STABILIZATION OF LATERITE SOIL FOR UNPAVED ROADS USING MOLASSES IN BUTERE AND MUMIAS SUB COUNTIES

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(Construction Engineering and Management)

JOMO KENYATTA UNIVERSITY OF

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2020

Stabilization of Laterite Soil for Unpaved Roads Using Molasses in Butere and Mumias Sub Counties

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A thesis submitted in partial fulfillment for the degree of Master of Science in Construction Engineering and Management in the Jomo Kenyatta University of Agriculture and Technology

2020

DECLARATION

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

Signature …………………………………. Date ……..…………………….

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This thesis has been submitted for examination with our approval as University Supervisors.

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DEDICATION

To my Beloved Wife Linnet, Daughter Valentine and Sons Beullah and Shalom.

ACKNOWLEDGEMENT

First and foremost, I would like to extend my heartiest gratitude to Prof. Kiptanui Arap Too, my first supervisor during this time that I prepared the thesis. He gave me the chance to finish the studies and with his guidance the study was finished smoothly. Besides that, his patience and encouragement led me to complete this study in time.

In addition, I would like to thank Dr. Eng. Charles Kabubo, my very able supervisor for his kind advice and information that assisted me to be able to complete my studies promptly. Also of great assistance was the staff of the Ministry of Transport & Infrastructure Bungoma, especially those in the Department of Materials. I wish to thank them for their continued support during the time that we tested the materials and also their assistance in analyzing the data.

I wish to thank the Lord Almighty for granting me knowledge, wisdom and understanding in addition to good health and sound mind that enabled me to work diligently on my thesis. Not forgetting my parents and sisters for their full support, my wife for helping in editing the scripts and my Pastor for his prayers throughout the research. Last but not least, to all my friends for their support, advice and their help at the time whenever I needed them.

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LIST OF ABBREVIATIONS AND ACRONYMS

CBR California Bearing Ratio

LL Liquid Limit

MDD Maximum Dry Density

OMC Optimum Moisture Content

PL Plastic Limit

PI Plasticity Index

UCS Unconfined Compressive Strength

LIST OF NOMENCLATURE

AI_2O_3	Aluminum Oxide
CaO	Calcium Oxide
Fe_2O_3	Iron Oxide
K_2O	Potassium Oxide
MgO	Magnesium Oxide
NaO	Sodium Oxide
SiO_2	Silicon Oxide
TiO_2	Titanium Dioxide
P_2O_5	Phosphorus Pentoxide
Cl	Chlorine
S	Sulphur
Mn	Manganese
Na_2O	Sodium Oxide
kN/m^2	Kilonewtons per square meter
DC	Days Cure
DS	Days Soak
N	Newtons
ε_0	Strain

kN/m^3	Kilonewtons per cubic meter

ABSTRACT

The gravel wearing course used on the unpaved roads within the area covering the sub counties of Butere and Mumias wears out too fast. This makes the roads to be in such a bad state as rutting and potholes develop hence making the re-graveling to be done frequently. This study analyzed processes involved in the stabilization of laterite gravel soil with cane molasses. The main objective was to establish the feasibility of using sugarcane molasses in stabilizing laterite soils for gravel wearing course on unpaved roads in Butere and Mumias counties. Other objectives were; to determine the physical, mechanical and chemical properties of laterite gravel soil used on unpaved roads in Butere and Mumias counties, to establish the chemical properties of sugarcane molasses used to stabilize the laterite gravel soil for unpaved roads and to determine the optimum performance of laterite gravel soil stabilized with sugarcane molasses for unpaved roads. Molasses was used in this study because it contained some elements/compounds which are known to react with laterite soil and change characteristics of the soil. Tests were carried out to determine the chemical composition of molasses and those of laterite gravel. It was evident that 2% cane molasses by weight of dry soil was the optimum for effective stabilization of lateritic soil. The study established that neat laterite soil specimens gave lower California Bearing Ratio values than one mixed with cane molasses. The increase in California Bearing Ratio values for laterite soil mixed with cane molasses higher than those of neat laterite soil was an indication that cane molasses caused the strength of the soil to increase and therefore it stabilized laterite soil. Sugarcane molasses improved the engineering qualities of the soil i.e. California Bearing Ratio values and the density and decreased the Optimum Moisture Content and Plasticity Index of soil.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Many parts of the sugarcane growing zone within Butere-Mumias District in Kakamega County are mostly rural and the roads used for transportation of cane from farms and for access are mostly unpaved roads. However, these roads deteriorate too fast due to the poor methods of stabilization of the gravel wearing course. This is the soil that is usually used as sub-grade material during the construction of paved roads. The material being used as the gravel wearing course in Butere and Mumias sub-counties is laterite gravel. This is gravel when in use as wearing course, is intermixed with sand and little proportions of clay with stones sized roughly between 0.075 and 20 mm. Visual inspection done during quarrying, when making unpaved roads in this region has revealed that most gravel is found in quarries which are dug at approximate depth of 1000 – 2500 mm where large concentrations of gravel are obtained. The Ministry of Transport and Infrastructure Road Design Manual Part III (1987), establishes that the depth of the pit for sampling shall in no case be less than 1.5 metres and should be at least 0.5 metres below the expected formation level. However, the gravel used has diminished with time as more has been excavated from the gravel pits for the purpose of maintenance of surface courses on unpaved roads. This has also resulted in having many disused gravel pits which fill with rain water and pose danger to the public. Cane transportation is usually done by use of trailers which exert a lot of pressure on the unpaved roads due to increased loads. These gravel roads therefore, require frequent maintenance. The wheel motion shoves the gravel wearing surface course material to the outside (as well as in between travelled lanes) leading to rutting, reduced water run-off and eventually destruction if unchecked.

Johnson (2012) published patent, records that the wearing course for gravel roads should have a hard and even surface and yet be elastic in order to withstand traffic and weather, in order not to dust and to manage the ground frost in the winter. He adds that in order to achieve this, the wearing course should comprise wearing course gravel with a grain size of 0 – 18 mm and a mixture of clay and lignin in the form of powder or granulate. He further records that the wearing course should comprise additives of starch, kaolin, lime, cement, vegetable substances, minerals or chlorides. He concludes that the objective of using these additives is to seal the wearing course such that no leaching occurs. Water should be able to flow off on top of the wearing course layer after application without penetrating down into the said wearing course layer. Edvardson (2010) notes that application of the proper dust suppressant like calcium chloride to a gravel road ensures road safety and riding comfort as well as creating a cleaner and healthier environment for residents.

The Ministry of Transport and Infrastructure Road Design Manual Part III (1987), recommends that the grading requirement for gravel wearing course after compaction should be between 37.5 mm and 0.075 mm. The manual recommends a Plasticity Modulus of a minimum of 200 and a maximum of 1200. The plasticity index should be a minimum of 5 and a maximum 20 in wet areas whereas in dry areas the plasticity index should be minimum of 10 and maximum of 30. The California Bearing Ratio at 95% Maximum Dry Density (Modified AASHTO) and 4 days' soak is recommended to be a minimum of 20. These requirements apply when neat gravel is used on the wearing course.

Various methods have been used to stabilize laterite gravel for wearing course surfaces. Lim, Wijeyesekera, & Bakar (2014),carried out research on stabilization techniques of rural roads. They attempted to bring together soil road stabilization technologies for the extremes of dry and wet conditions. The advantages of using chemical stabilization for soil road stabilization were reviewed. They came up with several methods that are used to stabilize the gravel wearing course surface.

The first one uses Chlorides which include Calcium Chloride in liquid form, Magnesium Chloride in liquid form and Sodium Chloride (Road Salt). They are the most commonly used products for dust suppression in unbound road surfacing. They draw moisture from the air to keep the road surface moist and help resist evaporation of road surface moisture, thereby reducing the amount of dust generated (Lim et al., 2014). They facilitate compaction and promote soil stabilization. These products are very effective if used. They are also easy to use but costly.

The second method utilizes resins/Lignosulfonates. These are products available as stabilizers. The basic composition is lignin sulfonate which is a by-product of pulp milling industry. The products work best when incorporated into the surface gravel. Lim et al. (2014), notes that they provide cohesion to bind the soil particles together. Lignosulfonates also draw moisture from the air to keep the road surface moist. They are well suited for dust suppression because they bond soil particles together and help to maintain a moist road surface and also reduce dust generation. Lignosulfonates increase the compressive strength and load-bearing capacity of the treated material, bind materials to reduce particle loss and provide a firm hard dust-free surface. However, these products are not readily available within Butere-Mumias region.

Lastly, electrolyte emulsions are also used to stabilize soils. They contain chemicals that affect the electro - chemical bonding characteristics of soils and replace water molecules within the soil structure. The treated soil loses its affinity for water. Lim et al. (2014), notes that when applied at low rates to the surface of the unbound road surface, electrolyte emulsions perform well for dust suppression. They bond soil particles together and reduce dust generation. At higher application rates, electrolyte emulsions can be used to stabilize soils. When applied and compacted properly, the treated soil can be stabilized to form a firm hard bound layer that can be used on the wearing course of unpaved roads.

According to a Food Outlook report released in November 2018 on sugar, the world sugar production was estimated by Food Agricultural Organization to reach 179.3 million tons in the year 2018/2019. In a technical document titled “analysis of incentives and disincentives for sugar in Kenya” production increased from 516,820 metric tons in the year 2005 to 547,999 metric tons in the year 2010. However, there has been a decline in sugar production due to underperformance of some factories. Mumias Sugar Company which was a major producer of sugar in Kenya ceased operating optimally. This led to a drop in sugar production to 410,000 tons by the year 2018.

Molasses production in Butere and Mumias sub counties is believed to be in large quantities as West Kenya Sugar Company and Butali Sugar Mills are situated within Kakamega County. According the Business Daily Edition of May 2019, West Kenya Sugar Company owns a market share of 22% translating to a production of 90,200 metric tons per year. Butali Sugar Mills owns a market share of 9.6% translating to a production of 39,360 metric tons per year. This makes a total of 129,560 metric tons for the two factories. For every tone of sugar produced we obtain a ⅓ of a ton of molasses. This implies that molasses production for the two factories is currently at 43,186 metric tons. Small quantities of molasses are supplied by the factories locally to the farmers who buy the molasses for cattle feed. More molasses is left which can be used in ethanol production. However the companies do not have ethanol plants and may incur transport costs while taking molasses to other places where ethanol plants are located. This is considered adequate for stabilization of wearing course on unpaved roads within the two sub counties due to the fact that the road network coverage to be stabilized using molasses is 70 kilometres.

The National guide for Sustainable Municipal Infrastructure - Canada (2005), notes that the control or minimizing of dust from unpaved roads in rural and urban areas can be done by using dust suppressants. It adds that dust emissions from unpaved roads can impair the vision of drivers making it a safety hazard. The guide reports that losses of fine particles from unpaved roads can reduce surface longevity and increase maintenance costs. It also informs that inhaling fine dust particles can be a health hazard to road users and residents.

Other effects mentioned include nuisance, environmental and economic implications like reduced crop yields and cleaning expenses to the residents living along the unpaved roads. It summarizes by stating that lignin derivatives, synthetic polymer emulsions, bitumen, calcium chloride, magnesium chloride and water can be used as dust suppressants. This research determined the suitability of using molasses to stabilize laterite soil for unpaved roads in the Butere and Mumias sub counties, without making use of the methods mentioned above.

1.2 Statement of the Problem

According to weather atlas Kenya (2020), Kakamega County experiences rainfall all year round with more rainfall in the months of April, May, June, July and August averaging 250mm. This causes the unpaved roads to be in poor state most of the time during the year. The poor state of roads in Butere and Mumias sub counties in Kakamega County pose a challenge to the West Kenya Sugar Factory, farmers and residents of the area while using the unpaved roads. Trailer drivers and other ordinary drivers while driving on these unpaved roads require far more attention to variations of the surface and occasionally lose control. In addition to potholes, ruts and loose stony or sandy ridges at the edges or in the middle of the road, problems encountered while driving on these unpaved roads include the following: Dust thrown up from a passing vehicle reducing visibility, washboard corrugations causing loose of control or damage to vehicles due to excessive vibration and lost binder in the form of road dust while mixed wearing away the painted surface of vehicles. Blackstrap molasses is sometimes used for the production of ethanol, as an ingredient in cattle feed and as fertilizer. However, if not utilized as mentioned, molasses may pose challenges on its disposal from the factory. Unused excess molasses can cause serious environmental problems like pollution if they are drained into rivers. There is need to consider other appropriate ways of handling and disposing molasses especially where it is in plenty supply. Paving roads require a comprehensive plan.

The average Daily Traffic volumes (ADT) on roads dictate the paving of roads. Paved roads are expensive as they are wider and the road base is built up with stronger materials. The total road costs and the maintenance costs of paved roads put together are higher as compared to unpaved road costs. Most of the roads in the Butere and Mumias sugar growing zone experience heavy truck usage hence may be surfaced with gravel and left unpaved. The gravel wearing surface course is the part of unpaved road that is of great concern. Therefore, this research aimed at exploring how best the material could be made more stable so as to alleviate most of the problems listed above. The material stabilized here was laterite gravel which is a locally available material.

1.3 Justification

This research was aimed at solving economic and social problems related to the use of unpaved roads by the community within Butere and Mumias sub-counties.

(a) Use of locally available raw materials

The county government of Kakamega would find this method of stabilization of the wearing course quite appropriate as they would make use of molasses which would be sourced from the local sugar factories. Being in charge of such feeder roads within the county, the county government would also extend the same technology to other areas within. The high costs of bitumen and paving on these feeder roads would be avoided. Socially, the wearing course of unpaved roads when stabilized would guarantee comfort to the users whether they are motorists or pedestrians

(b) Policy formulation to the factories

The Kenya government would find it necessary to make it a policy to the sugar companies to ensure they preserve a determined percentage of molasses produced. This would ensure enough and constant supply of molasses to avoid shortage especially where maintenance of unpaved roads within the counties is required. Environmentally, the policies formulated would also ensure that there are proper ways of disposing and handling molasses to avoid pollution especially where production is plenty.

1.4 General Objective

To establish the feasibility of using sugarcane molasses in stabilizing laterite soils for gravel wearing course on unpaved roads in Butere and Mumias sub counties.

1.5 Specific Objectives

1) To determine the chemical, physical and mechanical properties of laterite gravel soil used on unpaved roads in Butere and Mumias sub counties.
2) To establish the chemical properties of sugarcane molasses to be used to stabilize the laterite gravel soil for unpaved roads in Butere and Mumias sub counties.

3) To determine the optimum performance of laterite gravel soil stabilized with sugarcane molasses for unpaved roads.

1.6 Research Questions

1. What are the chemical, physical and mechanical properties of lateritegravel soil used on unpaved roads?
2. What are the chemical properties of sugarcane molasses used as stabilizer for gravel wearing course?
3. What is the optimum performance of laterite gravel soil stabilized with sugarcane molasses for unpaved roads?

1.7 The Scope

This study focused on unpaved roads within Butere and Mumias sub counties. The total road network coverage that serves the purpose of transporting cane within this area is approximately 70 kilometers. The Atterberg Limit tests, Compaction tests, California Bearing Ratio tests and Unconfined Compressive Strength tests were done on the treated and untreated laterite gravel soil. Grading test was also done on untreated laterite gravel soil.

1.8 Limitations

For the purpose of this research, the 7 km long Bukura-Shibuli road was taken as a representative sample for the tests to be done. The gravel used for testing in the study was taken as a representative sample for the entire region. Long-term performance was not studied because of lack of sufficient time.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this literature review, a thorough examination was done on the previous studies/research carried out on the use of molasses while stabilizing on different types of soils. Several scholars as indicated below have done research on the effect of mixing molasses with other types of soils. Previous work on the mechanisms of the stabilization of soils with molasses, with the aim of finding out whether or not sugar cane molasses could be used as a stabilizing agent on the different types of soils has been done. Additionally, strength assessments of different types of soils mixed with cane molasses as reflected by California Bearing Ratio was done. The laterite soils were looked into to show how best their properties could be improved.

2.2 Effect of Cane Molasses on Properties of Different Types of Soils

2.2.1 Effect of cane molasses on strength of expansive clay soil

M'Ndegwa (2011) carried out studies on the effect of cane molasses on strength of expansive clay soil. He carried out tests on the pH value of the soil, organic matter content, Cation Exchange Capacity (CEC), elemental oxide composition, particle size distribution, texture, specific gravity, Atterberg Limits on untreated & treated soils and free swell. CBR test was carried out as the main test in the study hence making the following conclusions;-

Stabilization of expansive clay soil with molasses increased the CBR values of expansive clay soil and thus the load bearing ability of the soil. Therefore molasses could be used as stabilizing agent for expansive clay soil. Ash-Shu'Ara & Ajayi (2018) also found that course sand particles could solve the problem of swelling and shrinkage in expansive clay. As observed by M'Ndegwa (2011), molasses mixed with expansive clay soil reduced its swelling tendencies as well. Lime mixed with expansive clay soil provided higher CBR values than those provided by expansive clay soil mixed with molasses.

Abdul, Karthick and Manikandan (2015) carried out a study on the effectiveness of molasses for improving the shear strength and CBR value of two types of fine grained soils i.e. the intermediate compressible clay soil and highly compressible clay soil. The results showed that with the use of molasses, the Unconfined Compressive Strength and California Bearing Ratio of both soils improved. The UCS of soil increased with increment ratio of 1.57 to 2.01 for both types of soils. CBR value of soils had increment ratio of 2.0 to 3.5 in both types of soils. The values increased with increase in treatment duration.

2.2.2 Innovation in road construction using natural polymer

Shirsavkar & Koranne (2010) carried out studies on innovation in road construction using natural polymer. The aim of the research was to study the different aspects, regarding changes in properties of soil due to mixing in different proportion of molasses in it. The important geotechnical properties tested were liquid limit, atterberg limits, compaction and CBR. The study was carried out on soft murram soil. The following results were obtained.

By addition of 6.5% of molasses the value of liquid limit and plastic limit increased and plasticity index of modified soil reduced. M'Ndegwa (2011) observed that the reduced clay content due to the addition of molasses contributed to a reduction of the PI of the soil.The value of maximum dry density of modified soil increased due to proper rearrangement of modified mix and due to improved binding capacity. The value of CBR increased due to increase in density of modified mix, which led to soil mass having more strength.

2.2.3 Bio-enzymes as soil stabilizers in road construction

Shankar,Kumar & Mithanthaya (2009) carried out research on the effect of using "bio-enzyme." Bio-enzyme is a natural, non-toxic, non-flammable, non-corrosive liquid enzyme formulation fermented from sugar cane extracts. The study was carried out on the ability of the available laterite soil in Dakshina and Udupi districts in India, to be used as a base course material in pavements. In order to improve its properties, the soil was blended with sand and Bio-Enzyme added as a stabilizing agent. The effect of addition of enzyme on soil and blended soil in terms of Unconfined Compressive Strength (UCS), CBR and Compaction was studied. It was observed that laterite soils stabilized with bio-enzyme had shown medium improvement in physical properties. This improvement was due to chemical constituents of soil which had low reactivity with bio-enzyme. For a higher dosage of 200 ml/m^3 of soil, the CBR value of laterite soil increased by 300 percent after four weeks of curing. Unconfined Compressive Strength of the soil increased. Addition of bio-enzymes in laterite soils facilitated higher soil compaction and increased strength of soil. Bio-enzymes could be used to increase the Maximum Dry Density values of a marginal material to achieve specified standards for a base course. Suresh, Balakrishna & Nitesh (2017) also observed that bio-enzyme when mixed with black cotton soil could improve the CBR and UCS of the soil.

Akiije (2015) used lateralite, a chemical stabilizer locally produced in Nigeria to stabilize three selected laterite soil samples.

This was for the purpose of improving the sub grade, sub base and base course materials. The results obtained at 14% lateralite addition to each of the three laterite soil samples showed improved values of Maximum Dry Density, California Bearing Ratio and Unconfined Compressive Strength.

2.2.4 Molasses as a dust suppressant material

Elsholz (2012) recorded that dust suppressants played an important role in minimizing the impacts that occur on unpaved roads. He found out that molasses used as suppressant had a number of advantages. These included the findings that molasses was effective at keeping aggregate stable and in place, very effective at reducing dust, cost effective when compared to paving and other dust suppressants. He also found out that molasses' impacts to water quality were minimal and below thresholds. In his observation, it was also noted that molasses was not toxic to sensitive aquatic life and remained hygroscopic at higher temperatures.

2.2.5. Stabilization of sub-base layer using molasses

Mogute (2014) carried out a study of stabilization of subbase road pavement layer using molasses and cement mix. In his study, laboratory tests were carried out and the results from the study indicated that molasses could be used as an additive to cement. His study involved an investigation on the effect of molasses on some geotechnical properties of laterite soil for subbase purposes. It included evaluation of properties such as compaction, Atterberg limits, and strength of soil with molasses and cement content of various ratios by weight of dry soil. In his study, he noted that a stabilizing agent led to particle aggregation which led to the lowering of the liquid limit of the lateritic gravel while raising the plastic limit. This, he observed was due to high affinity of water. He also noted that the blends which had both cement and molasses shrank less than those with cement alone. It was also deduced that there was an increase in the CBR due to gradual formation of cementitious compounds in the soil by the reaction among cement, molasses and soil minerals like CaOH.

Onyebuchi (2013) found out that when laterite soil is blended with a given optimum percentage of pozzolana by dry weight, the MDD increased while the OMC increased with pozzalana content. He also noted that there was a reduction in PI and CBR with increasing pozzolana content.

Adeboje (2016) noted that stabilization of laterite soil with pulverized palm kernel improved the CBR and UCS of the soils. He also observed that there was a reduction in OMC of the laterite soils.

2.2.6 Improvement of geotechnical properties on clay stabilized using cement with molasses

Rafa'i, (2006) carried out research onimprovement of geotechnical properties on clay stabilized using cement with molasses adding as one of the infrastructure retrofitting method. His study aimed at finding out the effectiveness of using unconventional liquid soil stabilizer like molasses for improving the shear strength and CBR value of two types of fine grained soils. He used molasses, intermediate compressible clay soil and highly compressible clay soil. The results showed that there was appreciable increment in unconfined compressive strength and CBR value for both soils. The values increased with increase in treatment duration. Onyebuchi (2013) further noted that addition of pozzalana to laterite soils improved the CBR but the CBR reduced with more pozzalana content.

2.2.7 Usage of molasses in concrete as water reducing and retarding admixture

Yildirim and Altun (2012) carried out research on the usage of molasses in concrete as water reducing and retarding admixture. The research was carried out using Ordinary Portland Cement, crushed limestone as coarse aggregate, crushed stone sand as fine aggregate and an admixture of lignosulphonate based water reducer and molasses from three different sources.

In this study, a comparison was made between molasses with 40% purity grade and lignosulphonate with respect to the improvements in properties of concrete. Density of the lignosulphonate and molasses - based admixtures were 1190 and 1200 kg/m^3 respectively. The results showed that usage of molasses based and lignosulphonate plasticizers caused reduction of coefficient of capillary due to the increase in setting time as well as decrease in water/cement ratio. It also deduced that molasses based plasticizers were effective in reducing of capillary coefficient than lignosulphonate based plasticizers.

2.2.8 Effect of bio¬enzyme stabilization on Unconfined Compressive Strength of expansive Soil

Puneet and Suneet (2014) carried out research on the effect of bio-enzyme stabilization on UCS of expansive soil. The materials used for the tests included the black cotton soil and terrazyme (bio-enzyme). The terrazyme used was a natural, non-toxic, non-corrosive and non-flammable liquid produced by formulating vegetable extracts. The Terrazyme was perfectly soluble in water, brown in colour with a smell of molasses. The Unconfined Compressive Strength was evaluated by stabilization with variable dosages of enzyme i.e. 0.0 ml, 0.25 ml, 0.5 ml, 0.75 ml, 1.0 ml, 2.0 ml, 3.0 ml and 4.0 ml/per 5 kg of soil for one and seven days of curing. The study came up with findings that, stabilization of the soil using terrazyme resulted in significant increase in the UCS of the black cotton Soil up to 200%. It was also found out that duration of treatment of soil with terrazyme played a vital role in improvement of strength and soil treated with terrazyme for 7 days gave a higher strength

2.2.9 Experimental studies on laterite soil stabilized with cement and aggregate

Sunkara, Someswara and Venkata (2015) carried out a study in order to evaluate the use of low contents of cement and aggregate in the modification of laterite soil properties concerning the behavior of mixtures to use in the base construction.

Effect of addition of 10 mm size aggregates and below to the soil was studied. The optimum cement content was also determined in order to evaluate the extent of modification on Maximum Dry Density, Optimum Moisture Content and California Bearing Ratio of the soil. The tests showed that there was a tremendous increase in the CBR value of the soil treated with cement aggregate modification. The soaked CBR at 3 % of cement increased up to 48% at 28 days curing period when compared to that of untreated soil. The results also showed that when soaked CBR was conducted with optimum percentages of cement of 3% with 10% aggregate, its strength increased up to 76%. Jaritgam, Somchainkek and Taneerananon (2014) carried out research to compare the strength characteristics of cement- enhanced lateritic soil against those of crushed. The results showed that when cement was added to the laterite soil at 3% by weight, the UCS and CBR of the laterite soil increased. It was also noted that the resulting laterite-cement mixture exhibited compressive strength as high as that of crushed rock.

2.2.10 Lime stabilization requirement of laterite soil samples as pavement construction materials

Olugbenga et al. (2011) carried out a study to determine the suitability and lime stabilization requirements of some selected laterite soil samples as pavement construction materials. The results showed that the suitability of the samples was improved by the optimum lime stabilization. The addition of lime to the samples caused a reduction in the plasticity indices of the samples. The CBR and the Compressive strength improved. The optimum lime contents for samples A, B and C were 8, 6 and 6% respectively.

It was noted that sample A and B were suitable for sub grades and fairly for sub bases but unsuitable for base courses, while C was unsuitable for any of these.

Adewuyi & Okosun (2014) in their study on an attempt to improve geotechnical properties of some highway laterite soils also found that increasing the lime content in the soils resulted to soils with reduced plasticity. They also noted that with the optimum range of 6 to 8%, the UCS and CBR improved.

2.3 Critique of the Existing Literature

In the above literature, very useful information has been brought out. However, in the research carried out on how stabilization with cane molasses affects the strength of expansive clay, the researcher, M'Ndegwa (2011), was clear that he was testing treated expansive clay and not treated lateritic gravel. In his study, he showed how expansive clay soil could be improved upon to make it more stable.

Additionally, he mentioned that he was stabilizing expansive clay soil used for engineering purposes but there was no mention on where the soil was to be applied i.e., whether as sub base or base.In the research done on “Innovation in Road Construction Using Natural Polymer (Molasses)”, by Shirsavkar and Koranne (2010), a number of tests conducted produced positive results on the strength of materials. However, it is not clear whether the soft murram that was used on the sub-base could also be applied on surface wearing course of unpaved roads. The soil in his study was also blended with sand. In my study, molasses is used without blending with other materials. The surface wearing course on unpaved roads was an area not fully exhausted in this report which is why there was need to examine the possibility of stabilizing the wearing course on unpaved roads, using molasses. In the research on the use of Bio-Enzymes as soil stabilizers in road construction Shankar et al, (2009), the laterite soil was blended with sand. My study undertook to use laterite gravel in its natural state without addition of sand. Concerning the research on molasses as a dust suppresant material, the researcher Elsholz (2012) concentrated his study on how molasses could be used as a dust palliative and hence, no mention of the study of molasses as a stabilizer on the wearing course was done. Suresh et al. (2017) carried out a study on improvement of black cotton soil properties using terrazyme as an admixture. His objective was to use it on highway pavementsand not on wearing course of unpaved roads as my research intents.Finally, the other studies that have been done on molasses according to the literature above were on mixing of molasses with cement/soil mix when stabilizing the soils. My study aimed at finding out the ability and suitability of molasses to stabilize laterite soils on unpaved roads without addition of any other additive. As demonstrated in the Figure 2.1, obtaining an improved UCS, CBR and MDD depended on mixing of molasses and laterite gravel soilin optimum ratios.

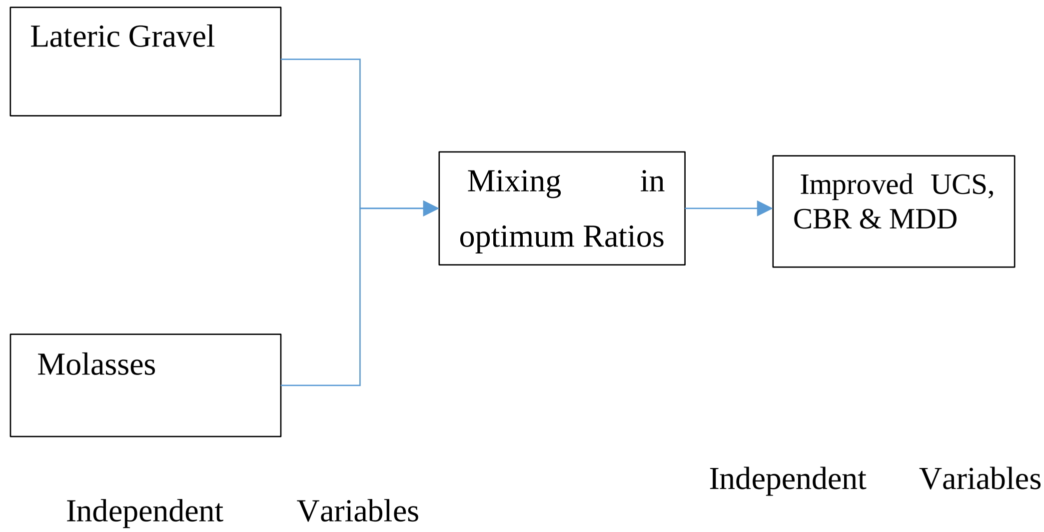


Figure 2.1: Conceptual framework

2.3 Summary

From these studies, it was deduced that molasses when added to different types of soils improved the strength properties of the soils hence stabilizing them. M'Ndegwa (2011) found out that this enhanced increased California Bearing Ratio Strength (CBR) thus increasing the load bearing ability of the soil and increasing the maximum dry density of the modified soil. In the the study, the Unconfined Compressive Strength of the stabilized laterite gravel soil improved. Onyebuchi (2013) noted that the value of the liquid limit and plastic limit were increased thus the plastic index of the modified soil was decreased.

Finally, the stabilization of the soils using molasses in road construction was economical compared to other methods of soil stabilization. Most of the studies had concentrated on improved pavement layers for paved areas. This research aimed at finding out how the properties of the gravel wearing course could be improved by addition of optimum ratios of molasses to the laterite soils inorder to make the unpaved roads within the Butere and Mumias region be strong and durable.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the collection and analysis of data in order to ascertain the strength of laterite gravel soil when mixed and when not mixed with different proportions of molasses. It described the materials that were used and procedures that were followed to obtain samples from the field. It also illustrated the tests that were performed on those materials. The chapter examined the study area and sampling techniques that were used for the laterite gravel soil. Data collection and analysis of the desired variables was done. Methods of determination of optimum mix ratios were explained.

3.2 Research Design

The research design involved determination of strength and properties of gravel wearing course (laterite gravel) material to be stabilized using molasses. Besides analyzing the chemical composition of molasses and laterite gravel, the research was done in order to determine the quantity of molasses that would be applicable as an additive to the laterite gravel materials. Most importantly, the research determined the optimum ratios of molasses that would be applied to guarantee the most desirable gravel wearing course in terms of strength and durability. In this chapter data was collected and analyzed in order to ascertain the strength of laterite gravel soil when mixed with different proportions of molasses.

3.3 The study area and sampling technique for laterite gravel soil

The site from which the laterite gravel soil was excavated for testing was located along the 7km. Bukura – Shibuli road. The site was located there because it is at the centre of the unpaved roads region whose network coverage is 70 km. The disturbed sample was excavated in selected test pit after the removal of the overburden and the materials taken for testing in the laboratory. Figure 3.1 shows a sketch map of material site indicating position of the trial pit selected.

According to the behaviour of the gravel wearing course that had been in use previously, there was no major change in soil type. This is evident from the visual inspection done on the many excavated pits during the time of excavating the gravel for use on the unpaved roads during maintenance. Therefore, one sample was chosen on the entire 7 km stretch.

The sample was randomly taken from a gravel borrow pit located along the road at the area between the 7 km stretch of the Shibuli – Bukura road. The sample chosen was representative of the whole lot from which it was taken. It was not possible to pick on many samples as this would have resulted to carrying out too many tests which time could not allow. The disturbed sample was used and chosen with care ensuring that it was large enough to contain the representative particles, sizes and fabric.

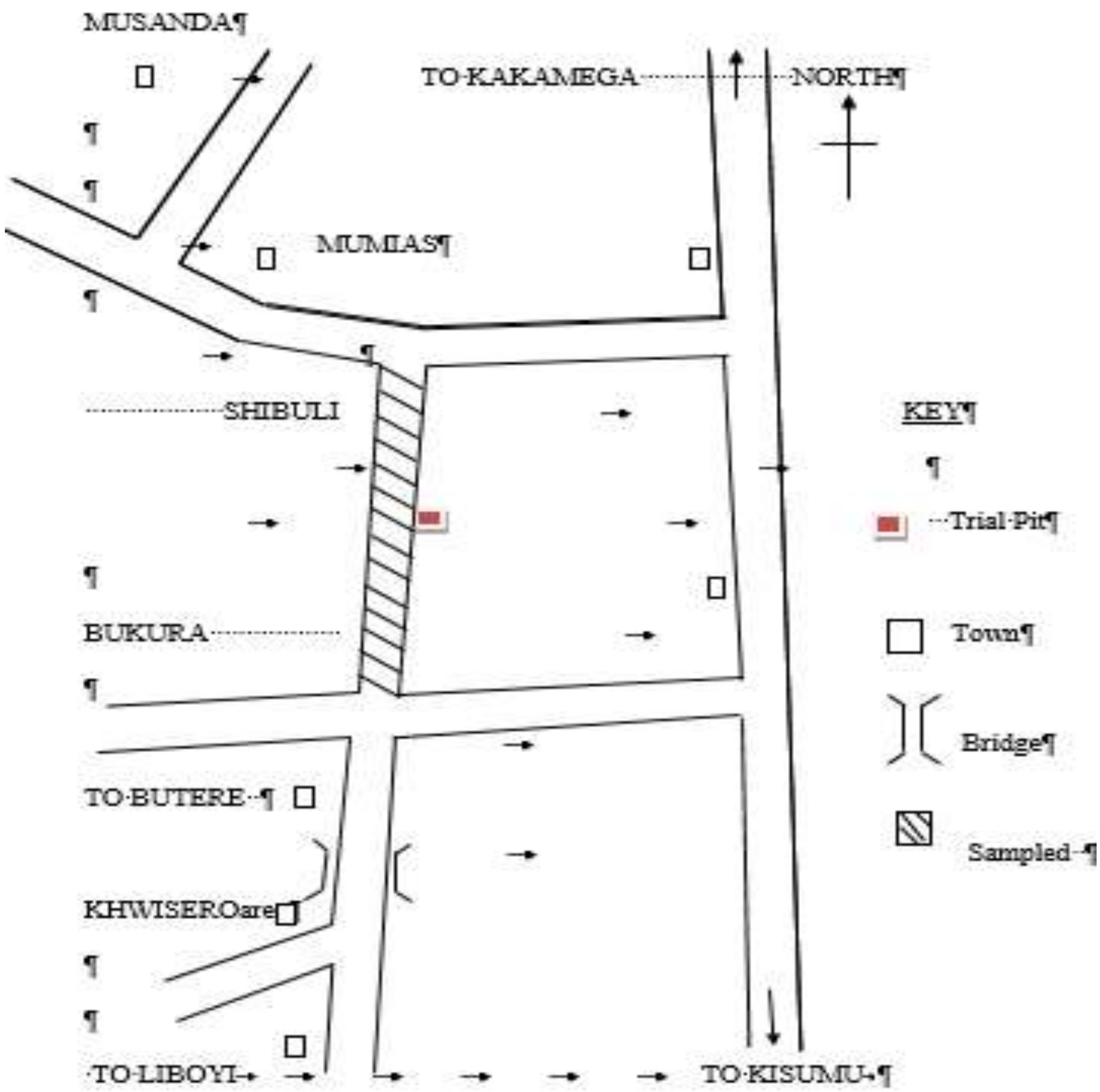


Figure 3.1: Sketch map of material site showing position of trial pit

3.4 Determining the physical, mechanical and chemical properties of laterite Gravel

The physical properties of laterite gravel that were tested were the particle size distribution and the atterberg limits. The mechanical properties tested included the compaction test, California Bearing Ratio and the Unconfined Compressive Strength. The chemical tests on laterite gravel were done to determine its chemical composition.

3.4.1 Experimental set-up

a) Particle Size distribution

The particle size distribution in the laterite gravel material down to the fine sand size was carried out in accordance with BS 1377, Part 2; 1990, Test 7A – Wet sieving method, except that sieves, based on ISO 565 – 1972 (E), were used; the sieves used ranging between sizes 0.075 mm to 20 mm, arranging them from the smallest to the largest size in ascending order from the pan. Wet sieving was done to remove silt and clay sized particles, followed by dry sieving of the remaining coarse material. The test sample was obtained by air drying for twelve hours. A representative sample was obtained by riffling where a mass of 2.5 kg was used for the test. Sieves were arranged with descending sieve size from top to the bottom with a receiver fixed below the smallest sieve. The sample was put on the top sieve and hand shaken.

b) Atterberg Limit Tests

These tests were performed on prepared samples to ascertain their plastic limits and liquid limits. The liquid limits and the plastic limits were obtained in the laboratory according to BS 1377; Part 2; 1990, from which the plasticity index was determined.

c) Compaction test

The standard compaction test was carried out. This test was performed using a 2.5 kg rammer in accordance with AASHTO T 99 except in place of 4.75 mm and 19.0 mm test sieve, the 5.00 mm and 20.0 mm test sieves were used. Moulds and rammers to BS 1377; part 2; 1990 (diameter: 105 mm, volume 1 liter) were used. Five samples each of about 3 kg of laterite gravel soil passing the 20 mm test sieve were prepared. Each sample was mixed thoroughly with different amounts of water to give a suitable range of moisture contents. Each of the five portions was sealed in an airtight container and allowed to cure for at least 4 hours. As the layers were filled in the moulds, compaction was achieved by applying 27 blows to them. This test was done to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the laterite gravel

d) California Bearing Ratio

The CBR test was performed in laboratory to determine the index strength of soil and bearing capacity. The test was carried out in accordance with BS 1377: Part 4: 1990, using CBR moulds complying with AASHTO M193. It was carried out on the laterite gravel material whose sample was about 25 kg of material passing the 20 mm sieve. Moisture content of sample was determined according to the BS Heavy compaction test and then the sample was stored for 24 hours in a sealed place before compaction into the moulds. The moulds were tamped full of the laterite gravel material using the 4.5 kg rammer, in five layers and applying 62 blows per layer. 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 mould was drained for 15 minutes before CBR penetration

e) Unconfined Compressive Strength for uncured laterite gravel soil

The UCS test was carried out in accordance with BS 1924-test 10 and according to TMHI – 1986, method A14. In order to establish the required stabilizer content to produce a mixture conforming to a specific UCS, three specimens were used for each stabilizer content. The tests were done on the uncured samples that were with and without molasses content

f) Chemical composition

After excavation of the laterite gravel soil from the trial pit to a depth of 2.5 metres, the disturbed samples were air-dried to reduce the moisture content. The soil sample was dried then ground to the desired fineness using a mechanical grinder, homogenized and sieved at 0.025 mm particle sizes at the Ministry of Mining Laboratory on Machakos road, Nairobi and chemical property tests carried out in the laboratory using the X-ray fluorescence spectrometer (XRF).

3.4.2 Data collection and analysis procedure

a) Particle Size distribution

The mass of sample retained on each sieve was obtained by subtracting the weight of the empty sieve from the mass of the sieve and that of the retained sample. This mass was recorded on the data sheet as the weight retained. The percentage retained on each sieve was obtained by dividing the weight retained on each sieve by the original sample mass. The percentage passing was obtained by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure. The data was obtained and presented in the form of a graph plotted on a grading chart.

b) Atterberg Limit Tests

Test samples weighing about 400 g which pass the 0.425 mm sieve were used. The plastic limit and the liquid limit of neat laterite gravel were determined.

i) Liquid Limit

The moisture content of each of the liquid limit moisture cans was obtained. The relationship between the moisture content and the number of blows was plotted on a semi-logarithmic chart with percentage moisture content as ordinates on the linear scale and the number of blows as abscissa on the logarithmic scale and the best line of fit drawn through the resulting points. The liquid limit (LL) was determined as the water content at 25 blows

ii) Plastic limit

The water content of each of the plastic limit moisture cans was obtained. The average of the water contents was computed to determine the plastic limit,

iii) Plasticity Index

The Plasticity Index is the difference between the Liquid Limit (LL) and the Plastic Limit (PL) and is calculated from the equation: - PI=LL- PL

c) Compaction test

The moisture content of each compacted soil sample was obtained by using the average of the two water contents. The wet density was computed in Kg/m^3 of the compacted soil sample by dividing the wet mass by the volume of the mold used. The dry density is computed using the wet density and the water content obtained by applying the formula: $\rho d = \rho \div (1+w)$.

Where:

w = moisture content in percent divided by 100, and

ρ = wet density in Kg/m^3.

The dry density values were plotted on the y-axis and the moisture contents on the x-axis. A smooth curve was drawn connecting the plotted points. The optimum moisture content and the maximum dry density were identified from the smooth curve as in Figure 4.3 below.

d) California Bearing Ratio

The force applied to the plunger from each reading of the force measuring device observed during the penetration test was calculated. A graph showing force on the plunger against penetration was plotted and smooth curve was drawn through the points. From the test curve, the forces corresponding to 2.5 and 5.0 mm penetration were read off. The corresponding CBR values were calculated from the equation:

CBR value in (%) = P x (100÷13.2).

Where;

P is the plunger force (in kN) at 2.5 mm penetration

The plunger force values at 5.0 mm penetration from the force – penetration curves were recorded. The corresponding CBR values were calculated from the equation:

CBR value in (%) = P x (100÷20.0).

Where;

P is the plunger force (in kN) at 5.0 mm penetration.

The CBR value was calculated at penetrations of 2.5 and 5.0 mm and the higher value was taken.

e) Unconfined Compressive Strength for uncured laterite gravel soil

The dial readings were converted to the appropriate load and length units, and these values were entered on the data sheet in the deformation and total load columns. The sample cross-sectional area and strain were computed. The corrected area was then calculated from the formula: $A' = A_0 (1- e)$.

Where: A_0 = cross - sectional area of sample

e = strain of the sample.

The stress was finally obtained from the formula:

$s_c = P \div (A')$.

Where:

P is the force exerted on the sample.

A’ is the corrected area of the sample

The UCS results for the uncured samples were recorded and a graph of the stress against strain for various stabilizer contents i.e., 0%, 1%, 2%, 3% and 4% was plotted and the peak stress obtained at 15% strain.

f) Chemical composition

Analysis was carried out at the Ministry of Mining Laboratory on Machakos road, Nairobi, the XRF analyzer having as excitation source a miniaturized 30Kv X-ray tube. By automatically adjusting for matrix effects the XRF analyzer was able to determine the content of the laterite gravel soil sample in seconds. The sample name, spectrum and elemental composition were stored in a dedicated library. Each soil sample was analyzed five times for 240 seconds using two X-ray filters, one for elements from K (Potassium) to Cu (copper) and the second for elements from Zn (Zinc) to Sb (Antimony).

3.5 Establishing the chemical properties of sugarcane molasses

3.5.1 Collection of molasses

The Molasses selected was Blackstrap Molasses from West Kenya Sugar Company. The molasses at the factory was sampled from a large storage tank. It was collected in a four litre can and kept in a cool place. Further sampling was done at the testing Laboratory where only 300 mililiters of the collected molasses was subject to testing for the chemical properties.

3.5.2 Experimental set-up

The chemical properties of molasses were determined using the X-ray fluorescence spectrometer (XRF) based on the dry sample. The method used was as in test 3.3.1 (f) above. Atomic Absorption Spectrometer (AAS) based on sample as it was. The (AAS) is a technique that was used in determining the presence of metals in liquid samples. It also measured the concentrations of metals in the samples.

3.5.3 Data collection and analysis procedure

Analysis was carried out at the Ministry of Mining laboratory on Machakos road, Nairobi. The XRF analyzer had a miniaturized 30Kv X-ray tube as an excitation source. By automatically adjusting for matrix effects the XRF analyzer was able to determine the content of the molasses sample in seconds. The sample name, spectrum and elemental composition were stored in a dedicated library.

The molasses sample was analyzed five times for 240 seconds using two X-ray filters, one for elements from K to Cu and the second for elements from Zn to Sb. The chemical elements examined were silicon oxide, potassium oxide, aluminium oxide, iron, manganese, titanium, Sulphur, phosphorus, potassium oxide, and calcium oxide.

3.6 Determining the optimum mix ratio for molasses to laterite gravel

The variables measured were, atterberg limits (consistency tests), compaction test, UCS and CBR. The tests were done on samples that were mixed with molasses content in the range of 1%, 2%, 3% and 4% by dry weight of the laterite gravel, in order to find out how the addition of molasses in the lateritic gravel affects the these properties.

3.6.1 Atterberg Limit Tests

The experimental set-up, data collection and analysis procedure were done as in section 3.3.1(b) and 3.3.2(b) respectively, in order to find out how the addition of molasses in the lateritic gravel affects the LL, PL and PI of the stabilized materials.

3.6.2 Heavy Compaction Test

a) Experimental set-up

The modified proctor test was carried out. This test was done to determine the MDD when stabilized laterite gravel was compacted over a range of moisture contents. This test was performed using a 4.5 kg rammer in accordance with AASHTO T 180 except in place of 4.75 mm and 19.0 mm test sieve, the 5.00 mm and 20.0 mm test sieves were used. Moulds and rammers to BS 1924; part 2; 1990 (diameter: 152 mm, volume 2.3 litres) were used.

b) Data collection and analysis procedure

The data collection and analysis procedure were done as in section 3.3.2(c) above in order to determine the Optimum Moisture Content (OMC) at which the Maximum Dry Density (MDD) is obtained.

3.6.3 California Bearing Ratio

The experimental set-up, data collection and analysis were done as in section 3.3.1(d) and 3.3.2 (d) respectively. The CBR test was performed in laboratory to determine the index strength of soil and bearing capacity.

3.6.4 Unconfined Compressive Strength for cured laterite gravel soil

The experimental set-up, data collection and analysis were done as in section 3.3.1(e) and 3.3.2 (e) respectively. The specimens were cured for seven days in plastic bags immersed in a water bath at a maintained temperature of 25^0C. The average UCS of the three specimens of each stabilizer content was used. UCS results were recorded and graphs of stress against strain plotted.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the test results, discussions and the analysis of all the tests that were performed on the neat laterite gravel soils and the tests that were carried out on laterite gravel mixed with molasses stabilizer in varying proportions. The conducted laboratory tests were presented in a tabular or graphical manner. The recorded results were compared with the specific standard values as recommended by the Ministry of Transport and Infrastructure Road Design Manual Part III (1987).

4.2 Physical, Mechanical and Chemical Properties of Laterite Gravel Soil

4.2.1 Physical properties

4.2.1.1 Particle size distribution

The results of the particle size distribution tabulated in appendix I are presented graphically as shown in Figure 4.1.

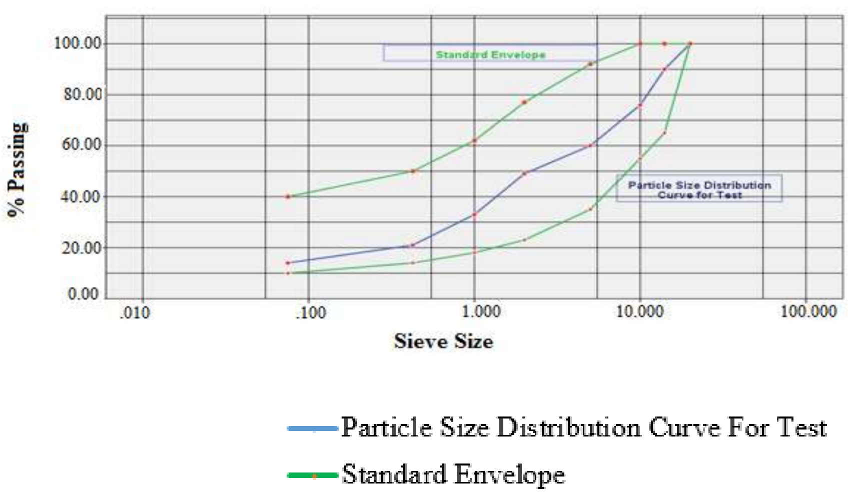


Figure 4.1: Particle Size Distribution curve comparison

In this study, it was noted that the grading after compaction of the laterite gravel was well within the standard particle size distribution envelope. It was clear that 100% of the particles passed the 20 mm test sieve whereas 90% of the particles were passing the 14 mm sieve. The 10 mm sieve had 76% of the particles passing while the 5 mm and 2 mm sieve had 60 and 49% passing them respectively. The finer material had 33, 21 and 14 % of them passing the 1 mm, 0.425 mm and 0.075 mm sieves respectively. The soil was classified as well graded gravel as more than half of the gravel fraction was larger than no. 4 (4.75mm) sieve. It was clean gravel with little fines whose group symbol is [GW].

Onyebuchi (2013) in his research observed similar behavior on grading of laterite gravel soils as particles above size 20 mm had 75% passing, whereas 65% of the particles were passing on the 10 mm sieve. The 5 mm and 2 mm sieve had 52% and 53% passing on them respectively. This also concurred with a research by Ganjo (2000) which identified the particle size distributions in similar ranges to this study. According to the Ministry of Transport and Infrastructure Road Design Manual Part III (1987), the grading requirement for gravel wearing course after compaction for class 1 envelope is between 12 – 32% and 95 – 100% by weight passing for sieve sizes 0.075 mm and 20 mm respectively. For class 2 envelope, it recommends between 10 – 40% and 85 – 100% by weight passing for sieve sizes 0.075 mm and 20 mm respectively.

4.2.1.2 Atterberg Limits

The consistency test was used for the classification of laterite gravel soil. A value of Liquid Limit of 41.40 was obtained from the three moisture contents of 44.3, 40.6 and 39.3%. After wet sieving was done for the Plastic Limit test, the results reflected moisture contents of 20.8 and 21.5%, giving a plastic limit value of 21.2. The Plasticity Index was derived from the difference between the Liquid Limit of 41.40 and the Plastic Limit of 21.2, which resulted to a value of 20.2. From the particle size distribution curve in Figure 4.2, the laterite gravel soil was composed of 14% silt. It was expected that the amount of attracted water was influenced to a greater extend by the amount of silt content that was present in the soil. The silt content of 14% is expected to have resulted to a plasticity index of 20.27. This is shown in Figure 4.2. The Ministry of Transport and Infrastructure Road Design Manual Part III (1987), specifies that the plasticity index for wet areas should be between 5 and 20, whereas in dry areas it should be a minimum of 10 and a maximum of 30.

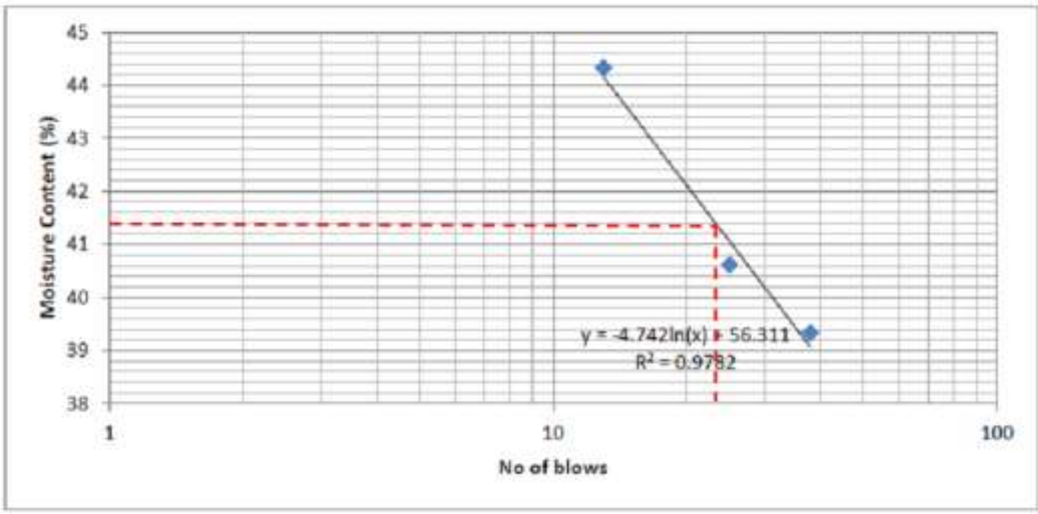


Figure 4.2: Atterberg Limits- Neat Gravel

4.2.2 Mechanical properties

4.2.2.1 Compaction

The results shown in Figure 4.3 indicated that during compaction of the neat laterite gravel soil, dry densities increased with the increase in the moisture content. The Maximum Dry Density for moisture content of 10.5% was 1524 kg/m^3. The MDD for the moisture content of 11.5% was 1605kg/m^3. For the water content of 15.1%, the MDD was 1708 kg/m^3. However, as the moisture of the laterite gravel soil was increased to 17.2%, the MDD reduced to 1643 kg/m^3. As more moisture was added to the laterite gravel soil (at low moisture content), it was easier for the soil particles to move past one another during the application of the compacting forces. As the laterite gravel soil compacted, the voids reduced and this resulted to increased dry densities. However, after attaining the maximum moisture content, which gave the maximum dry density, further moisture content increases, resulted to a reduction in dry density. Figure 4.3 shows the behaviour of Maximum Dry Density in relation to moisture content as obtained during the compaction of laterite gravel soil. The optimum moisture content was 14.6%, giving a Maximum Dry Density of 1712 kg/m^3.

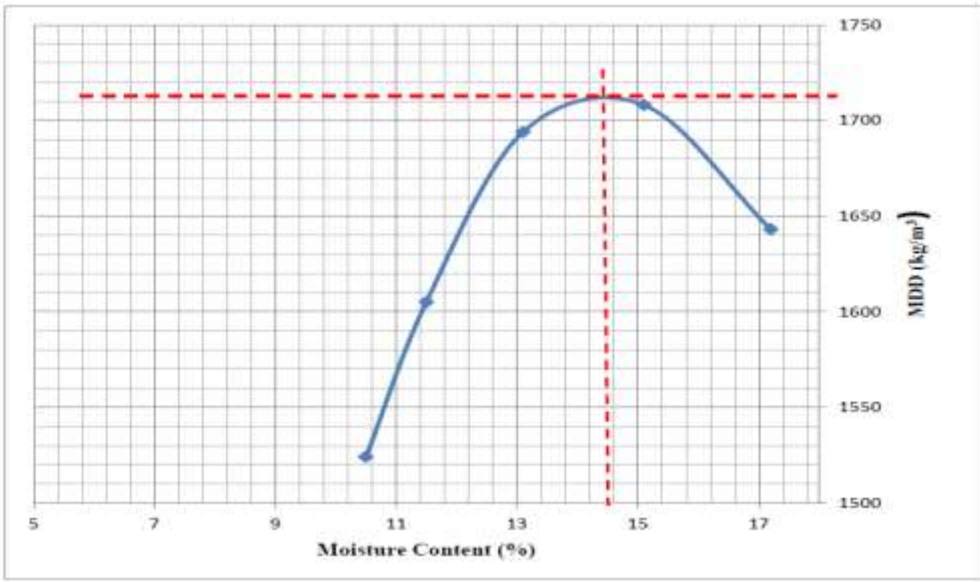


Figure 4.3: Proctor Compaction- Neat Gravel

4.2.2.2 California Bearing Ratio

The CBR results for neat laterite gravel soil were obtained after 4 days soak. A swell of 0.2% was recorded after 4 days soak. The CBR results were obtained at penetrations of 2.5 and 5.0 mm. The 2.5 mm penetration was used to assess the CBR of the neat laterite gravel soil. Figure 4.4showshowthe CBR for the neat laterite gravel soil was obtained. A graph showing force against penetration was plotted and a curve drawn through the points as shown. The CBR value obtained was 19.4%. The Ministry of Transport and Infrastructure Road Design Manual Part III (1987), recommends that the CBR at 95% MDD and 4 days soak should be a minimum of 20. The results show that the neat laterite gravel soil had a slightly lower CBR than the recommended minimum.

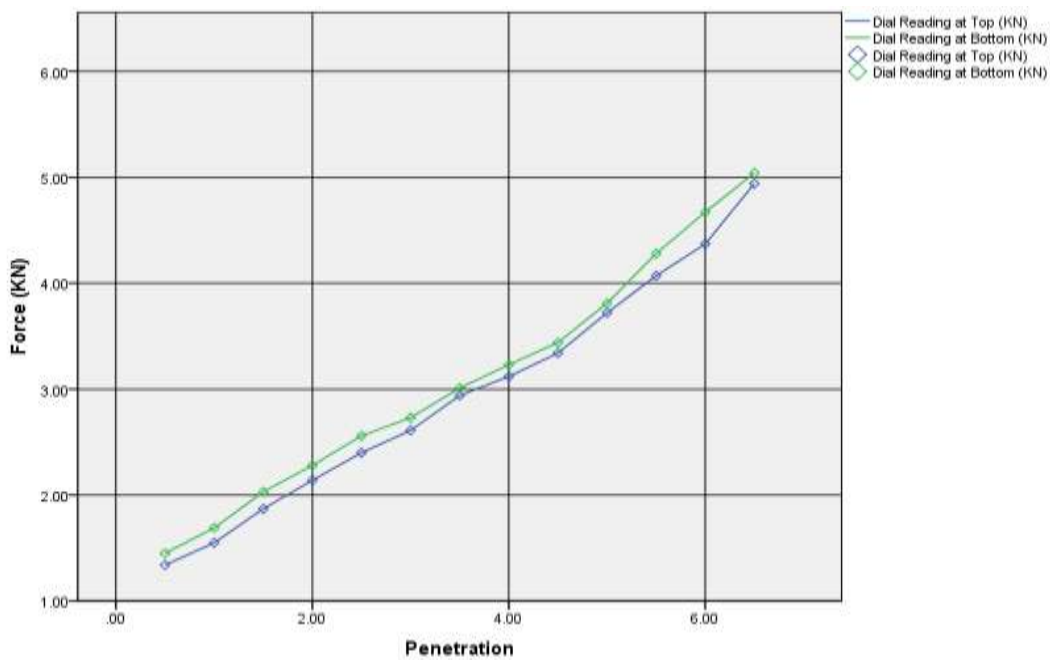


Figure 4.4: CBR Value – Neat Gravel

4.2.2.3 Unconfined Compressive Strength

The results for the UCS were obtained after subjecting the prepared specimen of lateritic gravel soil to an increasing load until failure. These were specimens that were both cured and uncured but not stabilized with molasses. The tests showed that for the uncured specimen, failure occurred after a load of 110.6 Newtons was applied to it. This was applied on an area of specimen of 0.00137 m^2, which resulted to a compressive strength of 81.9 kN/m^2. The results for UCS of cured specimen indicated that the deformation occurred after a load of 207.0 Newtons was exerted on an area of specimen of 0.00135 m^2. This gave a compressive strength of 153.5 kN/m^2. These results indicate that for the cured specimens, they require more load to deform than the uncured ones. This is shown in Figure 4.5.

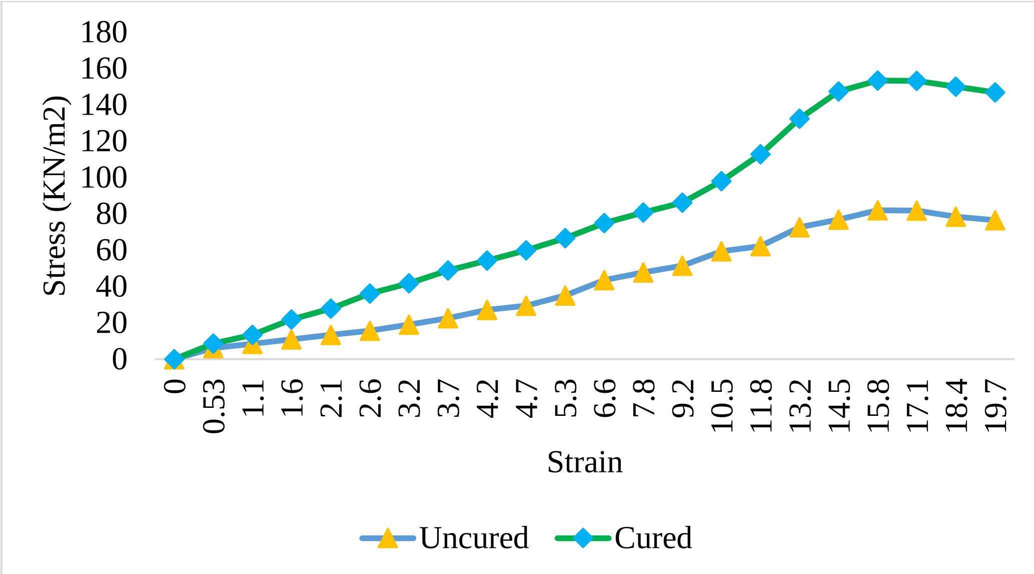


Figure 4.5: UCS for Uncured/cured Laterite Gravel Soil with 0% molasses

4.2.3 Chemical properties of laterite gravel soil

The results presented here are a reflection of the tests done in order to find out the chemical composition of laterite gravel soil.The results were as outlined in Table 4.1. Other researchers also carried out research on chemical composition of laterite gravel. The results of the major chemical components were as outlined in Table 4.1.

Table 4.1: Chemical Composition of Laterite Gravel

S/No.	Chemical Composition	Researcher Laterite Gravel (%)	Other Researchers		
		Amunga	Mustapha	Adewuyi	Osuji
1.	AI_2O_3	24.76	36	39	23
2.	Fe_2O_3	22.44	1.8	6.5	13
3.	SiO_2	46.94	30	73	47
4.	CaO	1.04	-	0.3	0.1
5.	K_2O	0.93	0.3	1.4	0.2
6.	TiO_2	1.78	-	1.3	2.1
7.	P_2O_5	0.57	-	-	-
8.	S	0.67	-	-	-
9.	Mn	0.59	-	-	-

In this study, the chemical composition of laterite gravel samples given in Table 4.1 shows the presence of 22% of iron oxide, followed by 25% aluminum and 47% of silicon oxide. There was very minimal chemical composition in the lateritic gravel soil of 0.59, 0.67 and 0.93% for manganese, sulphur and potassium oxide respectively. According to Bell (1997), the soils having silica to sesquioxide ratio of greater than 2 are considered non lateritic. For laterite soils, silica (SiO_3) to sesquioxides (Fe_2O_3 + $Al_2O_{3)}$ ratio lies between 1.33 and 2.0. For true laterite, the ratio is less than 1.33. The soil under investigation has silica to sesquioxide ratio of 1.0. This suggests that it is true laterite soil. These results compared very favorably with those of Mustapha and Alhassan (2012), whose results for silicon oxide ranged from 29 to 39% and those for aluminum oxide ranged from 36 to 38%. Onyebuchi (2013) in his research also found that laterite soil was mainly composed of oxides of silicon, aluminum and iron in the ranges of 35, 26 and 5% respectively. Kamtchueng et al. (2015) in there research noted that lateritic soil was mainly composed of oxides of silicon, iron and aluminium in the ranges of 35, 41 and 21% respectively. Osuji and Akimwamide (2018) in their study found laterites were mainly composed of oxides of silicon, iron and aluminium in the ranges of 47, 13 and 23% respectively. (Fookes (1997) named laterites based on hardening , such as "ferric" for iron-rich cemented crusts ,"alcrate" or bauxite for aluminium rich cemented crusts,"calcrate" for calcium carbonate rich crusts, and "silcrate" for silica rich cemented crusts.

4.3 Chemical composition of sugarcane molasses

The results which are recorded here are a reflection of the tests done in order to find out the chemical composition of molasses. The results were as shown in Table 4.2. Other researchers also carried out research on chemical composition of molasses. The results of the major chemical components were as outlined in Table 4.2.

Table 4.2: Chemical Composition of Sugarcane Molasses

S/No.	Chemical Composition	Researcher	Other Researchers		
		Amunga	Shirsavkar	Ndegwa	Olbrich
1.	AI_2O_3	2.95	0.07	0.3	0.07
2.	Fe_2O_3	2.44	0.07	-	0.07
3.	SiO_2	5.77	0.50	0.3	0.5
4.	CaO	26.12	1.5	1.1	1.5
5.	K_2O	39.11	3.5	3.0	3.5
6.	TiO_2	0.55	-	-	-
7.	P_2O_5	2.64	-	-	-
8.	MgO	13.54	0.1	0.15	0.1
9.	MnO	0.37	-	-	-
10	Na_2O	0.07	0.07	0.02	0.07
11	S	4.66	-	-	-
12	Cl	1.47	-	-	-

Analysis of the chemical composition of molasses showed that it contained the following major oxides; potassium oxide 39.11%, calcium oxide 26.12% and magnesium oxide 13.54%. The minor oxides that molasses material was composed of included phosphorus oxide 2.64%, silicon oxide 5.77%, iron oxide 2.44% and aluminum oxide 2.95% with the inclusion of other compounds, i.e, titanium oxide, manganese oxide, chlorine and sodium oxide.

Shirsavkar (2010) and Olbrich (2006), concured in their research findings when they noted that molasses contained silica oxide,potassium oxide, calcium oxide and magnesium oxide 0.5,3.5,1.5 and 0.1% respectively.

Hasan & Baris (2012) established that these oxides found in molasses were also the chemical components found in cement. They found that cement was composed of silica oxide 21%, aluminum oxide 5.61%, iron oxide 2.95%, calcium oxide 63.72% and manganese oxide 1.66%.

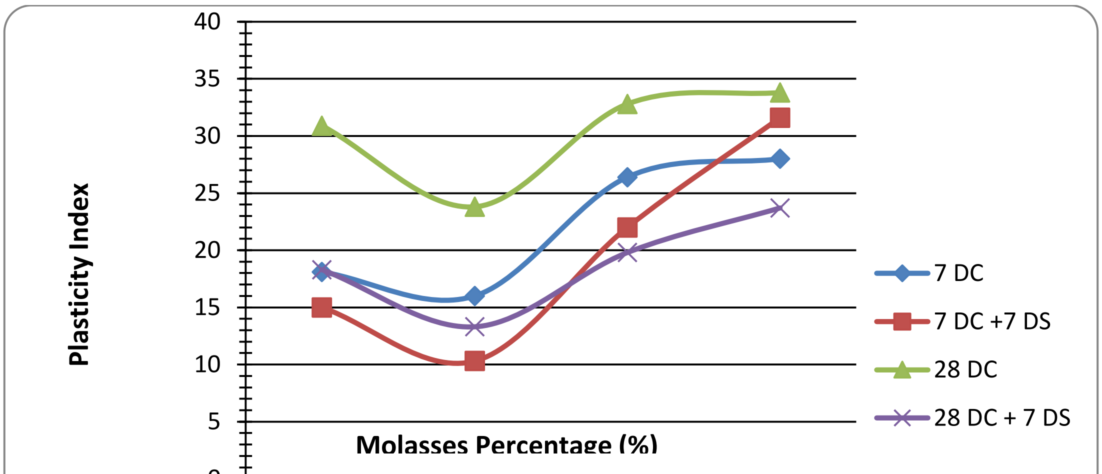
M'Ndegwa (2011) noted that cane molasses had the following major elements; calcium 1.09%, magnesium 0.15%, silicon 0.3%, sodium 0.02% and potassium 2.97%. However, he added that molasses composition is influenced by the soil where the cane is grown, climatic conditions, variety of the cane and processing conditions at the factory. The study showed that there existed a substantial amount of calcium, potassium, Silicon and magnesium elements which were responsible for the binding of the lateritic gravel soil particles and the dust suppression.

M'Ndegwa (2011) observed that molasses has sucrose as its major component, which is literally sugar. From these results, it can be seen that for every sample of molasses tested by the researchers, Potassium Oxide occupied the largest fraction of all the other chemicals. It was followed by Calcium Oxide, Silicon Oxide and Magnesium Oxide respectively. As with the study of M'Ndegwa (2011) who observed that sugar has various component groups and hydroxyl (OH) group responsible for the properties of sugar and thus those of molasses, my study on sugarcane molasses composition showed that molasses contained elements which were active in causing chemical rection. The chemical reaction resulted to cation exchange which brought about stabilization of laterite gravel soil. These elements included calcium oxide, silicon oxide and magnesium oxide.

4.4 Optimum performance of laterite gravel soil stabilized with sugarcane molasses for unpaved roads.

4.4.1 Effect of molasses on Atterberg limits

This can be seen from Figure 4.6.



	1	2	3	4
7 DC	18.1	16	26.4	28
7 DC +7 DS	15	10.3	22	31.6
28 DC	30.9	23.8	32.8	33.8
28 DC + 7 DS	18.3	13.3	19.8	23.7

Figure 4.6: Effect of molasses on Atterberg limits

The trend observed here was that an increase in the amount of percentage of molasses reduced the plasticity index from a value of 20.28 for neat laterite gravel to 10.7 after addition of 2% molasses. As reflected in Figure 4.7results show that after additions of 2% molasses by dry weight of laterite gravel soil, the Plasticity Indexes reduced. After addition of 2%molasses for 7 days cure of laterite gravel soil, the Plasticity Index reduced from 18.1 to 16.0. It subsequently increased to 26.4 and 28.0 after additions of 3 and 4% molasses respectively. For the 7 days cure + 7 days soak of laterite gravel soil, the

Plasticity Index reduced to 10.7 for 2% molasses from 15% when 1% addition of molasses was applied. The Plasticity Index increased with the additions of 3 and 4% molasses resulting to 22.0 and 31.6 respectively. After the 28 days cure, the Plasticity Index was 30.9, 23.8, 32.8 and 33.8 with additions of 1, 2, 3 and 4% molasses respectively.

The same trend was observed when laterite gravel soil was subjected to 28 days cure + 7 days soak. The plasticity Index for 1, 2, 3 and 4% molasses was 18.3, 13.3, 19.3 and 23.7. According to Misinguzi (2019), the cation exchange reaction and the adhesivity property of molasses are responsible for reducing the water holding capacity of the soils. The treatment of laterite gravel soil with molasses facilitates the decrease in liquid limit and increase in plastic limit resulting to a reduction in plasticity index. The chemical reaction between soil and elements of calcium oxide in molasses results in a reduction in water content hence; lowers the PI of the laterite gravel. The cation exchange process is associated with the pozzolanic reactions which reflect in the hydration of the lime content present in molasses. The pozzolanic action is induced by Calcium Hydroxide produced from the hydration process. Molasses when added to laterite gravel as a stabilizing agent led to particle aggregation which led to lowering of the liquid limit of the soil while the plastic limit was raised. However, the addition of excess proportions of molasses resulted to huge plasticity indexes which rendered the laterite gravel unsuitable as gravel wearing course material.

4.4.2 Effects of molasses on compaction properties of laterite gravel soil

4.4.2.1 Maximum Dry Density

The effect of molasses on MDD and of the treated laterite gravel was recorded as illustrated in the Figure 4.7

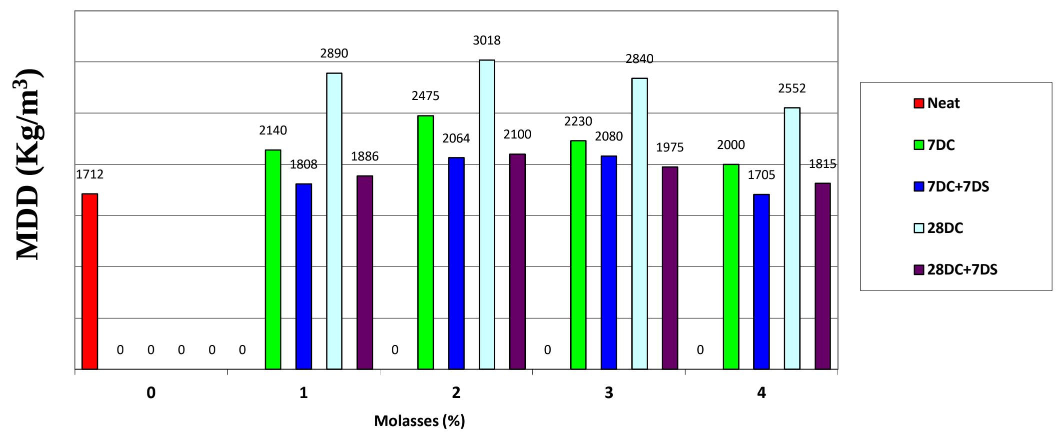


Figure 4.7: Effect of molasses on Maximum Dry Density

The values for MDD were noted to significantly increase with the addition of molasses from a neat value of 1712 kg/m^3 when molasses was added to the laterite gravel soil. with additions of 1, 2, 3 and 4% molasses for 7 days cure, the values for MDD were 2140, 2475, 2230 and 2000 kg/m^3 respectively. For the 7 days cure + 7 days soak, additions of 1, 2, 3 and 4% molasses resulted to MDDs of 1808, 2064, 2080 and1705 kg/m^3. The MDDs for 28 days cure for 1, 2, 3 and 4% molasses were, 2890, 3018, 2840 and 2552 kg/m^3. Similarly, the MDDs for 28 days cure + 7days soak with additions of 1, 2, 3 and 4% molasses were 1886, 2100, 1975 and 1815 kg/m^3. It can be clearly seen from these results that the optimum percentage of molasses required was 2% of the dry weight of laterite gravel soil. It can be said that the voids ratio decreased when optimum percentages of molasses were added. Rajesh (2018) notes that increase in density and decrease in water content is observed due to the reduction in the thickness of diffuse double layer of water added to the laterite gravel soil. This made the samples with optimum amounts to record higher dry densities than the others.

However, addition of higher amounts of molasses i.e., 3% and 4% increased the voids and this caused the dry densities to decrease. As more molasses was added this meant there was addition of more moisture to the samples, resulting to reduced dry densities. According to Olbrich (2006), molasses contains 20% water held as hydration water. Rajesh (2018), observed that water surplus to the optimum moisture content dilutes the ion exchange and agglomeration capacity of potassium chloride leading to an increased thickness of double layer of water with subsequent volume expansion and decreased density of mix. When the moisture in molasses was combined with moisture in the laterite gravel soil, the voids were filled with water, resulting to loss of grain- to- grain contact. This eventually weakened the lateritic gravel soil and showed low dry densities.

4.4.2.2 Optimum Moisture Content

The effect of Molasses on OMC was as shown in Figure 4.8

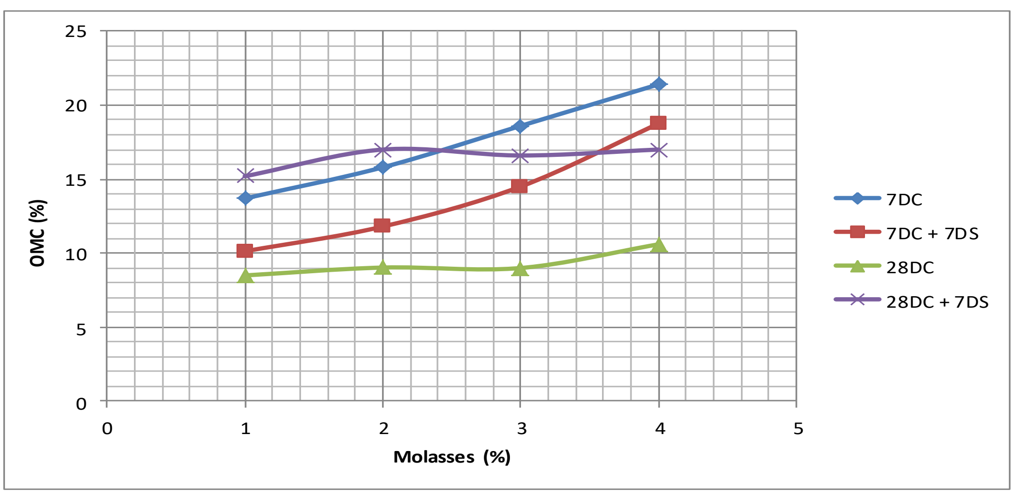


Figure 4.8: Effect of molasses on Optimum Moisture Content

The OMC increased as the molasses content increased. For 28 days cure of laterite gravel soil with additions of 1, 2, 3 and 4% molasses, the OMC percentages were 8.5, 9.0, 9.2 and 10.5% respectively. For 7 days cure, the OMC percentages were 13.3, 16.0, 18.5, and 21.4% respectively. For the 7 days cure + 7 days soak, laterite gravel soil exhibited OMCs in the ranges of 10.0, 12.0, 14.5 and 18.5% for 1, 2, 3 and 4% molasses additions respectively. The OMCs observed after additions of 1, 2, 3 and 4% for the 28 days soak + 7 days cure were 15.2, 17.0, 16.8 and 17.0% respectively.

The OMCs that facilitated maximum compaction of the laterite gravel soil were 9.0, 12.0, 16.0 and 17.0% at 2% molasses content. M'Ndegwa (2011) attributed this to the addition of molasses which decreased the quantity of free silt and clay fraction forming coarser materials with larger surface area hence the process required water to achieve a desired compaction. In relation to my study, the optimum amount of 2% molasses content added to laterite gravel caused the soil particles to move closer for maximum compaction. Figure 4.8 illustrates how the OMC of laterite gravel was affected by the addition of more percentages of molasses respectively.

4.4.3 Effect of molasses on Unconfined Compressive Strength of laterite gravel

The results of the UCS of the stabilized laterite gravel soils are presented in Figures 4.9, 4.10 and 4.11 respectively.

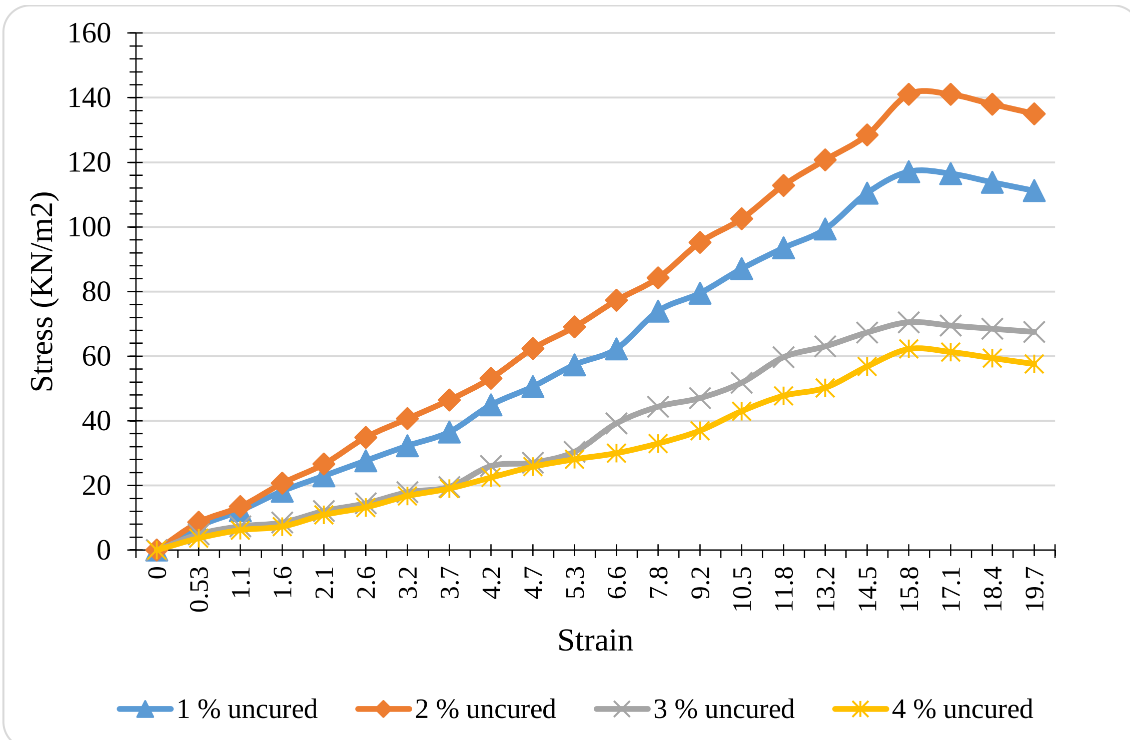


Figure 4.9: Effect of molasses on Unconfined Compressive Strength of uncured laterite gravel

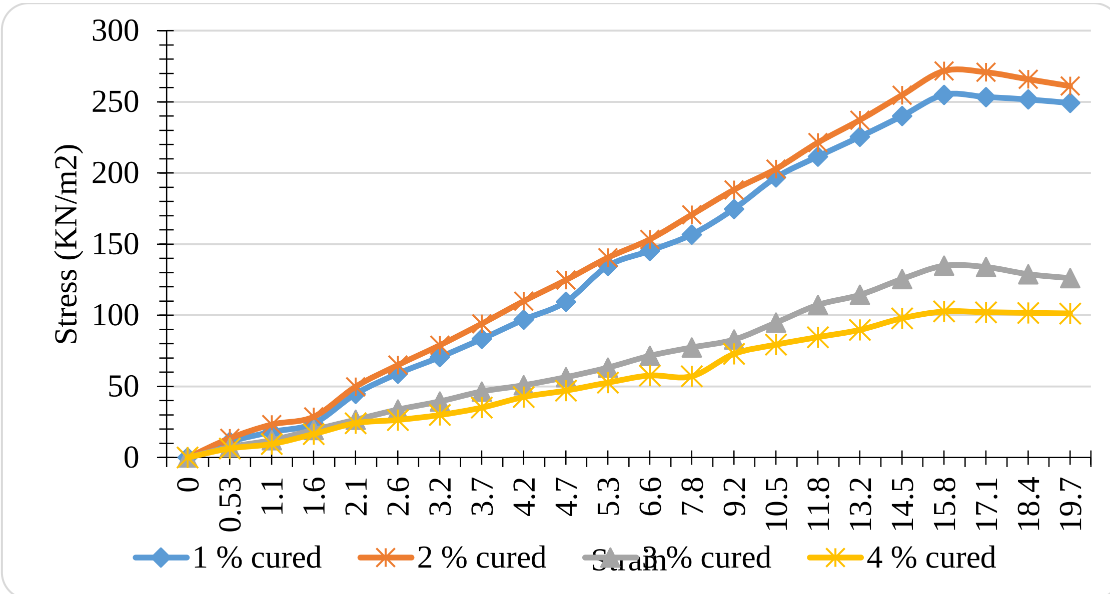


Figure 4.10: Effect of molasses on Unconfined Compressive Strength of cured laterite gravel

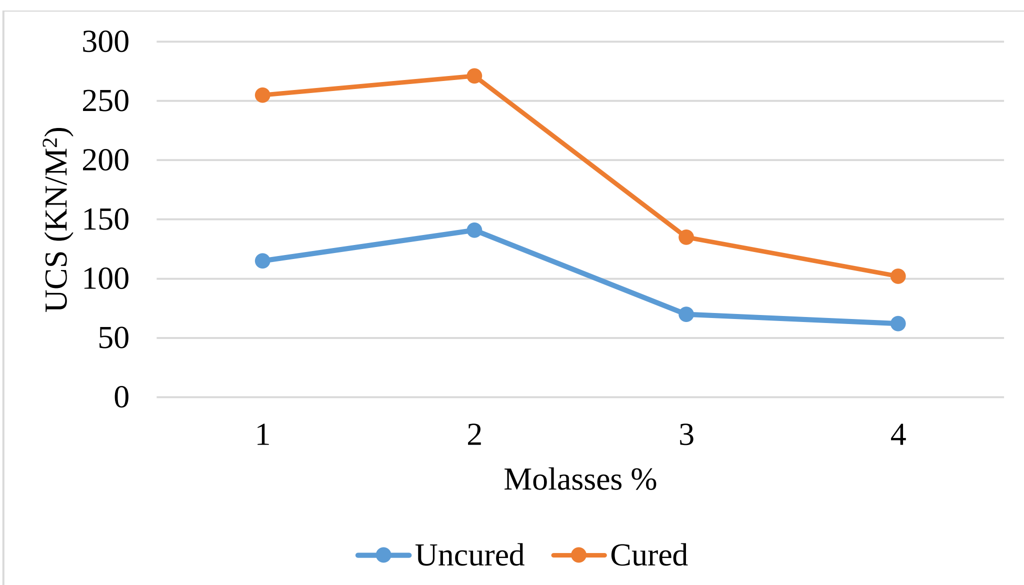


Figure 4.11: Effect of molasses on Unconfined Compressive Strength

It was observed that the UCS for the cured laterite gravel soils was higher than the uncured ones. After addition of 1, 2, 3 and 4% of molasses, the UCS for the uncured laterite gravel soil samples was observed to be 115, 141, 70 and 62 kN/m^2 respectively. For the cured laterite gravel soil the UCS after additions of 1%, 2%, 3% and 4% of molasses was observed to be 255,271, 135 and 102 kN/m^2 respectively.

It was also observed that as the soils were stabilized their UCS continued to increase to a certain level of stabilization percentage, however as more molasses was added to the samples i.e. 3 and 4% the UCS for both cured and uncured soils reduced considerably. For example in the uncured samples, the UCS increased to 141 kN/m^2 after addition of an optimum amount of 2% molasses after which subsequent additions resulted to a drop in UCS. Similarly, for the cured samples the UCS increased to 271.70 kN/m^2 after addition of 2% molasses, after which subsequent additions resulted to a drop in the UCS. Rajesh (2018), records that the addition of potassium chloride more than the optimum amount can develop a repulsive force between soil particles which leads to loose packaging. The addition of large amounts of potassium chloride through molasses increases the cations in the soil mix and the additional cations are responsible for the reverse action which reduces the maximum dry density and increases the optimum moisture content. This could have contributed to the reduction in the UCS of laterite gravel soil. The compressive strength values for the cured stabilized samples gained strength over time.

This was because the moisture which was lubricating the contact areas of the stabilized soil had been released by curing thus increasing the friction between the particles. Therefore a higher load was required to deform the cured samples.

4.4.4 Effect of molasses on California Bearing Ratio of laterite gravel soil

The results of CBR for stabilized laterite gravel soil were as presented in Figure 4.12

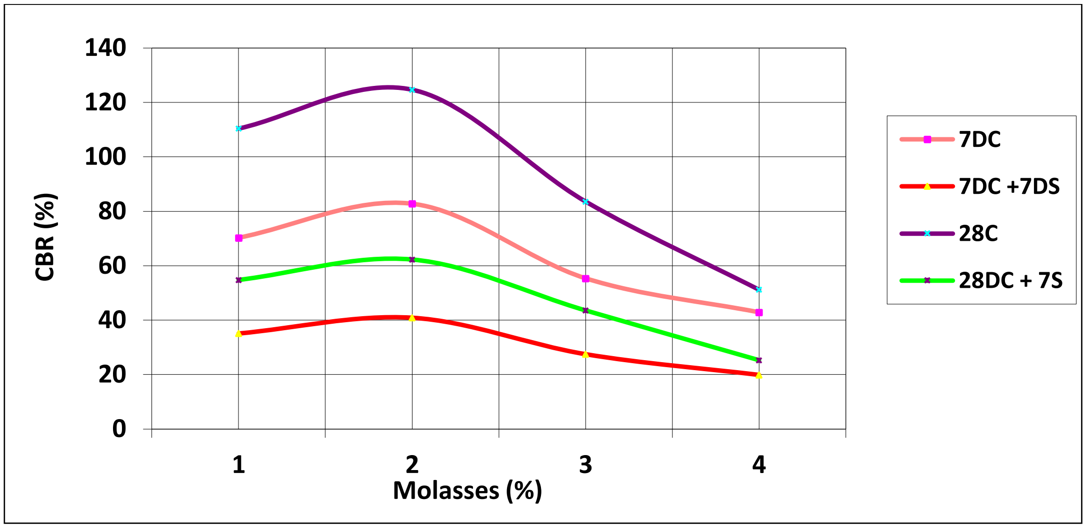


Figure 4.12: Effect of molasses on California Bearing Ratio

It was a general observation that the values for laterite gravel soil stabilized with optimum molasses content were generally higher than those of neat sample under similar conditions. As noted by M'Ndegwa (2011) the molasses content and curing duration of the specimens before testing had an effect on CBR values. Increasing the molasses content in the soil resulted in increased CBR values of the soils. However, further increase beyond 2% molasses resulted in the reduction of CBR values. It was also observed that the higher the optimum moisture content, the lesser the CBR value. The moisture content therefore was a major factor which caused detrimental effect on bearing resistance of the laterite gravel soil.

It was visualized that free water which was absorbed into the soil specimens during soaking increased the water content of compacted soil specimens. It occupied the pore spaces within the compacted soil mass (M'Ndegwa, 2011).

When the load was applied to bear on the soil during testing, pore pressures were increased. They therefore pushed soil particles apart and in so doing, reduced the contacts between them. Reduced contacts led to reduced development of antiparticle friction, which led to low load bearing strength of the specimens, hence the low CBR values for specimens with higher percentages of molasses i.e., those with 3% and 4%. As observed by M'Ndegwa (2011), the reduction of CBR values with increasing content beyond a certain limit was also attributed to coating of individual soil grains with molasses. As molasses coated the soil grains, its thickness around each grain increased with increase in the distances in individual grains. The bond caused by adhesivity of molasses then acted alone but was not strong enough to offer high resistance to deformation caused by the load applied to the compacted soil. Zubair (2017), recorded that increasing of Calcium Oxide content to 10% and 28 days cured, caused the bearing capacity of the soil to increase 300%. In his test, he reported that pozzolanic reaction causes pozzolanic strength which causes dry and dense soil due to Calcium Oxide and water reaction, where calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) form a cementation layer matrix causing the increase of soil strength.

4.5 Summary

From the results shown, the laterite gravels soils showed that it was mainly composed of the silicon oxide chemical elements i.e., 46.94%. Also present in the laterite gravels soils were aluminum oxide, iron and calcium oxide in considerable amounts i.e. 24.76, 22.44 and 1.04% respectively. This was an indication of a material posessing a binding ability similar to that of cement according to Hasan & Baris (2012). The molasses sample was found to be mainly composed of calcium oxide i.e., 26.12% which is a key ingredient for the process of making cement, magnesium oxide, potassium oxide and silicon oxide elements were found to be in reasonable amounts in molasses i.e. 13.54, 39.11and 5.77% respectively. Dunuweera (2018) established that cement is composed of major chemical elements like silicon dioxide, iron oxide, aluminium oxide, calcium oxide and magnesium oxide in reasonable amounts i.e. 21, 3.0, 5.5, 64 and 2.0% respectively. The chemical composition for molasses therefore gives similar pattern to those of cement, though not in similar percentages. It was also noted that the addition of molasses to the laterite gravel did not alter the particle size distribution. However, addition of an optimum percentage i.e., 2% of molasses to the laterite gravel resulted into a reduced PI of 10.7 from 15.0 which was very ideal for the gravel wearing course in the area

Adeboje (2016) in his study also observed that when laterite soil is stabilized with pulverized palm kernel shell, the MDD, UCS and CBR of the soils improved. This was because just like molasses, pulverized palm kernel shell contained major chemical elements like Potassium and calcium. It was also evident from the study that the addition of optimum percentages of molasses in the laterite gravel resulted to improved MDD, CBR and UCS. Other elements found in molasses like sulphur, phosphorus, sodium oxide, and manganese were found in molasses but in very small proportions. As noted by M'Ndegwa (2011), these may have been elements which were added during sugar processing as clarification agents and decadents. During crystallization of the sugar juice, those elements remain in molasses and are then included in the natural molasses ingredients. However, these elements being in very small proportions had no significant effect on MDD, UCS and CBR of the treated laterite gravel soil. Generally, it was evident from this study that molasses was suitable for use in stabilizing laterite soils for gravel wearing course.

Table 4.3: Summary of the geotechnical properties/results

Property	Required Minimum Standard	Neat Gravel Results	2% Stabilized Gravel Results 28DC + 7DS	Suitability of stabilized gravel
Particle Size Distribution	Between Class 1 & 2 Envelopes	Between Class 1 & 2 Envelopes	-	
		Atterberg Limit		
Liquid Limit		41.40	31.30	Suitable
Plastic Limit		21.20	18.0	Suitable
Plasticity Index	Min. 5, Max. 30	20.20	13.30	Suitable
		Compaction		
MDD (Kg/m^3		1712	2100	Suitable
OMC (%)		14.6	17.0	Suitable
		CBR (%)		
CBR	Min. 20	19.4	62.3	Suitable
		UCS		
7 DC (kN/m^3)		153.48	271.70	Suitable
Uncured (kN/m^3)		81.92	141.03	Suitable

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1) After examining the laterite gravel soil in this study, it was found out that the material had a mixture of red, brown and yellow colour and was characterized by the presence of iron, aluminium oxide and silica oxide which when mixed with molasses enabled the binding of laterite gravel soil particles. The combinations of iron oxide, silicon oxide and aluminium oxide chemical elements in amounts of 22.44, 46.94, and 24.76% in this material made it qualify as a material that could be used on the wearing course of unpaved roads. Laterite gravel soil sampled from this region had almost similar chemical composition elements like those of cement although not in the same percentage proportions. The grading after compaction of the laterite gravel was well within the standard particle size distribution envelope. The Plasticity Index was 20.20 while the MDD was 1712 Kg/m^3 at OMC of 14.6%. The UCS for uncured and cured laterite gravel was 81.92 and 153.48 kN/m^3 respectively while the CBR was 19.4%. The laterite gravel soil chosen for this study could be improved when used on wearing course of unpaved roads within the Butere and Mumias sub counties.

2) The molasses was found to contain calcium, magnesium and potassium oxides as the major chemicals. Calcium oxide was the major oxide found in molasses with 26.12% while silica oxide was the major oxide found in laterite gravel soil with 46.94%. These were the most important oxides that were responsible for the strength of the treated laterite gravel soil.

3) The optimum mix ratio of molasses to the laterite gravel soil required for stabilization was 2% by weight and was recommended for use. At 2% optimum percentage of molasses addition, the PI went down from 20.20 to 13.30; the MDD improved from 1712 to 2100 Kg/m^3, the UCS improved from 153.48 to 271.70 kN/m^3 and the CBR improved from

19.4 to 62.3. This was due to the increase in density of the modified laterite gravel soil mix and due to improved binding capacity which led to the soil mass having more strength.

5.2 Recommendations

Industrial wastes like molasses can be used to add value to road users through being utilized on unpaved roads to make the wearing course of the roads stronger because molasses promotes stabilization of the laterite gravel soil. This is an indicator that the unpaved roads stabilized with molasses can give efficient service to the users. The durability of the unpaved roads will also be enhanced.

5.3 Recommendations required for further research

Industrial wastes like molasses have significant potential to be used and can be used on wearing course on unpaved roads. More research should therefore be carried out on other locally available materials to assess whether if incorporated in molasses could improve the wearing course qualities. More in-situ based studies using molasses need to be carried out to ascertain the ability of molasses to be used as a stabilizer on wearing courses of unpaved roads.

Further investigations need to be done on the type of sugarcane and best nutrients that support cane growth to enable these chemical elements to be present in plenty in molasses during sugar manufacture.

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APPENDICES

Appendix I: Grading Analysis of Neat Lateritic Gravel

NUMERICAL DATA ANALYSIS

Neat Gravel

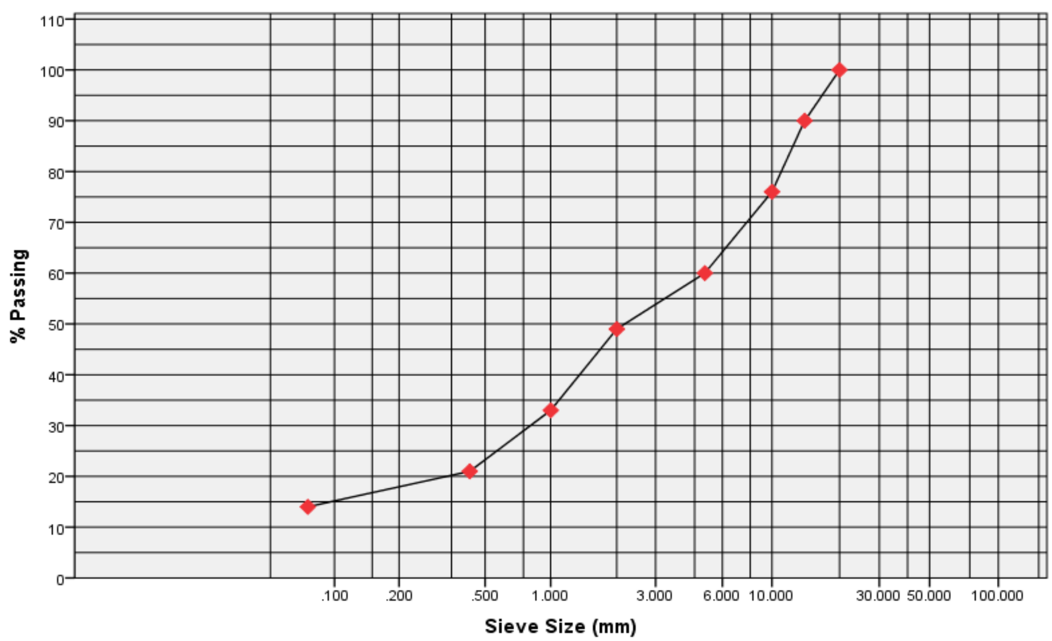
Sample Type	**Laterite Gravel**		
Sample Source	**Bukura -Shibuli Road**		
Sample Date	2015	Sample No.	63/B/S/16
Test Date	22/08/2015		
Specification	**According to BS 1377:1990**		

Sieve Analysis

Pan Mass (g)	100
Initial Dry Sample Mass + Pan (g)	400
Initial Dry Sample Mass (g)	300
Washed Dry Sample Mass +Pan (g)	370
Washed Dry Sample Mass (g)	270

Grading Analysis of Neat Laterite Gravel

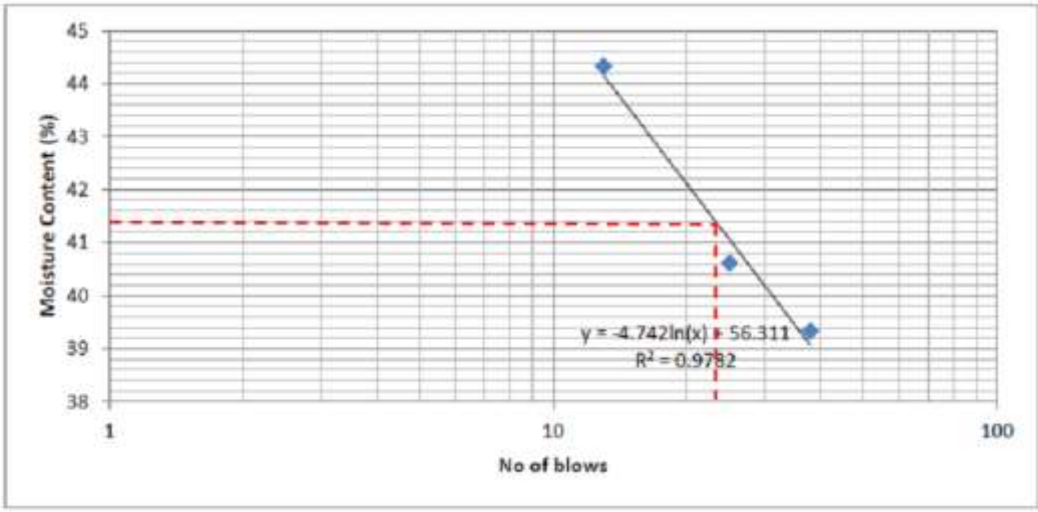
Sieve Size (mm)	Retained Mass (g)	% Retained	% Passing
20	0	0	100
14	27	10	90
10	38	14	76
5	43	16	60
2	57	21	49
1	43	16	33
0.425	32	12	21
0.075	19	7	14
Pan	**259**	**11**	**0**



Grading Analysis of Neat Laterite Gravel

Appendix II: Atterberg Limits (neat gravel)

RATIO	NEAT GRAVEL						
SAMPLE COURSE	BUKURA – SHIBULI ROAD						
TEST DATE	01/09/2015						
SPECIFICATION							
	Liquid Limit					Plastic Limit	
Container No.		1	2	3		A	B
No. of Blows		**13**	**25**	**38**			
wt. of Container + Wet Soil (g)		40.66	33.84	28.17		20.57	21.22
wt. of Container + Dry Soil (g)		34.15	29.69	25.7		19.70	20.23
wt. of Container (g)		19.46	19.47	19.42		15.52	15.62
wt. of Moisture (g)		6.51	4.15	2.47		0.87	0.99
wt. of Dry Soil (g)		14.69	10.22	6.28		4.18	4.61
Moisture Content (%)		**44.32**	**40.61**	**39.33**		**20.81**	**21.48**



L.L=41.42

P.L=21.15

PI=LL-PL=20.27

Atterberg Limits- Neat Gravel

Appendix III: Proctor Compaction (Neat Gravel)

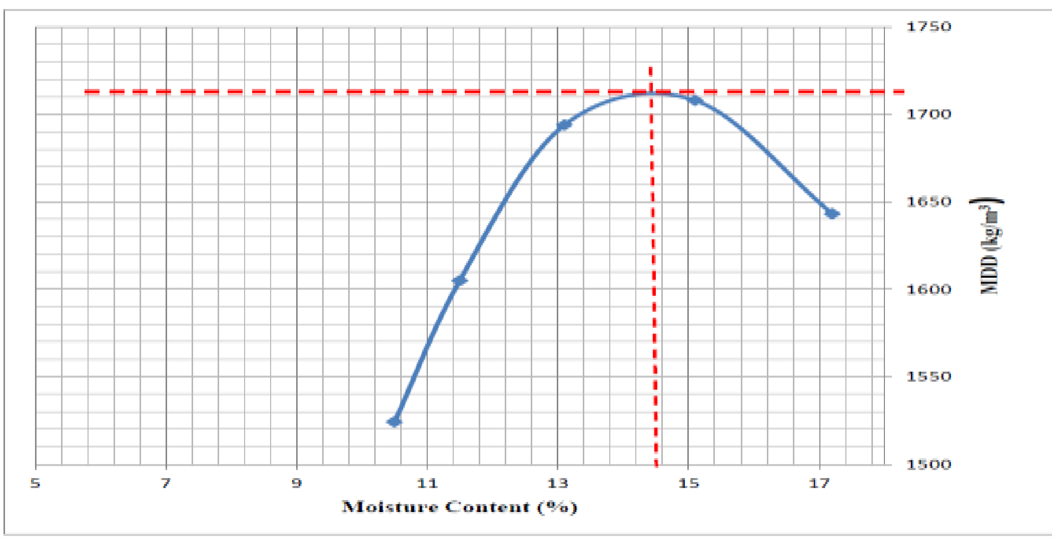
Water Content Determination

Compacted Soil Sample No.	1		2		3		4		5	
Water Content Sample No. 1	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Moisture Can No. – Lid No.	1	2	3	4	5	6	7	8	9	10
M_C = Mass of Empty Clean Can + Lid (g)	27.1	27.9	27.3	23.0	24.0	30.3	29.7	30.5	24.2	29.6
M_{CMS} = Mass of Can, Lid& Moist Soil (g)	45.0	41.6	41.6	41.8	39.8	48.10	46	44	42	43
M_{CDS} = Mass of Can, Lid & Dry Soil (g)	43.5	40.2	40.0	40.1	38.0	46.0	43.9	42.2	39.7	41.0
M_S = Mass of Soil/Solids (g)	16.4	12.3	12.7	17.1	14.0	15.7	14.2	11.7	13.7	11.4
M_W= Mass of Pore Water (g)	1.50	1.40	1.6	1.78	1.80	2.10	2.10	1.80	2.30	2.0
W = Water Content (%)	9.5	11.4	12.6	10.4	12.8	13.4	14.8	15.4	16.8	17.5

Proctor Compaction

Proctor Compaction Test - Neat Gravel

Compacted Soil-Sample No.	1	2	3	4	5
Average Water Content (%)	**10.5**	**11.5**	**13.1**	**15.1**	**17.2**
Mass of Mould + Base	2200	2200	2200	2200	2200
Mass of Mould + Base + Soil	3800	3900	4020	4040	4024
Mass of Compacted Soil	1600	1700	1820	1868	1830
Vol. of Mould (m^3)	0.950	0.950	0.950	0.950	0.950
Bulk Density (Kg/ m^3)	1684.20	1789.50	1915.80	1966.3	1926.3
Dry Density (Kg/ m^3)	**1524**	**1605**	**1693.9**	**1708**	**1643**



Optimum Moisture Content (%)	**14.6**
Maximum Dry Density (Kg/ m^3)	**1712**

Proctor Compaction- Neat Gravel

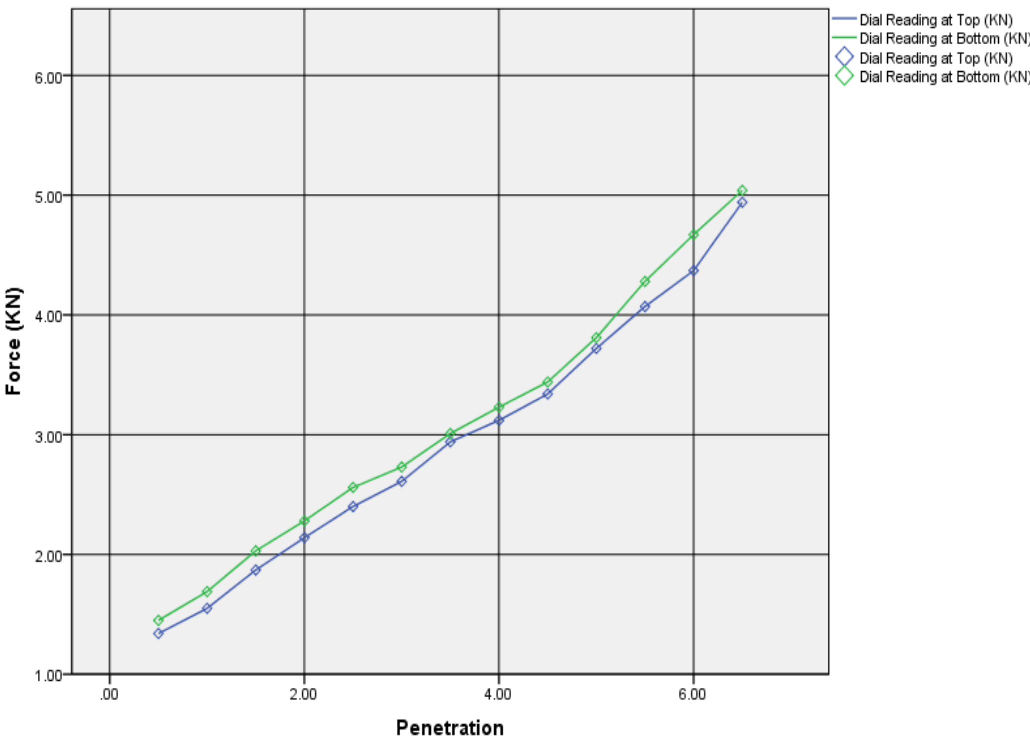
Appendix IV: CBR (Neat Gravel)

Heavy Compaction (4.5 Kg Rammer); 62 Blows/Layer. 4 days Soak.

Table 9: CBR Value – Neat Gravel

Mould No.	1		MDD = 1712Kg/m³		
Mould Wt. (g)	2500		Immersed on 06/09/2015		
Mould + Wet Soil (g)	6665		Tested on 10/09/2015		
wt. of Wet Soil (g)	4165				
Compaction MC (%)	14.6		Ring Factor = 0.01		
Dry Density Kg/m³	1708				
Compaction (%) MDD	95				
Swell Data					
Final Reading	120				
Initial Reading	100				
Swell	20				
% Swell	0.2				
Penetration (mm)	Dial Reading at Top (KN)	Dial Reading at Bottom ((KN)	**CBR Obtained (mm)**	**Top %**	**Bottom %**
0.5	1.34	1.45	**2.5**	**18.3**	**19.4**
1.0	1.55	1.69	**5.0**	**18.2**	**19.1**
1.5	1.87	2.03	**CBR = 19.4%**		
2.0	2.14	2.28			
2.5	2.40	2.56			

3.0	2.61	2.73	
3.5	2.94	3.01	
4.0	3.12	3.23	
4.5	3.34	3.44	
5.0	3.72	3.81	
5.5	4.07	4.28	
6.0	4.37	4.67	
6.5	4.94	5.04	



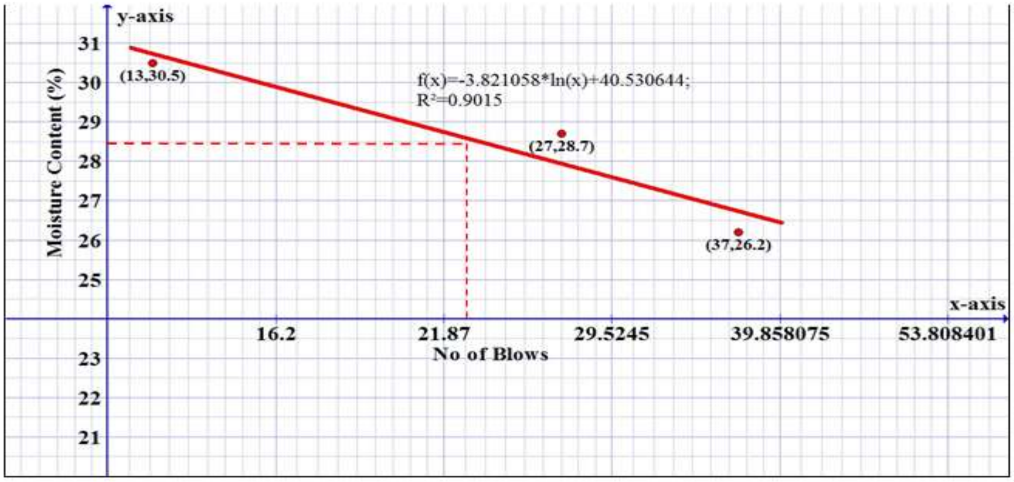
CBR Value – Neat Gravel

Appendix V: Atterberg Limits (Treated Laterite Gravel Soil)

Atterberg Limits – 2% Molasses 7DC

Averages for test samples 1, 2 & 3

RATIO	2% MOLASSES				
SAMPLE SOURCE	BUKURA – SHIBULI ROAD				
TEST DATE					
	Liquid Limit			Plastic Limit	
Container No.	4A(i)	5A(i)	6A(i)	AC1	AD2
No. of Blows	**13**	**27**	**37**		
wt. of Container + Wet Soil (g)	29.3	29.3	30.0	29.7	31.7
wt. of Container + Dry Soil (g)	26.8	26.6	26.3	27.8	29.7
wt. of Container (g)	18.6	17.2	12.2	14.2	12.5
wt. of Moisture (g)	2.5	2.7	3.7	1.9	1.9
wt. of Dry Soil (g)	8.2	9.4	14.1	13.6	17.2
Moisture Content (%)	**30.5**	**28.7**	**26.2**	**14.0**	**11.0**



L.L=28.47

P.L=12.50

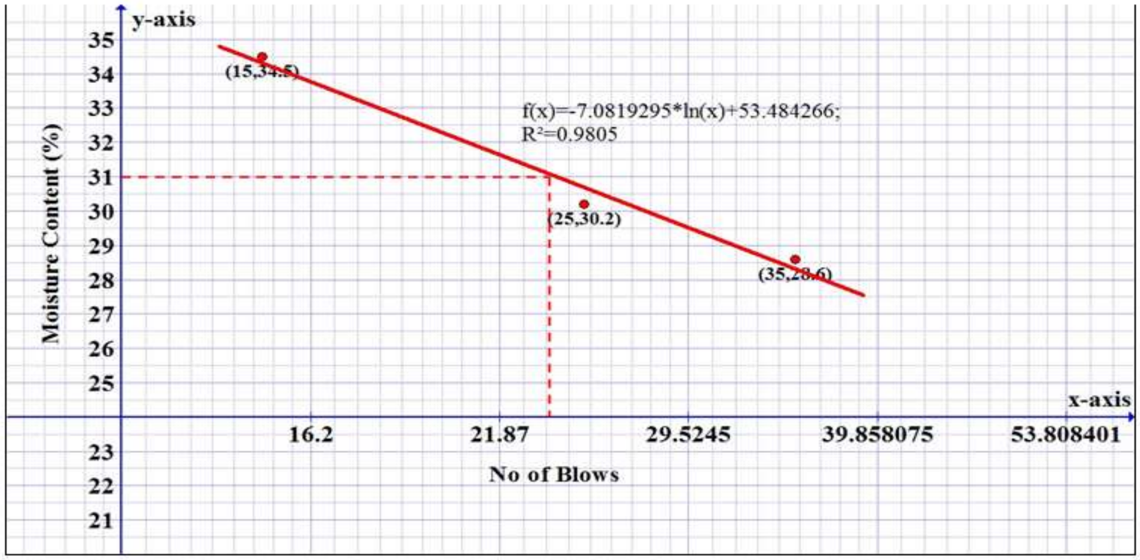
PI=LL-PL=15.97

Atterberg limits: Averages for test samples 1, 2 & 3, 2% molasses, 7DC

Atterberg Limits - 2% Molasses, 7 Days Cure + 7 Days Soak

Averages for test samples 1, 2 & 3

RATIO	2% MOLASSES				
SAMPLE SOURCE	BUKURA – SHIBULI ROAD				
TEST DATE					
	Liquid Limit			Plastic Limit	
Container No.	4A	5A	6A	AC	AD
No. of Blows	**15**	**25**	**35**		
wt. of Container + Wet Soil (g)	40.3	35.0	30.7	26.2	26.0
wt. of Container + Dry Soil (g)	34.2	30.0	26.1	24.3	24.0
wt. of Container (g)	16.5	13.0	10.0	15.5	14.5
wt. of Moisture (g)	6.1	5.1	4.60	1.9	2.0
wt. of Dry Soil (g)	17.7	16.7	16.1	9.1	9.6
Moisture Content (%)	**34.5**	**30.2**	**28.6**	**20.8**	**20.8**



L.L=31.1

P.L=20.8

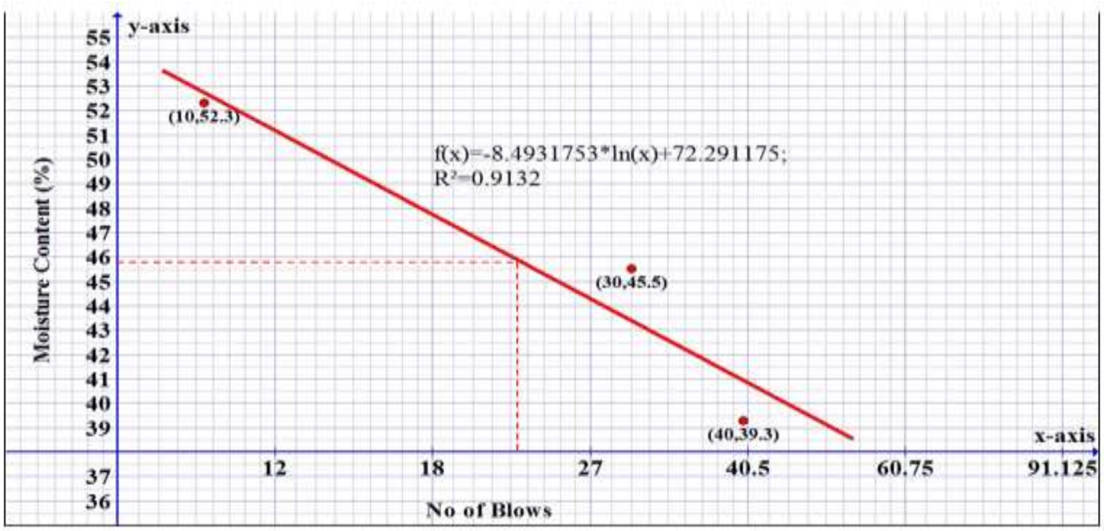
PI=LL-PL=10.3

Atterberg limits: Averages for test samples 1, 2 & 3, 2% molasses, 7DC + 7DS

Atterberg Limits - 2% Molasses, 28 Days Cure

Averages for test samples 1, 2 & 3

RATIO	2% MOLASSES						
SAMPLE SOURCE	BUKURA – SHIBULI ROAD						
TEST DATE							
	Liquid Limit					Plastic Limit	
Container No.		16A	17A	18A		AK	AL
No. of Blows		**10**	**30**	**40**			
wt. of Container + Wet Soil (g)		34.1	30.9	34.7		39.9	40.3
wt. of Container + Dry Soil (g)		28.5	26.9	30.1		35.8	35.7
wt. of Container (g)		17.8	18.1	18.4		17.3	14.5
wt. of Moisture (g)		5.6	4.0	4.6		4.1	4.6
wt. of Dry Soil (g)		10.7	8.8	11.7		18.5	21.2
Moisture Content (%)		**52.3**	**45.5**	**39.3**		**22.2**	**21.7**



L.L=45.7

P.L=21.95

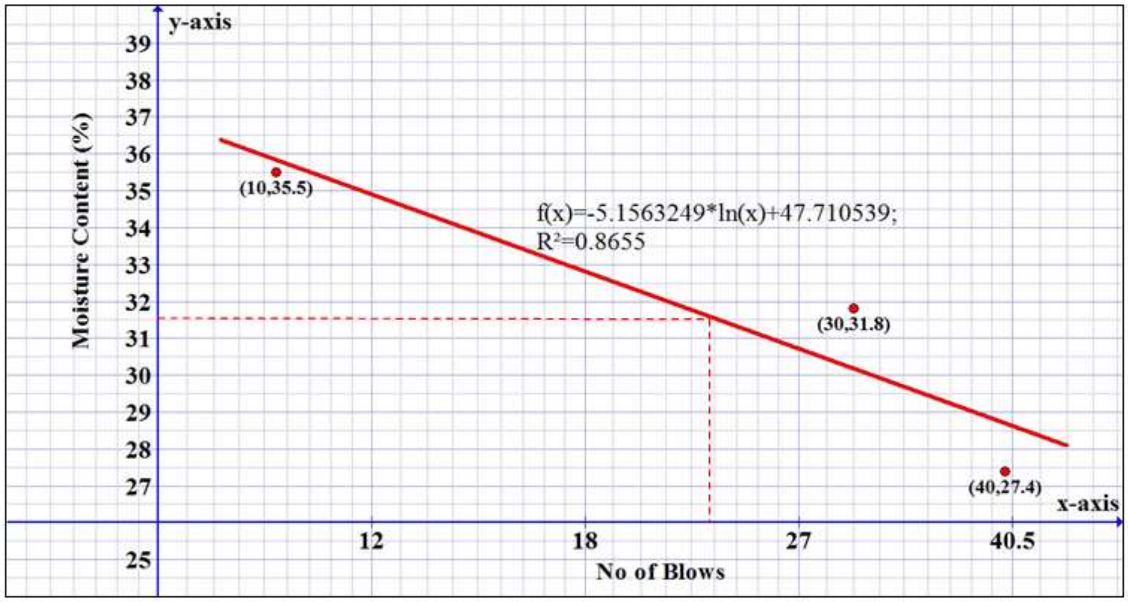
PI=LL-PL=23.75

Atterberg limits: Averages for test samples 1, 2 & 3, 2% molasses, 28 DC

Atterberg Limits - 2% Molasses 28DC + 7DS

Averages for test samples 1, 2 & 3

RATIO	2% MOLASSES						
SAMPLE SOURCE	BUKURA – SHIBULI ROAD						
TEST DATE							
	Liquid Limit					Plastic Limit	
Container No.		28A	29A	30A		AS	AT
No. of Blows		**10**	**30**	**40**			
wt. of Container + Wet Soil (g)		32.8	28.6	25.5		34.6	34.8
wt. of Container + Dry Soil (g)		29.0	25.9	22.9		32.0	31.5
wt. of Container (g)		18.3	17.1	13.2		17.2	14.1
wt. of Moisture (g)		3.8	2.8	2.6		2.6	3.3
wt. of Dry Soil (g)		10.7	8.8	9.5		14.8	17.4
Moisture Content (%)		**35.5**	**31.8**	**27.4**		**17.6**	**19.0**



L.L=31.56

P.L=18.30

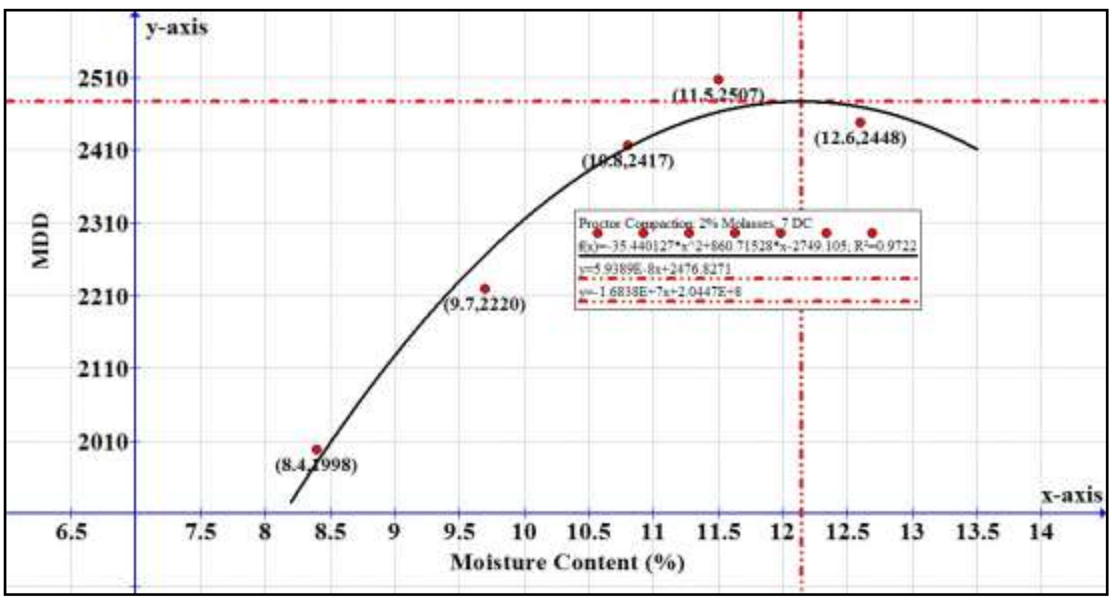
PI=LL-PL=13.26

Atterberg limits: Averages for test samples 1, 2 & 3, 2% molasses, 28 DC + 7DS

Appendix VI –Heavy Compaction (Treated Laterite Gravel Soil)

Averages for 2% Molasses, 7DC test samples 1, 2 & 3

Compacted Soil Sample No.	1	2	3	4	5
Mass of Mould + Base (g)	4200	4200	4200	4200	4200
Mass of Mould + Base + Soil (g)	9181	9801	10360	10629	10540
Mass of Compacted Soil (g)	4981	5601	6160	6429	6340
Volume of Mould (m^3)	2.300	2.300	2.300	2.300	2.300
Bulk Density Kg/m^3	2166	2435	2678	2795	2757
Moisture Content (%)	**8.4**	**9.7**	**10.8**	**11.5**	**12.6**
Dry Density (Kg/ m^3)	**1998**	**2220**	**2417**	**2507**	**2448**



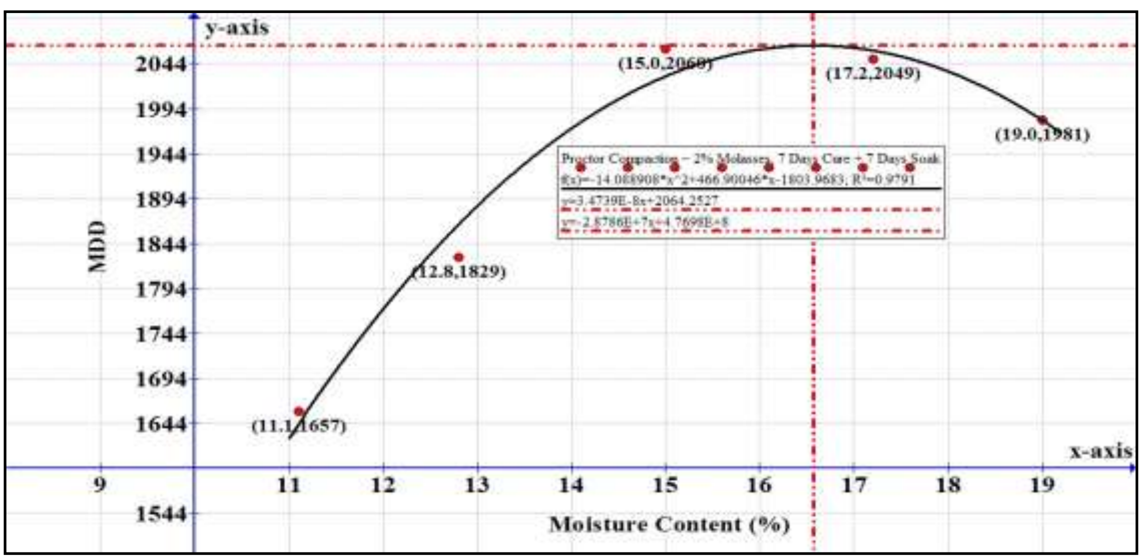
Optimum Moisture Content (%)	**12.2**
Maximum Dry Density (Kg/ m^3)	**2475**

Proctor Compaction: Averages for test samples 1, 2 & 3, 2% Molasses,7DC

Proctor Compaction – 2% Molasses, 7 Days Cure + 7 Days Soak

Averages for test samples 1, 2 & 3

Compacted Soil Sample No.	1	2	3	4	5
Mass of Mould + Base (g)	4200	4200	4200	4200	4200
Mass of Mould + Base + Soil (g)	8436	8946	9649	9724	9620
Mass of Compacted Soil (g)	4236	4746	5449	5524	5420
Volume of Mould (m^3)	2.300	2.300	2.300	2.300	2.300
Bulk Density Kg/m^3	1841	2063	2369	2402	2357
Moisture Content (%)	**11.1**	**12.8**	**15.0**	**17.2**	**19.0**
Dry Density (Kg/ m^3)	**1657**	**1829**	**2060**	**2049**	**1981**



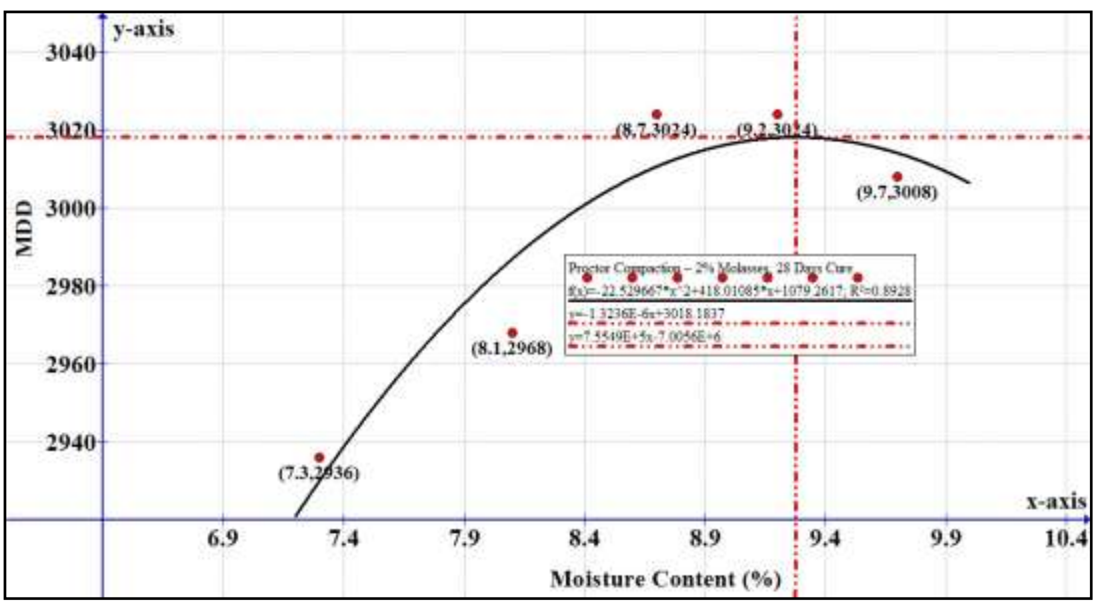
Optimum Moisture Content (%)	**16.6**
Maximum Dry Density (Kg/ m^3)	**2064**

Proctor Compaction: Averages for test samples 1, 2 & 3, 2% Molasses, 7 DC + 7DS

Proctor Compaction – 2% Molasses, 28 Days Cure

Averages for test samples 1, 2 & 3

Compacted Soil Sample No.	1	2	3	4	5
Mass of Mould + Base (g)	4200	4200	4200	4200	4200
Mass of Mould + Base + Soil (g)	11446	11578	11759	11802	11791
Mass of Compacted Soil (g)	7246	7378	7559	7602	7591
Volume of Mould (m^3)	2.300	2.300	2.300	2.300	2.300
Bulk Density Kg/m^3	3150	3208	3287	3305	3300
Moisture Content (%)	**7.3**	**8.1**	**8.7**	**9.2**	**9.7**
Dry Density (Kg/ m^3)	**2936**	**2968**	**3024**	**3027**	**3008**



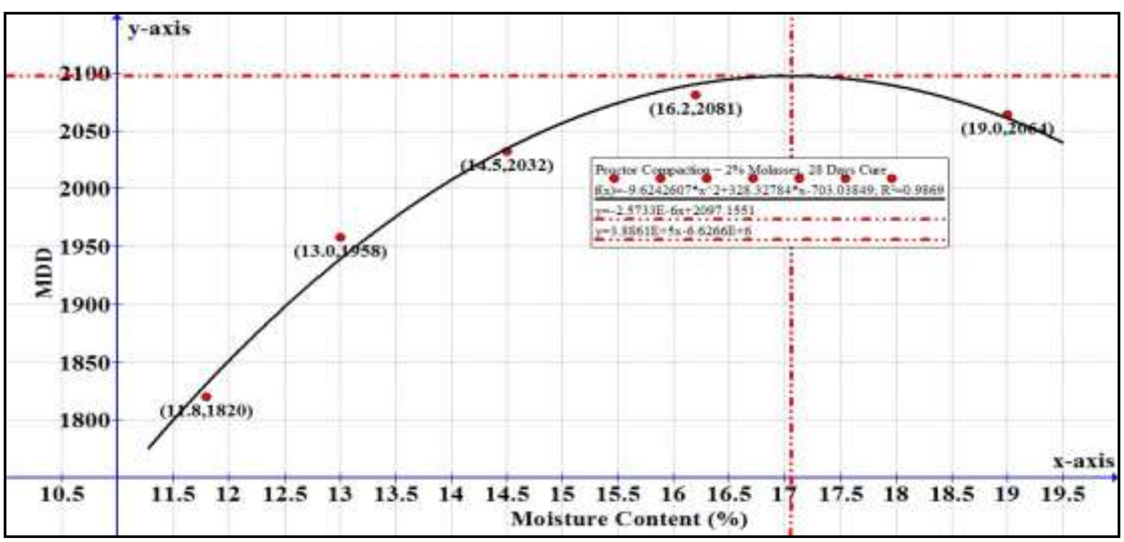
Optimum Moisture Content (%)	**9.3**
Maximum Dry Density (Kg/ m³)	**3018**

Proctor Compaction: Averages for test samples 1, 2 & 3, 2% Molasses, 28 DC

Proctor Compaction – 2% Molasses, 28 Days Cure + 7 Days Soak

Averages for test samples 1, 2 & 3

Compacted Soil Sample No.	1	2	3	4	5
Mass of Mould + Base (g)	4200	4200	4200	4200	4200
Mass of Mould + Base + Soil (g)	8881	9289	9552	9761	9848
Mass of Compacted Soil (g)	4681	5089	5352	5561	5648
Volume of Mould (m³)	2.300	2.300	2.300	2.300	2.300
Bulk Density Kg/m³	2035	2213	2327	2418	2456
Moisture Content (%)	**11.8**	**13.0**	**14.5**	**16.2**	**19.0**
Dry Density (Kg/ m³)	**1820**	**1958**	**2032**	**2081**	**2064**



Optimum Moisture Content (%)	**17.0**
Maximum Dry Density (Kg/ m³)	**2100**

Proctor Compaction: Averages for test samples 1, 2 & 3, 2% Molasses, 28 DC + 7DS

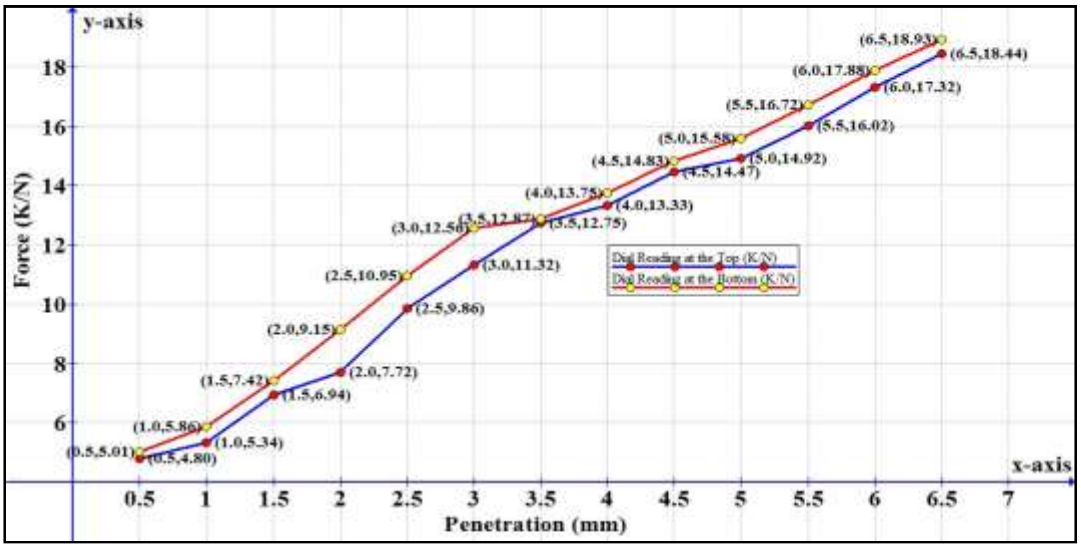
Appendix VII – CBR Heavy Compaction (Treated Laterite Gravel Soil)

CBR Worksheets –Heavy Compaction (4.5 Kg Rammer); 62 Blows/Layer.

CBR Value: averages for Samples 1, 2 & 3, 2.0% Molasses 7, Days Cure.

Mould No.	1B				
Mould Wt. (g)	4200		MDD = 2450Kg/m³		
Mould + Wet Soil (g)	9186		Immersed on…		
Wt. of Wet Soil (g)	4986		Tested on …		
Compaction Mc (%)	8.4				
Dry Density Kg/m³	2502				
Compaction (%) MDD	95				
Swell Data					
Final Reading					
Initial Reading					
Swell					
% Swell					
Test Data					
Penetration (mm)	Dial Reading at the Top (KN)	Dial Reading at the Bottom (KN)	CBR Obtained (mm)	Top %	Bottom %
0.5	4.80	5.01	**2.5**	**74.70**	**82.95**
1.0	5.34	5.86	**5.0**	**74.60**	**77.90**
1.5	6.94	7.42	**CBR = 82.95%**		
2.0	7.72	9.15			
2.5	9.86	10.95			

3.0	11.32	12.56	
3.5	12.75	12.87	
4.0	13.33	13.75	
4.5	14.47	14.83	
5.0	14.92	15.58	
5.5	16.02	16.72	
6.0	17.32	17.88	
6.5	18.44	18.93	



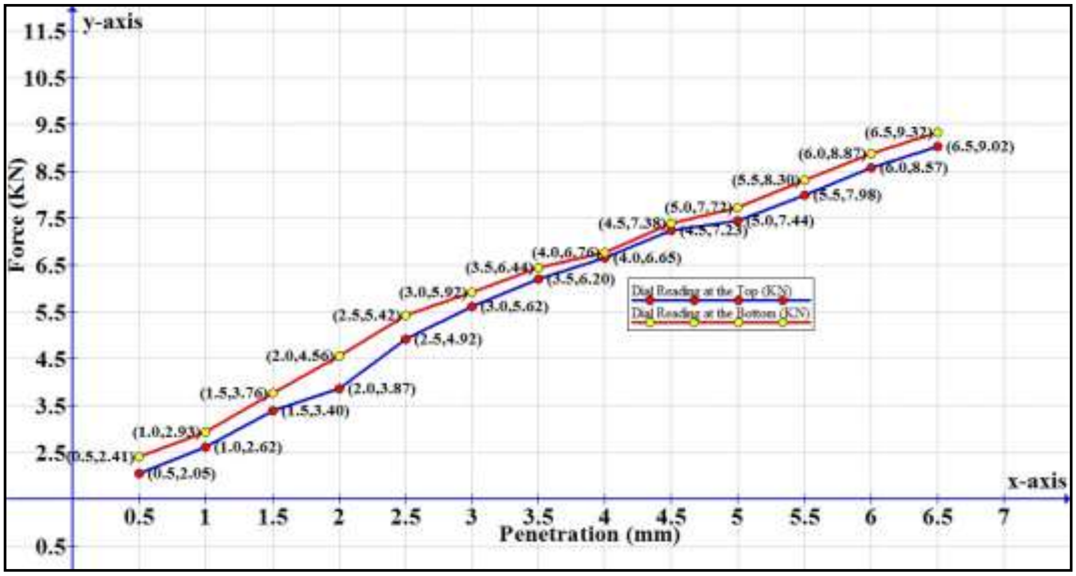
CBR Value: averages for Samples 1, 2 & 3, 2.0% Molasses 7, Days Cure.

CBR Worksheets –Heavy Compaction (4.5 Kg Rammer); 62 Blows/Layer.

CBR Value: Averages for Sample 1, 2& 3, 2.0% Molasses, 7 DC +7 DS

Mould No.	2B		
Mould Wt. (g)	4200		MDD = 2070Kg/m³
Mould + Wet Soil (g)	8945		Immersed on……..
Wt. of Wet Soil (g)	4745		Tested on ………...
Compaction Mc (%)	12.8		Ring Factor = 0.01

Dry Density Kg/m³ Compaction (%) MDD	1829 95				
Swell Data					
Final Reading	112				
Initial Reading	100				
Swell	12				
% Swell	0.12				
Penetration (mm)	Dial Reading at the Top (KN)	Dial Reading at the Bottom (KN)	**CBR Obtained (mm)**	**Top %**	**Bottom %**
0.5	2.05	2.41	**2.5 mm**	**37.3**	**41.0**
1.0	2.62	2.93	**5.0 mm**	**37.2**	**38.6**
1.5	3.40	3.76			
2.0	3.87	4.56			
2.5	4.92	5.42	**CBR =41 %**		
3.0	5.62	5.92			
3.5	6.20	6.44			
4.0	6.65	6.76			
4.5	7.23	7.38			
5.0	7.44	7.72			
5.5	7.98	8.30			
6.0	8.57	8.87			
6.5	9.02	9.32			



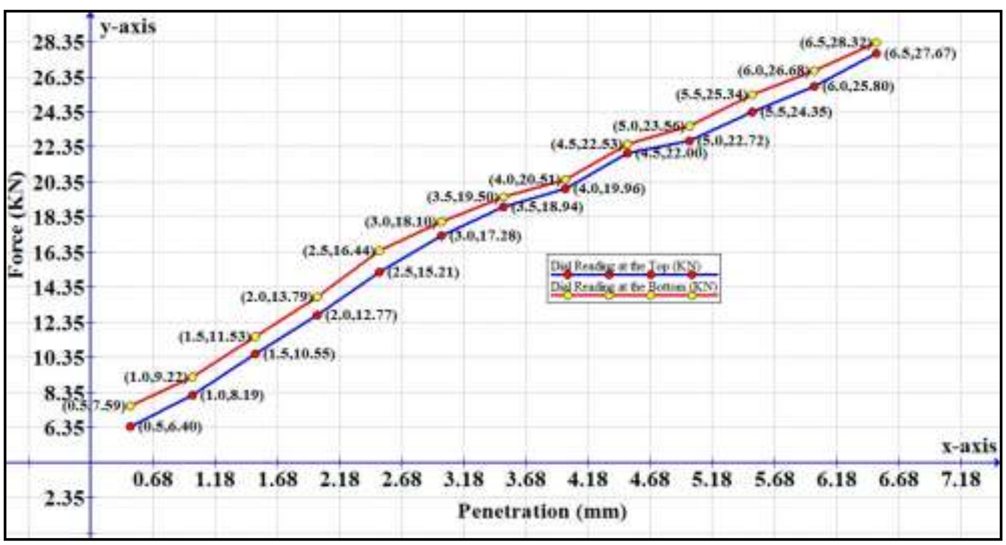
CBR Value: Averages for Sample 1, 2& 3, 2.0% Molasses, 7 Days Cure 7 Days Soak

CBR Worksheets –Heavy Compaction (4.5 Kg Rammer); 62 Blows/Layer.

CBR Value: averages for test samples 1, 2 &3:2.0% molasses, 28 Days Cure.

Mould No.	3B		
Mould Wt. (g)	4200		MDD = 3025Kg/m³
Mould + Wet Soil (g)	11659		Immersed on……..
Wt. of Wet Soil (g)	7459		Tested on ………...
Compaction Mc (%)	8.1		
Dry Density Kg/m³	3000		
Compaction (%) MDD	95		
Swell Data			
Test Data			

Penetration (mm)	Dial Reading at the Top (KN)	Dial Reading at the Bottom (KN)	**CBR Obtained (mm)**	**Top %**	**Bottom %**
0.5	6.40	7.59	**2.5 mm**	**115.2**	**124.50**
1.0	8.19	9.22	**5.0 mm**	**113.60**	**117.8**
1.5	10.55	11.53			
2.0	12.77	13.79			
2.5	15.21	16.44	**CBR = 124.50 %**		
3.0	17.28	18.10			
3.5	18.94	19.50			
4.0	19.96	20.51			
4.5	22.00	22.53			
5.0	22.72	23.56			
5.5	24.35	25.34			
6.0	25.80	26.68			
6.5	27.67	28.32			

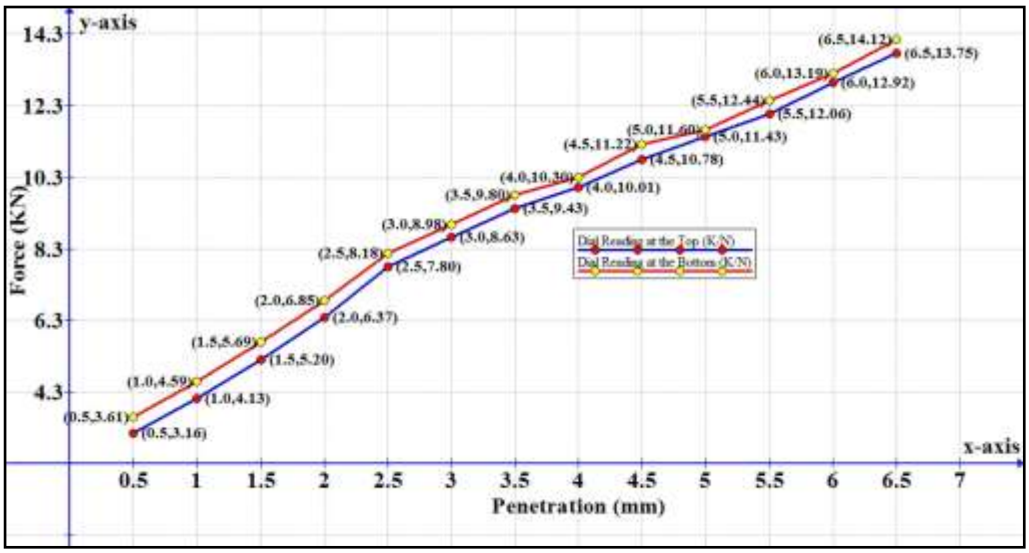


CBR Value: averages for test samples 1, 2 &3:2.0% molasses, 28 Days Cure.

CBR Value: Averages for Sample 1, 2& 3, 2.0% Molasses, 28 Days Cure 7 Days Soak

Mould No. Mould Wt. (g) Mould + Wet Soil (g) Wt. of Wet Soil (g) Compaction Mc (%) Dry Density Kg/m³ Compaction (%) MDD	2B 4200 8945 4745 12.8 1829 95		 MDD = 2070Kg/m³ Immersed on…….. Tested on ………... Ring Factor = 0.01		
Swell Data Final Reading Initial Reading Swell % Swell	 112 100 12 0.12				
Penetration (mm)	Dial Reading at the Top (KN)	Dial Reading at the Bottom (KN)	**CBR Obtained (mm)**	**Top %**	**Bottom %**
0.5	3.16	3.61	**2.5 mm**	**59.1**	**62.0**
1.0	4.13	4.59	**5.0 mm**	**57.2**	**58.0**
1.5	5.20	5.69			
2.0	6.37	6.85			
2.5	7.80	8.18	**CBR =62 %**		
3.0	8.63	8.98			
3.5	9.43	9.80			
4.0	10.01	10.30			
4.5	10.78	11.22			

5.0	11.43	11.60
5.5	12.06	12.44
6.0	12.92	13.19
6.5	13.75	14.12



CBR Value: Averages for Sample 1, 2& 3, 2.0% Molasses, 28 Days Cure 7 Days Soak

Appendix VIII – UCS (Uncured/ treated Laterite Gravel Soil)

Unconfined Compressive Test Data – Uncured

Date Tested………………14/05/2016

Tested By…………………Department of Infrastructure (Bungoma Regional Laboratory)

Project Name………………Bukura—Shibuli Road

Visual Classification………Red, Brown & Yellow Residual Gravels

Sample Data

Diameter (d) =38mm

Length (Lo) = 76 mm

Mass = 170.28g

Moisture Content Determination

Molasses % Uncured						**Molasses % Cured**				
Sample No	0	1	2	3	4	0	1	2	3	4
Moisture Can-Lid Number	01	02	03	04	05	06	07	08	09	10
M_C=Mass of Empty Clean Can+Lid (g)	16.8	17.2	18.5	18.9	19.4	18.4	19.5	19.2	18.6	19.0
M_{CMS}=Mass Can, Lid + Moist Soil (g)	72.4	72.3	74.4	77.2	82.3	87.5	75.4	72.5	75.6	70.5
M_{CDS}= Mass of Can,Lid + Dry Soil (g)	68.5	67.5	69.0	70.4	75.0	83.1	71.1	68.3	70.1	65.4
Ms=Mass of Soil Solids (g)	51.7	50.3	50.5	51.5	48.3	64.7	51.6	49.0	51.5	46.4
M_w=Mass of Pore Water (g)	3.9	4.8	5.4	6.8	7.3	4.4	4.3	4.20	5.1	5.1
W=Water content W%	7.5	9.5	10.7	13.2	15.1	6.8	8.3	8.5	9.9	11.1

Area (Ao) = π d^2 /4 = π x 3.8^2 /4 = 11.34 cm^2

Volume = Area x h = 11.34 x 7.6 = 86.18 cm^3

Wet Density = 1.98g/cm^3

Dry Density = 1.82g/cm^3

Unconfined Compression Test Data – 0% Molasses Uncured

Deformation dial :1 Unit = 0.02 mm **Load dial : 1 Unit = 1.4 Newtons**							
Deformation Dial Reading	Load Dial Reading	ΔL (mm) Sample Deformation	Strain ε_0	% Strain	Corrected Area (A) m^2	Load (N)	Stress (KN/m^2)
0	0	0	0	**0**	1.134x10^{-3}	0	**0**
20	5	0.4	0.0053	**0.53**	1.140x10^{-3}	7.0	**6.140**
40	7	0.8	0.011	**1.10**	1.146x10^{-3}	9.8	**8.550**
60	9	1.2	0.016	**1.60**	1.152x10^{-3}	12.6	**10.94**
80	11	1.6	0.021	**2.10**	1.158x10^{-3}	15.4	**13.500**
100	13	2.0	0.026	**2.60**	1.164x10^{-3}	18.20	**15.640**
120	16	2.4	0.032	**3.20**	1.171x10^{-3}	22.40	**19.13**
140	19	2.8	0.037	**3.70**	1.176x10^{-3}	26.6	**22.62**
160	23	3.2	0.042	**4.20**	1.184x10^{-3}	32.2	**27.20**
180	25	3.6	0.047	**4.70**	1.190x10^{-3}	35.0	**29.40**
200	30	4.0	0.053	**5.30**	1.196x10^{-3}	42.0	**35.10**
250	38	5.0	0.066	**6.60**	1.214x10^{-3}	53.20	**43.65**
300	42	6.0	0.078	**7.80**	1.230x10^{-3}	58.80	**47.80**
350	46	7.0	0.092	**9.20**	1.250x10^{-3}	64.40	**51.52**
400	54	8.0	0.105	**10.50**	1.270x10^{-3}	75.5	**59.40**
450	62	9.0	0.118	**11.80**	1.290x10^{-3}	86.2	**62.29**

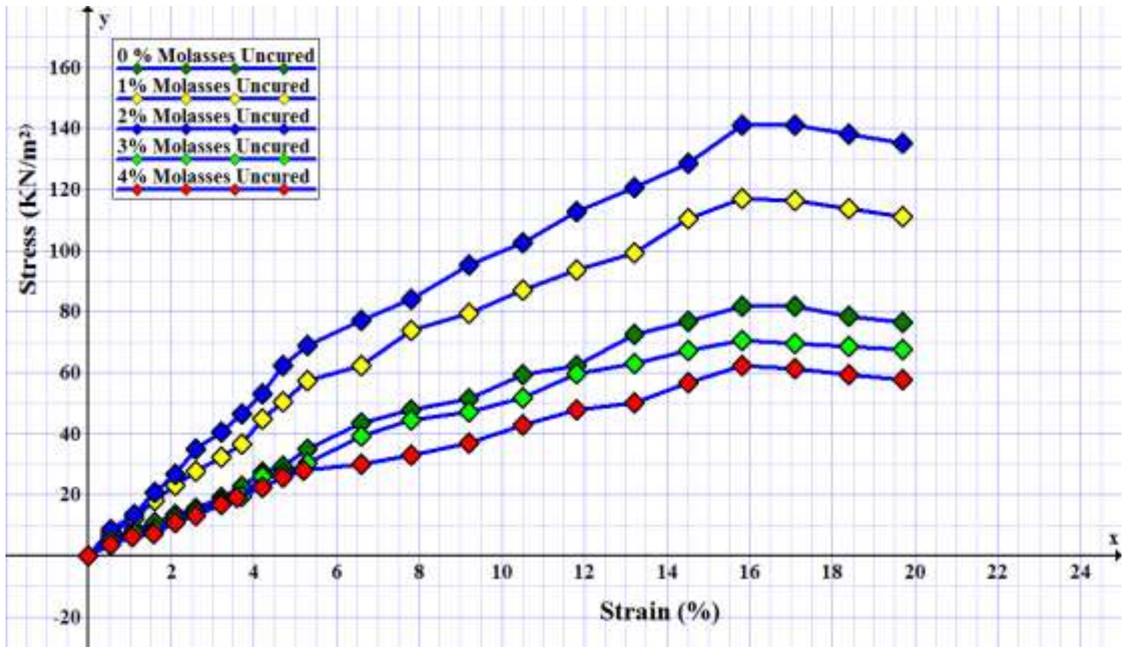
500	68	10.0	0.132	**13.20**	$1.31x10^{-3}$	95.2	**72.67**
550	73	11.0	0.145	**14.50**	$1.33x10^{-3}$	102.2	**76.84**
600	79	12.0	0.158	**15.80**	$1.35x10^{-3}$	110.6	**81.92**
650	80	13.0	0.171	**17.10**	$1.37x10^{-3}$	112	**81.75**
700	78	14.0	0.184	**18.4**	$1.39x10^{-3}$	109.2	**78.56**
750	77	15	0.197	**19.7**	$1.41x10^{-3}$	107.8	**76.45**

Unconfined Compression Test Data – 2.0% Molasses Uncured

UCS Value: Averages for Sample 1, 2& 3, 2.0% Molasses, Uncured.

Deformation dial :1 Unit = 0.02 mm **Load dial : 1 Unit = 1.4 Newtons**							
Deformation Dial reading	Load Dial Reading	ΔL (mm) Sample deformation	Strain ε_0	% Strain	Corrected Area (A) M^2	Load (N)	Stress (KN/m^2)
0	0	0	0	**0**	$1.134x10^{-3}$	0	**0**
20	8	0.4	0.0053	**0.53**	$1.140x10^{-3}$	11.2	**9.82**
40	12	0.8	0.0110	**1.10**	$1.146x10^{-3}$	16.8	**14.66**
60	17	1.2	0.016	**1.60**	$1.152x10^{-3}$	23.8	**20.66**
80	23	1.6	0.021	**2.10**	$1.158x10^{-3}$	32.2	**27.81**
100	29	2.0	0.026	**2.60**	$1.164x10^{-3}$	40.6	**34.88**

120	32	2.4	0.032	**3.20**	$1.171x10^{-3}$	44.8	**38.26**
140	38	2.8	0.037	**3.70**	$1.176x10^{-3}$	53.2	**45.24**
160	44	3.2	0.042	**4.20**	$1.184x10^{-3}$	61.6	**52.03**
180	51	3.6	0.047	**4.70**	$1.190x10^{-3}$	71.4	**60.0**
200	57	4.0	0.053	**5.30**	$1.196x10^{-3}$	79.8	**66.72**
250	66	5.0	0.066	**6.60**	$1.214x10^{-3}$	92.4	**76.11**
300	72	6.0	0.078	**7.80**	$1.230x10^{-3}$	100.8	**81.95**
350	83	7.0	0.092	**9.20**	$1.250x10^{-3}$	116.2	**92.96**
400	88	8.0	0.105	**10.5**	$1.270x10^{-3}$	123.2	**97.00**
450	103	9.0	0.118	**11.80**	$1.290x10^{-3}$	144.2	**111.78**
500	112	10.0	0.132	**13.20**	$1.31x10^{-3}$	156.8	**119.69**
550	122	11.0	0.145	**14.50**	$1.33x10^{-3}$	170.8	**130.38**
600	136	12.0	0.158	**15.8**	$1.35x10^{-3}$	190.4	**141.03**
650	137	13.0	0.171	**17.10**	$1.37x10^{-3}$	191.8	**140.0**
700	136	14.0	0.184	**18.4**	$1.39x10^{-3}$	190.4	**136.98**
750	136	15.0	0.197	**19.7**	$1.41x10^{-3}$	190.4	**135.04**



UCS for 1,2,3&4% Uncured Laterite Gravel Soil

Appendix IX – UCS (7 Days Cured/ Treated Laterite Gravel Soil)

Unconfined Compression Test Data – 0% Molasses, 7 Days Cured

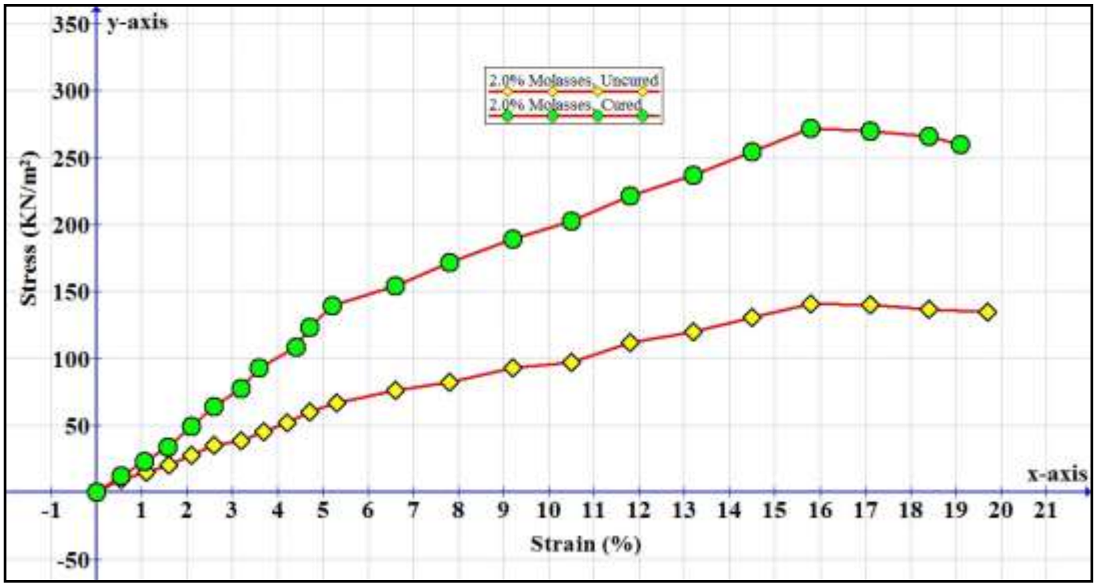
Deformation dial:1 Unit =0.02 mm **Load dial : 1 Unit =1.4 Newtons**							
Deformation Dial reading	Load Dial Reading	ΔL (mm) Sample Deformation	Strain ε_0	% Strain	Corrected Area (A) M^2	Load (N)	Stress (KN/m^2)
0	0	0	0	**0**	$1.134x10^{-3}$	0	**0**
20	7	0.4	0.0053	**0.53**	$1.140x10^{-3}$	9.8	**8.59**
40	11	0.8	0.0110	**1.10**	$1.146x10^{-3}$	15.4	**13.44**
60	18	1.2	0.016	**1.60**	$1.152x10^{-3}$	25.2	**21.88**
80	23	1.6	0.021	**2.10**	$1.158x10^{-3}$	32.2	**27.81**
100	30	2.0	0.026	**2.60**	$1.164x10^{-3}$	42.0	**36.08**
120	35	2.4	0.032	**3.20**	$1.171x10^{-3}$	49.0	**41.84**
140	41	2.8	0.037	**3.70**	$1.176x10^{-3}$	57.4	**48.81**
160	46	3.2	0.042	**4.20**	$1.184x10^{-3}$	64.4	**54.40**
180	51	3.6	0.047	**4.70**	$1.190x10^{-3}$	71.4	**60.0**
200	57	4.0	0.053	**5.30**	$1.196x10^{-3}$	79.8	**66.72**
250	65	5.0	0.066	**6.60**	$1.214x10^{-3}$	91.0	**74.96**
300	71	6.0	0.078	**7.80**	$1.230x10^{-3}$	99.4	**80.81**
350	77	7.0	0.092	**9.20**	$1.250x10^{-3}$	107.8	**86.24**
400	89	8.0	0.105	**10.50**	$1.270x10^{-3}$	124.6	**98.11**
450	104	9.0	0.1180	**11.80**	$1.290x10^{-3}$	145.6	**112.87**
500	124	10.0	0.132	**13.20**	$1.31x10^{-3}$	173.6	**132.50**
550	140	11.0	0.145	**14.50**	$1.33x10^{-3}$	196.0	**147.37**
600	148	12.0	0.158	**15.80**	$1.35x10^{-3}$	207.2	**153.48**

650	150	13.0	0.171	**17.10**	1.37x10^{-3}	210.0	**153.28**
700	149	14.0	0.184	**18.4**	1.39x10^{-3}	208.6	**150.07**
750	148	15.0	0.197	**19.4**	1.41x10^{-3}	207.2	**146.95**

Unconfined Compression Test Data – 2.0% Molasses, 7 Days Cured

UCS Value: Averages for Sample 1, 2& 3, 2.0% Molasses, Cured.

Deformation dial:1 unit=0.02 mm **Load dial : 1 unit =1.4 Newtons**							
Deformation Dial reading	Load Dial Reading	ΔL (mm) Sample deformation	Strain ε_0	% Strain	Corrected Area (A)M^2	Load (N)	Stress (KN/m^2)
0	0	0	0	0	1.134x10^{-3}	0	**0**
20	10	0.4	0.0053	**0.53**	1.140x10^{-3}	14.0	**12.28**
40	19	0.8	0.0105	**1.05**	1.146x10^{-3}	26.6	**23.20**
60	26	1.2	0.0158	**1.58**	1.152x10^{-3}	39.2	**34.02**
80	41	1.6	0.021	**2.10**	1.158x10^{-3}	57.4	**49.57**
100	53	2.0	0.026	**2.60**	1.164x10^{-3}	74.2	**63.75**
120	65	2.4	0.032	**3.20**	1.171x10^{-3}	91.0	**77.71**
140	78	2.8	0.036	**3.60**	1.176x10^{-3}	109.2	**92.86**
160	92	3.2	0.042	**4.40**	1.184x10^{-3}	128.8	**108.78**
180	105	3.6	0.047	**4.70**	1.190x10^{-3}	147.0	**123.53**
200	119	4.0	0.052	**5.20**	1.196x10^{-3}	166.6	**139.30**
250	134	5.0	0.066	**6.60**	1.214x10^{-3}	187.6	**154.53**
300	151	6.0	0.078	**7.80**	1.230x10^{-3}	211.4	**171.87**
350	169	7.0	0.092	**9.20**	1.250x10^{-3}	236.6	**189.28**
400	184	8.0	0.105	**10.50**	1.270x10^{-3}	257.6	**202.83**
450	204	9.0	0.118	**11.80**	1.290x10^{-3}	285.6	**221.40**
500	222	10.0	0.132	**13.2**	1.31x10^{-3}	310.8	**237.25**
550	242	11.0	0.145	**14.50**	1.33x10^{-3}	336.0	**254.73**
600	262	12.0	0.158	**15.80**	1.35x10^{-3}	366.8	**271.70**
650	264	13.0	0.171	**17.10**	1.37x10^{-3}	369.6	**269.78**
700	264	14.0	0.184	**18.4**	1.39x10^{-3}	369.6	**265.90**
750	262	15.0	0.191	**19.1**	1.41x10^{-3}	366.8	**260.14**



UCS: Averages for samples1, 2&3, 2% molasses, cured/uncured