. It is in this vein that geotechnical engineers are faced with increasing challenges as a result of oil spills and hence the need for laboratory studies in order to develop methodologies for testing, identification, classification, engineering behavior, stabilization, utilization and remediation technologies for such soils.

OCS could also be the waste product of cleaning up oil spills or due to oil spillage. Left unattended, these soils pose a threat to human health and the environment. Numerous remedial technologies are available to eliminate or significantly reduce the risk that OCS poses, such as conversion of oily soil to road base material or a topping layer for car parks and roads after mixing with aggregate or a consolidation agent (Bund, 2012). Other methods include containment in large burial sites, incineration, biological methods, absorption methods, soil washing methods, and vacuum extraction. Most of these methods are expensive and uneconomical, considering the large quantities of materials involved.

Lateritic soil as a soil group rather than well-defined materials is most commonly found in the leached soils of the humid tropics where they were first studied. Lateritic soils are formed under weathering systems productive of the process of laterization (Wooltorton, 1975). The most important characterization is the decomposition of ferro-aluminium silicate minerals and the permanent deposition of sesquioxide (i.e., oxides of iron and Aluminum - Fe_2O_3 and Al_2O_3) within the profile to form the horizon of materials known as laterite.

The term “laterization” describes the processes that produce laterite soils (Gidigasu, & Kuma, 1987). Construction Industry Research and Information Association (CIRIA, 1988) proposed the following definition for lateritic soils which states that ‘laterite in all its form is a highly weathered natural material formed by the concentration of the hydrated oxides of iron and aluminum. This concentration may be by residual accumulation or by solution, movement and chemical precipitation.

For the purpose of this study a modified definition is used which states that laterite is a highly weathered material rich in secondary oxides of any of iron, aluminum, manganese, or titanium(Ijimdiya, 2011).

The purpose of this study was to investigate the effect of used oil on the strength and compressibility behavior of lateritic soils. Laboratory testing program was carried out on a reference soil- laterite taken from Shika-Zaria, Kaduna State, Nigeria. The soil was contaminated with used motor oil at stepped concentrations of 0, 2, 4, 6 and 8 % by dry weight of soil (Al-Sanad et al., 1995). Similar researches were carried out by Shin and Das (2001) on the bearing capacity of unsaturated oil-contaminated sand in Kuwait. Shin and Das (2001) reported that the bearing capacity of oil-contaminated sands drastically reduced.

During the last two decades, the results of a number of studies related to the physical properties and behavior of oil and petroleum contaminated soils have been published by many researchers like Al-Sanad *et al*. (1995), Aiban (1997), Meegoda and Ratnaweera (1994), Mohammed (1995), Khamehchiyun *et al*. (2006) and Ijimdiya (2007, 2010, 2011).

1.2 Problem Statement

Good infrastructure has been and still is the desire of many nations especially in the developing world and indeed even in the developed world. This has been a daunting task to many governments though it has been declared a millennium development goal to be achieved in this century. The Kenya government has also outlined this to achieve its Vision 2030 which is the country's new development blue print covering the years 2008 to 2030. This goal cannot be achieved if expensive construction methods and approaches are still used as is the case today.

With the high levels of poverty and uncertainty of the world's economy, there is need for cheaper and locally available construction materials. First and foremost, Portland cement, fly ash and ordinary bitumen which are widely used in stabilization of road sub-bases albeit being readily available in most countries are significantly more expensive in contrast with the used lube oil being investigated in this research. The monthly waste is estimated at 1.5 million litres and the figure is always escalating and this will soon be exacerbated by the recent discoveries of oil in Turkana, north-eastern Kenya, and the coast region compounded with the overall accelerated development towards Vision 2030.

Used lube oil is a generic of fractional distillation just like bitumen and is discharged or drained as waste in numerous waste generators including petrol stations and mechanics' garages with the discharge rate now creating inter-alia; unprecedented public health concerns, detrimental impacts on the flora and fauna, soil degradation, compromising on the quality and the standard of living and image and rating at a global scale. For years, motor oil commonly has been used and reused or discarded in ways that neither protected the environment nor conserved its resource value.

All possible and current modes of disposal are known to contaminate the environment, very little if not nothing is being done to address the problem. The country lacks a legal framework that encompasses handling of harmful waste with the exception of toxic and radioactive waste (Karanja et al., 2005).

This research seeks to come up with an appropriate technology that is suitable, sustainable and economically adaptable and to provide enhanced soil improvement technique while contributing to waste oil management.

The research is aimed at obviating the costs associated with the use of alternative foundation types like piles or at worst the cost of hiring mechanical plant to scoop vast quantities of black cotton soil and associated municipal disposal costs compounded with EMCA (1999) and regulations as enforced by NEMA.

The civil engineer is faced with the practical problems raised by use of soil as a foundation and construction material. A consideration of careful experimental investigation and the need for simplicity in the means employed has to be attained. In Kenya, the non-availability of generalized relevant data in this area, particularly for initial preliminary engineering planning and designs, has been the major cause of failure of most of subgrade.

The construction material, which is used for engineering highway projects, is therefore as important, as other engineering design factors. Thus in road pavement design, the soil materials used in the pavement construction transmit the axle-load to the sub-soil or sub grade. Hence, the durability of a highway pavement is a function of the ease and rigidity of the pavement soil to transmit the stress induced in it to the sub-soil such that unnecessary deformation is avoided.

Large amount of waste product from the automotive industry and by-product of frying can impose adverse impact if not disposed properly. Recycling of the waste product can be seen as sustainable options, which offers conservation of natural resources and economic benefits.

Waste oil which is discarded into the environment without any treatment prominently produce adverse impact to the environment. The effect can be seen by eutrophication process. The thin layer of oil that appears on the surface of river or lake can block the sunlight, the photosynthesis and also disrupt the oxygen supply to the aquatic life (El-Fadel & Khoury, 2001; Hamad et al., 2003). These processes lead to the excessive growth of micro-organism, phytoplankton and algea that use the waste oil as a food source. Lake or river quality deteriorates and also disrupts the intrinsic equilibrium of aquatic ecosystem. The source of waste oil pollution to the river can be contributed by engine oil from automotive industry and also waste cooking oil from residential area. With the concern of high construction cost and natural resource conservation, waste oil recycling is becoming the viable alternative in mitigating these problems (El-Fadel & Khoury, 2001). After years of exposure to traffic loads and climate change, the road will experience aging and reduction in binder performance. The pavement distinctive feature is that after the end of its design life, the pavement surfaces can be milled and recycled which is known as RAP (Jamshidi et al., 2012; NAPA, 2009). This renewability process can be done through 'rejuvenation'. Higher RAP content in the mixture can significantly increase the mixture's stiffness. However, too much RAP can reduce the mixtures performance. Therefore, through rejuvenation the properties of the old asphalt pavement particularly the binder properties can be improved to restore the original ratio of asphaltenes to maltenes and compensate this hardening effect (You et al., 2011; Garcia et al., 2011; Romera et al., 2006). Economic improvement has a direct impact on commercial activities and road network facilities in a country. This situation can lead to an increase in the number of vehicles on the road. In Malaysia, there are a total of 22 million registered vehicles which can contribute to the WEO that can lead to environmental pollution if not disposed of properly or recycled (Road Transport Department, 2012). Generally, engine oil also referred as oil lubricants, oil cylinder, crankcase oil and motor oil (Ssempebwa & Carpenter, 2009; Romera et al., 2006). Vehicle workshops and factories with heavy machinery are seen as primary sources that generate waste engine oil (WEO). If the discharge of WEO is not well managed or disposed, it will affect human health, aquatic life and ground pollution. According to previous studies, little waste engine oil is enough to ruin millions of gallons of fresh water (Moghaddam et al., 2011).

1.3 Justification of the Study

A study of this nature is very useful and it has far-reaching benefits. It is imperative to note that to date there is no policy on used oil management and micro-managing the same by limited entrepreneurs including credit for collection of used oil in Nairobi has not born any fruits hitherto.

This comes hot on the heels of vast quantities of used lube oil discharge into the liquid and solid waste stream currently estimated at 1.5 Million Litres Monthly and this figure is conservative.

Any legislation based on this research on used lube oil will be to assign common points for generating and collecting used lube oil for purposes of ensuring safe disposal and ultimate use for the improvement of our engineering foundations through treatment of the same.

It will be useful to the National and County Governments (for roads, airstrips, building foundations, harbours, earth-dams, retaining walls and related engineering works) as well as related professional bodies like Engineers Board of Kenya, Institution of Engineers, the National Construction Authority ,the National

Environmental Management Authority and others ,all in an endeavor to address economy in construction, the ever glaring eco-challenges of waste management and disposal , enhancement of small & medium size industries for used oil storage, handling and disposal. Professionally it will help set precedent in defining other frontiers within this research context for our universities towards achieving our national goals.

This research is an integrated effort towards sustainable development as defined in Agenda21 of the United Nations Conference on Environment and Development held at Rio de Janeiro,Brazil,3rd to 14th June,1992 and as well the provisions of EMCA (1999) laws of Kenya. Specifically, it will facilitate in drafting of the relevant legislation and policy making for this cause.

The research is aimed at obviating the costs associated with the use of alternative foundation types like piles or at worst the cost of hiring mechanical plant to scoop vast quantities of black cotton soil and associated municipal disposal costs and further NEMA (2003) regulations regarding the same.

Used Lube Oil for black cotton soil improvement for foundations was extracted from a lube bay at Shell Petrol Station on Latema road in Nairobi City. In Kenya, used lube oil is predominantly treated as waste and is cheaply dispensed with to prospective buyers and is extremely cheap citing the example of far flung sites across the country like Kakuma where the retail prices of items is at least 3times the normal cost in towns like Nairobi. This makes used lube oil quite versatile for use in stabilization and is expected to cut down the cost of stabilization significantly.

This study is considered very important as it investigates the effect of used engine oil as an additive in soil stabilization. This research is meant to evaluate and compare the engineering characteristics of normal soil and that contaminated with used engine oil. If the required objectives such as improvement of volume stability, strength and stress strain properties, permeability and durability are met using engine oil, it would be a breakthrough in the applicability of waste material like used engine oil in the construction industries, particularly in Kenyan roads which are most often not satisfying the expected standard design life span and which also would reduce the exorbitant cost in road construction.

1.4 Research Hypothesis

It is conjectured that there is a significant impact in the physical and mechanical properties of black cotton soil and red coffee soil with the application of used lube oil for engineering foundations within the ranges of replacement of 0%, 5%, 10%, 15% and 20%.This is predicated on the properties of used lube oil on the engineering and index properties as well as permeability as per the research objectives.

1.5 Research Objectives

1.5.1 Main Objective

The main objective of the study was to assess the suitability of used lube oil for improvement of engineering foundations as experimented with black cotton and red coffee soils.

1.5.2 Specific Objectives

1. To determine the fundamental properties of used engine oil.
2. To explore the effect of used lube oil on the strength and engineering and index properties of the soils such as liquid limit, plastic limit, plasticity index, optimum moisture content, California Bearing Ratio.
3. To assess the effect of used lube oil on the permeability of soil.

1.6 Limitations of the Research

This study is an assessment on the applicability of used lube oil in black cotton soil and red coffee soil. The work is limited to black cotton soil and red coffee soil samples collected from Kakuma food distribution center camp site in Turkana County and Red Coffee Soil from Kwa-Vonza Urban Center in Kitui County, although any other soil with the same chemical characteristics as the ones studied can also benefit from the results obtained.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

This chapter gives the review of the literature on the application of used lube oil for soil improvement. There was once a five acre property in Pennsylvania which was formerly the location of a fuel oil recycling and solvent recovery facility between the late 1970s and early 1990s. During this time period, used oils were re-refined into fuel oil for sale to residual fuel users and lubricating oil was also manufactured from the used oils. This process generated a clay filter cake waste that was stockpiled on the property. The property came to the attention of the Pennsylvania Department of Environmental Protection (PADEP) due to community complaints and non-compliance issues on the solid waste mess. In 1988, they conducted a site inspection of the property and identified volatile organic compounds (VOCs). Analytical results, for samples collected by the United States Environmental Protection Agency (USEPA) Region III, from staged waste materials (sludges, clay filter cake) on-site recommended remedial measures.

Remedial investigation for the property was transferred to the Potentially Responsible Parties (PRPs) group in the late 1990s. Following preparation, submittal and approval of the Remedial Investigation Work Plan (2000), investigative activities were conducted from 2000 to 2004 and included collection and analysis of surface soils, subsurface soils, groundwater, sediment, surface water and light non-aqueous phase liquid (LNAPL).

Results from the five phases of the remedial investigation reported no site contaminants were detected in surface water samples and the results of the stream sediment data did not indicate that the site contaminants had impacted sediments.

A human health risk assessment was conducted that evaluated both industrial and residential receptors based on current and projected future use of the property. Site-specific remedial objectives were identified and included in the Feasibility Study.

The Remedial Investigation Report (including the human health risk assessment) and Feasibility Study Report were approved by USEPA Region III in 2005 and 2006. EPA issued the Record of Decision (ROD) for the site in the spring of 2007. A remedial design investigation is anticipated for late 2010 or 2011.

Evaluated human health exposure pathways included vapour intrusion into future commercial buildings, direct contact risks to future construction workers, and direct contact risks to future residents on offsite, down gradient properties.

Improved lubricating oils usually contain special additives, such as detergents and dispersants to prevent carbon-forming deposits, as well as antioxidants and corrosion inhibitors to protect metallic surfaces. Viscosity-index improvers, wetting agents, extreme pressure additives and pour point depressants are added to motor oils to improve overall performance.

Engine oil is a complex mixture of hydrocarbons and other organic compounds, including some organometallic constituents (Butler & Mason, 1997) that is used to lubricate parts of an automobile engine, in order to smoothen engine operation (Hagwell et al., 1992). Used motor oil contains metals and heavy polycyclic aromatic hydrocarbons that could contribute to chronic hazards including mutagenicity and carcinogenicity (Keith &Telliard, 1979; Hagwell et al., 1992; Boonchan et al., 2000). Prolonged exposure to high oil concentration may cause the development of liver or kidney disease, possible damage to the bone marrow, and an increased risk of cancer (Propst et al., 1999; Mishra et al., 2001; Lloyd & Cackette, 2001).

Large amounts of spent or used engine oil are liberated into the environment when motor oil is changed and disposed into gutters, water drains, open vacant plots and farmlands, a common practice in Nigeria by motor mechanics and generator mechanics (Odjegba & Sadiq, 2002). In some developing countries, used engine oil is discharged into the environment.

In Nigeria and some developing countries, about 20 million gallons of waste engine oil are generated annually from mechanic workshops and discharged carelessly into the environment (Faboya, 1997; Adegoroye, 1997). According to US Environmental Protection Agency, USEPA (1996), only 1 litre of used engine oil is enough to contaminate one million gallons of freshwater. Used engine oil also renders the environment unsightly and constitutes a potential threat to humans, animals, and vegetation (Edeworet et al., 2004; Adelowo et al., 2006). Environmental pollution with petroleum and petrochemical products has attracted much attention in recent times. The presence of various kinds of automobiles and machinery vehicles has caused an increase in the use of motor oil. Spillages of used motor oils such as diesels or jet fuels contaminate our natural environment with hydrocarbon (Husaini et al., 2008). As the usage of petroleum hydrocarbon products increase, soil contamination with diesel and engine oils is becoming one of the major environmental problems (Ameh et al., 2012). To investigate the countermeasure to remediate soils contaminated with oils, bioremediation provides an effective and efficient strategy to speed up the clean-up processes (Mandri & Lin, 2007). Various factors may limit the rate of petroleum hydrocarbon degradation including lack of essential nutrients such as nitrogen. Therefore, the addition of inorganic or organic nitrogen-rich nutrients (biostimulation) is an effective approach to enhance the bio-remediation process (Hollender et al., 2003; Semple et al., 2006; Walworth et al., 2007).

There are relatively large amounts of hydrocarbon in the used oil, including the highly toxic polycyclic aromatic hydrocarbons. Also most heavy metals such as Vanadium (V), Lead (Pb), Aluminium (Al),Nickel (Ni), and Iron (Fe), which are below detection in unused lubricating oil, have been reported to give high values in (ppm) in used oil (Vwioko et al., 2006). In addition, the oil is also released into the environment from the exhaust system during engine use and due to engine leaks (Anoliefo & Edegbai, 2000). Spent engine oil, when present in the soil, creates an unsatisfactory condition for life in the soil, which is due to the poor aeration it causes in the soil, immobilization of soil nutrients and lowering of soil pH (Achuba &

Peretiemo-Clarke, 2008). Petroleum hydrocarbon contamination will not just affect the quality of the soil but will also alter the physical properties of oil contaminated soils. This will lead to geotechnical and foundation problems related to construction of buildings and other Civil Engineering structures such roads, dams, water/oil retaining structures.

Used oil was defined by the US Environmental Protection Agency (USEPA, 1996) as oil that has been refined from crude oil or any synthetic oil; this has been used and as a result of such use is contaminated by chemical impurities which contribute to chronic hazards including mutagenicity and carcinogenicity as well as environmental hazard with global ramifications (Udeani et al., 2009). The term, used engine oil, refers to any lubricating oil that has served its service properties in a vehicle withdrawn from the meant area of application and considered not fit for its initial purpose (Ameh et al., 2012). Used engine oil, which is also known as used mineral based crankcase oil, is a brown-to-black liquid produced when new mineral-based crankcase oil is subjected to high temperature and high mechanical strain (Arise et al., 2012).

Used engine oil (UEO) is a mixture of several different chemicals (Wang et al., 2000), including low and high molecular weight (C15-C20) aliphatic hydrocarbons, aromatic hydrocarbons, polychlorinated biphenyls, chlorodibenzofurans, lubricative additives, decomposition products, heavy metal contaminants such as aluminium, chromium, tin, lead, manganese, nickel, and silicon that come from engine parts as they wear down. Used oil can also originate at seaports from ocean going vessels which can contain salt sea water, heavy and intermediate fuel oil along with various heavy metals common to such fuel oil.

Appreciable quantities of used oil motor spills are common at and around mechanic workshops. Laboratory testing program has been carried out to determine the effect of used motor contamination on the strength properties of lateritic soils. Contaminated specimens were prepared by mixing the soil with used oil by weight of dry soil.

2.1.1 Uses of Used Lube Oil

According to Sriniwas (2012, the waste lube oil is used for the following purposes:

i) *Wood Preservative*

Used to preserve metal equipment and as well used in formworks preparatory to concreting.

ii) *Dust control*

Can be used for stabilization.

2.2 Effects of Used engine Oil on Soil

The method used in the sample collection is the trial pit method. One (1) undisturbed block sample and several disturbed samples were collected from one location at the Engineering workshop complex site. A trial pit is simply a hole dug in the ground that is large enough for a ladder to be inserted, thus permitting a close examination of the sides. With this method, relatively undisturbed samples of soils were collected. The depth of the trial pit was 1.8m (6ft) and about (1.2m) 4ft x (1.2m) 4ft wide i.e. 1.2m x 1.2m x 1.8m pit. The pit was sunk by hand excavation with the aid of spade and digger.

In the study, used engine oil collected from a motor mechanic workshop near the university campus was used to contaminate the soil samples. The used engine oil of 0, 2, 4, 6, 8 and 10% by weight of the dry soil samples was mixed with the soil samples. The five (5) mixed samples (soil-oil) were put in containers and allowed to equilibrate with time in line with the procedure adopted by Khamehchiyan *et al*. (2007).

Soil index property and classification tests namely, natural moisture content, specific gravity, particle size analysis, Atterberg limits and compaction tests were performed on the soil. Strength tests (CBR and unconfined compression tests) were then performed on the uncontaminated soil and all the used engine oil (UEO) contaminated soil samples.

2.2.1 Soil Characterization Results (Uncontaminated Soil)

For this lateritic soil, the percentage passing sieve No. 200 (0.075 mm), No. 40 (0.425 mm) and No. 10 (2.00 mm) are 32.80%, 49.58% and 79.25%, respectively. The specific gravity of the soils was 2.72. The soil is classified as A-2-7 with a group index of 3 according to the Association of American States Highway and Transportation Officials Classification System (AASHTO). It is also classified as sandy clay (SC), according to the Unified Soil Classification System (USCS). The results of the index properties (mechanical and physical analysis), compaction characteristics, unconfined compressive strength and California bearing ratio (CBR) for the uncontaminated soil are summarized below:

For the compaction test, the standard proctor method was adopted for this study. This test was used to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the lateritic soil. The results for the compaction tests performed on the uncontaminated and variably contaminated lateritic soils using the standard proctor method are presented in graphical plots in Figure 2. Both the maximum dry density (MDD) and the optimum moisture content (OMC) decreased with increase in the used engine oil concentration in the soil. This is clearly indicated by the downwards and left side shift of the compaction curves from the uncontaminated soils' curve. This is probably due to the fact that oil has partially occupied the soil inter-particle spaces and the occurrence of oil has resulted in some loosening of the soil matrix. The change in the composition of the pore fluid would also affect the microstructure of the clayey lateritic soil**.**

In conclusion, the MDD for the lateritic soil decreased from 1795 kg/m^3 to 1698 kg/m^3 with increase in used engine oil concentration. The OMC values dropped from 15.3% to 10.9%. The CBR value of the lateritic soil decreased from 22.05 % to 14.45%. The unconfined compressive strength (q_u) value for uncontaminated soils was 204kN/m^2. This reduced to 140kN/m^2 at an oil content of10%. These results reveal that the addition of used engine oil has adverse effects on the compaction and strength characteristics of this lateritic soil. Used engine oil contamination does not just affect the quality of the soil and ground water; it also alters the physical and geotechnical properties of the oil contaminated soil. The high indices of correlation (the coefficient of determination, R2) for the established relationships between geotechnical characteristics and the used engine oil content, suggest that these expressions are suitable for the determination of the compaction and strength characteristics for similar lateritic soils at different degrees of used engine oil contamination.

In Kenya attempts have been made to manage used lube oil mess but the challenge still remains unabated .Motor vehicle mechanics are given small loans which they use for buying tools and improving their business. The mechanics repay the loans by supplying used oil drained from motor vehicles they repair.

This project aims to reduce water pollution by used oil generated by mechanics who then dispose the oil into the environment. Through this scheme, participants access loans by trading in waste. In return for safely collecting and recycling the used oil, the mechanics get small loans for improving their motor vehicle repair business. Provision of small loans to 70 mechanics enables the project to safely collect 31,000 litres of used oil. According to the KNBS (2015), it is estimated that there are over two million vehicles on Kenyan roads. With the increasing number of vehicles being registered daily used lube oil is overwhelmingly being discharged to the environment and the need to bridge this gap.

2.3 Soil types

Soils are sediments or other unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter. Soil has distinct advantages as a construction material, including its relative availability, low cost, simple construction techniques, and material properties, which can be modified by mixing, blending, and compaction. However, there are distinct disadvantages to the use of soil as a construction material, including its non-homogeneity, variation in properties in space and time, changes in stress-strain response with loading, erodability, weathering, and difficulties in transitions between soil and rock.

Prior to construction, engineers conduct site characterization, laboratory testing, and geotechnical analysis, design and engineering. During construction, engineers ensure that site conditions are as determined in the site characterization, provide quality control and quality assurance testing, and compare actual performance with predicted performance.

Numerous soil classification systems have been developed, including geological classification based on parent material or transportation mechanism, agricultural classification based on particle size and fertility, and engineering classification based on particle size and engineering behaviour. The purpose of engineering soil classification is to group soils with similar properties and to provide a common language by which to express general characteristics of soils.

Selection of the type of soil for use in this project is based on prior knowledge of the widely used red coffee soils, especially in Nairobi. Conclusions and recommendations of the project are meant to bring about an insight on any necessary improvements on the same.

2.3.1 Black Cotton Soil

Black clay soils or tropical black earth or black cotton soils are known to be potentially expansive soils. They classify in pedological parlance as *vertisols* and have been subject of considerable agricultural and engineering research especially in India and some African countries. The black cotton soils are considered "problematic" and sometimes as "potential natural hazard" because they cause extensive damage to light structures founded on them due to excessive seasonal volumetric changes (swell & shrinkage).

Considering the widespread prevalence of black cotton soils around the world and the geomechanical challenges they pose to structures founded on them, we need to understand the peculiar characteristics and behaviours to enable effective utilization of these soils for engineering purposes. As a first step there is a need to assemble, correlate and integrate useful information on the genesis, nature and distribution as well as some basic geotechnical characteristics of the black cotton soils useful for civil engineering purposes scattered in various journal papers, proceedings of conferences, symposia, workshops, etc.

Secondly, there is also the need to add value to existing knowledge in terms of technical information relating to geology and geomechanics of the black cotton soils occurring in Ghana through laboratory and field studies.

Black cotton soils are major problematic soils of some tropical countries especially in Africa and India. They are poor materials by temperate zone standards and difficult to use for road and air field construction because they are often expansive due to the presence of large percentages of expansive clay minerals, i.e. montmorillonite. These soils swell when in contact with water and shrink on drying. The soil deposits are usually extensive making it impossible to avoid or by pass during construction of engineering projects. Many roads and foundations of light buildings have been reported distressed due to the seasonal volume change (i.e. swell and shrinkage) of these soils (Chen, 1988). These soils have reportedly inflicted billions of dollars in damages and repairs annually to earth structures and facilities.

Definition and Nomenclature:

Black clays or tropical black earth or black cottons are known to be potentially expansive soils which are "black" or "greyish black" or in their eroded phase "greyish white" heavy loam or clay (usually 50%), with predominantclay mineral of the smectite group, rich in alkali earth elements and the horizons sometimes contain calcium carbonate or magnesium oxide concretions. Many other terms have been applied locally, such as "regur"soils in India, "margalitic" soils in Indonesia, "black turf"in Africa and "tirs" in Morocco. Although there are several names,the term "black cotton soil" is adopted in this paper because of its extensive use in literature. The term "black cotton"is believed to have originated from India where the locations of these soils favour cotton growth.

Black cotton soils have been defined differently by different authors, for instance Mohr and Van Baren (1959) proposed the term "margalitic soils" which they defined as "black or greyish black, grey or in the eroded phase greyish-white" heavy loam or clays; which crack when dry and swell when moistened, they are mostly rich in alkaline earths; horizons of calcium concretions develop sometimes or lime concretions are found scattered throughout the profile; they are characterized by montmorillonite or other minerals of the smectite group as clay compound. USAID/BRRI (1971) also defined the tropical black cotton clay to be dark grey to black soil with a high content of clay usually over 50%, in which montmorillonite is the principal clay mineral and are commonly expansive. Morin (1971) defined black cotton soil as dark grey to black soil which has high clay content usually over 50% and are potentially expansive. Bucher and Sailie (1984) described black cotton soil as rich in montmorillonite and therefore prone to high volume change in the presence of water.Black cotton soils have been identified on igneous, sedimentary and metamorphic rocks. They are formed mainly by the chemical weathering of mafic (basic) igneous rocks such as basalt, norite, andesites, diabases, dolerites, gabbros and volcanic rocks and their metamorphic derivatives (e.g. gneisses) which are made up calcium rich feldspars and dark minerals which are high in the weathering order, in poorly drained areas with well-defined wet and dry seasons. All constituents weather to form amorphous hydrous oxides and under suitable conditions clay minerals develop. The absence of quartz leads to the formation of fine grained, mostly clay size, plastic soils which are highly impermeable and easily becomes waterlogged. In addition abundant magnesium and calcium present in the rock adds to the possibility of formation of black cotton soil with its attendant swelling problem (Ola, 1983). The black cotton soils have also formed over sedimentary materials such as shales, limestones, slates etc.

Topography:

Kattietal. (2002) reported that the black cotton soil deposits are formed under conditions where the slope of the terrain is less than 3°. The most frequent physiographic position of black cotton soils is flat, alluvial plains (Dudal & Eswaran, 1988; Eswaran et al.,1988) such as those found in Sudan, Texas in the USA, Darling Downs in Australia, the Accra plains, Ho-Keta plains and the Winneba plains in

Ghana (USAID/BRRI, 1971; BRRI, 1985). Other fewer occurrences are the Lufina valley of Zaire, the Kafue Flats of Zambia and the Panamalenga plains and the Springbok flats in Botswana, and South Africa respectively. However, black cotton soils also occur in surfaces with greater slopes (Ahmad, 1983).

Age:

Clemente et al., (1996) reported that time of formation of vertisols are usually inferred from the age of the underlying parent material from which the soil has developed. Furthermore, they realised that most vertisols are derived from cenozoic era materials including Tertiary and Quaternary. Some sediments of Cretaceous age have also formed vertisols (Gidigasu & Gawu, 2013). They indicated however, that the age of the parent material gives information only on the maximum chronological point, the age of the geomorphic surface and the soils would be much younger.

Distribution of Black cotton soils:

Black cotton soils (vertisols) have been reported all over the world and have been found to occupy about 2% (257 million hectares) of the total ice-free land area of the earth with 72million hectares occurring in India, 71million hectares in Australia (Swindale, 1988) and 43million hectares is in Africa(Virmani, 1988). Countries reported to have black cotton soils are Australia (Aitchison, et. al., 1962; Ingles &

Metcalf, 1972), Algeria (Afes &Didier, 2000), Botswana, Ethiopia (Mgangira & Paige-Green, 2008), Bulgaria, Hungry, Italy (Dudal & Eswaran, 1985), Togo (Oscar et al.,1977), Nigeria (Ola, 1976, 1983; Osinubi, 2006), South Africa (Van Der Merwe, 1964), Morocco, Chad, Cameroon,Kenya, Zambia, (USAID/BRRI, 1971),Tanzania (Bucher & Sailie, 1984), Sudan (Charlie et al., 1984), India (Michael,2006; Rao et al., 2001), Ghana (Building & Road Research Institute, 1985; USAID/BRRI, 1971).

The roads laid on Black cotton soil (BC soil) bases develop undulations at the road surface due to loss of strength of the sub grade through softening during monsoon. The black color in Black cotton soil (BC soil) is due to the presence of titanium oxide in small concentration. The Black cotton soil (BC soil) has a high percentage of clay, which is predominantly montimorillonite in structure and black or blackish grey in color. The physical properties of Black cotton soil (BC soil) vary from place to place.

About 40 to 60% of the Black cotton soil (BC soil) has a size less than 0.001 mm. At the liquid limit, the volume change is of the order of 200 to 300% and results in swelling pressure as high as 8 kg/cm^2/ to 10 kg/cm^2. As such Black cotton soil (BC soil) has very low bearing capacity and high swelling and shrinkage characteristics. Due to its peculiar characteristics, it forms a very poor foundation material for road construction. Soaked laboratory CBR values of Black Cotton soils are generally found in the range of 2 to 4%. Due to very low CBR values of Black cotton soil (BC soil), excessive pavement thickness is required for designing for flexible pavement. Research & Development (R&D) efforts have been made to improve the strength characteristics of Black cotton soil (BC soil) with new technologies.

2.3.1.1 Problems of Highway Construction in Black Cotton Soil Areas

There are problems arising out of water saturation. It is a well-known fact that water is the worst enemy of road pavement, particularly in expansive soil areas. Water penetrates into the road pavement from three sides viz. top surface, side berms and from sub grade due to capillary action. Therefore, road specifications in expansive soil areas must take these factors into consideration. The road surfacing must be impervious, side berms paved and sub grade well treated to check capillary rise of water.

It has been found during handling of various road investigation project assignments for assessing causes of road failures that water has got easy access into the pavement. It saturates the sub grade soil and thus lowers its bearing capacity, ultimately resulting in heavy depressions and settlement. In the base course layers comprising of Water Bound Macadam (WBM), water lubricates the binding material and makes the mechanical interlock unstable. In the top bituminous surfacing, raveling, stripping and cracking develop due to water stagnation and its seepage into these layers.

Generally, road construction agencies do not pay sufficient attention to the aspects of construction and maintenance of side berms. It is emphasized that road formation consisting of carriageway and berms must be considered as one single unit. In expansive soil areas, unpaved berms pose the maximum problem as they become slushy during rains, as they are most neglected lot.

2.3.1.2 Design Problems in Black cotton soils

As we all know, the problem with black cotton soils is that their large volume changes with moisture content means that are a big problems with foundations. Tomlinson (1980) notes that seasonal swelling and shrinkage can extend down as far as 4-5m and says that piled foundations to below this level may be needed even for light buildings, or that raft foundations may be needed for important structures. Black cotton soils are a large problem in India. Khanna (1999) notes that in such soils: 1. Foundation loads are limited to 5 to 10t per m2 (way below your load). 2. Foundations are taken below the cracking zone 3. Trenches filled with sand or other material may be used alongside the foundation trench to prevent intimate contact of the black cotton soil with the foundation concrete and masonry. Sand piling (sand columns below the foundation) is not so useful in black cotton soils because of the risk of sand loss through cracks. He recommends that for ordinary buildings, foundations should be taken 15cm below the depth of cracking and complicated foundation arrangements with sand. Of course, a key issue is to avoid creating problems from the roof water by taking it away from the foundations. It is also a good idea to check what local practices are. If they normally use piles or raft foundations locally, then these are probably a good idea.

In India, CBR method developed in USA is generally used for the design of crust thickness. This method stipulates that while determining the CBR values in the laboratory and in the field, a surcharge weight of 15 kg and 5 kg per 62 mm and 25 mm thickness respectively should be used to counteract the swelling pressure of Black cotton soils (BC soils). BC soils produce swelling pressure in the range of 20-80 tons/m^2 and swelling in the range of 10-20%. Therefore, CBR values obtained are not rational and scientific modification is required for determining CBR values of expansive soil.

Having heavy-duty traffic of 4500 commercial vehicles per day and msa 150 as generally found on our National Highways and taking CBR value of 2%, total crust thickness of flexible pavement works out to 830 mm which is practically an impossible preposition. It is felt that CBR design curves require modification for expansive soils.

Assuming heavy traffic intensity of 4500 commercial vehicles per day and msa 150, crust thickness of rigid pavement works out approximately 300-320 mm, which is about one third of thickness needed for flexible pavement. Therefore, it sounds reasonable to adopt cement concrete pavement in Black cotton soil areas. This type of pavement may save the engineers from day to day maintenance problems also.

Another approach to the problem can be in having semi rigid sub-bases. It is discernible that the CBR value of the BC soil be improved by giving a suitable treatment with the appropriate technology and then work out the crust thickness. This will substantially reduce the required crust thickness.

Uncompacted berms without any treatment cannot withstand the traffic stresses. It is a common sight and experience that heavy vehicles get stuck up while overtaking and sometimes results in serious accidents. Development of separate specifications for berms need to be evolved.

2.3.1.3 Technologies for Improving CBR of Black cotton soils

2.3.1.3.1 Materials for Soil Stabilization

The engineering properties of Black cotton soil (BC soil) can significantly be improved with lime or cement treatment. This technology has been very common at global level and is in vogue for the last several years. Cement or hydrated lime in the range of 3 to 5 per cent brings remarkable improvement in the engineering characteristics of Black cotton soil (BC soil). The test results of typical Black cotton soil (BC soil) samples are given in Table 2 to indicate the improvement in its characteristics.

Cement/ Lime–soil stabilization technology has been found useful cost-effective and suited to manual methods of construction. This technology has been found 20-30% cheaper than conventional WBM construction. The cement or lime treatment is being utilized for the following purposes:

To provide a pavement foundation of marginally weaker in strength than that of concrete pavement, but much improved strength than natural Black cotton soil (BC soil).

To consolidate subgrades and base courses for concrete pavement in order to make them resistant to volume changes and displacement or erosion in the presence of moisture even under the rocking action of curled slabs, if any.

To overcome the susceptibility of foundations to volume change and to increase their shearing resistance and bearing capacity.

2.3.1.3.2 Pulverization and Mixing Methodology

The method of pulverization of Black cotton soil (BC soil) and mixing with cement and murram or lime and murram shall be as follows:

The Black cotton soil (BC soil) is dug from the ground where the embankment is to be constructed and clods broken with pick-axes so as to reduce them to a maximum size of 50 mm. Alternatively disc harrows with tractor could be employed. Soil clods are spread over the prepared and compacted surface of excavation and a smooth wheeled 8 tonne power roller passed over them a number of times, accompanied by frequent raking of the crushed material. About 8 passes of the roller combined with raking should normally be able to achieve the degree of pulverization. The degree of pulverization should be such that at least 80 per cent of soil passes through 475 micron sieve and there are no lumps larger than 25 mm size.

The pulverized Black cotton soil (BC soil) is mixed uniformly in given proportion by weight with cement and murram in-situ field conditions by using rotavator machine or motor grader. Portland cement or lime and Black cotton soil (BC soil) mixed at the proper moisture content has been used to build stabilized bases under concrete pavements for highways/ expressways and air fields .Cement/ lime-modified Black cotton soil (BC soil) is a mix that generally contains less than 5 per cent cement by volume.

This forms a semi-rigid system, improves the engineering properties of the soil and reduces the potential of the soil to expand by absorbing water. OPC or lime, when mixed with pulverized Black cotton soil (BC soil) reduces the liquid limit (LL), the plasticity index (PI) and the potential for volume change. It increases the shrinkage limit and shear strength. Due to the strength increase incorporated by the use of cement, the Black cotton soil (BC soil) cement mixture can increase the subgrade bearing capacity and strength significantly. This technique is relatively cheap and quite effective. At the ingress of moisture in cement stabilized black cotton soil mix, the water increases the strength of cement matrix and imparts strength to the mix.

Use of geo-textile fabric has found extensive application in highway engineering, particularly in expansive soil area. It was used in USA in early 70’s and in India it is initial stage. Geo-textiles are manufactured from petroleum derivatives such as polypropylenes, polyesters, polyamides etc. These have high tensile strength, burst and puncture strength, permeability and abrasion resistance etc. The use of geotextile fabric is made to provide a separation barrier between subgrade and sub-base courses. This technique has tremendous potential for its application in Black cotton soil (BC soil) area, and it has further been found that this geo-textile layer acts as a reinforcing layer, acts and can also be used to combat reflective cracking in the pavement structure. Also with the use of geo-textile, a reduction in the thickness of the pavement has been predicted ranging from 10 to 25 per cent. The cost of the geotextile has been the stumbling factor for its wider application in India. However, in special areas, such as Black cotton soil (BC soil) area, geo-textile offers a solution to highway engineering problems.

Use of murram layer as a barrier between subgrade and sub-base layer has been in practice in view of its cost–effectiveness. Murram of low plasticity index has been found effective and does not allow intrusion up of soft subgrade soil into the interstices of stone aggregates and ingress of water through it. It is a common old practice to provide about 225 mm thick sand blanket layer on soft soils as a barrier to stop intrusion of subgrade soil into interstices of granular base/ sub-base layer and serves as drainage layer, and also to give uniform support.

2.3.1.4 Choice of Top Wearing Courses on Flexible Pavement

In Black cotton soil (BC soil) areas, choice of bituminous surfacing on road crust is an important parameter in enhancing the life of the pavement. In order to eliminate the ingress of water into the pavement crust, it is preferred to adopt impervious surfacing of low void content, such as dense asphaltic concrete, premix carpet with liquid seal coat, bituminous macadam with seal coat etc. It has been found that open graded bituminous surfacings develop unevenness, waviness and depression during rainy season due to softening of subgrade caused by seeping of water through such open graded bituminous surfacings. In case of construction of new surfacings, it should be ensured that it is laid much before the monsoon season. It is felt that time slot of at least one month should be given between the end of construction and beginning of monsoon so that surface course gets additional compaction due to traffic. It ensures consolidation and compaction.

Shoulders of roads need special treatment, as these are the vulnerable points for vehicles getting stuck up during overtaking. It is felt that special treatment is needed to make the berms paved and separate specifications should be formulated.

2.3.2 Red Coffee Soil

Nairobi red coffee soils have been chosen for geotechnical tests under this research. Also known as lateritic soils. Various studies on red coffee soils or laterite soils or red soils have been carried out over the years. These have been defined and described by a number of researchers in several different ways.

Ola (1978), used local terminology in defining laterite soils as all product of tropical weathering with reddish, brown colour with or without nodules or concretion but not exclusively found below hardened ferruginous crust of hardpan.

Osula (1984) defined laterite as a highly weathered tropical soil; rich in secondary oxides of combination of iron, aluminium and manganese. Laterite (also known as "red soils") is used to cover all tropically weathered soil that has been involved in the accumulation of oxides of iron, aluminium or silica (Malomo, 1977).

In other words, red soil is a highly weathered material rich in secondary oxides of iron, aluminium, or both. According to Alexander and Candy (1962), it is nearly devoid of bases and primary silicate, but it may contain large amount of quartz and kaolite. It is either hard or capable of hardening on exposure to wetting and drying (Agbede, 1992).

Red soils derive their name from their red colour. Kenyan red soils are tropical soils that result from weathering of parent rock (any type of parent rock containing iron) which is enriched with oxides of iron and alumina in the form of clay mineral especially kaolinite group and secondary clays like geothite and haematite. These soils are the traditional materials for road and airfield construction in Africa and many parts of the world. They have varied behaviour depending on the origin and formation. Location also determines their behaviour, thus Kenyan red clays present problems to engineers due to their unique properties which vary from site to site.

In any study of engineering properties of red clay, it is very essential to include the geological aspects that are involved in the soil formation. Goetechnical engineering therefore does have an inetrrelationship with geology. The use of geology helps an engineer answer pertinent questions that include;

i) What materials are present in the structure and what effects do they have as far as the strength characteristics of the soil are concerned?
ii) By what process did these materials arise?
iii) What are the mechanical properties of the materials?
iv) Are they subject to risk of failure due to future changes within the engineering true scale due to geotechnical effects?

Certain aspects of red soils in Kenya have been studied although no comprehensive, universal and coordinated study has been done. Basically experts involved in various engineering undertakings in different parts of the country tackle the isolated problems as they are encountered. Therefore there arises a need for a well-coordinated study that will bring together all that has been done and single out what that has yet to be done. On the other hand, there are certain generalizations as regards red soils that are not true for all cases. For instance the Kenyan red coffee soil (red friable clays) has been taken to have a bearing capacity of 80 kn/m^2. This may not be true for all cases of red soils across the country.

2.3.2.1 Formation of Red Soils

Red clay soils are found as in-situ products of weathering of many types of soils (extrusive and intrusive). Igneous, metamorphic and sedimentary rocks all contribute to the formation of red soils provided the right conditions prevail. Deep weathering profiles develop on volcanic deposits. In most cases most of the original parent rock has been lost but the gravel sized fragments of parent rock usually themselves get weathered and relic discontinuities may be encountered. Red soils are therefore formed from all types of rock:

i) Metamorphic rocks
ii) Igneous rocks (volcanic rocks)
iii) Sedimentary rocks.

2.3.2.1.1 Red soils from metamorphic rocks

When rocks are subjected to heat and pressure, metamorphic rocks are formed which are entirely different from their original parent rocks. These rocks when subjected to weathering decompose to form red soils (if enriched with oxides of iron and alumina). The common types of red soils that result in red soils include;

a) Migmatites
b) Phyllites
c) Silicate Minerals

Migmatites

The introduction of igneous (e.g. granite) into country rock of igneous kinds produces mixed rock or migmatite when subjected to processes of metamorphism. These rocks are found in areas of high grade metamorphism in many belts. When these rocks are weathered the iron coating present gives it red colour for which red soil is identified.

Phyllites

When rock are subjected to pressure they are converted into new products. In this case shale is converted into slates which in turn are converted to phyllites. Further subjection of phyllites to greater pressure results in micas and schist from which weathering breaks them.

In Kenya, these metamorphic rocks are the other major red soils forming red soils forming rocks other than volcanic. However most Kenyan red soils are also found where volcanic rocks are dominant.

Silicate minerals

Metamorphic rocks also result in silicate minerals the most important being the mica group. These are monoclinic minerals whose property of splitting into thin flakes is their main feature and easily recognized. The most commonly occurring micas are muscorites which also occur in granites and other acid rocks. They have silver crystals and are stable minerals. Other metamorphic rocks include quartzite and gneisses with quartz as the main mineral.

The weathering of these rocks leads to soils of various minerals. Silty red soils are also a result of these.

2.3.2.1.2 Red soils from igneous rocks

These are molten rock material generated from within or below the earth's crust which reaches the surface from time to time and flows through orifices as lava while some cool within the crust as intrusive. The most significant igneous rocks in formation of red soils include:

a) Pyroclastics
b) Biotites

Pyroclastics

Pyroclastics are deposits formed by consolidation of fragments ejected during a volcanic eruption. If the ejected mass forms near the vent then we have agglomerates. Small particles of ash and dust may be blown by wind and spread over large areas in layers which harden to form tuffs. Weathered soil containing course grained silts and clays are formed.

Biotites

Biotites occur in many igneous rocks including granites, then in lavas and dykes. They occur in crystal brown colour. Feldspars and quartz are the other common mineral in igneous

When feldspars of granites decompose, the clay mineral kaolinite is formed which is the main mineral in red soils.

2.3.2.1.3 Red soils in sedimentary rocks

In the sedimentary group of rocks the most important group of soils that are responsible for the formation of red soil of the ferruginous deposits. These are the sedimentary rock deposits that contion iron which is either precipitated as primary mineral or in crystalline lattice. The most common types are iron stones, mudstones, micaseous sandstones. However in Kenya these types of soils are not prevalent.

2.3.2.2 Red soil forming processes

The primary mineral weathers through illite or montimorillonite, forming kaolinite, hydrated aluminium and oxide. More resistant quartz and mica particles may remain. As weathering proceeds the contents of kaolinite decreases and hydrated oxides progressively alter to sesquioxides which upon drying harden to form laterites, cementing agents and concentrations.

i) Acid igneous rock – mainly sand or gravely soils with little clay
ii) Basic rocks – fine grained silts and clays
iii) Quartz – sand
iv) Feldspar – kaoline (clay mineral)

v) Product of kaolinization – sandy clay

The specific gravity of the soil increases as the weathering proceeds. This is because the specific gravity of iron bearing mineral is high compared to most other rock and tropical soil forming minerals.

Soluble irons are removed leaving iron and aluminiumsesquioxides plus kaolinitic clay mineral. Most residual clays contain the mineral kaolinite aggregated with oxides and hydroxides of iron and alumina. The parent rock can therefore be from any of the following sub-groupings:

a) Agglomerates basalt
b) Trachytes
c) Tuffs (Volcanic)
d) Phonolite
e) Quartzite
f) Gneiss and Schist
g) Phyllites

2.3.3 Engineering Characteristics of Kenyan Red Soils

In Kenya red clays from volcanic tuff is very common especially around Nairobi (Kabete, Limuru) with high contents of clay. Generally volcanic red soils are the most widespread in Kenya. These soils are free draining and those formed on volcanic ash deposits are much younger whereas those containing mineral halloysiteare much older.

2.3.3.1 General

The engineering characteristics of red soil influence its use and performance as a subgrade in the construction of road pavements. In general the tropical red soils have properties that are unique to the tropics hence it would not be in order to adopt testing techniques developed in the temperate areas. It is thus essential to develop techniques to soils in the tropics.

2.3.3.2 Texture of the soil

The texture and the structure of the red soils of East Africa differs greatly from those in temperate zones. Tropical red soils have concretionary structure as compared to dispersed structure of temperate zone soil. The clay fraction may vary from 10% to 30%. In terms of texture, laterites for instance can be categorized into the following categories:

i. Lateritic clays (diameter<0.002)

ii. Lateritic silts (diameter=0.002-0.06mm)

Improvement of red coffee soil using volcanic tuffs from Ngurunga:

i. Lateritic sands (diameter=0.06-2.0mm)

ii. Lateritic gravels (diameter=2.0-60mm)

iii. Lateritic stones and cuirasses (diameter>60mm)

Lateritic gravels and gravelly soils have high contents of fines. These soils exist as hard medium or weak granules.

2.3.3.3 Structure of red soils

The Kenyan red soil has a concretionary structure which influences its engineering properties. The physical hardening of laterites for example and its minerology affect the genesis of laterite soil and the physio-chemical aspects which involve coating of the soil by iron oxide and alumina. The soil particles later coagulate into clusters with subsequent reduction of specific surface.

In Kenya, Sasumua clay for example, has aggregated particles that formed clusters due to the presence of halloysites with iron coating.

2.3.3.4 Colloidal activities

Colloidal activity is the ratio of plasticity index to the clay mineral contents. The predominant clay mineral in the red soil in Kenya is kaolinite which is inactive hence low colloidal activity for Kenyan red soils. Residual red soils found in Kenya have colloidal activity between 0.4-1.0 while non residual soils have values greater than

1.0. Low colloidal activity can also be due to method of weathering which involves coatings of soil particles with sesquioxides hence surface activity suppression.

2.3.3.5 Shrinkage and swelling characteristics

In general, kaolinite particles swell very little but red soils in Kenya undergo an amount of swell that depends on the initial density and moisture content, the composition and the method of drying. The swell charecteristics of the Kenyan red soils are normally found in soils whose permanent rock is of volcanic origin. Weathering transforms volcanic ash into montimorillonite (black brown), halloysite and kaolinite.

The high moisture absorption leads to water being held in porous oxide surface structure. Oven drying leads to water loss hence high index results. On the other hand prolonged mixing of the soil in the laboratory breaks down the surface structure of the soil leading to release of iron oxide particles and destruction of any aggregation of soil particles and hence an increase in the index values of the soil. The breakdown in structure consequently leads increase in clay content. Linear shrinkage test can be performed for tropical red soils and it has been found to be more reliable than Atterberg limits tests hence it has been successfully used in selecting materials for road construction.

The Kenyan experience(Road Design Manual Part III-Materials and Pavement Design)) andfrom various studies shows that the soil has the following index characteristics:

i) Plastic limit=35%

ii) Liquid limit =75%

iii) Strength properties of the soil

Strength tests on red soils vary mainly with texture. The main tests include penetration test, vane shear test and plate loading test. The difference in strength illustrates the variation in the homogeneity of the soil profile and degree of laterization. The strength therefore is a function of chemical composition, age and homogenity. Iron rich soils are harder than alumina rich red soils. Homogeneous profiles have less impurities hence stronger soils. Older laterites are stronger than recently formed. The most important strength test is the California bearing ratio test (CBR test) which expresses the strength of subgrades and base courses of pavements.

The CBR test was developed by the California division of highways as a method of classifying soils for suitable use in highway construction especially for the classification of base course as for the support of flexible pavements. CBR measures the shearing resistance of the soil under controlled density and moisture conditions because it has been found that certain soils are very sensitive to such variables as slight changes in moulding moisture, compactive effort and soaking of the specimen. The CBR is expressed as a percentage of the unit load required to force a piston into the soil divided by the unit load required to force the same piston on the same depth into a standard sample of compacted crushed stone.

2.3.3.6 Consolidation and permeability characteristics

Permeability and consolidation characteristics of tropical red soils in Kenya have been studied by a few researchers using soil from certain areas as representative of the entire country. In these areas, Kabete, Limuru, Sasumua the parent rock is mainly of volcanic origin. Under normal conditions, clay minerals are expected to have high compressibility and low permeability. The Kenyan red soils have low compressibility and high permeability. The angle of shearing resistance is also usually high.

These phenomena can be due to the coarse grained nature of the soil (high permeability) due to aggregated particles into clusters due to the presence of hallosites with iron oxide coating. Due to this aggregation of particles in red clay soils, there is less change in water content and volume changes in compression is less hence the low compressibility (Das, 2010; Anitha et al., 2010).

2.4 Reseach developments in application of used lube oil for engineering applications

A number of research developments have been carried out to assess the suitability of used oil in stabilizing soils for engineering foundations and generally.

For instance Nazir Ashraf K(International Review of Civil Engineering;Nov2012, Vol. 3 Issue 6, p487) studied the effect of using oil on some of geotechnical properties of collapsible soil. The testing included basis properties of collapse potential, Atterberg limits, compaction and direct shear tests on collapsible soil stabilized with oil in the amount of 0%, 4%, 8%, and 12% by dry weight. The results indicated decrease in collapse potential, Atterberg limits, maximum dry density, optimum moisture content and frictional angle, while the cohesion of soil is increased significantly. The overall shear strength was slightly increased as the oil content increased for unsoaked soil and slightly decreased for soaked soil.

In 2012,Ijimdiya, T.S.a and Igboro, T. researched on the compressibility behaviour of lateritic soil upon application of used oil.From the results of the study carried out, it was observed that the presence of oil inthe lateritic soil led to reduced values of UCS, void ratios and increased values of volume

compressibility, Mv, and coefficients of consolidation, cv. Where these

soils exist, they are not suitable for engineering purposes and will require some remediation orstabilization processes in order to improve the bearing capacity of the affected soil.

There is still more research in this area of study in a bid to find a lasting solution.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 An overview of the tests and test procedures

The research method used in this study was experimental. I, the researcher gathered information through laboratory experiments and tabulation after obtaining the used lube oil and black cotton soil and red coffee soil from Kakuma in Turkana and Kwa-Vonza town in Kitui areas. The information that was gathered from the analysis was analyzed to aid in making sound conclusions and inferences in addressing the research objectives.

The study involved samples collection and laboratory tests. Each test was done several times, varying the quantities of lube oil and average of results considered; all based on a work schedule.

In this thesis, experimental design was employed and deduction derived purely from the results obtained.

The research samples and data were collected in the following ways:

1) Visiting the site to collect black cotton soil and red coffee soil and visit to petrol station to buy used lube oil and packing the same in polythene bags and containers ready for laboratory testing.
2) Laboratory tests to ascertain the engineering properties of these soils under investigation.
3) Laboratory tests on improved black cotton soil with waste lube oil.

Laboratory tests were conducted at the Jomo Kenyatta University of Agriculture and Technology and at the Kenya Material Testing and Research Laboratories according torelevant ASTM and BS standards.

The summary of tests carried out were:

1) Determination of used lube oil properties according to ASTM- D445-06, namely:
    i) Density
    ii) Kinematic Viscosity
    iii) Dynamic Viscosity
2) Determination of engineering properties of soil according to BS 1377-1990, namely:
    i) Moisture content,
    ii) Atterberg limits, and
    iii) Particle size distribution
    iv) Compaction,
    i) Permeability, and
    v) California Bearing Ratio.

Detailed laboratory tests carried out and both lube oil and the soil were mixed in percentages of 0%, 5%, 10%, 15% and 20% by weight.

3.2 Viscosity Test

The determination of viscosity of Used Lube-Oil was done using a Redwood Efflux Viscometer (No.1) according to ASTM- D445-06. The apparatus is universal for viscosity less than 2000seconds.

3.2.1 Preamble

Viscosity is the property of a fluid that determines its resistance to flow. It is the property that retards flow so that when the force is applied to a fluid, the lowest the viscosity, the greater the flow ability; in this sense viscosity is a 'pure' measure of consistency.

If the space between two parallel surfaces is filled with a liquid, and one of the surfaces is moved parallel to the other, a force which resists movement is set up as a result of the presence of the liquid. If the force of the resistance is denoted by **F**, the area of the surface by A, the velocity of movement of one surface relative to the other by υ, and the distance between the surfaces by d, then Fis found to be proportional to Aυ/d. If a factor η, which is called the coefficient of viscosity, is introduced into the relationship, then the following equation can be written:

$$F=\eta.A\upsilon/d$$

At given temperature, ηhas a constant value for any one liquid, but generally it is different for different liquids.

In this test , I have measured the time in seconds for a fixed quantity of the used lube-oil (50ml) to flow from a cup through a standard orifice standardized at 10mm under an initial standard head and at a known test temperature of 50degrees Celsius.

3.2.2 Apparatus

i) Red Wood Viscometer (No. 1).

ii) Oil cup-holds the test sample of lube oil,

iii) Water bath-surrounds the oil cup for adjusting the temperature,

iv) Stop watch,

v) Measuring flask,

vi) Funnel,

vii) Thermometers, and

viii) Filter Paper.

3.2.3 Procedure

i. Selected the viscometer

ii. Cleaned the viscometer cup properly with the help of suitable solvent like $CCL_{4,}$ ether, petroleum, spirit or benzene and dry it to remove any traces of solvent,

iii. Leveled the viscometer with the help of leveling screws,

iv. Filled the outer bath with water for determining the viscosity at 50^{0}C and below,

v. Placed the ball valve on the jet to close it and pour the test oil into the cup up to the tip of indicator,

vi. Placed clean dry measuring flask immediately below and directly in line with discharging jet,

vii. Inserted a clean thermometer and a stirrer in the cup and cover it with a lid,

viii. Heated the water filled in the bath slowly with constant stirring. When the oil in the cup attains a desired temperature, stop the heating,

ix. Lifted the ball valve and start the stop watch. Oil from the jet flows into the flask,

x. Stopped the stop watch when the lower meniscus of the oil reached the 50millilitre mark on the neck of receiving flask,

xi. Recorded the time taken for 50millilitres of the oil to collect in the flask,

xii. Repeated the experiment to get more readings.

Precaution

(i) The oil was filtered thoroughly with a muslin cloth to remove solid particles that could clog the jet,

(ii) The receiving flask was placed in such a manner that the oil stream from the jet struck the neck of receiving flask and did not cause any foaming,

(iii) After each reading the oil was completely drained out of receiving flask.

3.2.4 Observation

Viscosity was recorded as Red Wood seconds. The conversion constants for Red Wood time units were:

Constant A=0.26

Constant B=172

$$\text{Kinematic viscosity } \upsilon = A\,.t - B/t \text{ (c-st or } mm^2/s)$$

Dynamic viscosity from kinematic viscosity is obtained by:

$$\eta = \upsilon\,.\rho.10^{-3}$$

where;

η= dynamic viscosity, mPa.s

υ= kinematic viscosity, mm^2/s

ρ= density, kg/m^3at the same temperature used for the determination of the kinematic viscosity.

Mass of Lube Oil in 50ml Beaker = Mass with Oil – Mass When Empty

Volume=50Ml= $0.00005m^3$

And, Density ρ=Mass/Volume

Therefore, Dynamic Viscosity, $\eta = \upsilon\,.\rho.10^{-3}$

3.3 Determination of Particle Size Distribution

This was aimed at determining the size of particles of which the soil consisted of the mass percent of the grain at selected boundaries. The grain size distribution was determined by sieving the sample and by further hydrometer test according to BS1377:1990 Part 2:9.

3.4 Atterberg Limits

If the water content of a thick soil-water mixture is gradually reduced, the mixture passes from a liquid state to a plastic state, then to a semi-solid state and finally to a solid state.

The water contents corresponding to the transition from one state to another are called Atterberg limits or consistency limits.

These limits (the liquid limit and plastic limit) are determined by arbitrary but standardized tests as represented by BS1377:1990 Part 2:4 & 2:5.

Note: The difference between the liquid limit and plastic limit is the plasticity index.

3.4.3 Linear shrinkage

This is a measure of one –dimensional shrinkage.

Apparatus: brass moulds, silicone grease or petroleum jelly, distilled water, two palette knives, a flat glass (plastic) plate, drying oven and vernier calipers.

Procedure

The inner walls of the mould were cleaned and internal length measured accurately. A thin film of silicone grease was applied to the inner walls to prevent any soil adhering on the sides. The proportion of soil passing 2.00mm sieve was determined. An air-dry soil was passed through 425µm sieve and this material passing used to prepare a soil paste on the glass plate. The consistency of the soil paste was at approximately that of the liquid limit.

The soil paste was placed in the mould taking care not to include any air pockets and leveled on top. The specimen was allowed to dry in the air first until it detached itself from the walls of the mould. It was then transferred into the drying oven and dried at $105^{+}_{-} 5$ for about 12 hours.

The mould was then removed from the oven and allowed to cool. The mean length of the soil bar was then measured and recorded. If the specimen cracked badly or broke such that the measurements were difficult, the test was repeated. The results were tabulated in the standard tables as attached.

3.5 Compaction Test

This test is done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. It was done on the soil sample and then various percentages of Used Lube Oil was added on the black cotton soil and MDD and OMC determined.

3.5.1 Standard Proctor Test

To obtain the moisture content at which the dry density is maximum when the soil is compacted in standard manner. This is a dynamic method of compaction by repeated application of dead load according to BS1377:1990 Part 4:4.

3.6 Permeability Tests

This test is described in detail in BS 1377(1990).

3.7 California Bearing Ratio (CBR) Test

The dynamic CBR test was carried out according to BS1377:1990 Part 4:7. A sample passing through 20mm was used; moisture content of sample determined and then stored for 24hrs in a sealed place before compaction. This test was done on the sample with various percentages of used lube oil.

3.7.1 Equipment

BS sieve 20mm

CBR mould (internal diameter of 152mm and internal effective height of 127mm) with detachable base plate and top plate and a collar 50mm deep

Cylindrical plunger of hardened steel and cross sectional area 1935mm^2 approximately 250mm long

Machine for applying force to plunger

Three steel basins

Means of measuring penetration of plunger into the specimen

Three annular surcharge discs each having a mass of 2kg, internal diameter of 14.5mm to 150mm

Metal rammer 4.5kg with a weight of fall being 450mm

Steel straight edge (dimensions 300mm*25mm*3mm)

Spatula (blade of approximately 100mm*20mm dimensions)

Means of measuring movement of top of specimen during soaking

Weighing balance accurate 5g

Moisture tins

Filter papers 150mm in diameter

3.7.2 Moulding

Moulding was done for three points i.e. 100%-62blows, 95%-25 blows, and 90% - 10blows.

The mould was cleaned and weighed, then assembled on base plate and the collar fitted on it.

Required amount of water was mixed with the sample portion thoroughly

5 layers were compacted, each layer compacted with 62 blows such that the fifth layer will end immediately at the brim of the mould

The collar was removed carefully and excess material trimmed to flush with the top of the mould using steel straight edge

The mould with base plate after removing any external material stuck on mould and base plate using a brush was weighed

The moulding procedure was repeated for the 95% and 90% moulding points.

3.7.2.1Submersion/soaking

Soaking was done to determine the materials rate of absorption of water and degree of swell

The perforated mould with surcharge weights was soaked for 4 days and then removed from water and after removing surcharge weights the moulds was drained for 15mins before CBR penetrations

3.7.3 CBR Penetration

(i) Each mould was placed on CBR machine with plate in position

(ii) Surcharge masses to be placed on the specimen and machine set such that the plunger was set on the specimen.

(iii) Readings gauges were set and adjusted to prevent zero errors

(iv) When the machine was switched and for bearing ratio above 30% the plunger was made to penetrate the specimen at a uniform rate of 1mm/min (at a plunger force of 250N) the readings of force were taken at intervals of penetration of 0.5m a to a total penetration not exceeding 7.5m

(v) Penetration on the mould was done for both top and bottom and readings taken as before. This is to be done for the three point moulds

(vi) A graph showing force on the plunger against penetration was plotted and a smooth curve drawn through the points

(vii) The force read from the smooth curve required to cause a given penetration expressed as a percentage of force required to cause the same penetration on standard curve is defined as the CBR value of the penetration

(viii) The CBR value was calculated at penetrations of 2.5 and 5.0mm and the higher value taken. A graph was drawn for penetrations against dry densities in mould

(ix) After penetrations the mould were removed and wet soil from the 100% - 62 blow moulds oven dried and graded to determine the particle distribution as influenced by compaction.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Viscosity Test Results

Properties of unused and used lube oil are based on the three tests which are:

1) Density,
2) Kinematic Viscosity, and
3) Dynamic.

The density of used lube oil obtained was 800kg/m^3 while that of unused lube oil was 872kg/m^3 (Bejan, 2004). The results of kinematic viscosity and dynamic viscosity are shown in Table 4.1 and were determined at the test temperature of 50°C. Also, the dynamic viscosity is derived from the kinematic viscosity and modified by certain constants.

Table 4.1 Dynamic Viscosity Results

Test Run	Red Wood Seconds	Kinematic Viscosity (mm^2/s)	Dynamic Viscosity (mPa.s)
1	268	69	55.2
2	262	67.5	54
3	264	68	54.4
Average viscosity		**68.17**	**55**

The average kinematic viscosity of the used lube oil, obtained after three consecutive tests at 50°C, was 68 mm^2/s. Similarly, the average dynamic viscosity was 55 mPa.s.

4.2 Test Results on Soils

The results attained of the stabilized black cotton soil and red coffee soils were compared with data available from both virgin soils tests.

4.2.1 Moisture Content

This test was done to establish the field moisture content of soil samples. The soils were the black cotton soil and the red coffee soil. The approximate field moisture content for the black cotton soil, for example, was 60% as shown in Table 4.2.

Table 4.2 Field Moisture Content

A(Wet+Tin)	B(Dry+Tin)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%
68.2	54.8	31	13.4	23.8	56.30252
69.2	54.8	30	14.4	24.8	58.06452
73.2	56.4	28.6	16.8	27.8	60.43165
77.4	61	34.6	16.4	26.4	62.12121
Average Moisture Content					**60**

4.2.2 Particle size distribution

This was done according to BS1377 part 2 (1990) in order to determine the percentage particle size distribution of a given sample of the soil. Dry sieve analysis was done. The results obtained for the black cotton soil were tabulated and presented in a typical graph illustrated in fig. 4.1.

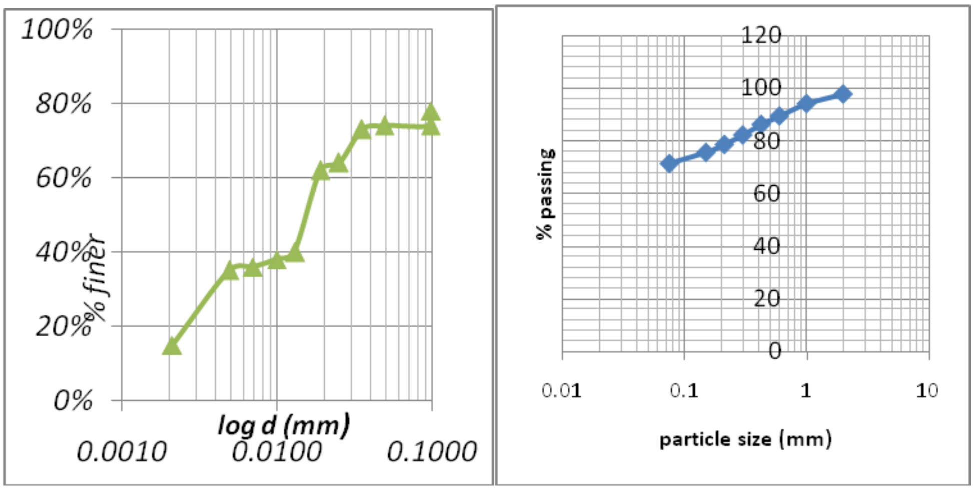

Figure 4.1 Typical grading curve for neat black cotton soil.

Similarly, the results of the red coffee soil are presented as Figure 4.2.

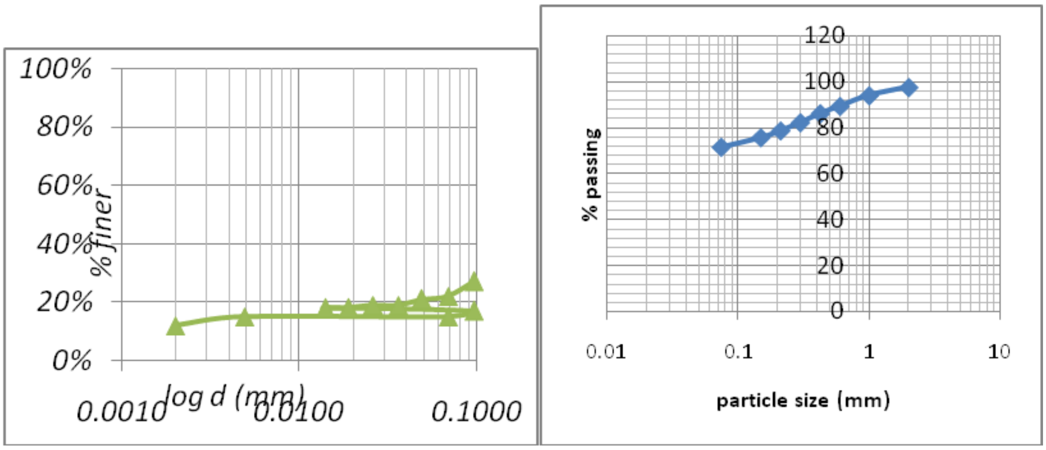

Figure 4.2 Typical grading curve for neat red coffee soil

Both soils were classified as silty CLAY.

4.3.3 Atterberg Limits

4.3.3.1 Liquid limit

The liquid limit of the samples was determined using cone penetrometer method. The data was recorded and presented as Figures 4.2 and 4.3 for the black cotton soil and red coffee soil respectively.

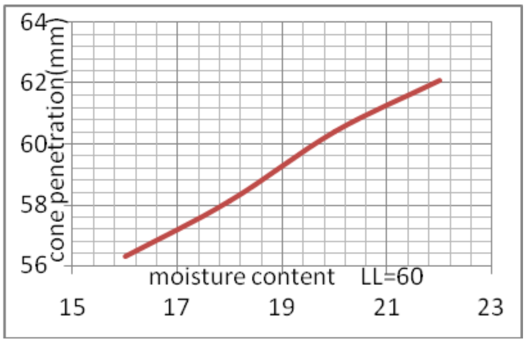

Figure 4.3 Liquid limit for neat black cotton soil

4.3.3.2 Plastic limit

This is the moisture content at which the soil becomes dry to be plastic. The test was carried on a disturbed soil sample dried at room temperature and the gravel passed through 0.425mm sieve.

Table 4.3 plastic limit test- black cotton soil

A (Wet+Tin)	B (Dry+Tin)	C (Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%
35.4	34.4	30.8	1	3.6	27.78
37	35.8	31.8	1.2	4	30
		A V E R A G E Plastic Limit			29

4.3.3.3 Plasticity index

Plasticity index is calculated from the equation, Plasticity index (PI)

PI = LL – PL = 60-29 =31%

4.3.3.4 Linear shrinkage

It was calculated from the equation:

Half of P.I. = 31/2 = 15.5%

or Linear Shrinkage = $(1 – L_d/L_o)\times100\%$

LS = (20mm/140) ×100=14.3%

Where:

L_o – length of sample before oven drying=length of shrinkage mould

L_d– length of sample after oven drying.

4.3.3.5 Statistical Evaluation of Results

Table 4.4 Typical Comparison of Properties of Virgin and Treated black cotton soil

Properties of neat Soil at 0%	Properties of improved soil at 10%	Percentage Change at 10%
• LL = 60% • PL = 29% • PI = 31% • LS = 14.3% • MDD=1255Kg/ m^3 OMC=26.5% • CBR= 1	• LL = 44% • PL = 22% • PI = 22% • LS = 11% • MDD=1655Kg/ m^3 • OMC=13.8% • CBR= 8	• LL =26% • PL =25% • PI =29% • LS =23% • MDD=32% • OMC=48% • CBR= 700%

Observation:

The following is mathematically correct for all but CBR:-

- Arithmetic Mean =30.5% That is; A=1/6[26+25+29+23+32+48]
- Harmonic Mean = 29% That is;
- 1/H =1/6[1/26+1/25+1/29+1/23+1/32+1/48]
- Standard Deviation=2.28 That is; S.D. = $\sigma = \frac{\{\sum(X-x)2\}^{1/2}}{N}$

From the Atterberg Limits, it is possible to determine KARL PEARSON'S COEFFICIENT OF CORRELATION between neat soil and 10% treated soil :-

Where r between two variables x and y are defined by the relation,

$r = \frac{\sum XY}{[(\sum X^2)(\sum Y^2)]^{1/2}}$ where $X=\bar{x}$-x, $Y=\bar{y}$-y that is, X and Y are the deviations measured from their respective means.

Table 4.5: Mean of Atterbergs: at 0% = 33.6x, at 10% = 30.5y

x	y	X=x-33.6	Y=y-30.5	X^2	Y^2	XY
60	44	26.4	13.5	696.96	182.25	356.4
29	22	-4.6	-8.5	21.16	72.25	39.1
31	22	-2.6	-8.5	6.76	72.25	22.1
14.3	11	-19.3	-19.5	372.49	380.25	376.35
134.3	99	-0.1	-23	1,097.37	707	793.95

Here $\sum X^2$= 1,097, $\sum X^2$=707, $\sum XY$ = 793.95

$r = \frac{\sum XY}{[(\sum X^2)(\sum Y^2)]^{1/2}} = \frac{793.95}{(1097.37 \times 707)^{1/2}} = \frac{793.95}{880.82}$ = 0.9 *perfectcorrelation!*

Therefore, r = 0.9 confirms a very high (perfect) correlation between change of soil parameters upon application of used lube oil at 10% replacement (Dass & Rajnish, 2014).

Table 4.7 Typical Comparison of Properties of Virgin and Treated Red Coffee Soil

Properties of neat Soil at 0%	Properties of improved soil at 10%	Percentage Change at 10%
• LL = 60%	• LL = 44%	• LL =26%
• PL = 29%	• PL = 22%	• PL =25%
• PI = 31%	• PI = 22%	• PI =29%
• LS = 14.3%	• LS = 11%	• LS =23%
• MDD=1255Kg/m^3	• MDD=1655Kg/m^3	• MDD=32%
OMC=26.5%	• OMC=13.8%	• OMC=48%
• CBR= 1	• CBR= 8	• CBR= 700%

Observation:

The following is mathematically correct for all but CBR:-

- Arithmetic Mean =30.5% That is; A=1/6[26+25+29+23+32+48]
- Harmonic Mean = 29% That is; 1/H =1/6[1/26+1/25+1/29+1/23+1/32+1/48]
- Standard Deviation=2.28 That is; S.D. = σ = $\frac{\{\sum(X-x)2\}^{1/2}}{N}$

From the Atterberg Limits it is possible to determine KARL PEARSON'S COEFFICIENT OF CORRELATION between neat soil and 10% treated soil :-

Where r between two variables x and y is defined by the relation,

r = $\frac{\sum XY}{[(\sum X^2)(\sum Y^2)]^{1/2}}$ where X=$\bar{x}$-x, Y=$\bar{y}$-y that is, X and Y are the deviations measured from their respective means.

Table 4.8: Mean of Atterbergs: at 0% = 33.6x, at 10% = 30.5y

x	y	X=x-33.6	Y=y-30.5	X^2	Y^2	XY
60	44	26.4	13.5	696.96	182.25	356.4
29	22	-4.6	-8.5	21.16	72.25	39.1
31	22	-2.6	-8.5	6.76	72.25	22.1
14.3	11	-19.3	-19.5	372.49	380.25	376.35
134.3	99	-0.1	-23	1,097.37	707	793.95

Here $\sum X^2 = 1{,}097$, $\sum X^2 = 707$, $\sum XY = 793.95$

$$r = \frac{\sum XY}{[(\sum X^2)(\sum Y^2)]^{1/2}} = \frac{793.95}{(1097.37 \times 707)^{1/2}} = \frac{793.95}{880.82}$$ = **0.9 *perfect*** *correlation!*

Therefore, r = 0.9 confirms a very high (perfect) correlation between change of soil parameters upon application of used lube oil at 10% replacement (Dass and Rajnish, 2014).

4.3.4 Effect of Waste Lube Oil on Engineering Properties

The Atterberg limits and permeability tests were carried out on soils containing waste lube oil. The amount of used oil ranged between 0% and 20% and was increased at step percentages of 5%.

4.3.4.1 Atterberg Limits

The results for Atterberg limits with used lube oil treatment levels of 5% - 20% are presented in Table 4.4 for the black cotton and the red clay soils.

Table 4.10 Effect of used lube oil on Atterberg Limits for BC

Used Lube Oil (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)
		Black Cotton Soil		
0	60	29	31	14
5	82	41	41	21
10	44	22	22	11
15	83	39	44	21
20	74	27	47	24
		Red Coffee Soil		
0	66	26	30	15
5	54	26	28	14
10	51	29	22	11
15	39	21	18	9
20	43	26	17	8

The liquid limit, plastic limit and linear shrinkage exhibit variations with increase in used lube oil contents.

From the table of results for the black cotton soil liquid limit reduces to a minimum at 10% used lube oil application and so does plastic limit giving a minimum plasticity index overall, suggesting that at this percentage the soil is less plastic and so is linear shrinkage suggesting the minimum amount of used lube oil at which no further volumetric changes take place in the soil. The soil is thus medium plastic (15-30) at 10% used lube oil replacement.

From the table of results for red coffee soil the liquid limit reduces to a minimum between 10% and 15% and so does plastic limit. Despite a minimum plasticity index and linear shrinkage being a minimum at 20% the differences are minimal and the characteristics substantially correlate with those of the black cotton soil.The soil is thus medium plastic (15-30)at 10% used lube oil replacement.

4.3.4.2 Permeability

The results for the coefficient of permeability are presented in Table 4.12.4.4The results show a general improvement in permeability with increase in the amount of used lube oil added. This trend is maintained for the black cotton soil but it reaches a peak in the case of the red coffee soil at about 10% lube oil content.

Table 4.12Average coefficient of permeability for research soils

Percentage Lube Oil	Average Coefficient of Permeability (k) in m/sec	
	Black Cotton Soil	Red Coffee Soil
0%	0.048×10^{-7}	1.072×10^{-7}
5%	1.57×10^{-7}	2.76×10^{-7}
10%	1.97×10^{-7}	5.93×10^{-7}
15%	2.93×10^{-7}	4.91×10^{-7}
20%	3.73×10^{-7}	2.23×10^{-7}

4.3.5 Compaction Test

This test was done to establish maximum dry density (MDD) and optimum moisture content (OMC) of the material by graphical data analysis and representation. The present moisture content (PMC) for this test was determined like the ordinary moisture content test.

4.3.5.1 Proctor Compaction Test

The standard Proctor method was adopted. The results obtained were recorded and illustrated in graphs as shown in Figure 4.4 for the black cotton soil.

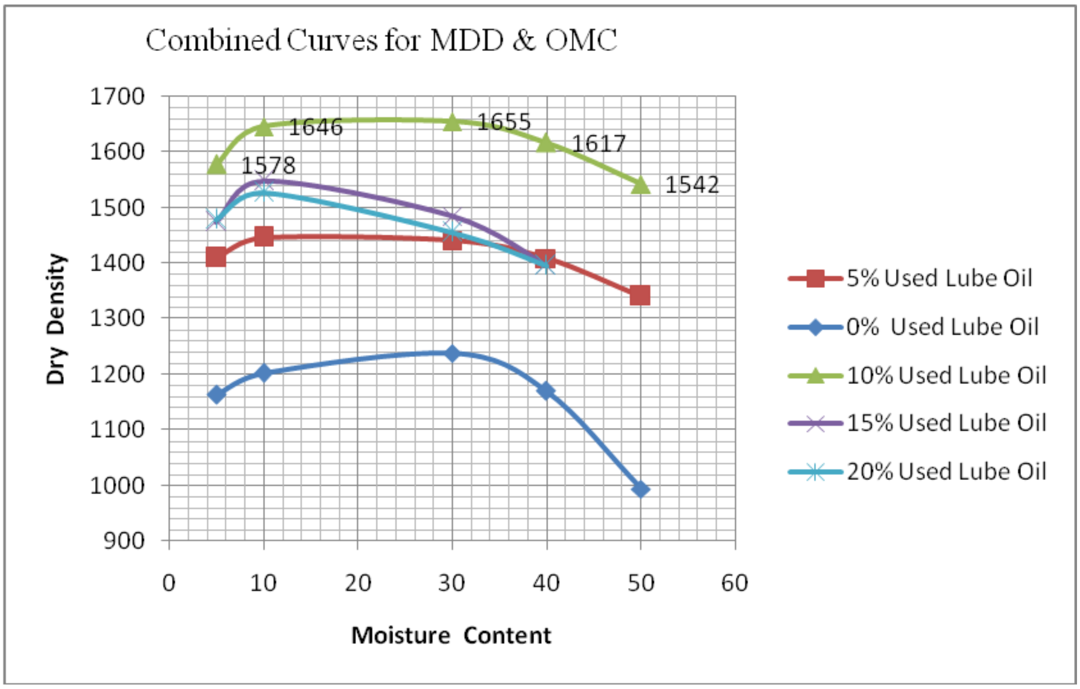

Figure 4.4 combined results for proctor analysis for black cotton soil

All the compaction results are also summarized and presented as in Table 4.13. The change in maximum dry density and optimum moisture content was noted in every change in Used Lube Oil content. Graphical analysis was done for every combination to illustrate the comparative effect of Used Lube Oil on black cotton and the red coffee soils.

Table 4.13Compaction results for research soils

Percentage Lube Oil	Black Cotton Soil		Red Coffee Soil	
	MDD	OMC	MDD	OMC
0%	1240	32.5	1220	34
5%	1450	15.5	1440	20
10%	1658	14.8	1523	16.8
15%	1555	9.5	1490	14.2
20%	1530	8.5	1425	12.6

The result shows the variation of OMC and MDD with increasing contents of Used Lube Oil. The results for both the black cotton soil and the red coffee soil show that the MDD increased with lube oil content whereas the OMC dropped.

The variation is attributed to the replacement of soil by Used Lube Oil in the mixture which has relatively different physical properties compared to that of the virgin soil.

It may also be attributed to the coating of the soil by the Used Lube Oil which results to large particles with larger voids and hence variation in density.

However, the MDD reached a peak value at about 10% of used lube oil content and then dropped as the OMC continued to fall. The MDD reduces because of the dispersion caused by the increased used lube oil. Figure 4.5 illustrates the variation in MDD with used lube oil content for the black cotton soil.

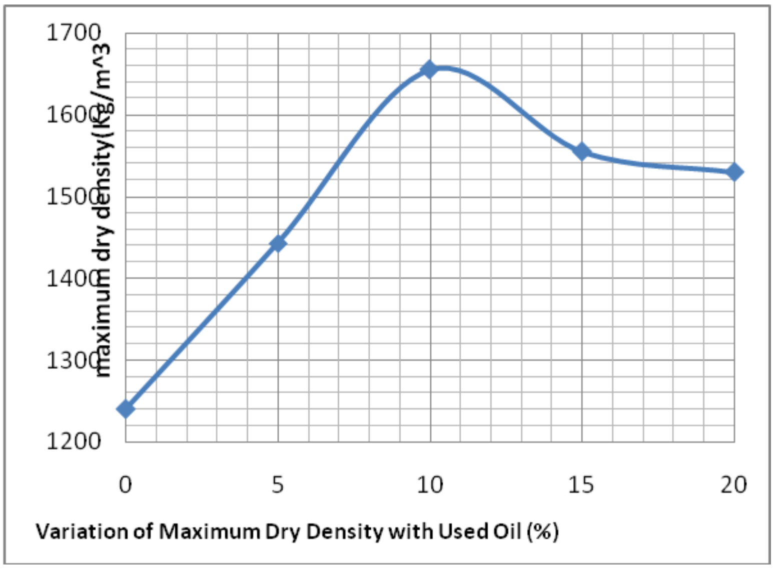

Figure 4.5 variation of maximum dry density with Used Lube Oil

The OMC varies within a certain range as shown in Figure 4.5. This trend may be attributed to the addition of Used Lube Oil which alters the quantity of free silt and clay fraction and forming coarser materials with larger surface areas (these processes need water to take place).

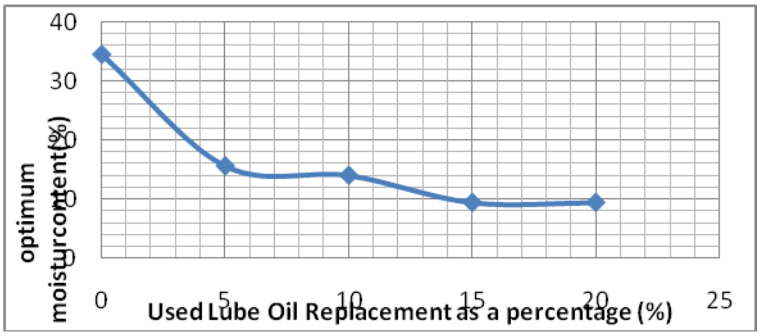

Figure 4.6 variation of OMC with Used Lube Oil

This may also suggest that water or more of it is needed in order to compact the soil-Used Lube Oil mixtures.

4.3.6 Dynamic CBR Test

The test was done on soils whose maximum particle size was 20mm. It was carried out to determine the strength of both the black cotton and the red coffee soils. This was obtained from the relationship between force and penetration when a standard cylindrical plunger was made to penetrate the soil at a given rate. The results obtained were recorded and the graphical analysis done.

The CBR results for the black cotton and the red coffee soils are presented in Table 4.14.

Table 4.14 CBR results for black cotton and red soils

Percentage Lube Oil	Black Cotton Soil	Red Coffee Soil
	CBR (%)	CBR (%)
0%	1	5
5%	3	9
10%	8	14
15%	6	10
20%	5	8

The results show that the CBR value of the black cotton soil varies with content of used lube oil. For the black cotton soil, this increases up to a value of 8 at 10% used lube oil replacement as illustrated in Figure 4.14. The reason for variation in CBR may be because of the gradual formation of bond in the soil by Used Lube Oil.

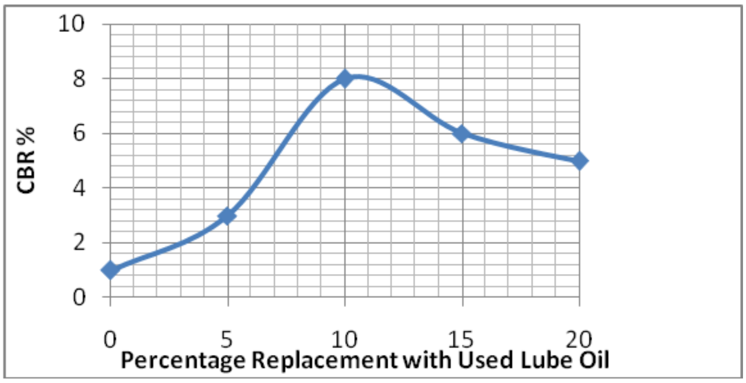

Figure 4.7 Variation of CBR for black cotton with used lube oil

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The chapter presents the conclusions that were drawn from the study and recommendations for further research.

5.1.1 Oil Viscosity

The dynamic viscosity and density of the used lube oil was determined at 50°Cto be 55mPa.s. and 800 kg/m^{3}respectively.

5.1.2 Soil Properties

From the table of results for the black cotton soil liquid limit reduces to a minimum at 10% used lube oil application and so does plastic limit giving a minimum plasticity index overall, suggesting that at this percentage the soil is less plastic and so is linear shrinkage suggesting the minimum amount of used lube oil at which no further volumetric changes take place in the soil. The soil is thus medium plastic (15-30) at 10% used lube oil replacement.

From the table of results for red coffee soil the liquid limit reduces to a minimum between 10% and 15% and so does plastic limit. Despite a minimum plasticity index and linear shrinkage being a minimum at 20% the differences are minimal and the characteristics substantially correlate with those of the black cotton soil.The soil is thus medium plastic (15-30)at 10% used lube oil replacement.

The liquid and plastic limits decreased with increase in used lube oil content up to 10%. As the percentage of used lube oil increased, the liquid limit and plasticity index increased while the plastic limit decreased and thus the oil is thought to cause an inter-layer expansion within the clay minerals, which may have accounted for the change in its plasticity and hence affecting the workability of the soil.

Used oil treatment gives enhanced consistency results compared with the standard results where Liquid Limit is 75 and Plastic Limit 35.

The maximum dry density (MDDfor black cotton soil and red coffee soil increased up to 1658 kg/$m^3$and 1523 kg/m^3 respectively at 10% used lube oil content. However, the OMC decreased with increased used lube oil content, so that OMC for the black cotton and red coffee soils were 14.8% and 16.8% respectively at 10% lube oil content.

Used lube oil gives enhanced results compared with the standard of 1560kg/m^3 at 20.10% OMC

The CBR results showed that the CBR value of black cotton soil increased from 1% to 8% with increased used lube oil content of 10%. For the red coffee soil, the CBR value increased to 14% for the same percentage replacement with used lube oil. This was due to the improved properties that caused improvement of the load bearing capacity of both soils.

Thus used lube oil treatment results in improved CBR as compared to the standard which is 3%.

The optimal values of the soils for Atterberg limits, compaction tests, California bearing ratio tests and permeability tests were obtained at the used lube oil content of 10%. For pure bitumen, this is usually at 4% content.

The permeability(k) of both black cotton soil and red coffee soil increased with the addition of used lube oil. At 10% used lube content k was $1.97\text{x}10^{-7}$m/sec and $5.93\text{x}10^{-7}$m/sec for black cotton and red coffee soils respectively.The standard permeability is 10^{-7}m/sec and therefore used lube oil treatment makes the soils more impermeable and hence restricts water ingress.

Karl Pearson's statistical coefficient of correlation r = 0.9 confirms a very high (perfect)correlation between change of soil parameters upon application of used lube oil at 10% replacement and so would the red coffee soil from the tabulated test results.

5.2 Recommendations

i. Foundations on black cotton and red coffee soils with enhanced stabilization based on extensive studies can be safe.

ii. Collaborative research work on diverse soil samples should be done to augment and corroborate the findings in this research.

iii. It is recommended that these findings be implemented as trial in selected roads

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APPENDICES

APPENDIX 1 - VISCOSITY TEST

Red Wood Efflux Viscometer Test (ISO 9000) ASTM- D445-06)

Viscosity Test: Red Wood Viscometer No. 1-Universal (for less than 2000seconds)

The conversion constants for Red Wood time units are;

Constant A=0.26

Constant B=172

Kinematic Viscosity $\upsilon = A .t - B/t$ (c-st or mm^2/s)

Dynamic Viscosity from Kinematic Viscosity is obtained by:

$\eta = \upsilon .\rho.10^{-3}$

where:

η= dynamic viscosity,mPa.s

υ= kinematic viscosity,mm^2/s

ρ= density, kg/m^3at the same temperature (50^0C) used for the determination of the kinematic viscosity.

Viscosity is recorded as Red Wood seconds.

Computation:

Mass of lube oil in 50ml beaker = mass with oil – mass when empty=75grammes-35grammes=40grammes = 0.04kg

Volume=50ml= $0.00005m^3$

Therefore Density=Mass/Volume = 0.04/0.00005 = $800kg/m^3$

And Dynamic Viscosity is given by: $\eta = \upsilon .800.10^{-3}$

Table 1-1 Dynamic Viscosity Results

Test Run	Red Wood Seconds	Kinematic Viscosity (mm^2/s)	Dynamic Viscosity (mPa.s)
1	268	69	55.2
2	262	67.5	54
3	264	68	54.4
Average viscosity		**68.17**	**55**

APPENDIX 2 - PARTICLE SIZE DISTRIBUTION

A) BLACK COTTON SOIL

Appendix 1 Dry Sieve Analysis: weight of total <5mm material

Table 2-1 Dry Sieve Analysis: weight of total <5mm material

BS Sieve mm	Wt. retained gms	% of total<5 retained	% of total<5 passing	≈% of total<5 passing
5				
2	11.8	2.4	97.6	98
1	17.8	3.6	94.0	94.0
600µ	23.6	4.7	89.3	89.0
425 µ	16.2	3.2	86.1	86.0
300	20.0	4.0	82.1	82
212 µ	18.2	3.6	78.5	79
150 µ	15.3	3.0	75.5	76
75 µ	21.0	4.2	71.3	71
<75 µ	356.2	71.3	-	-
Total 5mm material		100%		

Wt of <5mm material taken=500.0gms

Total wt of >75 µ = 143.8gms

Wt of materials <75 µ = 356.2 gms

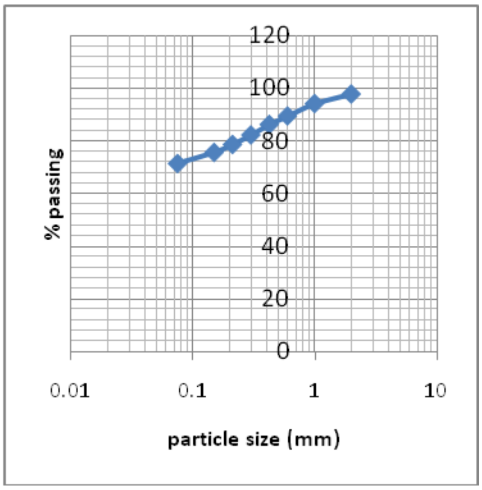


Figure 2-1 Dry Sieve Analysis

PERMEABILITY /HYDROMETER TESTS FOR BLACK COTTON SOIL

(0%,5%,10%,15% & 20%)

Table 2-2

<table>
<tr><td colspan="9">NEAT BLACK COTTON SOIL(0% USED LUBE OIL REPLACEMENT)</td></tr>
<tr><td colspan="5" rowspan="2"></td><td colspan="4">DEPTH</td></tr>
<tr><td colspan="4">LAB. NO.</td></tr>
<tr><td colspan="5">MINISTRY OF PUBLIC WORKS
MATERIALS DEPARTMENT-FOUNDATION SECTION</td><td colspan="4">SIGN.</td></tr>
<tr><td colspan="9">CROSS SECTION OF SPECIMEN A cm^2</td></tr>
<tr><td colspan="4" rowspan="7">HEIGHT OF SPECIMEN h cm
CROSS SECTION OF PLASTIC TUBE acm^2
HEIGHT OF MERCURY COLUMN H cm
MOVEMENT OF MERCURY COLUMN l cm
TIME FOR THE MOVEMENT t sec</td><td colspan="5">MOISTURE CONTENT</td></tr>
<tr><td>No.______</td><td>No. __</td><td colspan="3" rowspan="5"></td></tr>
<tr><td>ww____DT___</td><td>Ww__DT__</td></tr>
<tr><td>DW__TW___</td><td>DW_TW___</td></tr>
<tr><td>DW_WS__</td><td>DW__WS__</td></tr>
<tr><td>WO ________</td><td>WO ________</td></tr>
<tr><td colspan="5">AVE W =</td></tr>
<tr><td colspan="9"><u>CONSTANT HEAD</u>
COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN Ɣ= kN/m^3
=0.079 <u>ah1</u> $cm/_{sec}$ DRY DENSITY SPECIMEN yd= kN/m^3
AtH

<u>C_v</u>= 0.079
Ɣ$_{Hg}$ – yw</td></tr>
<tr><td>CELL PRESURE
6_3
Kg/cm^2</td><td>EVER AGE PORE
udv
Kg/cm^2</td><td>CONSOLIDATION PRESSURE
6_c
Kg/cm^2</td><td>BURETTE READING
Cm^3</td><td>EXPELLED PORE WATER
Cm^3</td><td>HEAD
H
cm</td><td>MOVEMENT OF HG
L
cm</td><td>TIME
t
sec</td><td>PERMIABILITY
K
Cm/sec</td></tr>
</table>

1	0		84		104		0	
			83		101		300	
			82		100		60	
			81		100		120	
			80		100		180	
			80		100		240	$0.048X10^{-7}$
3	2		84		104		0	
			83				300	
			83				60	
			82				120	
			82				180	
			81		101		240	$0.048X10^{-7}$
5	4		84		104		0	
			83				300	
			82				60	
			81				120	
			81				180	
			80		100		240	$0.048X10^{-7}$

$0.048X10^{-7}$

Table 2-3

BLACK COTTON SOIL AT **5%** LUBE OIL REPLACEMENT								
					DEPTH			
					LAB. NO.			
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION					SIGN.			
CROSS SECTION OF SPECIMEN				A cm^2				
HEIGHT OF SPECIMEN h cm CROSS SECTION OF PLASTIC TUBE acm^2 HEIGHT OF MERCURY COLUMN H cm MOVEMENT OF MERCURY COLUMN l cm TIME FOR THE MOVEMENT t sec				MOISTURE CONTENT				
				No.______	No. __			
				ww____D T___	Ww__ DT__			
				DW__ TW___	DW_ TW___			
				DW_ WS__	DW__ WS__			
				WO ________	WO ________			
				AVE W =				
CONSTANT HEAD COEFFICIENT OF PERMEABILITY BULK DENSITY SPECIMEN ƔIA= 1700kN/m^3 =0.079 ah1 cm/sec DRY DENSITY SPECIMEN Ɣd=1440kN/m^3 AtH C_v= 0.079 $Ɣ_{Hg}$ – yw								
CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
1	0		18.5		59.95	1.0	235	

			17.8			2.0	434	
			16.0			3.3	718	
			14.5			4.0	854	
						5.0	1075	
						6.0	1151	
						7.0	1620	$1.535 x10^{-7}$
3	2				58.5	1.0	85	
						2.0	195	
						3.0	285	
						4.0	210	
						5.0	506	$1.573 x10^{-7}$
4	3				58.0	1.0	90	
						2.0	200	
						3.0	280	
						4.0	385	
						5.0	509	$1.570 x10^{-7}$

$1.57x10^{-7}$

Table 2-4

BLACK COTTON SOIL AT **10%** LUBE OIL REPLACEMENT			
		DEPTH	
		LAB. NO.	
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION		SIGN.	
CROSS SECTION OF SPECIMEN A cm^2			
HEIGHT OF SPECIMEN h cm	MOISTURE CONTENT		
	No.______	No. __	
CROSS SECTION OF PLASTIC TUBE acm^2	ww____DT___	Ww__ DT__	

HEIGHT OF MERCURY COLUMN H cm	DW__ TW___	DW_ TW___	
MOVEMENT OF MERCURY COLUMN l cm	DW_ WS__	DW__ WS__	
TIME FOR THE MOVEMENT t sec	WO ________	WO ________	
	AVE W =		

CONSTANT HEAD

COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN Ϫ= Kn/m^3

=0.079 ah1 cm/sec DRY DENSITY SPECIMEN yd= Kn/m^3

AtH

C_v= 0.079

$Ϫ_{Hg}$ – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
1.0	0		19.0		59.0	1.0	82	
			15.0			1.0	83	
			13.0			1.0	97	
						1.0	97	
						1.0	97	$1.95x\ 10^{-7}$
3.0	2.0				58.0	0.1	22	
						0.1	22	
						0.1	21	
						0.1	22	$3.75x\ 10^{-7}$
5.0	4.0				57	0.1	14	

						0.1	15	
						0.1	15	
						0.1	15	1.35x 10^{-7}

1.97x10^{-7}

TABLE 2-5

<table>
<tr><td colspan="4">BLACK COTTON SOIL AT 15% LUBE OIL REPLACEMENT</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">DEPTH</td></tr>
<tr><td colspan="2">LAB. NO.</td></tr>
<tr><td colspan="2">MINISTRY OF PUBLIC WORKS
MATERIALS DEPARTMENT-FOUNDATION SECTION</td><td colspan="2">SIGN.</td></tr>
<tr><td colspan="4">CROSS SECTION OF SPECIMEN A cm^2</td></tr>
<tr><td rowspan="7">HEIGHT OF SPECIMEN h cm
CROSS SECTION OF PLASTIC TUBE acm^2
HEIGHT OF MERCURY COLUMN H cm
MOVEMENT OF MERCURY COLUMN l cm
TIME FOR THE MOVEMENT t sec</td><td colspan="3">MOISTURE CONTENT</td></tr>
<tr><td>No.______</td><td>No. __</td><td rowspan="5"></td></tr>
<tr><td>ww____D T___</td><td>Ww__ DT__</td></tr>
<tr><td>DW__ TW___</td><td>DW_ TW___</td></tr>
<tr><td>DW_ WS__</td><td>DW__ WS__</td></tr>
<tr><td>WO ________</td><td>WO ________</td></tr>
<tr><td colspan="3">AVE W =</td></tr>
<tr><td colspan="4"><u>CONSTANT HEAD</u>
COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN ϫ= kN/m^3
=0.079 <u>ah1</u> $cm/_{sec}$ DRY DENSITY SPECIMEN yd=kN/m^3</td></tr>
</table>

AtH

<u>C_v</u>= 0.079

$ɤ_{Hg}$ – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
1.0	0		18.1		58.8	1.50	120	
			17.1			1.60	120	
			17.0			1.70	120	
						1.60	120	
						5.0	200	
						5.0	200	
						5.0	200	4.69 x10^{-7}
3.0	2.0				58.8	5.0	15	
						5.0	33	
						5.0	36	
						5.0	44	
						5.0	45	
						5.0	46	2.04 x10^{-7}
5.0	4.0				58.0	5.0	38	
						5.0	41	
						5.0	41	
						5.0	4.	
						5.0	44	2.07 x10^{-}

								7

2.93x10^{-7}

Table 2-6

BLACK COTTON SOIL AT **20%** LUBE OIL REPLACEMENT	
	DEPTH
	LAB. NO.
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION	SIGN.
CROSS SECTION OF SPECIMEN A cm^2	

	MOISTURE CONTENT		
HEIGHT OF SPECIMEN h cm CROSS SECTION OF PLASTIC TUBE acm^2 HEIGHT OF MERCURY COLUMN H cm MOVEMENT OF MERCURY COLUMN l cm TIME FOR THE MOVEMENT t sec	No.______	No. __	
	ww____D T___	Ww__ DT__	
	DW__ TW___	DW_ TW___	
	DW_ WS__	DW__ WS__	
	WO ________	WO ________	
	AVE W =		

CONSTANT HEAD

COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN ϫ= kN/m^3

=0.079 ah1 cm/sec DRY DENSITY SPECIMEN yd= kN/m^3

AtH

C_v= 0.079

ϫ$_{Hg}$ – yw

CELL PRESURE 6_3	EVERAGE PORE udv	CONSOLIDATION PRESSURE 6_c	BURETTE READING	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG	TIME t sec	PERMIABILITY

Kg/cm^2	Kg/cm^2	Kg/cm^2	Cm^3			L cm		K Cm/sec
1	0		18.5		59.0	0.1	15.5	
			18.1			0.2	15.5	
			18.5			0.3	15.5	
						0.4	15.5	
						0.5	15.5	$5.8x10^{-7}$
3	2				58.3	0.1	22.5	
						0.2	22.5	
						0.3	22.5	
						0.4	22.5	$3.4x10^{-7}$
5	4				57.6	0.1	17.5	
						0.2	17.5	
						0.3	17.5	
						0.4	17.5	$4.45x10^{-7}$
7	6				57.1	0.1	37.5	
						0.2	37.5	
						0.3	37.5	
						0.4	37.5	$2.3x10^{-7}$

$1.2x10^{-7}$

B) RED COFFEE SOIL

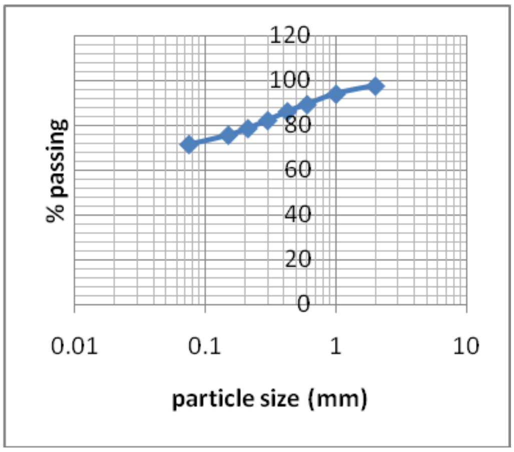


Figure 2-2 Typical grading (wet sieve) curve for Red Coffee soil (neat)

Hydrometer Tests

HYDROMETER TESTS FOR RED COFFEE SOIL(0%,5%,10%,15% & 20%)

Table 2-7

JOB:	RED COFFEE SOIL
SITE: KAKUMA SITE	
OPERATOR PAUL C.K.KIOKO	CHECKED BY
DATE: MAY,2013	
BORE HOLE NO.	DEPTH
SAMPLE NO. 447/13/F	
DESCRIPTION OF SAMPLE:	

CYLINDER NO. 2		
HYDROMETER NO. M.B. 109		
SPECIFIC GRAVITY OF PARTICLE (MEASURED/ASSUMED)	GS=	2.65

PERCENTAGE OF PARTICLE FINER THAN 200 MM K,	%
MENISCUS CORRECTION	CM = 0.4
DISPENSING AGENT CORRECTION	X = 4.0
CONTAINER NO.	
MASS OF CONTAINER = DRY SOIL	M_2 = 348.38
MASS OF CONTAINER	M_1 =291.48
MASS OF OVEN DRY SOIL AFTER PRETREATMENT	M = $M_2 - M_1$ =56.9
PERCENTAGE OF PARTICLE FINER THAN "D"	$K = \left[\frac{100\ GS}{M(GS-1)}\right] Rh + Mt - X)\ \% = 2.82$

TEMPERATURE T.C	
TEMPERATURE CORRECTION; Mt	

Mt: TEMPERATURE CORRECTION	Rh^1: HYDROMETER READING
D: PARTICLE DIAMETER IN mm	Rh: CORRECTED HYDROMETER READING

DATE	TIME	TEMP T^0 C	mt	ELAPSED TIME (MIN)	Rh^1	Rh= Rh^1 +CM	D (MM)	(Rh+ MT-X)	K (%)	% FINER $K.K_1$

										/100 %
				1						
				2						
				4						
	9:50			1/2	12	13.40	0.096	9.4	26.51	27
	9:51			1	11.5	11.40	0.069	7.9	22.28	22
	9:52			2	11.0	11.40	0.049	7.4	20.87	21
	9:54			4	10.5	10.90	0.036	6.9	19.46	19
	9:58			8	10.5	10.90	0.026	6.9	19.46	19
	10:05			15	10.0	10.40	0.019	6.4	18.05	18
	10:20			30	10.0	10.40	0.014	6.4	18.05	18
	10:50			60	9.5	9.90	0.0096	5.9	16.64	17
	11:50			120	9.0	9.40	0.0069	5.4	15.23	15
	01:50			240	9.0	9.40	0.0089	5.4	15.23	15
	9:50			24hrs	8.0	8.40	0.0020	4.4	12.41	12

HYDROMETER TEST GRAPH FOR NEAT RED COFFEE SOIL:

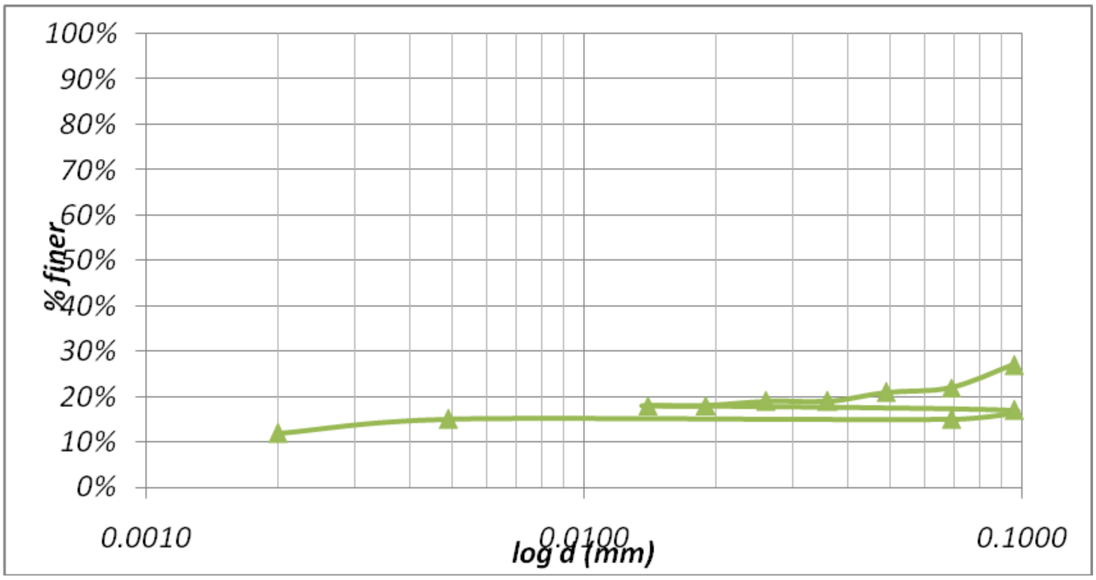


Figure 2-3

HYDROMETER PERMEABILITY TEST FOR RED COFFEE SOIL

Table 2-8

NEAT RED COFFEE SOIL(**0%** USED LUBE OIL REPLACEMENT)			
	DEPTH		
	LAB. NO.		
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION	SIGN.		
CROSS SECTION OF SPECIMEN A cm^2			
HEIGHT OF SPECIMEN h cm	MOISTURE CONTENT		
	No.______	No. __	
CROSS SECTION OF PLASTIC TUBE acm^2	ww____DT___	Ww__ DT__	
HEIGHT OF MERCURY COLUMN H cm	DW__ TW___	DW_ TW___	
MOVEMENT OF MERCURY COLUMN l cm	DW_ WS__	DW__ WS__	

TIME FOR THE MOVEMENT t sec	WO ________	WO ________	
	AVE W =		

<u>CONSTANT HEAD</u>

COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN γ= kN/m^3

=0.079 <u>ah1</u> cm/$_{sec}$ DRY DENSITY SPECIMEN yd= kN/m^3

AtH

<u>C$_v$</u>= 0.079

γ_{Hg} – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
1	0				147.9	0	0	
					"	0.3	8	
					"	0.7	15	
					"	1.0	30	
					"	1.4	60	
					"	2.4	120	
					"	4.5	240	
					139.7	8.2	480	1.345X10^{-7}
3	2				147.9	0	0	
						0.3	8	
						0.4	15	
						0.6	30	
						0.9	60	
						1.7	120	
						3.2	240	

					141.7	6.2	480	1.010X10^{-7}
5	4						0	
							8	
							15	
							30	
							60	
							120	
							240	
							480	8.0X10^{-8}

1.072X10^{-7}

TABLE 2-9

<table>
<tr><td colspan="4">RED COFFEE SOIL AT 5% USED LUBE OIL REPLACEMENT</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">DEPTH</td></tr>
<tr><td colspan="2">LAB. NO.</td></tr>
<tr><td colspan="2">MINISTRY OF PUBLIC WORKS
MATERIALS DEPARTMENT-FOUNDATION SECTION</td><td colspan="2">SIGN.</td></tr>
<tr><td colspan="4">CROSS SECTION OF SPECIMEN A cm^2</td></tr>
<tr><td rowspan="7">HEIGHT OF SPECIMEN h cm
CROSS SECTION OF PLASTIC TUBE acm^2
HEIGHT OF MERCURY COLUMN H cm
MOVEMENT OF MERCURY COLUMN l cm
TIME FOR THE MOVEMENT t sec</td><td colspan="3">MOISTURE CONTENT</td></tr>
<tr><td>No.______</td><td>No. __</td><td rowspan="5"></td></tr>
<tr><td>ww____DT___</td><td>Ww__ DT__</td></tr>
<tr><td>DW__ TW___</td><td>DW_ TW___</td></tr>
<tr><td>DW_ WS__</td><td>DW__ WS__</td></tr>
<tr><td>WO ________</td><td>WO ________</td></tr>
<tr><td colspan="3">AVE W =</td></tr>
</table>

CONSTANT HEAD

COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN Ɣ=19.35 kN/m^3

=0.079 ah1 cm/$_{sec}$ DRY DENSITY SPECIMEN yd=15.18 kN/m^3

AtH

C_v= 0.079

$Ɣ_{Hg}$ – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
100		100	20.7		57.6	2.0	120	3.19x 10^{-7}
			20.3		57.6	1.9	120	3.03x 10^{-7}
					57.6	1.9	120	3.03x 10^{-7}
300	200	300			57.0	2.1	120	3.39x 10^{-7}
						2.1	120	3.39x 10^{-7}
						2.2	120	3.55x 10^{-7}
500	400	500			56.2	1.8	120	2.29x 10^{-7}
						1.6	120	2.59x 10^{-7}
						1.5	120	2.43x 10^{-7}
700	600	700			55.5	1.5	120	2.46x 10^{-7}
						1.4	120	2.29x 10^{-7}

						1.6	120	2.60x 10^{-7}
900	800	900				1.2	120	1.99x 10^{-7}
						1.4	120	2.32x 10^{-7}
						1.3	120	2.15x 10^{-7}

2.76X10^{-7}

Table 2-10

RED COFFEE SOIL AT **10%** USED LUBE OIL REPLACEMENT			
	DEPTH		
	LAB. NO.		
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION	SIGN.		
CROSS SECTION OF SPECIMEN A cm^2			
HEIGHT OF SPECIMEN h cm CROSS SECTION OF PLASTIC TUBE acm^2 HEIGHT OF MERCURY COLUMN H cm MOVEMENT OF MERCURY COLUMN l cm TIME FOR THE MOVEMENT t sec	MOISTURE CONTENT		
	No.______	No. __	
	ww____DT___	Ww__ DT__	
	DW__ TW___	DW_ TW___	
	DW_ WS__	DW__ WS__	
	WO ________	WO ________	
	AVE W =		

CONSTANT HEAD

COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN
ϒ= kN/m^3

=0.079 ah1 cm/$_{sec}$ DRY DENSITY SPECIMEN
yd= kN/m^3

AtH

C_v= 0.079

$ϒ_{Hg}$ – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
100	0	100	21.5		60	0.8	60	2.45 x10^{-7}
			209		60	1.0	60	3.07 x10^{-7}
			20.7		60	0.9	60	2.76 x10^{-7}
			20.9	0.6				
3	2	3			59.5	1.7	60	5.26 x10^{-7}
					59.5	1.6	60	4.91 x10^{-7}
					59.5	1.8	60	5.57 x10^{-7}
5	4	5			59.5	2.3	60	7.11 x10^{-7}
					59.5	2.1	60	6.49 x10^{-7}
					59.5	2.2	60	6.80 x10^{-7}
7	6	7			59.0	2.9	60	9.04 x10^{-7}
					59.0	2.7	60	8.42

								x10^{-7}
					59.0	2.7	60	8.42 x10^{-7}
9	8	9			59.0	2.1	60	6.55 x10^{-7}
					59.0	2.0	60	6.24 x10^{-7}
					59.0	1.9	60	5.93 x10^{-7}

5.93X10^{-7}

Table 2-11

RED COFFEE SOIL AT **15%** USED LUBE OIL REPLACEMENT			
	DEPTH		
	LAB. NO.		
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION	SIGN.		
CROSS SECTION OF SPECIMEN A cm^2			
HEIGHT OF SPECIMEN h cm CROSS SECTION OF PLASTIC TUBE acm^2 HEIGHT OF MERCURY COLUMN H cm MOVEMENT OF MERCURY COLUMN l cm TIME FOR THE MOVEMENT t sec	MOISTURE CONTENT		
	No.______	No. __	
	ww____D T___	Ww__ DT__	
	DW__ TW___	DW_ TW___	
	DW_ WS__	DW__ WS__	
	WO ________	WO ________	
	AVE W =		

CONSTANT HEAD

COEFFICIENT OF PERMEABILITY BULK DNSITY SPECIMEN ϒ= kN/m^3

=0.079 ah1 cm/sec DRY DENSITY SPECIMEN yd= kN/m^3

AtH

C_v= 0.079

$ϒ_{Hg}$ – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
1	0	1	20.0		60	1.0	60	$3.07x10^{-7}$
			20.9		60	0.9	60	$2.76x10^{-7}$
			20.8		60	0.9	60	$2.76x10^{-7}$
						1.6	60	$4.91x10^{-7}$
3	2	3				1.6	60	$4.91x10^{-7}$
						1.7	60	$5.26x10^{-7}$
						1.9	60	$5.93x10^{-7}$
5	4	5				2.0	60	$6.24x10^{-7}$
						1.9	60	$5.93x10^{-7}$
						1.6	60	$4.91x10^{-7}$

7	6	7				1.7	60	5.26x10^{-7}
						1.9	60	5.93x10^{-7}
						1.6	60	4.91x10^{-7}
9	8	9				1.6	60	4.91x10^{-7}
						1.9	60	5.93x10^{-7}

4.91X10^{-7}

Table 2-12

RED COFFEE SOIL AT **20%** USED LUBE OIL REPLACEMENT			
	DEPTH		
	LAB. NO.		
MINISTRY OF PUBLIC WORKS MATERIALS DEPARTMENT-FOUNDATION SECTION	SIGN.		
CROSS SECTION OF SPECIMEN A cm^2			
HEIGHT OF SPECIMEN h cm CROSS SECTION OF PLASTIC TUBE acm^2 HEIGHT OF MERCURY COLUMN H cm MOVEMENT OF MERCURY COLUMN l cm TIME FOR THE MOVEMENT t sec	MOISTURE CONTENT		
	No.______	No. __	
	ww____DT___	Ww__ DT__	
	DW__ TW___	DW_ TW___	
	DW_ WS__	DW__ WS__	
	WO ________	WO ________	
	AVE W =		

CONSTANT HEAD

COEFFICIENT OF PERMEABILITY

BULK DNSITY SPECIMEN

ϫ= kN/m^3

=0.079 ah1 cm/$_{sec}$

DRY DENSITY SPECIMEN

yd= kN/m^3

AtH

C_v= 0.079

ϫ$_{Hg}$ – yw

CELL PRESURE 6_3 Kg/cm^2	EVERAGE PORE udv Kg/cm^2	CONSOLIDATION PRESSURE 6_c Kg/cm^2	BURETTE READING Cm^3	EXPELLED PORE WATER Cm^3	HEAD H cm	MOVEMENT OF HG L cm	TIME t sec	PERMIABILITY K Cm/sec
1.0	0	1.0	20.3		61	4	420	1.73 X 10^{-7}
			20.3		61	4.2	480	1.59 X 10^{-7}
					61	2.3	480	1.71 X 10^{-7}
2.0	1.0	2.0			61	10	89	
					61	13	428	2.52 X 10^{-7}
					61	8	480	3.03 X 10^{-7}
					61	18	1620	2.02 X 10^{-7}
4.0	3.0	4.0			60.7	5	1038	2.48 X 10^{-7}
					60.7	29	423	2.38

								X 10^{-7}
					60.7	10	360	2.40 X 10^{-7}
					60.7	10	660	2.77 X 10^{-7}
6.0	5.0	6.0			60	5	780	2.34 X 10^{-7}
					60	7	715	2.36 X 10^{-7}
					60	5	1025	2.14 X 10^{-7}
8.0	7.0	8.0			59.4	10	904	2.03 X 10^{-7}
					59.4	10	4606	2.10 X 10^{-7}
					59.4	6	3908	2.15 X 10^{-7}

2.23X10^{-7}

APPENDIX 3 - ATTERBERG LIMITS

Liquid Limit (LL), Plastic Limit(PL) and Plasticity Indices(PI) at **0% oil.**

Table 3-1 Liquid Limit

A(WET+TIN)	B(DRY+TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%
68.2	54.8	31	13.4	23.8	56.30252
69.2	54.8	30	14.4	24.8	58.06452
73.2	56.4	28.6	16.8	27.8	60.43165
77.4	61	34.6	16.4	26.4	62.12121
AVERAGE Liquid Limit(L.L)					60

Table 3-2 Plastic Limit

A(WET+TIN)	B(DRY+TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%
35.4	34.4	30.8	1	3.6	27.77778
37	35.8	31.8	1.2	4	30
AVERAGE Plastic Limit					29

P.I. =31

Liquid Limit (LL),Plastic Limit(PL) and Plasticity Indices(PI) at 5% oil.

Table 3-3 Liquid Limit

Cone Penetration	A(WET+TIN)	B(DRY+TIN)	C(Tin w
15.2mm	87.8	63.2	32

16.9mm	78	55.6	2
19.3mm	73	53.4	2
21.4mm	84.8	60	3
	A V E R A G E Liquid Limit(		

Table 3-4 Plastic Limit

A(WET +TIN)	B(DRY +TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C) %
33	32.4	30.8	0.6	1.6	37.5
34.8	34	32.2	0.8	1.8	44.4
A V E R A G E Plastic Limit					41.0

P.I. =31 L.S. =21

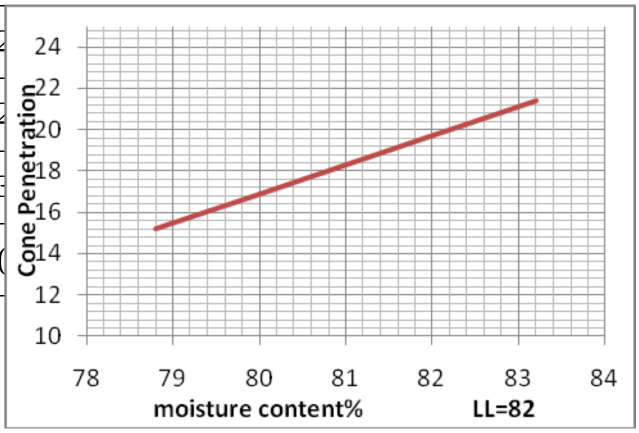


Fig. 3-1 Liquid Limit - 5% Used Lube Oil (PL=41,PI=41,LS=21)

Liquid Limit at 10% Used Lube Oil treatment

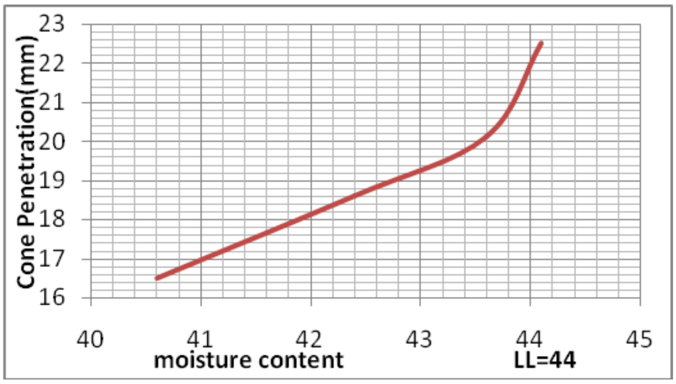
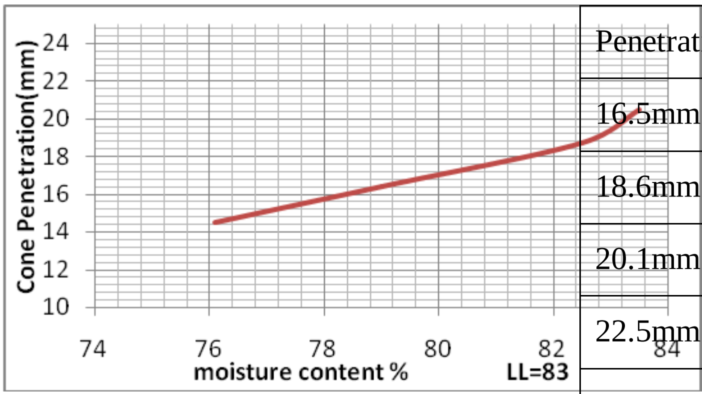


Figure 3-2 Liquid Limit - 10% Used Lube Oil (PL=22, PI=22, LS=11)

Liquid Limit at 15% Used Lube Oil treatment

Penetration	+TIN)	N)	
16.5mm	84.0	63.0	28.6
18.6mm	75.6	62.2	28.7
20.1mm	82.0	66.4	30.6
22.5mm	81.2	66.6	32.2
	A V E R A G E Liquid Limit(L.L)		



Fgure 3-3 Liquid Limit - 15% Used Lube Oil (PL=39,PI=44,LS=21)

Liquid Limit at 20% Used Lube Oil treatment

Liquid limit

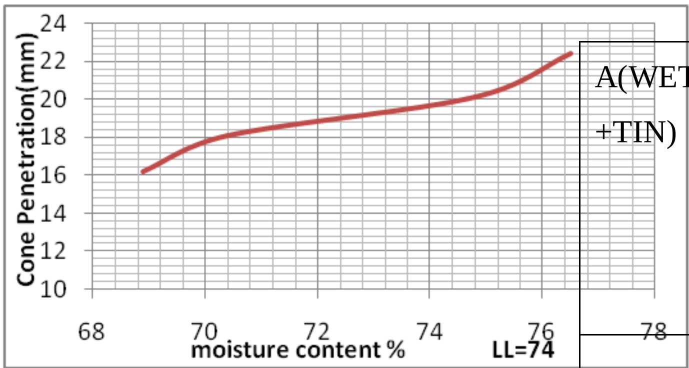


Figure 3-4 Liquid Limit - 20% Used Lube Oil (PL=27,PI=47,LS=24)

Liquid Limit(LL),Plastic Limit(PL) and Plasticity Indices(PI) at**10% oil.**

Table 3-6 Plastic Limit

A(WET +TIN)	B(DRY +TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%
42.4	40.4	21.8	2.0	8.6	23.3
41.2	39.2	29.8	2.0	9.4	21.3
A V E R A G E Plastic Limit					22.3

P.I. =22 L.S. =11

Table 3-5 Liquid Limit

Cone	A(WET	B(DRY+TI	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%

Liquid Limit(LL),Plastic Limit(PL) and Plasticity Indices(PI) at **15% oil.**

Table 3-7 Liquid Limit

Cone Penetration	A(WET +TIN)	B(DRY+TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C)%
14.5mm	86.0	61.2	28.6	24.8	32.6	76.1
16.4mm	72.2	53.4	29.6	18.8	23.8	79.0
18.7mm	67.8	50.8	30.2	17.0	20.6	82.5
20.5mm	70.8	51.6	28.6	19.2	23.0	83.5
	A V E R A G E Liquid Limit(L.L)					83

Table 3-8 Plastic Limit

A(WET +TIN)	B(DRY +TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C) %
45.4	41.2	30.0	4.2	11.2	37.8
39.0	36.4	30.0	2.6	6.4	40.6
A V E R A G E Plastic Limit					39

P.I. =44 L.S. =21

Liquid Limit(LL),Plastic Limit(PL) and Plasticity Indices(PI) at**20% oil.**

Table 3-9 Liquid Limit

Cone Penetration	A(WET +TIN)	B(DRY+TIN)	C(Tin wt)			%
16.2mm	71.2	54.8	31.0	16.4	23.8	68.9
18.1mm	76.0	57.0	30.0	19.0	29.0	70.4
20.1mm	66.8	51.4	29.6	15.4	20.6	74.8
22.4mm	71.6	53.4	30.2	18.2	23.8	76.5
	A V E R A G E Liquid Limit(L.L)					83

Table 3-10 Plastic Limit

A(WET +TIN)	B(DRY +TIN)	C(Tin wt)	(A-B)	(B-C)	(A-B)/(B-C) %
	40.4	21.8	2.0	8.6	23.3
	39.2	29.8	2.0	9.4	21.3
A V E R A G E Plastic Limit					39

P.I. =47 L.S. =24

APPENDIX 4 - COMPACTION

COMPACTION – BLACK COTTON

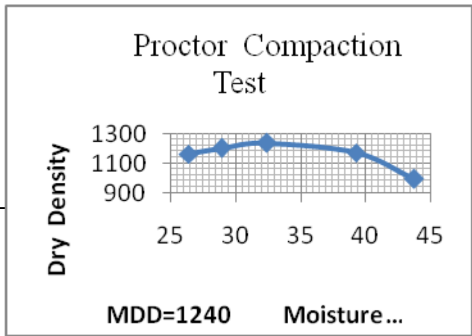


Fig 4-1 proctor analysis for black cotton soil at 0% Lube Oil

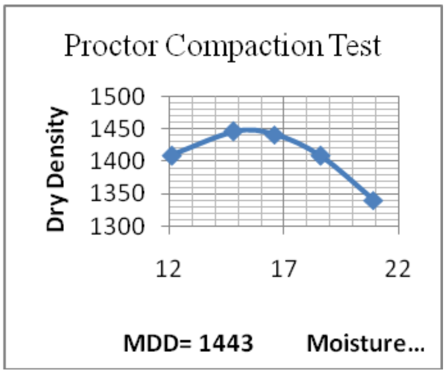


Fig. 4-2 proctor analysis for black cotton soil at 5% Lube Oil

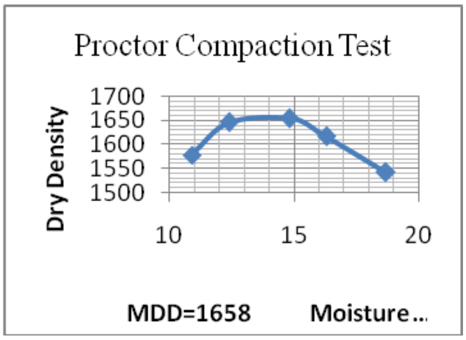


Fig. 4-3 proctor analysis for black cotton soil at 10% Lube Oil

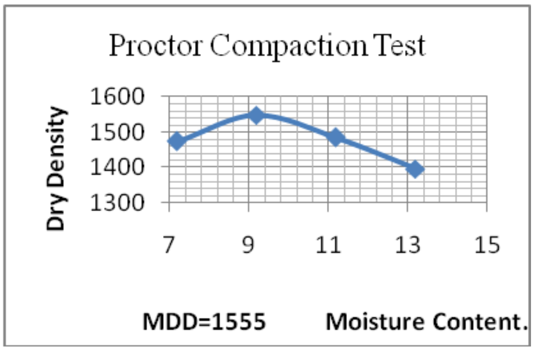


Fig. 4-4 proctor analysis for black cotton soil at 15% Lube Oil

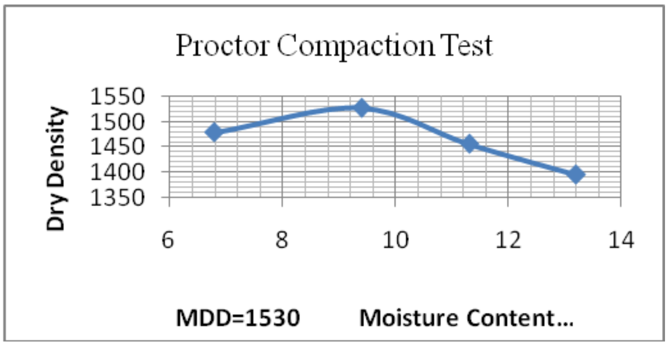


Fig. 4-5 proctor analysis for black cotton soil at 20% Lube Oil

Curves Summarised

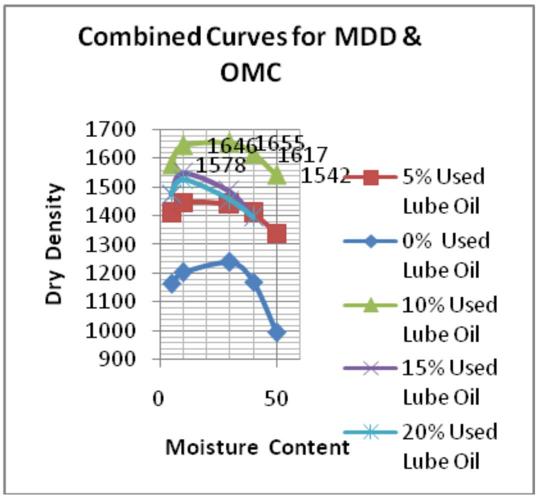


Fig. 4-6 combined results for proctor analysis for black cotton soil

COMPACTION/MAXIMUM DRY DENSITY –RED SOIL

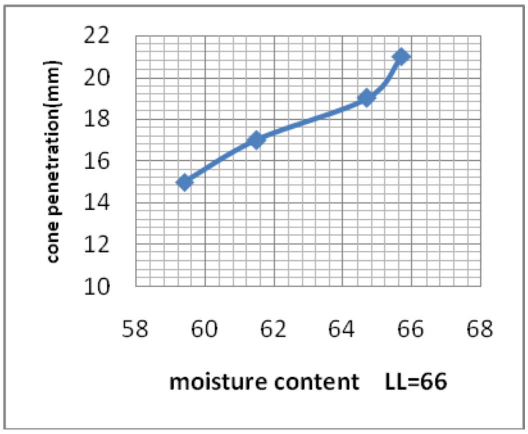


Fig. 4-7 liquid limit for neat red coffee soil 0% (PL=26,PI=30,LS=15)

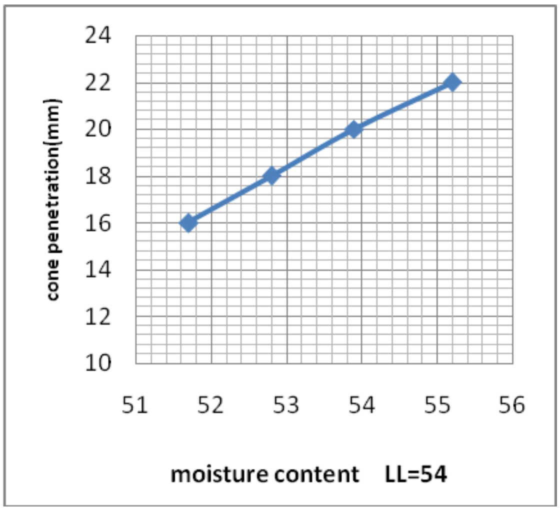


Fig. 4-8 liquid limit for red coffee soil 5%(PL=26,PI=28,LS=14)

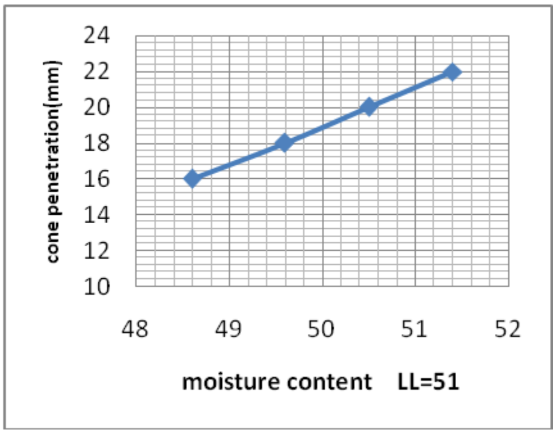


Fig. 4.9 liquid limit for red coffee soil 10%(PL=29,PI=22,LS=11)

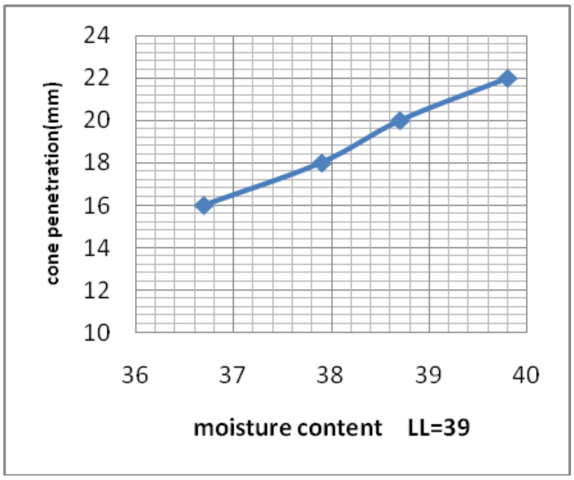


Fig. 4-10 liquid limit for red coffee soil 15%(PL=21,PI=18,LS=9)

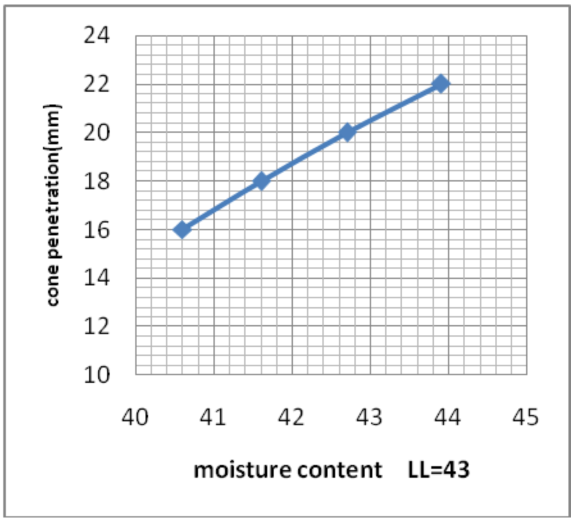


Fig. 4-11 liquid limit for red coffee soil 20%(PL=26,PI=17,LS=8)

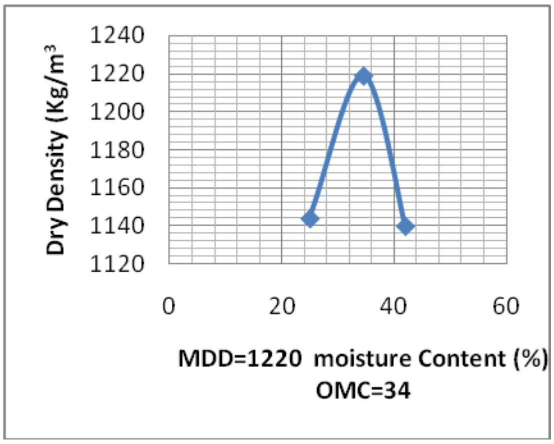


Fig. 4-12 proctor analysis for Red coffee soil at 0% Lube Oil

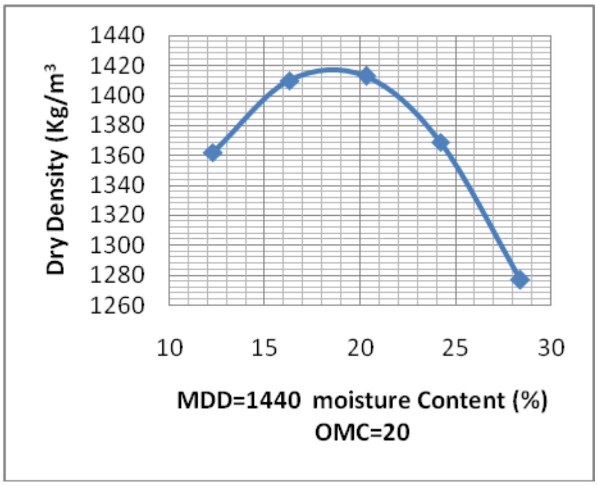


Fig. 4-13 proctor analysis for Red coffee soil at 5% Lube Oil

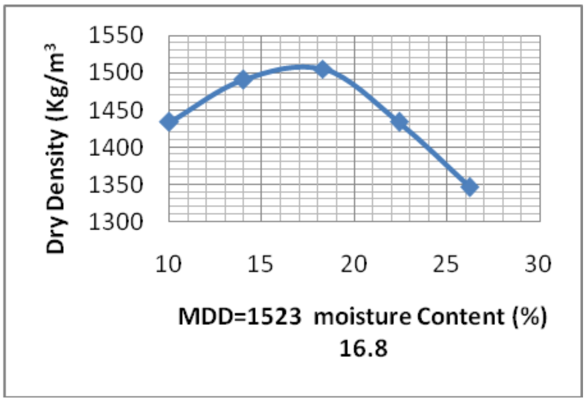


Fig. 4-14 proctor analysis for Red coffee soil at 10% Lube Oil

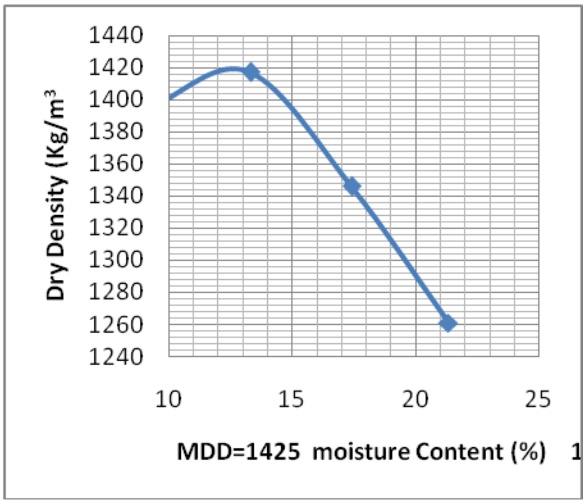


Fig. 4-16 proctor analysis for Red coffee soil at 20% Lube Oil

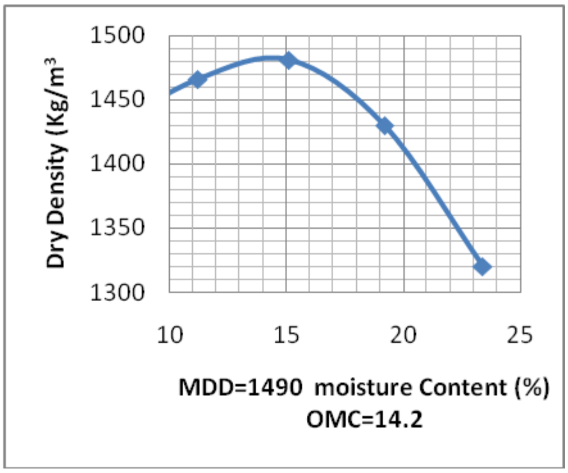


Fig. 4-15 proctor analysis for Red coffee soil at 15% Lube Oil

APPENDIX 5 - PERMEABILITY

Table 5-1 Permeability: Black Cotton Soil

Percentage Lube Oil Replacement	Average Coefficient of Permeability(k)
0%	0.048×10^{-7}
5%	1.57×10^{-7}
10%	1.97×10^{-7}
15%	2.93×10^{-7}
20%	3.73×10^{-7}

Table 5-2 Permeability: Red Coffee Soil

Percentage Lube Oil Replacement	Average Coefficient of Permeability(k)
0%	1.072×10^{-7}
5%	2.76×10^{-7}
10%	5.93×10^{-7}
15%	4.91×10^{-7}
20%	2.23×10^{-7}

APPENDIX 6 - CBR

A) BLACK COTTON SOIL

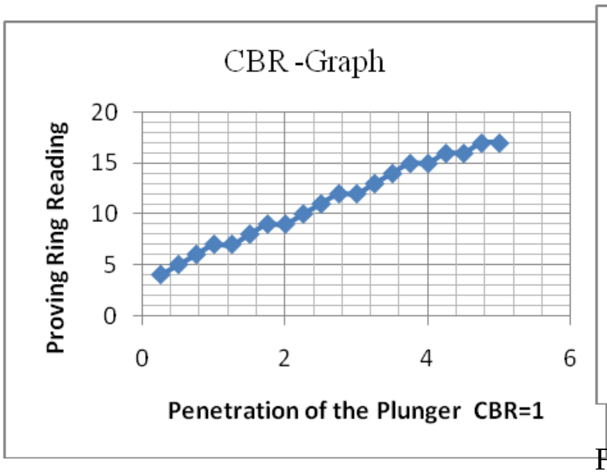


Figure 6-1CBR Analysis for black cotton soil at 0% Lube Oil

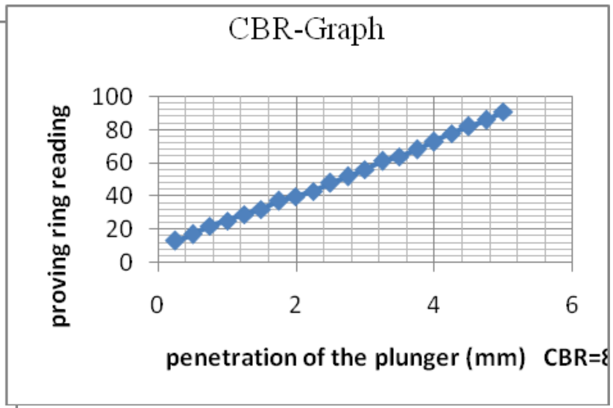


Figure 6-3CBR Analysis for black cotton soil at 10% Lube Oil

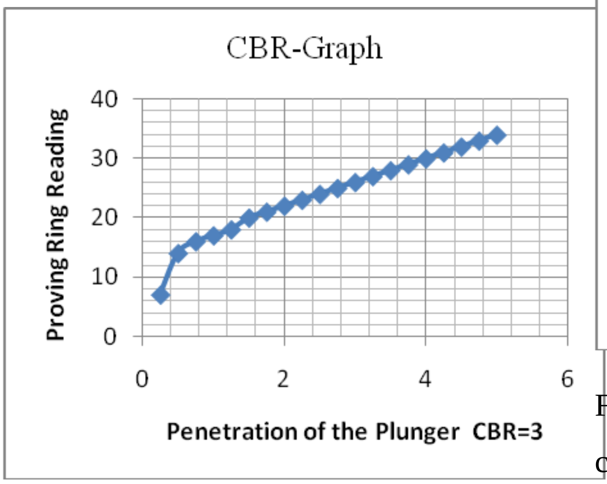


Figure 6-2CBR Analysis for black cotton soil at 5% Lube Oil

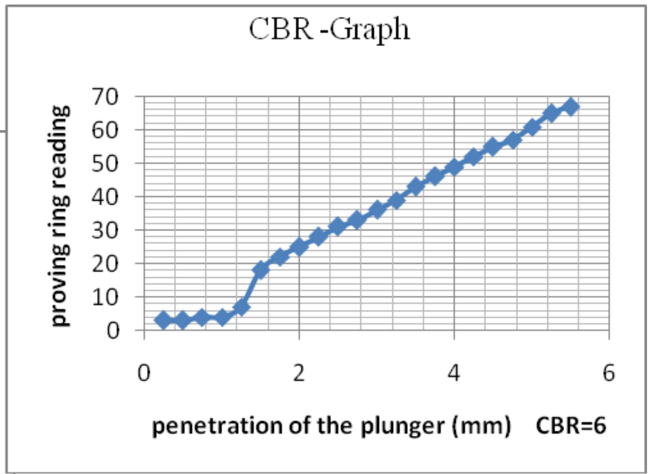


Figure 6-4CBR Analysis for black cotton soil at 15% Lube Oil

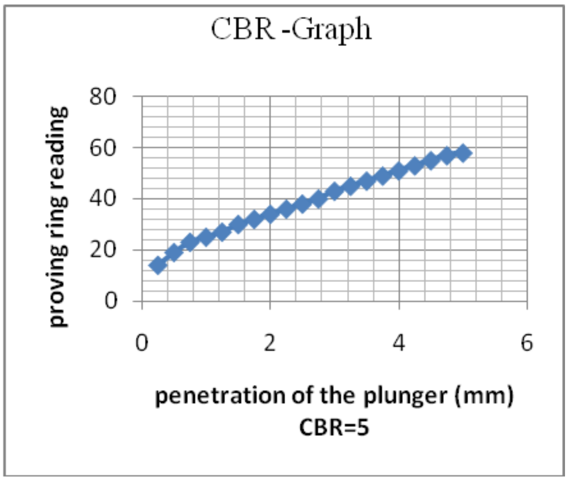


Figure 6-5CBR Analysis for black cotton soil at 20% Lube Oil

Values at **0%** Used Lube-Oil

Table 6-1 Dry Density, Moisture content and CBR Test Results

Moisture Content %	26.4	28.9	32.4	39.3	43.8
Dry Density 100ρ/100+w kg/m^3	1163	1202	1238	1170	994
MDD=1255 KG/M^{3}OMC=34.5% CBR=1					

Values at **5%** Used Lube-Oil

Table 6-2

Moisture Content %	12.1	14.8	16.6	18.6	20.9
Dry Density 100ρ/100+w kg/m^3	1409	1446	1441	1408	1340
MDD=1455 KG/M^{3}OMC=15.8% CBR=3					

Values at **10%** Used Lube-Oil

Table 6-3

Moisture Content %	10.9	12.4	14.8	16.3	18.7
Dry Density 100ρ/100+w kg/m^3	1578	1646	1655	1617	1542
MDD=1665 KG/M^{3}OMC=13.8% CBR=8					

Values at **15**% Used Lube-Oil

Table 6-4

Moisture Content %	7.2	9.2	11.2	13.2	
Dry Density 100ρ/100+w kg/m^3	1474	1548	1484	1396	
MDD=1555 KG/M^{3}OMC=09.5% CBR=6					

Values at 20%Used Lube-Oil

Table 6-5

Moisture Content %	6.8	9.4	11.3	13.2	
Dry Density 100ρ/100+w kg/m^3	1479	1527	1456	1396	
MDD=1530KG/M^{3}OMC=9.2% CBR=5					

B) RED COFFEE

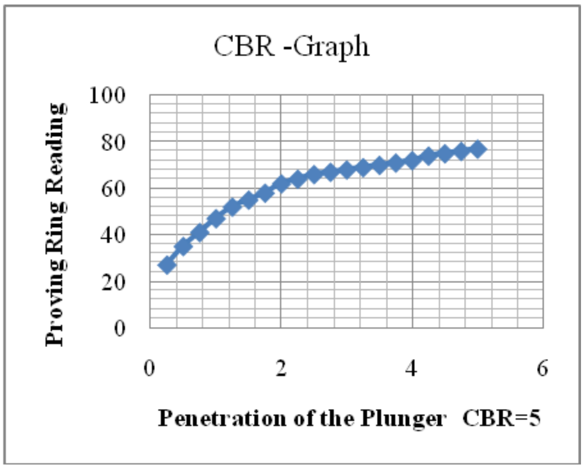


Fig. 6-6 CBR analysis for Red soil at 0% Lube Oil

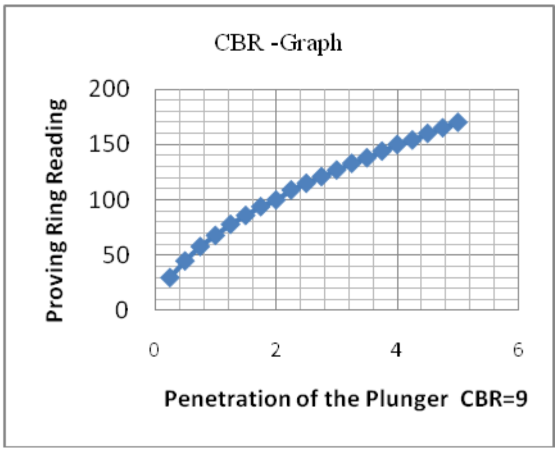


Fig. 6-7 CBR analysis for Red soil at 5% Lube Oil

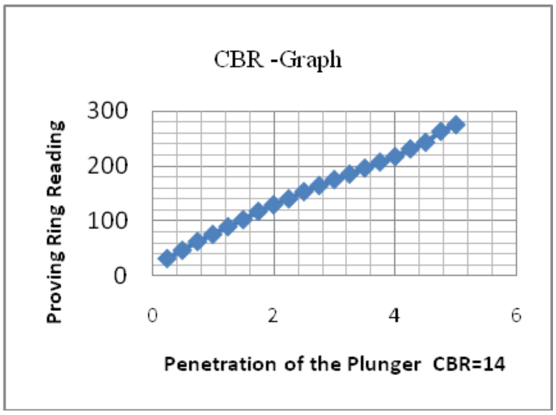


Figure 6-8 CBR analysis for Red soil at 10% Lube Oil

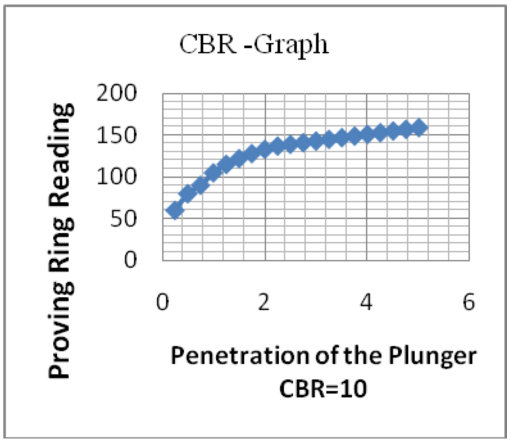


Figure 6-9CBR analysis for Red soil at 15% Lube Oil

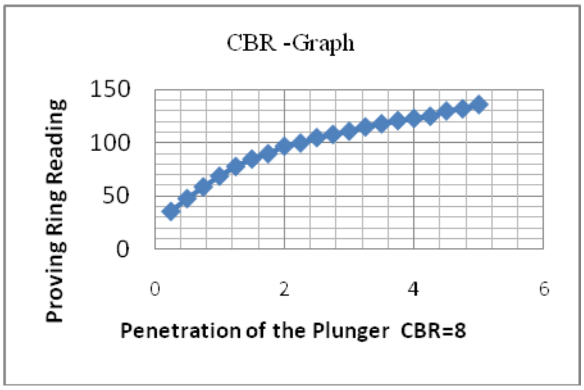


Figure 6-10CBR analysis for Red soil at 20% Lube Oil

APPENDIX 7 - MAPS

Fig. 7-1 KAKAUMA Site Plan Turkana West District: 95km to Juba in Sudan Google Online Maps-

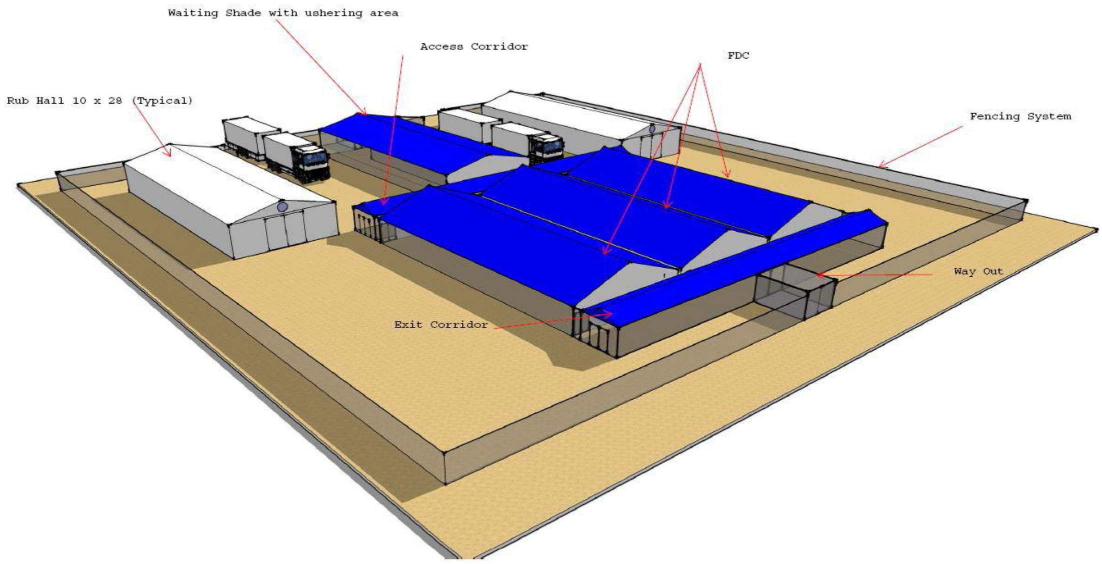


Fig. 7-2 View of The Finished Site Layout 85m*85m (7225 S.M.)-Food Distribution Centres at The Site

APPENDIX 8 - PHOTOGRAPHS

Fig. 8-1 Traversing the Black Cotton Soil Terrain between the Sites & Off-Loading Used Lube Oil for Use at the site.

Fig. 8-2 Off-Loading Used Lube Oil for Use at the Site

Fig. 8-3 Use lube oil as used at the site:June, 2012

Fig. 8-4 Embankment preparation size

85m x 85m (7225m^2)


Fig. 8-5


Fig. 8-6


Fig. 8-7

Viscosity tests during experiments at the JKUAT Mechanical Engineering Laboratory using Red Wood viscometer for less than 2000 seconds.

VARIOUS SOIL TESTS AT THE LAB

Fig. 8-8 Container with Used Lube Oil

Fig. 8-9 Used Lube Oil being weighed

Fig. 8-10 Mixed Red Black Cotton Soil and Lube Oil

Fig. 8-11 Mixed Red Coffee Soil and Lube Oil

Fig. 8-12 Sample for Cone Penetrometer to measure moisture content

Fig. 8-13 Cone Penetration Test in progress to measure moisture content

Fig. 8-14 Cone Penetrometer Test reading of the dial gauge

Fig. 8-15 Soaked samples for CBR Test

Fig. 8-16 CBR Readings

Fig. 8-17 CBR Readings