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Department of Environmental and Biosystems Engineering

Stabilization of Silt Clay Soil Using Molasses for Small Dam Embankment Construction as inner Zone

By

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May 2015

DECLARATION

I, Mwanga, Eliafie Wilson, hereby declare that this thesis report is my original work. To the best of my knowledge, the work presented here has not been presented for a thesis in any other university.

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ABSTRACT

The Agriculture sector contributes 45% of Tanzania's GDP and about 30% of its export earnings, while employing over 80% of the nation's work-force (National Irrigation Master Plan, 2002). The government of Tanzania is investing more in rainwater harvesting technology such as construction of earth fill dam in the country to continue supporting agricultural production.

This research work was aimed to stabilize silt clay soil using molasses for construction of small earthfill dam embankment as inner zone. The study used blackstrap molasses with a density of 1.4 g cm^{-3} and viscosity of 2.9 x 10^{-6} m^2 sec^{-1} for soil stabilization. Molasses can improve the adherence between soil particles and, thus, enable formation of a strong interparticle bond that enhances the stability of the constructed embankment.

This research was conducted to study the effect of adding molasses to silty clay soil as a construction material. Seven soil samples were collected in a test pit and modified by adding 0% ,5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% of molasses to soil sample .The soil was tested for shear strength, permeability and compaction. An optimum of 6.5% of molasses when added to a soil sample was found to increase soil cohesion from 6.0 kN/m^2 to 43.8 kN/m^2 and decreased the friction angle of soil from 22.1° to 8.6°. Also, 6.5% molasses treatment, increased the maximum dry unit weight of soil from 18.5kN/m^3 to 19.40kN/m^3. Unit bulk weight of soil increased from 20.72kN/m^3 to 21.34kN/m^3. The optimum moisture content of soil decreased from 12.0% to 10.0% with the increased in molasses percentage. The permeability of the soil decreased from 6.062 x 10^{-5} mm sec^{-1} to 2.105 x 10^{-5} mm sec^{-1} with increase of molasses up to 6%. These results showed that stabilization of silt clay soil with molasses increased strength properties of soil; implying that by using 6.0 to 6.5% molasses treatment improved properties of soil. More studies are recommended to determine organic decomposition of molasses and impacts on soil properties. Also field trials would be necessary to assess the performance of dam embankment constructed with soil stabilized with molasses.

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CHAPTER 1: INTRODUCTION

1.1 Background

Tanzania's crop production is still very low due to a number of reasons, which include inadequate and unevenly distributed rainfall resulting into marginal use of the potential for irrigation (National Irrigation Master Plan, 2002). Irrigation practice is one of the effective means in increasing and stabilizing food and cash crop production and productivity for curbing food shortages and increasing export of cash crop and its products. In this regard, a concise plan and implementation for the development of irrigation infrastructure is pertinent. Water is a central and basic natural resource, which sustains life and provides for various social and economic needs including irrigated agriculture (National Water Policy, 2002). It is considered as a key factor in the socio-economic development and the fight against poverty. The social and economic circumstances prevailing today have increased the competition in water demands by all users and thus creating a threat in its sustainability. It therefore entails integrated planning, development and management in support of food security and poverty reduction, as well as environmental safeguards amongst others.

The Agriculture sector contributes 45% of Tanzania's GDP and about 30% of its export earnings, while employing over 80% of the nation's work-force (National Irrigation Master Plan, 2002). The sector continues to drive economic growth in the country. Despite its importance, agriculture is very much affected by inadequacy, seasonality and unreliability of rainfall and periodic droughts. It is for this reason that irrigation is considered necessary for providing protection against drought, a means of stabilizing crop production and assurance of household food security.

In response to this, Tanzania launched the National Irrigation Master Plan (NIMP) in 2002 which identified a total irrigation development potential of 29.4 million ha, of which 2.3 million ha are classified as high potential; 4.8 million ha as medium potential; and 22.3 million ha as low potential. Under Big Results Now (BRN), it is planned to increase area under irrigation from 389,00Ha up to 450,392Ha by year 2014/2015 (Kayandabila, 2014).

Tanzania is also committed to the Millennium Development Goals (MDGs) as internationally agreed targets for reducing poverty, hunger, diseases, illiteracy, environmental degradation and discrimination against women by 2015. Until now number of policies, laws and programmes were put in place to create an environment that would ensure that woman's position moves from that of marginalization to that of partnership, dignity and equality (Asha-Rose, 2005). In this regard, the main objectives of the policies are gender mainstreaming, women's ownership of property; participation in decision-making and in developmental issues. There is currently a Bill, awaiting approval by the Parliament to provide for an increase of women members of Parliament from a minimum of 30 percent to 50 percent. This will be operational in the general elections of 2020.

Tanzania has put highest priority on the development of the agricultural sector as a means to meet both National Strategy for Growth and Reduction of Poverty (NSGRP) targets and Millennium Development Goals. However, the variability of rainfall and seasonal drought are major constraints on agricultural productivity and rural livelihoods. To address this issue, the government of Tanzania put more emphasis on construction of small and large earth fill dams for the purpose of collecting surface run-off water for irrigation and domestic consumptions. Although, in some areas construction of earth fill dam is costly due to lack of suitable soil, which necessitate soil to be borrowed from far distance.

Since reliable material for dam embankment construction is borrowed from great distances such that the haulage is high, the cost of construction is higher as compared to areas where the fill material is borrowed from within the reservoir or nearby material sites. With high costs associated with hauling suitable material from great distances, the possibility of construction of such dams is never realized, or is abandoned after kick off.

This research aimed to assess the suitability of using molasses in amending silt-clay soil for construction of small earth fill dam in a place where the only available soil is silt-clay.

1.2 Problem Statement

Water is essential to all life i.e. human beings, animals and vegetation. The majority of the populations in the semi-arid areas depend on agriculture and pastoralism for survival. It is therefore important that adequate supply of water to be developed to sustain all life. Water scarcity is experienced in many places and sectors in Tanzania due to unreliable rainfall. The recent droughts of 2011/12 and associated crop failures have led to severe hunger in many places of Tanzania that has forced the government to organize food aid to the people (Elisabeth, 2012). However, irrigation sector was found to be the only solution to combat drought caused by climatic change. In order to achieve food self-sufficiency to all, the government is now struggling to invest more in rainwater harvesting technology such as construction of small, medium and big earthfill dams for purpose of collecting run-off water for irrigation and domestic purposes. However, construction of dams was found to be difficult to some identified potential areas due to lack of suitable soil for dam embankment construction. Preliminary soil investigation conducted within a few listed potential sites for dam construction had revealed that, available soil in those sites is silt clay, which is practically not recommended for earthfill dam construction because this type of soil is permeable and difficult to compact when dry. Therefore, this study was aimed to stabilize silt clay soil with blackstrap molasses so as to improve shear strength, compaction, permeability and bulk density.

1.3 Overall objective

The overall objective of this research was to test the use of molasses to stabilize silt clay soil for use as inner core in small earth fill dam construction.

The specific objectives of this research were:

1. To assess the potential of molasses as a soil stabilizer
2. To optimize soil engineering properties pertinent to stabilization
3. To develop protocol for stabilizing silt clay soil for use in earth-fill dam

1.4 Research Justification

This research was focused on stabilization of silt clay soil using molasses for small dam embankment construction as inner zone. The study intends to change engineering properties of silt clay soil which causes permeability, poor compaction, heaving and viscous fluid behaviors when wetted so as to make it suitable for construction of small earth fill dam embankment works. Studies have found that soil amended with molasses by adding 5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% increased California Bearing Ratio (CBR) by 5.12%, 22.67%, 24.68%, 34.00% 23.12% and 22.02%, respectively (Shirsavkar, 2010) while research performed by M'Ndegwa, (2011) suggested that stabilization of expansive clay soil with molasses increased the California Bearing Ratio (CBR) values and load bearing ability of the soil. However, this research covered more on laboratory test for permeability, compaction and undrained triaxial compression test to determine the changes in cohesion, internal angle of friction and maximum dry density of soil specimens following soil stabilization.

1.5 Scope of Research

The study focused on stabilization silt clay soil using molasses to improve engineering properties of soil so as to make it suitable for construction of inner zone of small earth fill dam. The study was conducted at Goweko Village, Uyui district, Tabora region-Tanzania. It involved field work, laboratory work and data analysis. The study aimed to change engineering properties of silt clay soil which causes permeability, poor compaction, heaving and viscous fluid when wetted. The study did not cover field trial for earthfill dam embankment construction and the duration that molasses as soil additive will take to decay in the treated soil.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A lot of research has been done relating to the use of traditional stabilizers, namely lime and cement (Geiman, 2005). The stabilization methods for lime and cement are well documented, and the efficiency of these traditional stabilizers has been verified in many applications. However, little is known on the use of nontraditional stabilizers such as sodium chloride, magnesium chloride, calcium chloride, polymer and molasses. More studies are highly recommended to be conducted to determine suitability of non-traditional soil stabilizer and its efficiency in amendment of engineering properties of soil. This literature review intends to known how far other researchers have gone in researching on engineering properties of soil stabilized by nontraditional stabilizers, as applicable to this research.

2.1.1 Stabilization of soils

Soil stabilization is generally defined as making major improvements to the engineering properties of soils by amending the natural soil characteristics with an additive. These additives may include other soils or materials such as Portland cement, lime, fly ash, asphalt cement, polymers, and fibers (Air Force Civil Engineer, 2012). Traditionally, additives such as bitumen, cement, and lime have achieved widespread use. Bitumen is typically used as a soil surface treatment to limit dust and loss of fines. Cement is used to provide strength to soil. Lime is often used in clay soils to control plasticity.

2.1.2 Purpose of Soil Stabilization

There are three purposes for soil stabilization (Air Force Civil Engineer, 2012). The first one is strength improvement, to enhance its load-bearing capacity. The second purpose is for dust control by binding soil particles together, to eliminate or alleviate dust, generated by the operation of equipment and aircraft during dry weather or in arid climates. The third purpose is soil waterproofing, which is done to preserve the natural or constructed strength of a soil by preventing the entry of surface water (Army Corps of Engineering, 1984)

2.2 Traditional Soil Stabilizers

2.2.1 Lime stabilization

When stabilization of soil is done by mixing soil with lime in proper proportion, the process is known as soil-lime stabilization. Lime is an excellent choice for short term modification of soil properties. Lime can modify almost all fine grained soils but the greater improvement occurs in clay soils of moderate to high plasticity (National Lime

Association, 2004). Modification occurs because calcium cations supplied by hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system. Thus, the clay surface mineralogy is altered, producing the following benefits; Plasticity reduction, Reduction in moisture-holding capacity (drying), Swell reduction, Improved stability and Ability to construct a solid working platform.

Lime in the form of quicklime (calcium oxide-CaO), hydrated lime (calcium hydroxide-$Ca(OH)_2$), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone-$CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. When hydrated lime reacts with clay particles permanently transforms clay into a strong cementitious matrix. (American Road Builders Association, 2004)

2.2.1.1 Lime stabilization applications and advantages

Lime has been found to react successfully with medium, moderately fine and fine grained soils causing a decrease in plasticity and swell potential of expansive soils, and an increase in their workability and strength properties (Bulbul, 2013). The effect of lime on soil can be categorized into two groups; immediate and long-term stabilization. Increased workability of soil is the result of immediate improvement which is the main contributor in early construction stages. Increased strength and durability is considered long-term stabilization that takes place during and after curing.

2.2.1.2 Suitability

Lime works best for clayey soils, especially those with moderate to high plasticity index (PI>15). Little, (1995) suggested that soils classified by Unified Soil Classification System as CH, CL, MH, SC, SM, GC, SW-SC, SP-SC, SM-SC, GP-GC, and GM-GC can be stabilized by lime treatment. Aggregates with plastic fines, caliche and other marginal bases that contain appreciable amount of material passing #40 sieve are also capable of being stabilized with lime (Little, 1995).

Therefore, strengths of soil stabilized with lime must be verified through strength tests such as California Bearing Ratio (CBR), unconfined compressive strength, or resilient modulus. Lime contents between 2 to 10 percent are typically capable of producing significant strength gains (Little, 1995). While there is no universal definition of significant strength gain, most design procedures implement a requirement for a compressive strength increase of 50 psi for lime stabilization to be a viable option (Chou, 1987).

2.2.2 Portland Cement

When stabilization of soil is done by mixing with cement it is known as soil-cement stabilization. Soil-cement is a mixture of pulverized soil and measured amount of cement and water, compacted to the desired density and cured (Liu & Evett, 1998). The role of cement is to improve the engineering properties of available soil such as strength, compressibility, permeability, swelling potential, frost susceptibility and sensitivity to changes in moisture content. Soil cement materials range from semi flexible to semi rigid depending on the type of soil and amount of cement used.

Cement consists of numerous minerals and is manufactured by combining cement clinker with gypsum. Cement mixed with water forms calcium silicate hydrate and calcium hydroxide ($Ca(OH)_2$). Calcium silicate hydrate forms on the surfaces of the cement particles and because it has a strongly cementing effect, it binds the soil together and increases its strength (Swedish Deep Stabilization Research Centre, 2002). Since the hydraulic reaction takes place considerably faster than the pozzolanic reaction, cement stabilized soil normally attains higher strength than lime stabilized soil, particularly in the first 26 days.

2.2.2.1 Suitability

Cement stabilization is perfectly suited for well graded aggregates with a sufficient amount of fines to effectively fill the available voids space of the coarse aggregate particles. Little (1995), suggested that, plasticity index (PI) should be less than 30% for sandy materials, and less than 20% for fine-grained soils with more than 50 percent by weight passing 75μm. The liquid limit (LL) should be less than 40% in order to ensure proper mixing.

However, the water-cement ratio is primary factor governing behavior of cement stabilized soil. The water-cement ratio is defined as the ratio of moisture content of the soil to the cement content, with both the moisture content and cement content expressed in terms of dry weight of soil. Test results indicated that increasing water-cement ratio produced decreasing strength of the cement-stabilized soil. (Miura *et al*., 2002).

2.2.3 Fly ash

Fly ash is a by-product of coal combustion in power plants. Fly ash contains silica, alumina, and calcium oxides, iron oxide and alkalis in its composition, and is considered as a pozzolanic material (Das *et al*., 2005). The most common elemental compositions of fly ash include amorphous oxide (mainly SiO_2, Al_2O_3), and metal oxides i.e. TiO_2, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, SO_3 and organic carbons. A guideline for selecting fly ash as soil stabilizing agent is provided in ASTM C593.

There are two types of fly ash; type "C" and type "F". This classification is based on the chemical composition. Fly ash type "C" contains 10% to 16% amount of free lime (Cockrell *et. al*., 1970).

This type of fly ash produces pozzolanic and cementitious reactions. Cockrell *et. al*., (1970), publicized that, color is one of the important physical properties of fly ash in terms of estimating the lime content qualitatively. Lighter color of fly ash indicates the presence of high calcium oxide and darker colors of fly ash represent high organic content. Fly ash can be used to improve the engineering properties of soil. However it must be well-known that fly ash properties are highly variable and depend on chemical composition of coal and combustion technology.

2.3 Non-traditional stabilizers

Currently, an increasing number of non-traditional additives have been developed for soil stabilization purposes. Non-traditional stabilizers can be generally classified into major categories, including, salts, acids, enzymes, lignosulfonates, emulsions, polymers, tree resin, molasses and geofibers. The use of non-traditional additives can be cost-effective depending on the projects' objective, the type of in-place material, and cost of the additive. Unfortunately, only few researches have been conducted to verify the suitability of non-traditional stabilizers as construction materials. As a result, documentation on soil stabilization performed with non-traditional additives continues to be subjective. A review of the results of few researches conducted to examine the performance of non-traditional additives as a guide for future evaluations are presented below.

2.3.1 Stabilization using Salt (NaCl, $MgCl_2$, $CaCl_2$)

Hassnen, (2013) reported increase in unconfined compressive strength of soil treated with 8% Nacl up to $700kN/m^2$, also results showed that maximum dry density of soil was increased from $1.85\text{-}1.92gcm^{-3}$ with increase of 8% Nacl in soil sample. Soil samples were prepared from commercial clay, River Aire soil, sand, and gravel. The study further showed that addition of salt resulted in increase in resilient modulus. This is potentially useful for long-term highway pavement subgrade applications.

Tamadher (2007), conducted laboratory test to investigate the effect of adding different chloride compounds i.e. (NaCl, MgCl2, CaCl2) on the engineering properties of silty clay soil. Various amounts of salts (2, 4, and 8% by weight) were added to the soil to study the effect of salts on the compaction characteristics, consistency limits and compressive strength. Test results showed a maximum dry density increased from 17.5kN/m^3 to 19.0kN/m^3 and decreased the optimum moisture content from 15% to 13%. The liquid limit, plastic limit and plasticity index decreased with the increase in salt content. The unconfined compressive strength increased as the salt content increased.

2.3.2 Stabilization Using Polymers

Polymers consist of hydrocarbon chains, and these chains become entwined within the soil particles thus producing a stabilizing effect. In effect, the polymers act as a binder to glue the soil particles together reducing dust, and even stabilizing the entire soil matrix (Orts *et al*., 2007).

Tingle *et al*., (2003) performed unconfined compressive strength testing on lean clay and fat clay treated with various natural and synthetic polymers. For the lean clay, the greatest increase in strength compared to untreated samples was obtained from treatment with lignosulfonate. Treatment with synthetic polymer also showed an increase in strength for the lean clay, although not as great of an increase as encountered with lignosulfonate treatment. For the fat clay, treatment with synthetic polymer also showed increases in strength. Lignosulfonate treatment of the fat clay was not included in the testing program.

Jeb & Rose (2007) also demonstrated that lignosulfonate could be an effective stabilizer. The lignosulfonate was used to treat a soil-aggregate mixture, and then California Bearing Ratio (CBR) tests were performed on compacted samples. Unsoaked specimens showed the greatest increases in CBR value after curing for a week. Soaked specimens still showed an increase in strength after curing for a week, but the strength increase was markedly less than that seen with unsoaked specimens. This phenomenon seems to be linked to the hydrophilic nature of the lignosulfonate, as it will tend to dissolve in water.

Testing performed by Kim *et al*., (2012) using lignins mixed with Iowa class 10 soil (CL) results indicate that the biofuel products have excellent resistance to moisture degradation. However, Sinha et al., (1957) did imply that lignins could be more effective on granular soils than fine-grained soils.

2.3.3 Stabilization using Molasses

Molasses is the most valuable by-product from the sugar industry. The molasses referred to in this research is blackstrap molasses, which is the product of raw sugar from sugar cane. Blackstrap molasses is the final byproduct of the third boiling cycle in the sugar making process. This type of molasses has a very dark color and is extremely viscous and contains approximately 20% sucrose, 20% reducing sugar, 10% ash, 20% organic non-sugar, and 20% water (Lewis, 1993). Molasses products act as weak cement by binding the soil particles together (Expert Panel, 2002). When high additive contents are used (5% plus) gravel loss reduction realized (Phil, 2014).

Testing performed by Shirsavkar (2010) verified that molasses can be an effective soil stabilizer. Soil modified with molasses by adding 5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% to gravel-clay sample, test results show that, value of California Bearing Ratio (CBR) found to increase by 5.12%, 22.67%, 24.68%, 34.00% 23.12% and 22.02%. Also by adding 6.5% of molasses in soil sample, the value of liquid limit and plastic limit increased while plasticity index of modified soil get reduced.

M'Ndegwa, (2011) suggested that stabilization of expansive clay soil with molasses increased the California Bearing Ratio (CBR) values and load bearing ability of the soil. Therefore molasses can be used as stabilizing agent for expansive clay soil. Also, molasses mixed with expansive clay soil reduced its swelling tendencies.

Therefore, it is clear that laboratory works by other researchers have not highlighted the impact and improvement on permeability, cohesion and internal angle of friction of soil following the addition of molasses during field stabilization.

2.4 Environmental impact of molasses in soil stabilization

Food grade molasses do not contain chemicals that might cause site contamination; therefore, it can be used for soil stabilization (O'Neill, 2011). While, chemical products from industrial materials and waste products currently used as soil stabilizer contain compound that might be harmful for human being especially when it comes into contact with water (Metzler & Jarvis, 1985). Portland cement is chemical soil stabilizer which is corrosive. When contact with wet or dry material can cause serious, potentially irreversible tissue damage from chemical burns, particularly to the eyes. Eyes contact by larger amounts of wet or dry cement may cause blindness (Canada building material, 2010). Natural products are likely to biodegrade in the environment and therefore toxic effects are expected to be minimal. Organic petroleum products which include used oils, solvents, cutback solvents, asphalt emulsions, dust oils, and tars have higher environmental impacts. Several studies have shown that waste oils may contain known toxic and carcinogenic compounds (Metzler & Jarvis, 1985). Organic petroleum-based products have also been found to be toxic to avian mallard eggs. When the eggs were exposed to a concentration of 0.5 mL/egg, 60% death was observed by 18 days of development (Hoffman and Eastin, 1981).

Application of all types of chemical soil stabilizers should not be ruled out or permitted under all conditions. Instead, guidelines should be drafted to indicate where specific chemical soil stabilizer should be applied. Application of chemical soil stabilizer should be avoided near sensitive environments, near water bodies and fractured rock, in areas with a shallow groundwater table, and other areas where water could quickly reach the saturated zone. Site-specific characteristics should be considered when approving the use of chemical soil stabilizer.

Finally, information on environmental impacts and effectiveness of chemical soil stabilizer proposed for use in soil stabilization should be carefully assessed before approving it. The advantages (e.g., improved air quality) and disadvantages (e.g., cause contamination to soils) associated with chemical soil stabilizer should be considered in risk management analysis.

2.5 Underground Soil Sampling

Underground soil sampling is the process of gathering, or collecting, of soil samples in the field for Laboratory testing. There are two methods of sampling underground soil which includes; sampling of undisturbed soil sample using cylindrical samplers, and sampling of disturbed soil from open excavations and test pits. The extent and methods to be used for soil sampling will depend upon the time, precision required and equipment available. The method that provides the best results for disturbed and undisturbed soil sample collection is by taking samples from test pits. A test pit is an open excavation pit that is large enough for a person to enter and collect soil sample. The trial pits are either manually or mechanically excavated.

2.5.1 Disturbed Soil Samples

Disturbed soil sample is the soil samples which does not retain the in-situ properties of the soil during collection process. The majority of soil samples collected by engineers and geologists are disturbed samples because they are easier to collect and the precision required for collecting an undisturbed sample is not required for many soil tests. Disturbed soil samples are widely used for classification, moisture content, compaction, and similar soil properties.

There are a variety of methods for collecting disturbed soil samples. Basic methods include using a backhoe and spade to create a test pit where you collect soil sample for laboratory test. Another common method used for soil sample extraction from ground is by using hand auger which works best for cohesive soils but can be used on cohesionless soils above the water table, provided the diameter of the individual aggregate particles is smaller than the bit clearance of the auger. Auger borings are usually used for work at shallow depths, but if pipe extensions are added, the earth auger may be used to extract soil sample up to a depth of about 10m in relatively to soft soils. Samples obtained by this method are completely disturbed but are satisfactory for determining the soil profile below ground level and for laboratory test.

2.5.2 Undisturbed Samples

Undisturbed soil samples are those that are cut, removed, and packed with the least possible disturbance and retain the structural integrity of the in-situ soil. They are samples in which the natural structures, void ratio, and moisture content are preserved as carefully as possible. Samples of this type are used for determining the density (unit weight) of soil in the laboratory and investigating the strength of undisturbed soils in the laboratory by the CBR or unconfined compression tests. These samples may be shipped to laboratories for shear, consolidation, or other strength tests.

Undisturbed samples are collected using cylinder samples or the CBR mold equipped with a sampling cutter. The method of sampling chosen depends upon the equipment available, the tests required, and the type of soil. All undisturbed samples must be handled with care. Cohesionless soil samples must be kept in the container until ready for testing, and the container should be handled without vibration. Some soils are too hard or contain too many stones to permit sampling with the cylindrical samplers and can be sampled only by cutting out chunks by hand. Whatever method used, the sample must be taken and packed in the container for shipment without allowing its structure to change. Protection against change in moisture content during sampling and shipment is also required.

2.6 Performance of soil stabilized with molasses and bio-enzymes

The performance of the pavement is dependent on the type and properties of the sub-grade soil (Greeshma & Lamanto, 2015). Soil properties can be modified by using eco-friendly and liquid additives such as Bio-Enzymes or Molasses (Greeshma & Lamanto, 2015). They act on the soil to reduce the voids between soil particles and minimize absorbed water when soil is compacted at maximum dry density and optimum moisture content (Greeshma & Lamanto, 2015).

Greeshma & Lamanto (2015), conducted laboratory test to investigate behavior of Organic Clay stabilized with Bio-Enzymes on engineering properties of soil and results showed that value of Liquid Limit (LL) of soil increased by 28%, while decreasing Shrinkage limit (SL) by 30%. Unconfined Compressive Strength (UCS) of treated soil increased 12times that of untreated soil.

Also study performed by Ravi *et al.,* (2015) on effect of molasses on strength of soil showed that, Unconfined Compressive Strength of soil increased by 94% when 6% molasses content added to Intermediate Compressible Clay (CI) also California Bearing Ratio (CBR) of Intermediate Compressible Clay (CI) increased by 6.37%. This means that, molasses played a role in improvement of soil cohesion which ultimately lead to increase Unconfined Compressive strength and resistance to penetration during CBR test.

2.7 Earthfill dam embankments

2.7.1 Introduction

Earthfill dam embankments have been used since the earliest times to impound and divert water. They are simple compacted structures that rely on their mass to resist sliding and overturning and are the most common type of dam found worldwide. The main advantages involved in the construction of small earth dams are; Local natural materials are used for construction of embankments, design procedures for earthfill dams are straight forward, easily available plants and equipment are required during construction of dam embankment and also, earthfill dams resist settlement and movement better than more rigid structures and can be more suitable for areas where earth movements are common (FAO, 2010).

Disadvantages of construction of earthfill dams also exist and these are; an earthfill dam embankment can easily be damaged or destroyed when water is overtopping an embankment due to loss of free board. Thus, a spillway and adequate upstream protection are essential for any earthfill dam. If dam embankment is not adequately compacted during construction, the dam will offer weak structural integrity, offering possible pathways for preferential seepage and also earthfill dams require continual maintenance to prevent erosion, tree growth, animal damage and seepage.

2.7.2 Borrow Areas

Borrow areas within the reservoir area should be given first preference, followed by those located on the valley sides close to the proposed embankment (FAO, 2010). Borrow pits in the reservoir have the advantage of increasing the upstream storage capacity and require no remedial work once the dam is completed. Borrow pits should never be located close to the downstream toe area of the dam, the spillway or outfall or in any area prone to erosion. Also, borrow pits located some distance from the dam site will increase construction costs, wear and tear on plant and machinery and the timing of construction so always identify source materials as close to the dam site as possible(FAO, 2010).

Ideally, the entire earthfill material for dam construction should be drawn from within the reservoir area and, if necessary, from any cut from spillway areas. Care must be taken to make sure that by drawn soil within the reservoir area seepage line from upstream to downstream of dam embankment will not formed, otherwise dam will act only as recharge zone to another aquifer and will never fill up.

2.8 Soil materials recommended for core and cutoff construction

2.8.1 Clay soil

Clay soil is always recommended for the core and cutoff construction, and must be well compacted. Basically, the lower the clay percentage in the soil, the more compaction and care in construction is required. Sandy clay soils are more suitable for inclusion in upstream section as they compact well, have much reduced seepage characteristics but do not allow the buildup of high soil water pressures. Clays are not required in the downstream shoulder as it is essential that this section is free draining (FAO, 2010).

2.8.2 Silt soil

Avoid including silts in any section of the embankment. The lack of cohesion, poor soil structures, fine material and difficulty in compaction are their main drawbacks (FAO, 2010). A small proportion of silt soil is permissible for construction earthfill dam, e.g.

Silty-clay, but care must be taken in its use and application to ensure it is balanced with other soils and to keep percentage contents low. Silt soil can be confused with fine clay soil, therefore it is important to conduct laboratory analysis to differentiate their soil textures.

2.8.3 Sand soil

A soil with a predominance of sand should not be used in dam construction. A sandy soil can be used in the downstream shoulder but should not be used elsewhere unless there is no alternative (FAO, 2010). Sands can be used as filter materials during construction of larger dams.

2.8.4 Materials to avoid during construction of earthfill dam

During construction of earthfill dam embankment some materials should never be used in dam construction, in particular the following; Organic materials, material with a high proportion of mica, which forms slip surfaces in soils of low clay percentages, fine silts which are unsuitable for any zone of the dam and cracking clays that fracture when dry and may not seal up when wetted (FAO, 2010).

2.9 Typical soil properties for earthfill dam design and construction

2.9.1 Permeability:

The rate of movement of gravitational water through soil pores is termed the permeability of soil. Permeability of disturbed/undisturbed soil samples should be measured in the laboratory. Depending on the kind of soil permeability of soil can be categorized as permeable, semi permeable or impermeable as per the following limits (Spangler and Handy, 1982)

Impermeable: With permeability less than 1 x 10-6 cm/sec
Semi permeable: With permeability 1x 10-6 to 1x 10-4 cm/sec.
Permeable: With permeability more than 1x 10-4 cm/sec.
The dam embankments should be impermeable. The permeability of the downstream section of embankment should not be less than that upstream.

2.9.2 Unit Weights of soil

Typical values for dry unit weight of soil range from 16.76kN/m^3 for a very loose dry soil to 22.56kN/m^3 for dense wet soil (Carter and Bentley, 1991).

Table 2.1 Typical Values of Unit Weights of soils (Carter and Bentley, 1991)

Soil	γ_{sat} (kN/m^3)			γ_{dry} (kN/m^3)		
	Lower Limit	Upper Limit	Average	Lower Limit	Upper Limit	Average
Sands and gravels						
very loose	16.67	17.65	17.16	12.75	13.73	13.24
loose	17.65	18.63	18.14	13.73	14.71	14.22
medium dense	18.63	20.59	19.61	14.71	17.65	16.18
dense	19.61	21.57	20.59	16.67	19.61	18.14
very dense	21.57	22.56	22.06	19.61	21.57	20.59
Poorly-graded sands	16.67	18.63	17.65	12.75	14.71	13.73
Well-graded sands	17.65	22.56	20.10	13.73	21.57	17.65
well-graded sand/gravel mixtures	18.63	22.56	20.59	14.71	21.57	18.14
Clays						
unconsolidated muds	15.69	16.67	16.18	8.83	10.79	9.81
soft, open-structured	16.67	18.63	17.65	10.79	13.73	12.26
typical, normally consolidated	17.65	21.57	19.61	12.75	18.63	15.69
boulder clays (overconsolidated)	19.61	23.54	21.57	16.67	21.57	19.12
Red tropical soils	16.67	20.59	18.63	12.75	17.65	15.20

2.9.3 Cohesion (C)

Cohesion for dry loose sandy soil is almost zero and can rise to over 200kN/m^2 for hard clay soils. Cohesion for moist sandy loam soils are typically in the range of 5kN/m^2 to 15kN/m^2 and moist plastic clay soils, cohesion range from 12 to 50kN/m^2 (Day, 2006).

2.9.4 Angle of internal friction

Theoretically, pure clay have internal friction angle of 0° and these value rise with increasing sand content and density to approximately 40° for a compacted soil. Internal friction angle of clay soil range from 5° to 10° (Geotechdata.info, 2013).

2.10 Conclusion from literature review

It can be seen that use of traditional soil stabilizers as construction materials has been encouraged since long time compared to non-traditional stabilizer. Several studies have been carried out to assess impact of molasses as soil stabilizer for improving engineering properties of soil. Results showed that for soil treated with molasses there is significant improvement of Undrained Compressive strength of soil, California Bearing ratio of soil, maximum dry density and plasticity index of soil. Further soil laboratory test on use of non-traditional stabilizer must be conducted to verify suitability of stabilizers as construction materials in the laboratory before actual field trials.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area.

The study was conducted in Goweko village. The village is located on the South – Eastern part of Uyui District - Tanzania. The village is about 60km from Tabora Municipal Centre. The study area is located at Goweko Mlimani – Sub village on the northern part of Goweko village Centre at coordinate (0517800E, 9415300N) and elevation of 1220amsl. This area was chosen because of the following reasons:

- Catchment of study area is sufficient to discharge enough water needed for irrigated agriculture.
- Length of designed dam embankment is 730m and maximum dam height is 12.05m while estimated total reservoir capacity is 4,940,000.00m^3 at full supply level.
- Potential area suitable for irrigated agriculture is more than 400ha of paddy.

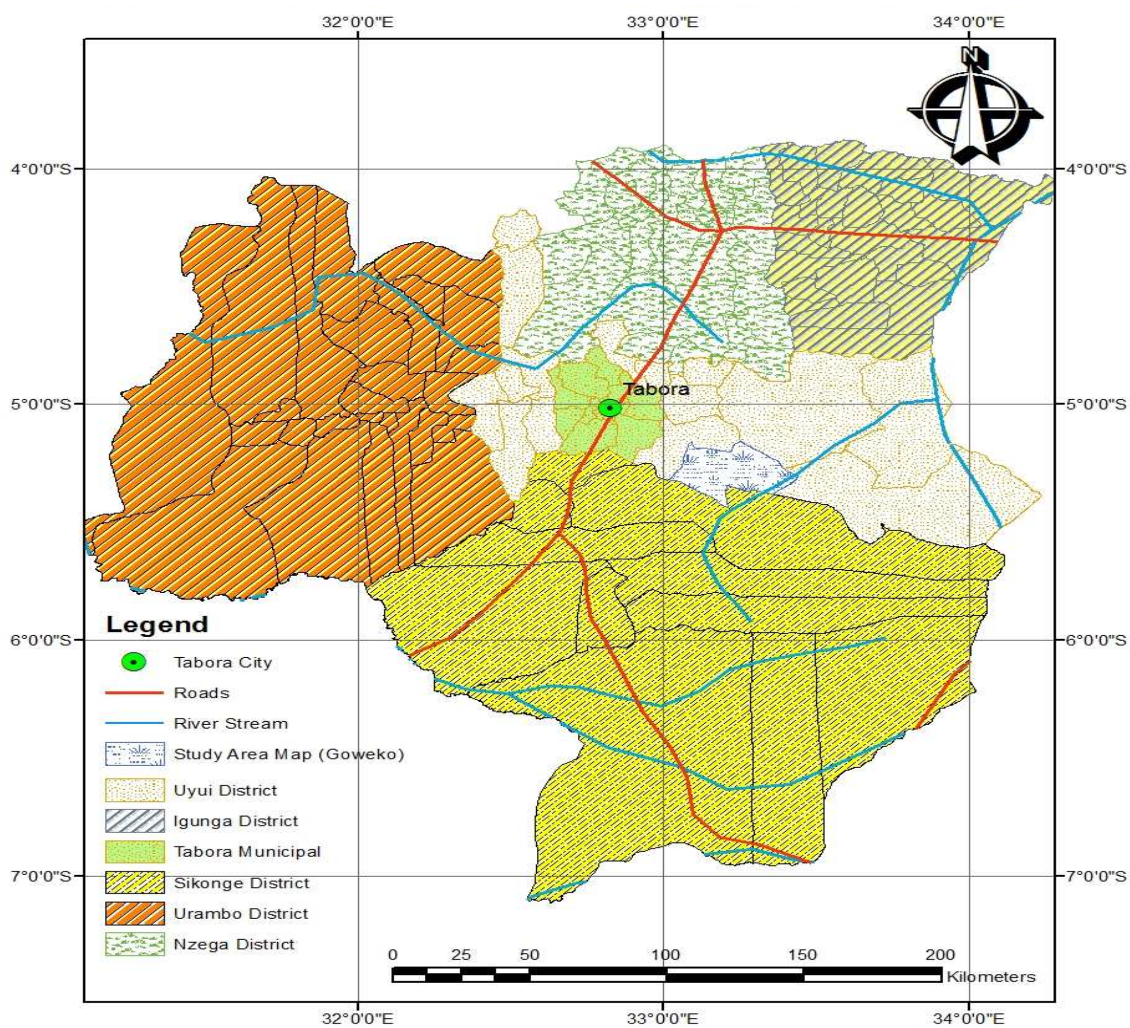

Figure 3.1 Map of Tabora Region showing study area

3.2 Characteristics of soil at the study area

Silty Clay soil was sampled from Goweko representing a widely spread typical soil in the study area. Seven soil samples were taken at a depth of about 1.5 – 2.5 m below the top surface. These samples were found to be loose silty clay. The properties of the soil and the results of the consistency limits are given in Table 3.1 while the classification of the soil is given in Figure 3.2. The soil lies above the A-line (as shown in Figure 3.2), thus the soil is classified as Silt Clay (CL - ML) soil according to the unified classification system.

Plate 3.1 Testing of soil liquid limit using Cone penetrometer (Left) Determining soil moisture content (Right).

Table 3.1 Properties of the soil used in this study

Sample	Moisture Content %	Bulk density (kN/m^3)	Atterberg Limits			Void ratio (e)	Specific Gravity (Gs)
			LL	PL	PI		
Silt Clay soil	8.66	16.74	28.68	21.89	6.89	0.66	2.61

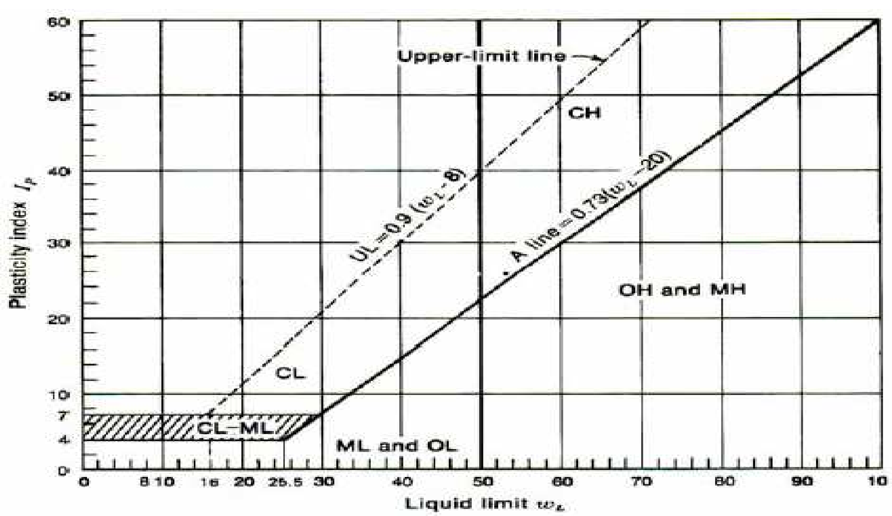

Figure 3.2 Plasticity Chart

3.3 Research Design

Seven soil samples were randomly taken at depth of about 2.5m from the open pit having cross-section of 1.5m x 1.5m within the proposed borrow pit site. Disturbed soil sample was collected using a backhoe, spade and auger while undisturbed soil sample was collected using cylindrical sampler. The classification of the soil in the trial pits was carried out visually before sample collection. In the laboratory, soil was treated with molasses by adding 0%, 5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% to soil sample (Shirsavkar, 2010).

Plate 3.2 Site clearance

Plate 3.3 Soil sampling by hand auger

Plate 3.4 Soil sampling kits

Plate 3.5 Excavation of open pit

Plate 3.6 Collection of undisturbed soil

Plate 3.7 Collected undisturbed soil

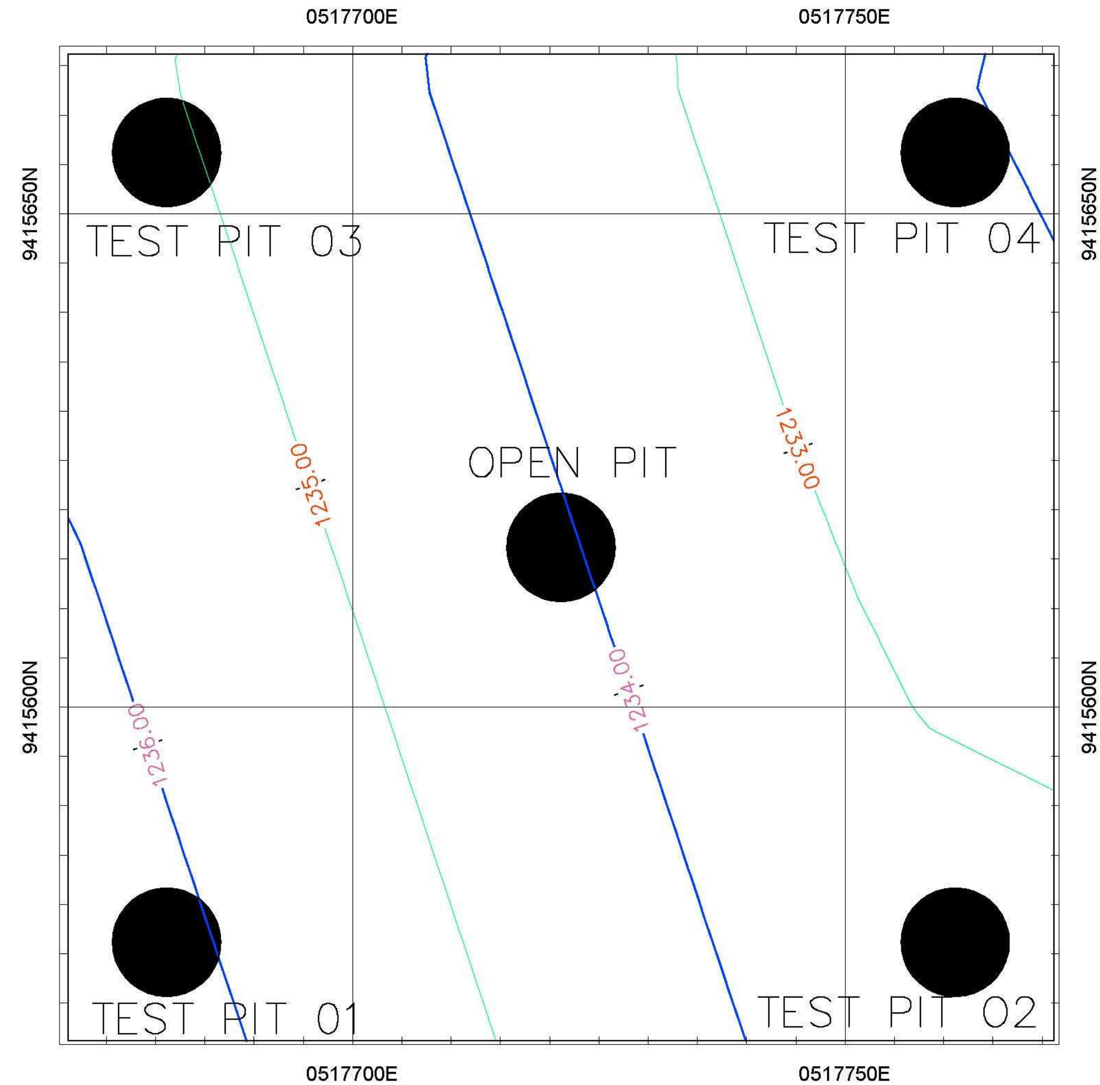

Figure 3.3 Soil sampling map

3.4 Data analysis

Laboratory experiments and data analysis was carried out on disturbed and undisturbed soil sample before and after analysis to check the objectives of adding molasses to the soil. Silt clay soil was treated with molasses by adding 5%, 5.5% 6.0%, 6.5%, 7.0% and 7.5% to soil sample (Shirsavkar, 2010). From these mixing techniques protocol for stabilizing silt clay soil using molasses was developed. All experiments and data analysis was done in accordance with British Standard (BS) for soil testing. (Central Material Laboratory Manual, 2000)

3.5 Consolidated-undrained triaxial test

In order to examine the strength behavior of stabilized soil in detail, seven soil samples treated with different percentage of molasses was tested for consolidated-undrained (CU) triaxial tests to determine strength improvement of soil. The laboratory test was very important because it allowed assessment of the suitability of stabilized soil as material for dam embankment construction to be carried out. During laboratory test, the axial load was increased by applying a constant rate of strain until specimen fail, normally within a period of 5-15 minutes, confining pressures were also varied from 0 to 150 kPa.

3.5.1 Specimen Preparation

Consolidated-undrained triaxial test was conducted on untreated soils as well as molasses treated soils. The dry soil material was mixed with 5-7.5% by weight of molasses thoroughly until a uniform color observed, untreated and treated soil was then prepared at optimum water content and maximum dry density. Later, soil samples were moulded in a special cylindrical mold having 70mm internal diameter and 140mm height. Each soil sample was compacted in three equal layers to achieve target density. It must be noted that each sample in this part of the study was prepared similar to triaxial specimens.

3.5.2 Data analysis of Consolidated-undrained triaxial test

The following steps were used for data analysis:

1) To calculate axial strain.

$$\varepsilon = \frac{\Delta L}{L} \quad \text{..........(3.1)}$$

Where ΔL = Vertical deformation of the specimen and

L = Original length of specimen.

2) To calculate vertical load on the specimen.

3) To calculate corrected area of the specimen (A_c)

$$A_c = \frac{A_o}{1-\varepsilon}, \text{ where } A_0 = \text{Initial cross-sectional area i.e. } A_o = \pi * \frac{D^2}{4} \quad \text{..........(3.2)}$$

4) To calculate the stress (σ) on the specimen.

Where,

$$\sigma = \frac{\text{Load}}{A_c} \quad \ldots\ldots(3.3)$$

5) To plot (σ) versus axial strain separately for three tests.
6) To plot deviator stress σ_d vs ε_a for three tests in the same plot.
7) To plot Mohr circle based on σ_1 and σ_3 at failure.
8) To make a straight line, which is a tangent to all Mohr's circles. This gives cohesion (C) and angle of internal friction (ø)

3.6 Soil permeability test

3.6.1 Falling head permeability test

The falling head permeability test is a common laboratory testing method used to determine the permeability of fine grained soils with intermediate and low permeability such as silts and clays. This testing method can be applied to disturbed and undisturbed soil sample. In order to investigate the effect of adding molasses to soil permeability, a series of laboratory permeability tests on non-stabilized and stabilized soils was conducted according to BS1377: Part 5:1990.

3.6.2 Steps used for soil testing in the laboratory

1) Permeameter cell was filled with soil compacted at optimum moisture content and maximum dry density in three layers.
2) Filter paper was placed on both sides of permeameter cell and porous stone on bottom of permeameter cell.
3) Manometer tubes were connected, but valves kept closed.
4) Air was removed from soil sample for 15 minutes through inlet tube located at top of permeameter cell.
5) Test was run and readings taken i.e. h_1 & h_2, and time taken to reach h_2
6) Then, soil sample was thoroughly mixed after adding 5% of molasses to total weight of soil, permeameter cell was filled with soil compacted at optimum moisture content and maximum dry density in three layers, step 1-5 was repeated to soil treated by adding 5.5% 6.0%, 6.5%, 7.0% and 7.5% of molasses to soil sample.

3.6.3 Data Analysis of permeability

Data was analyzed using the following equation

$$K = \frac{aL}{At} \ln \frac{h_1}{h_2} \quad \text{Where; } \ldots\ldots (3.4)$$

K: Coefficient of permeability

A: Cross section area of permeameter cell (mm^2)

a: Cross section area of the standing pipe (mm^2)

L: Length of sample (mm)

T: Time duration (sec.)

h_1: Initial head of soil sample (cm)

h_2: Final head of soil sample (cm)

3.7 Specific Gravity of soil (BS1377: Part 2:1990)

Values for specific gravity of the soil solids were determined by placing a known weight of oven-dried soil in a flask, then filling the flask with water. The weight of displaced water was then calculated by comparing the weight of the soil and water in the flask with the weight of flask containing only water. The specific gravity was then calculated by dividing the weight of the dry soil by the weight of the displaced water.

3.8 Compaction test

The modified proctor compaction test was carried out to determine the moisture content-dry density relationship according to BS1377: Part 4:1990. Soil sample was treated with molasses at different percentage i.e. 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% in order to investigate the effect of adding molasses on optimum water content and maximum dry density of the selected soils. The soil was compacted into $9.56 \times 10^{-4} m^3$ molds in 5 equal layers.

3.9 Bulk density of soil

Bulk density of a soil is an essential parameter in most of geotechnical engineering analysis, e.g. stability of slopes, consolidation settlement, earth pressure and bearing capacity analysis. In order to investigate the effect of adding molasses on bulk density of soil a series of laboratory tests on non-stabilized and stabilized soils was conducted according to BS1377: Part 4:1990.

3.9.1 Data analysis of modified proctor test

After having maximum dry density and optimum moisture content of soil treated with molasses at 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% from compaction test, bulk density of soil was analyzed from the following equation.

$$MDD(kN/m^3) = \frac{\text{Bulk density of soil}(kN/m^3)}{(1+OMC)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.5)$$

Where,

MDD = Maximum dry density of soil

OMC = Optimum moisture content of soil in percentage

3.9.2 Protocol for stabilizing silt clay soil for use in earth-fill dam

Protocol for stabilization of silt clay soil was determined after plotting in spreadsheet results of both seven samples obtained from compaction test, permeability test and Consolidated-undrained triaxial test. Seven graphs of compaction test, and consolidated undrained triaxial test will be superimposed to study effect of adding molasses on maximum dry density, optimum moisture content, cohesion and internal friction angle of soil. Percentage of molasses that produces higher value of Maximum dry density and cohesion will be recommended for field trial. Also for permeability, both seven soil samples will be treated with different percentage of molasses starting from 0%, 5%, 5.5% 6.0% 6.5%, 7.0% and 7.5%., results from laboratory will be plotted to determine percentage of molasses that produces small value of permeability, this value will then be recommended for field trial.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of laboratory tests on molasses treated soils and a discussion on their relevance to practice. The tests include, soil characterization, Consolidated-Undrained triaxial, Soil permeability and compaction.

4.2 Soil Characterization Tests

Soil characterization test was performed on soil sample collected in Goweko Village accordance to BS1377: Part 2:1990 procedures. The result according to unified soil classification system is classified as Silt Clay (CL - ML) soil.

4.3 Optimized soil engineering properties pertinent to stabilization

4.3.1 Consolidated-Undrained triaxial test

The consolidated – undrained triaxial test was performed to determine effect of adding molasses to soil particles. Seven soil samples were mixed with molasses at different treatment i.e. 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% of the total weight of soil sample. The testing procedures involved mixing the soil with the stabilizer before compacting the soil into the molds. Seven specimens were created for each soil treated with different percentage of stabilizers. The first specimen was compacted immediately after completion of mixing. Each specimen was covered with plastic bags to prevent loss of moisture content before testing.

The specimens were compacted in special brass mold having 70mm diameter, and 140mm height. Figures 4.1 to 4.7 show effective Mohr circles for non-treated and treated soil samples with different percentage of molasses. Results of the effect of adding molasses on cohesion and friction angle of Silt Clay soil are as shown in Figure 4.8. The results indicate that, the maximum strength of soil was found in the soil treated with 6.5% molasses. By adding 6.5% molasses to the soil, more strength of soil was observed as compared to the soil specimens containing other percentage of additives. It means that, addition of molasses to the soil increases force of attraction between soil particles, which resulting into the increase in soil cohesion.

Figure 4.1 to 4.7 show Mohr circles for untreated and treated soil sample with molasses.

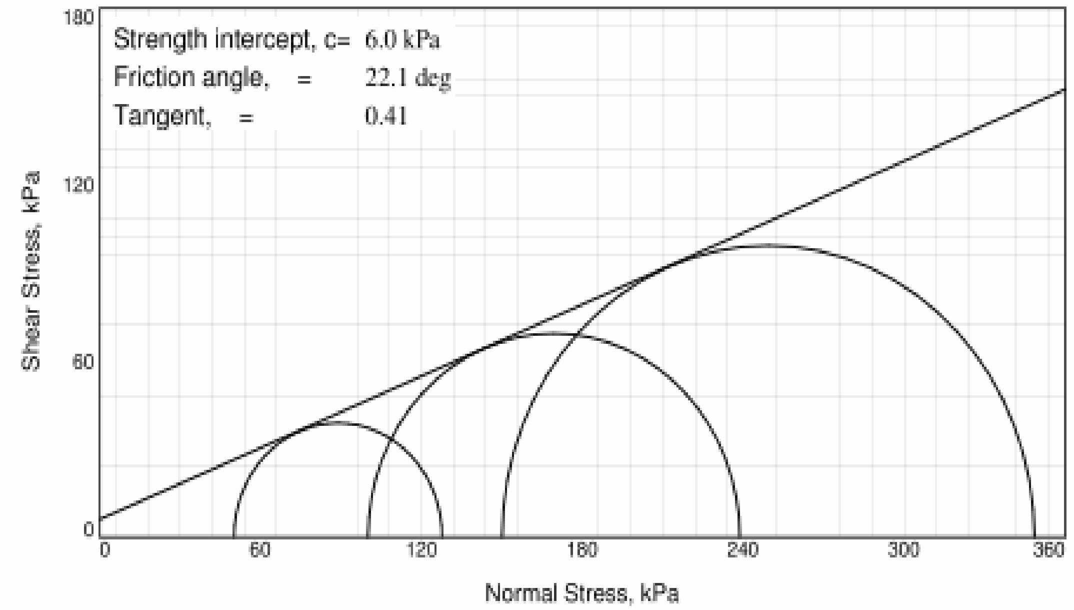

Figure 4.1 Mohr circle for untreated soil with molasses as stabilizer

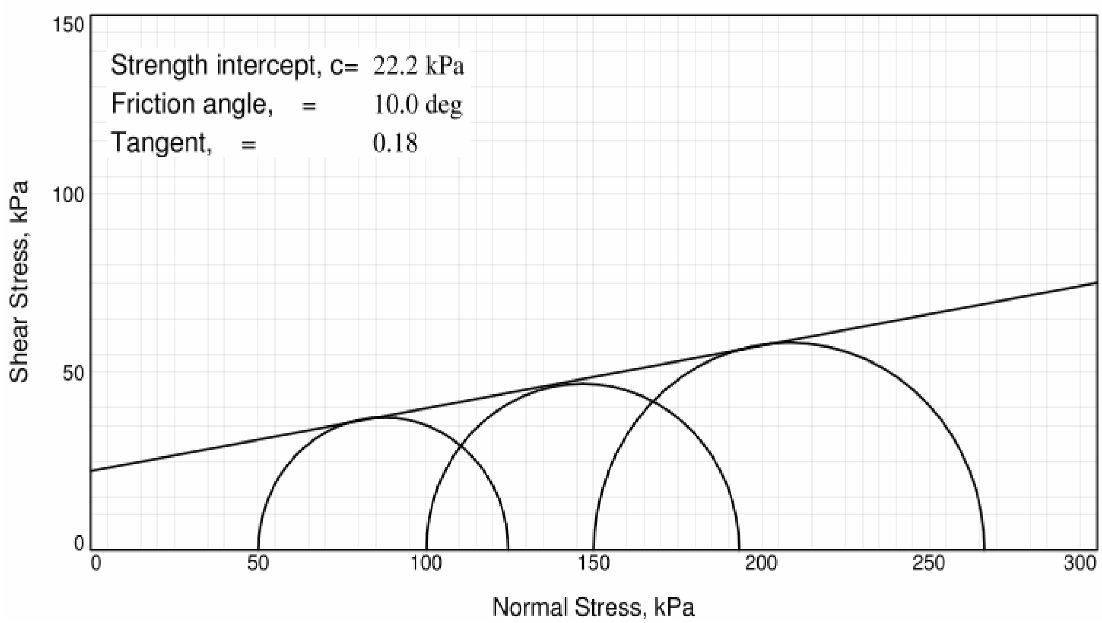

Figure 4.2 Mohr circle for 5% molasses added to soil sample

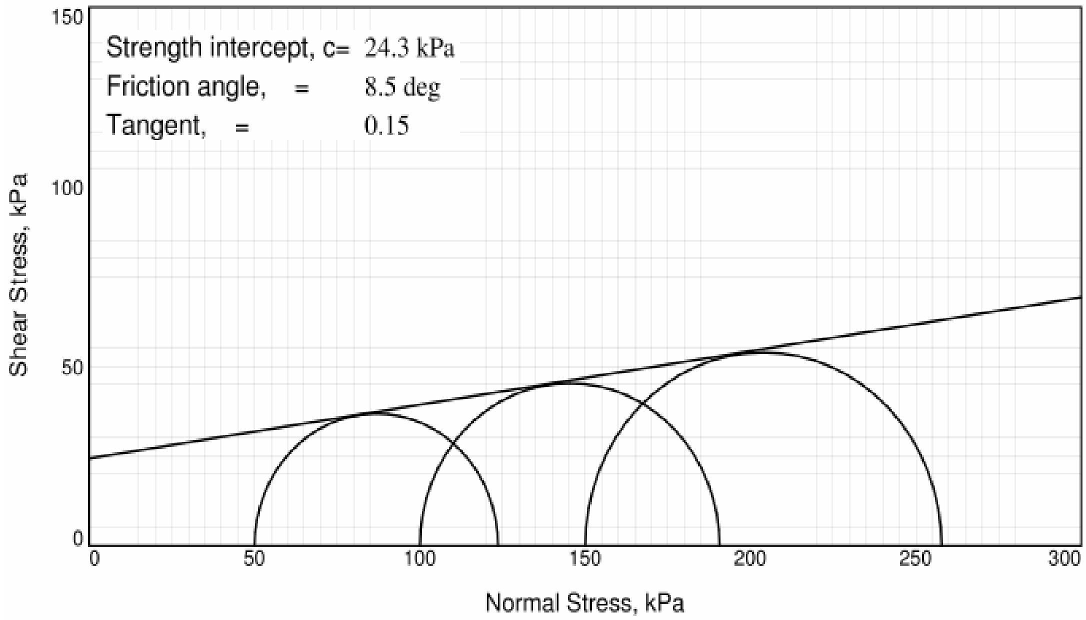

Figure 4.3 Mohr circle for 5.5% molasses added to soil sample

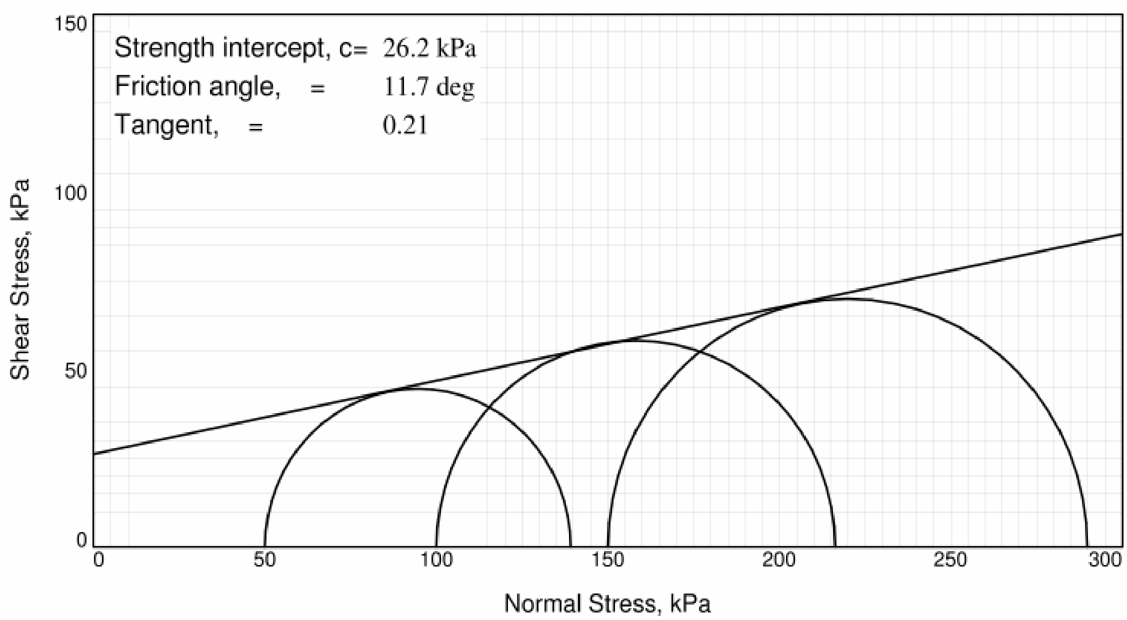

Figure 4.4 Mohr circle for 6.0% molasses added to soil sample

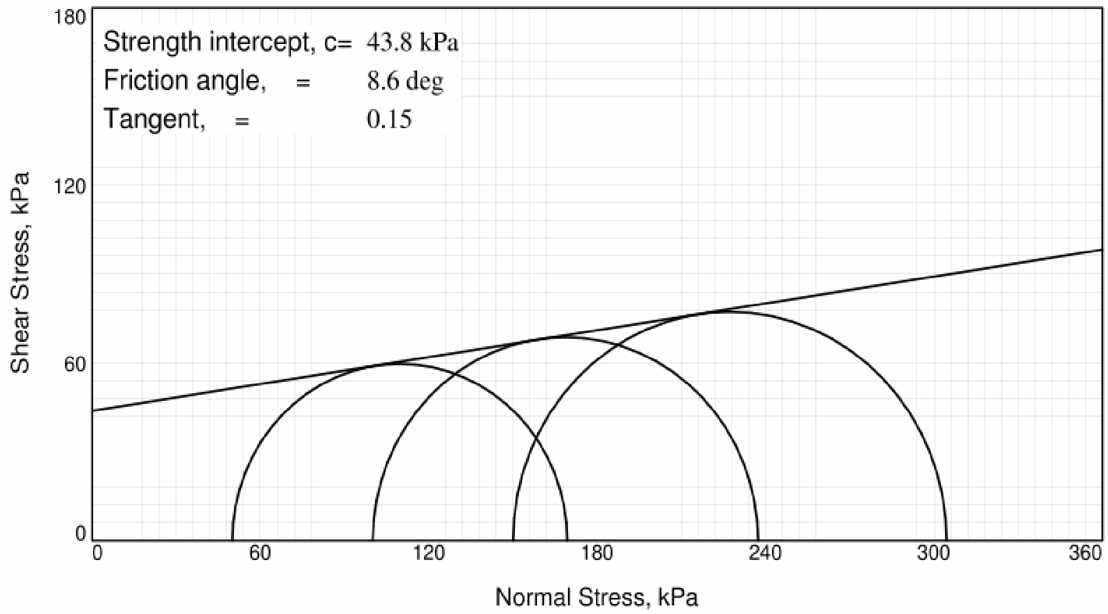

Figure 4.5 Mohr circle for 6.5% molasses added to soil sample

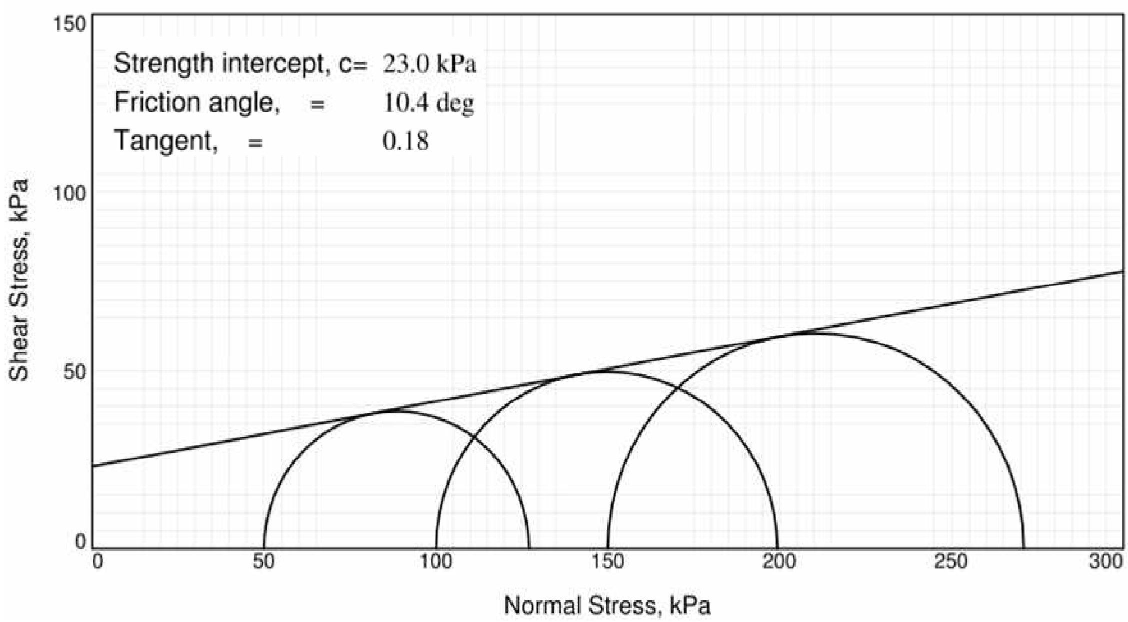

Figure 4.6 Mohr circle for 7.0% molasses added to soil sample

WW

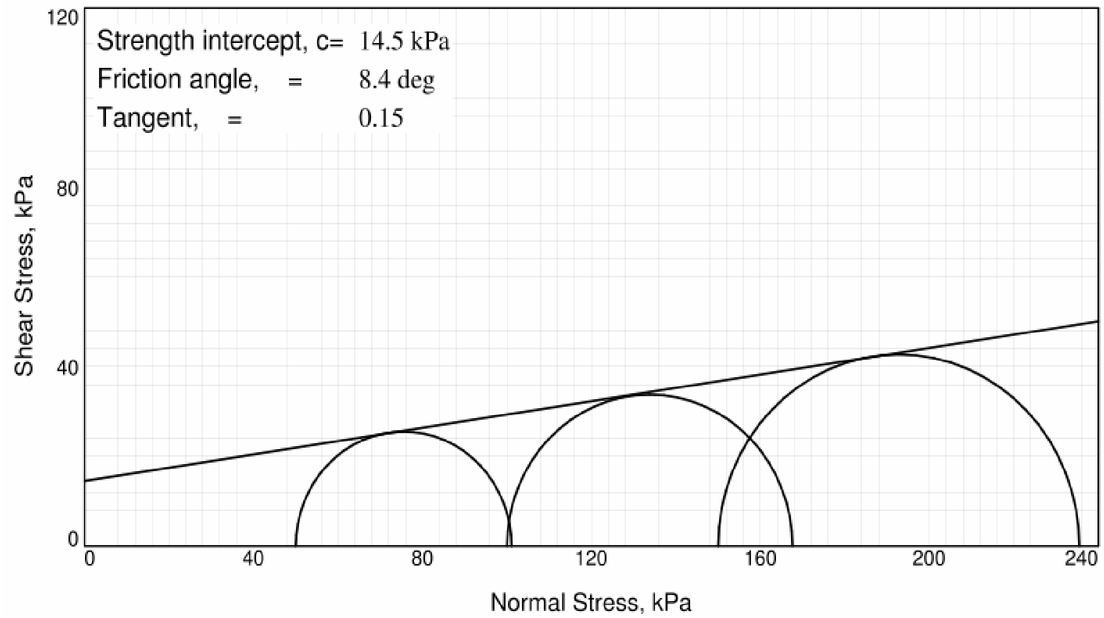

Figure 4.7 Mohr circle for 7.5% molasses added to soil sample

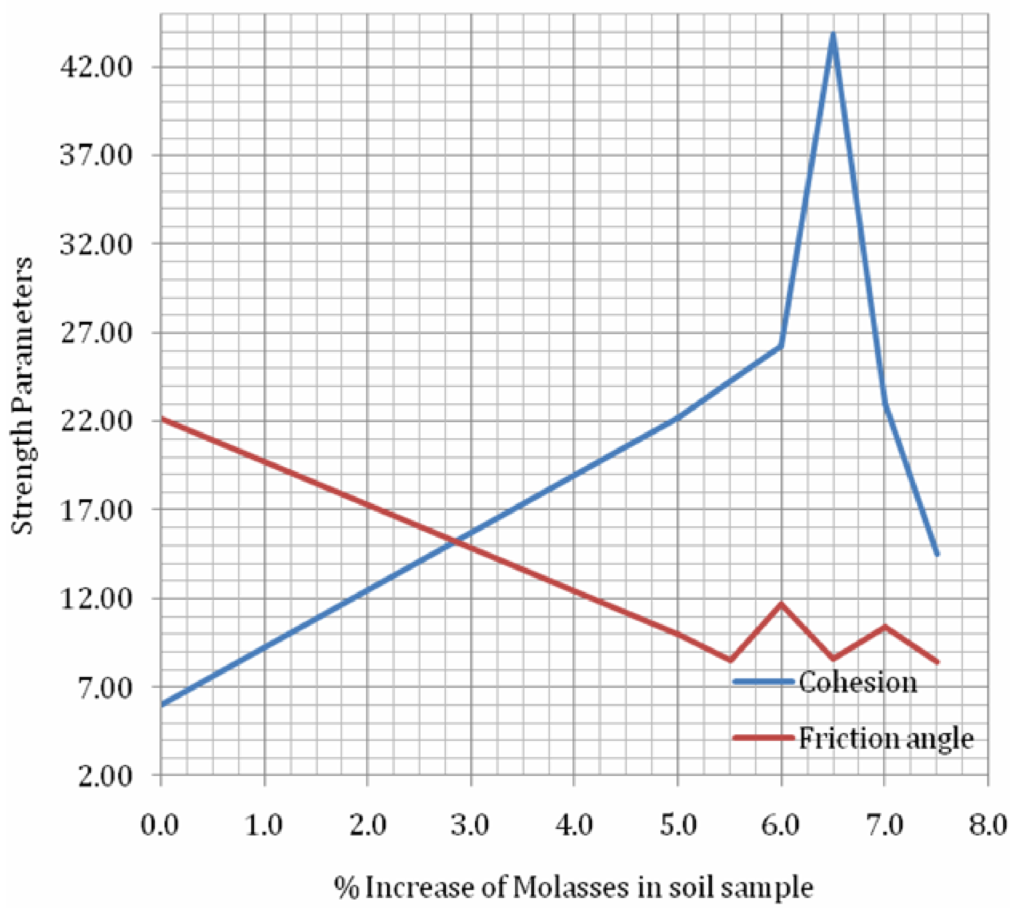

Figure 4.8 Effect of molasses treatment on cohesion and friction angle of the soils

The effects of molasses treatment on undrained stress and strain behavior of silt Clay soil are as shown in Figure 4.9 and results are as tabulated in Table 4.1. It is observed that the peak deviator stress decreased significantly due to molasses treatment, but the corresponding strain to peak deviator stress decreased slightly from 6% to 4.9%, then increased to 7.2% (Figure 4.10). This shows that, treated soils exhibited more resistance to deformation compared with non-treated soils.

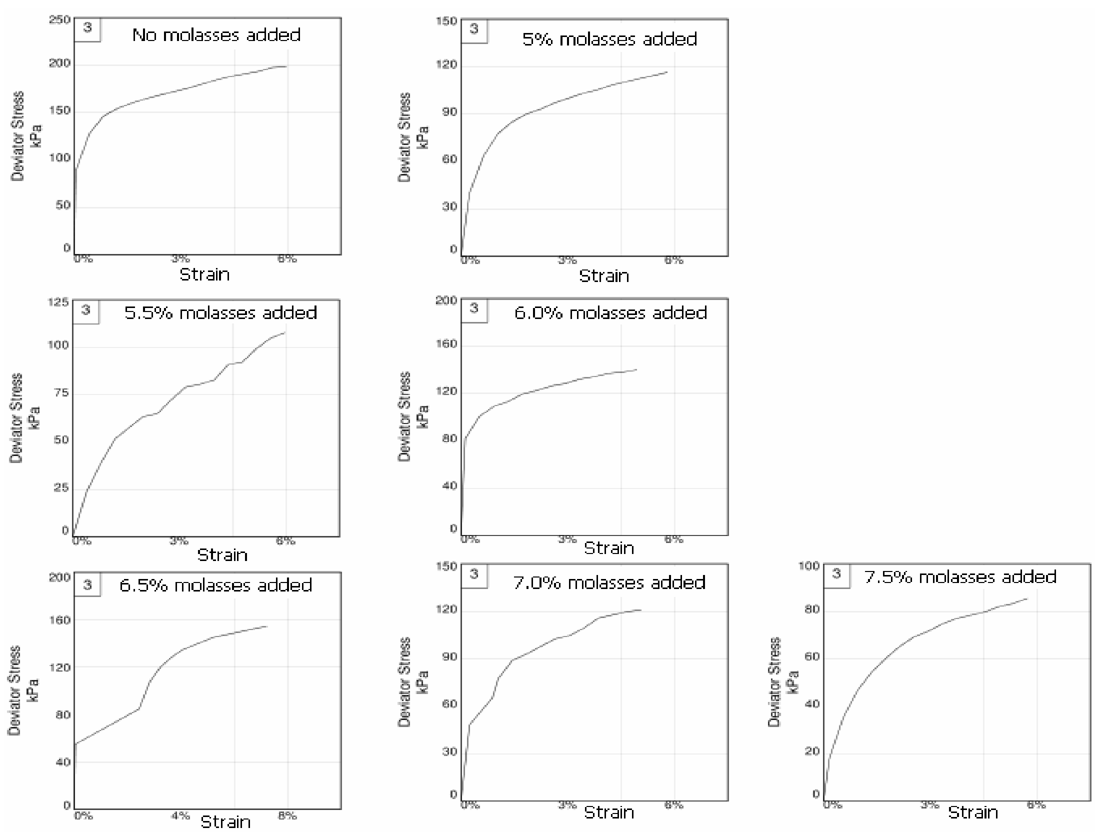

Figure 4.9 Effect of molasses treated soil on stress – strain

Table 4.1 Effect of molasses treatment on stress and strain behavior of Silt Clay soil

% increase of molasses	**0**		**5**		**5.5**		**6.0**		**6.5**		**7.0**		**7.5**	
Fluid cell pressure (kN/m²)	Stress (kN/m²)	Strain (%)	Stress (kN/m²)	Strain (%)	Stress (kN/m²)	Strain (%)	Stress (kN/m²)	Strain (%)	Stress (kN/m²)	Strain (%)	Stress (kN/m²)	Strain (%)	Stress (kN/m²)	Strain (%)
50	77.60	4.0	74.6	4.4.	73.6	4.4	89.1	4.7	119.3	4.4	77.1	4.7	51.1	4.7
100	138.60	4.4	93.6	4.6	90.6	4.7	116.3	5.1	137.3	5.0	99.3	5.3	67.6	4.2
150	198.50	6.0	116.4	5.8	107.8	6.0	139.8	4.9	154.5	7.2	121.0	5.1	85.5	5.7

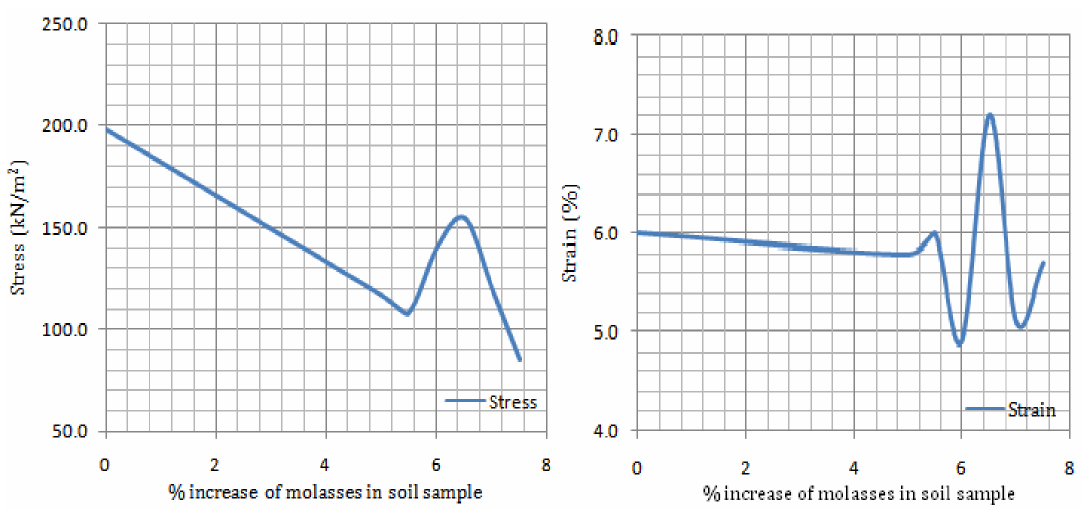

Figure 4.10 Effect of molasses treatment on stress and strain behavior of Silt Clay soil

A summary of strength parameters for consolidated – undrained triaxial test used for silt clay soil is given in Table 4.2. It can be seen that addition of small percentages of molasses to soil sample led to significant improvement in cohesion and friction angle of silt clay soil. This is due to increase in force of attraction between soil particles, which resulting into the increase in soil cohesion and decrease of friction angle.

Table 4. 2 Strength parameters for consolidated - undrained triaxial test for silt clay soil

% increase of molasses in soil sample	**0.0**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**
Cohesion (C) kN/m^2	6.0	22.2	24.3	26.2	43.8	23.0	14.5
Friction angle (ϕ^0)	22.1	10.0	8.50	11.7	8.60	10.4	8.40
Tan(ϕ)	0.41	0.18	0.15	0.21	0.15	0.18	0.15

4.3.2 Soil permeability test

The falling head permeability was performed to determine effect of adding different percentage of molasses to soil particles. Seven specimens were created in a permeameter cell at maximum dry density and optimum moisture content. Results of soil permeability as it was determined from falling head permeameter are as shown in Figure 4.11. It can be seen that, by adding small percentages of molasses to soil sample led to major improvement in particles of silt clay soil. It can also be seen that, silt clay soils attained minimum permeability at 6.0% molasses treatment. This occurs as result of increase in force of attraction between soil particles which subsequently minimizes pore space between soils. Table 4.3 show a typical permeability values in soils (Carter and Bentley, 1991).

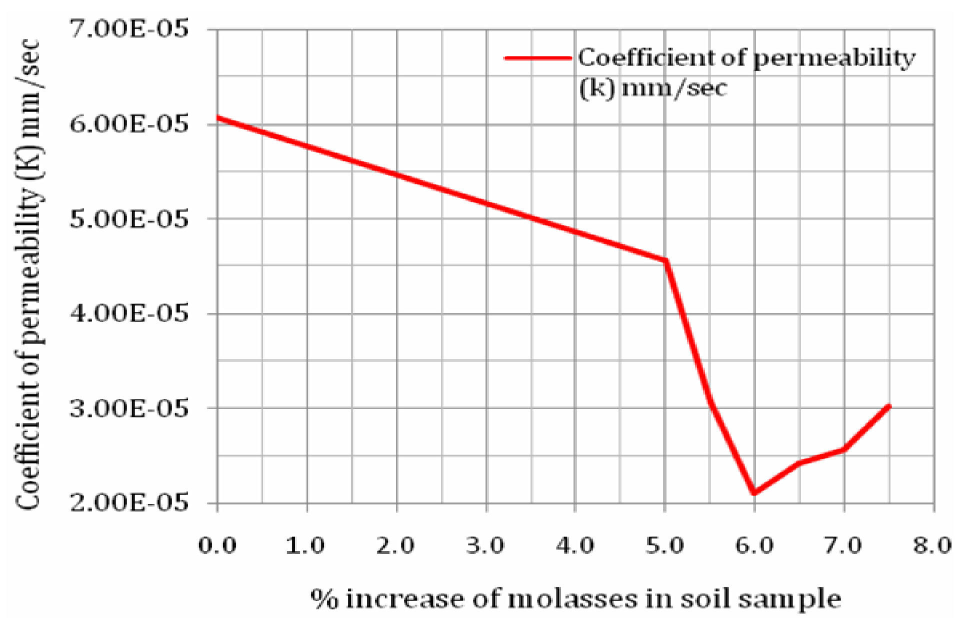

Figure 4.11 Effect of molasses treatment on permeability of Silt Clay soil

Table 4.3 Typical permeability values in soils (Carter and Bentley, 1991)

Coefficient of permeability (log scale) m/s	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1
cm/s	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10	100
Permeability:	Practically impermeable	Very low	Low	Medium	High							
Drainage conditions:	Practically impermeable	Poor	Good									
Typical soil groups:	GC → GM →	SM	SW →	GW →								
	CH	SC MH MC-CL	SM-SC	SP →	GP →							
Soil types:	Homogeneous clays below the zone of weathering	Silts, fine sands, silty sands, glacial till, stratified clays	Clean sands, sand and gravel mixtures	Clean gravels								
		Fissured and weathered clays and clays modified by the effects of vegetation										

Note: The arrow adjacent to group classes indicates that permeability values can be greater than the typical value shown.

4.3.3 Compaction characteristics

The effect of molasses treatment on optimum water content, bulk density and maximum dry density of soils were determined from modified compaction tests and results are as shown in Figure 4.12 and figure 4.13. It can be observed that, as molasses content increased, optimum water content decreased where as maximum dry density and bulk density of soil increased. Similar results were reported by Bulbul *et al*. The decrease in the optimum moisture content as the molasses content increased may be due to presence of small amount of water in the molasses which tends to lubricate soil particles.

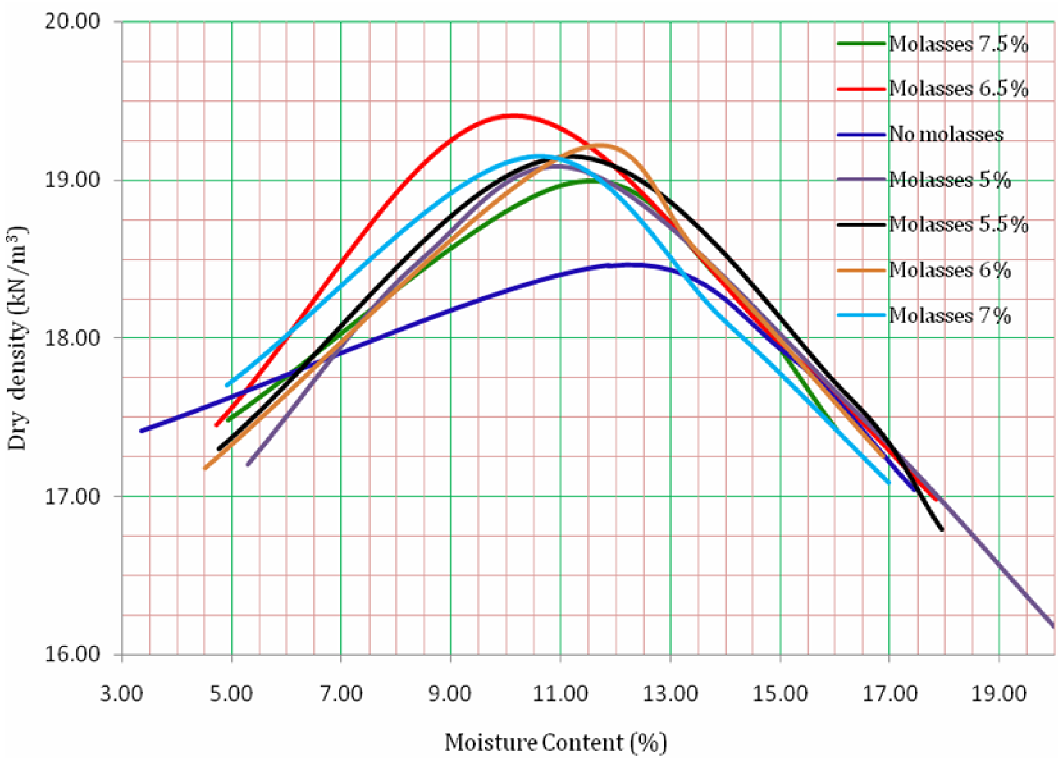

Figure 4.12 Effect of adding molasses on moisture content and maximum dry density of soil

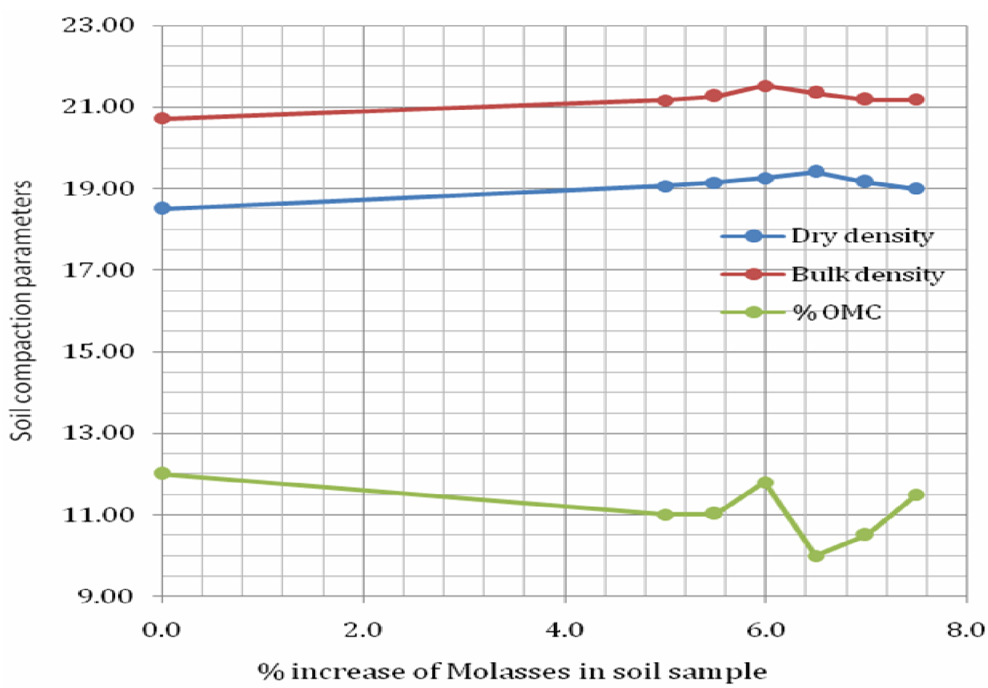

Figure 4.13 Effect of molasses treatment on optimum moisture content, bulk density and maximum dry density of the soils.

4.3.4 Specific Gravity of soil

Specific gravity of soil was performed to determine effect of adding molasses to soil particles. Each specimen was mixed with molasses at different treatment i.e. 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% of the total weight of soil sample. Effect of adding molasses on porosity, void ratio and specific gravity of soil are as shown in Figures 4.14 and 4.15 respectively. It can be observed that, as molasses content increased from 5-6.0%, porosity, void ratio and specific gravity of soil decreased. The results indicate that the minimum void ratio and porosity of soil was found in the soil treated with 6.0% molasses. Also from results, it can be observed that, beyond 6.0% molasses can no longer improve engineering properties of soil, therefore soil started being porous.

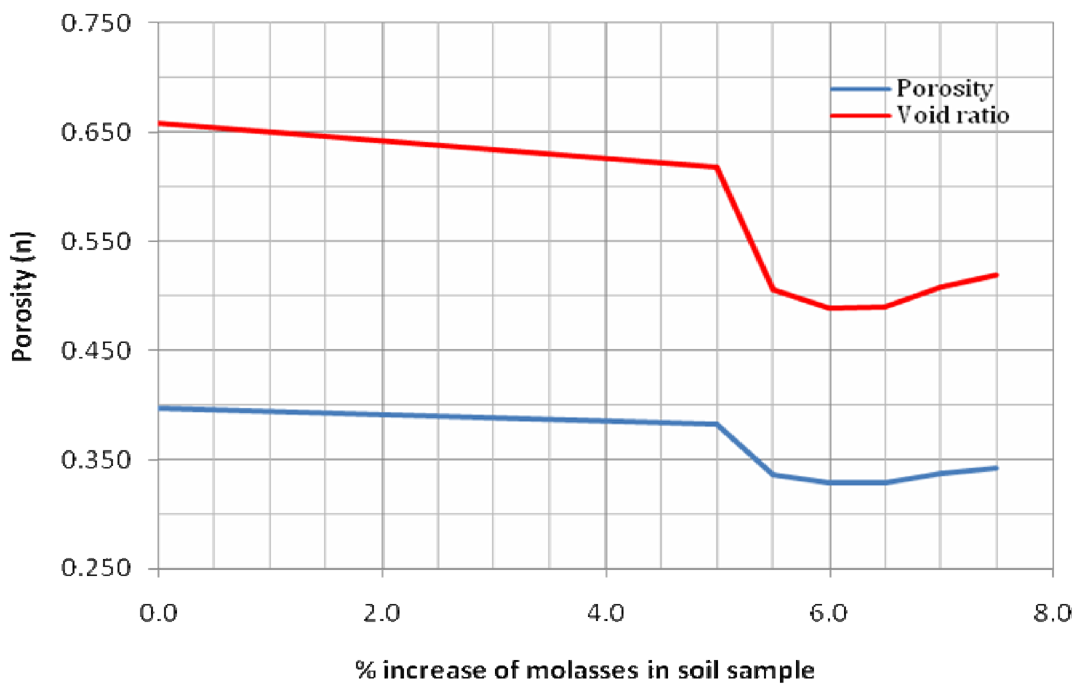

Figure 4.14 Effect of adding molasses on porosity and void ratio of soil

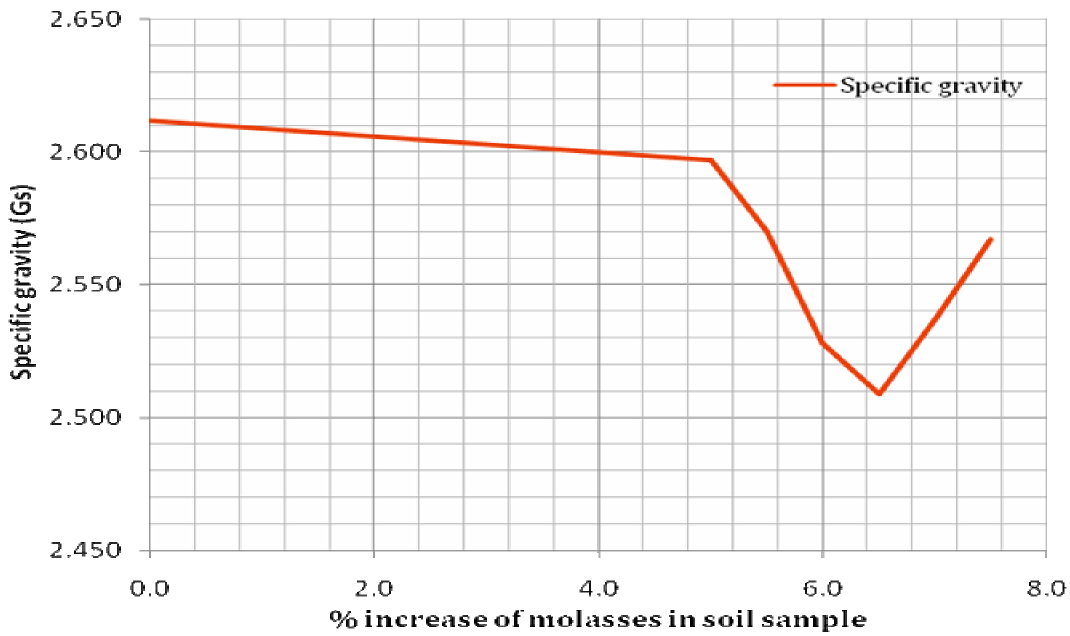

Figure 4.15 Effect of adding molasses specific gravity of soil

4.3.5 Bulk density of soil

Results of bulk density of soil derived from soil modified by adding 5.0%, 5.5%, 6.0% 6.5%, 7.0% and 7.5% of molasses treatment are as shown in figure 4.16. It can be observed that, as molasses content increased, maximum dry density of soil increased from 18.5kN/m^3 to 19.40k kN/m^3 also, bulk density of soil increased from 20.72k kN/m^3 to 21.34k kN/m^3. The increase in maximum dry density and bulk density of soil may be due to increase in cohesion and decrease of soil void ratios.

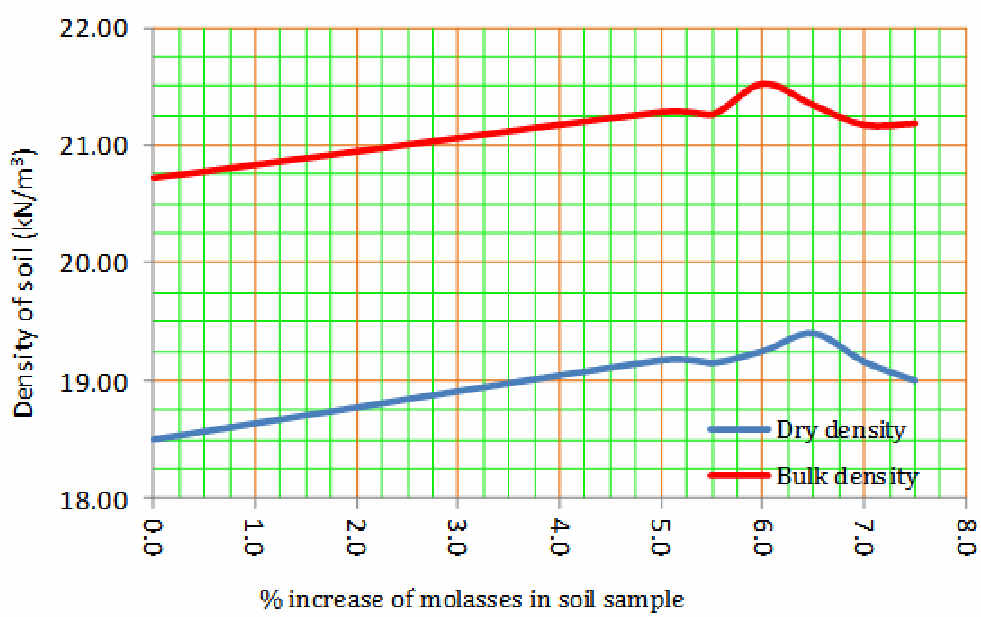

Figure 4.16 Effect of adding molasses on maximum dry density and bulk density of soil

4.4 Assessed potential of molasses as a soil stabilizer

Based on laboratory results, soil was tested for consolidated-undrained triaxial test, soil permeability and compaction. Laboratory experiment reveal that, by adding 6.5% of molasses to a soil sample, cohesion of soil was increased from 6.05kN/m^3 to 43.85kN/m^3, while decreasing friction angle of soil from 22.1^o to 8.6^o. Also, at 6.5% molasses treatment, maximum dry unit weight of soil was increased from 18.5kN/m^3 to 19.40kN/m^3. Unit bulk weight of soil increased from 20.72kN/m^3 to 21.34kN/m^3 at 6.0% molasses treatment. The optimum moisture content of soil decreased from 12.0% to 10.0% with the increased in molasses percentage. The permeability of the soil decreased from 6.062 x 10^{-5} mm sec^{-1} to 2.105 x 10^{-5} mm sec^{-1} with increase of molasses up to 6%. These results showed that, stabilization of silt clay soil with molasses increase strength properties of soil, therefore molasses can be used as stabilizing agent for silt clay soil.

4.5 Developed protocol for stabilizing silt clay soil for use in earth-fill dam

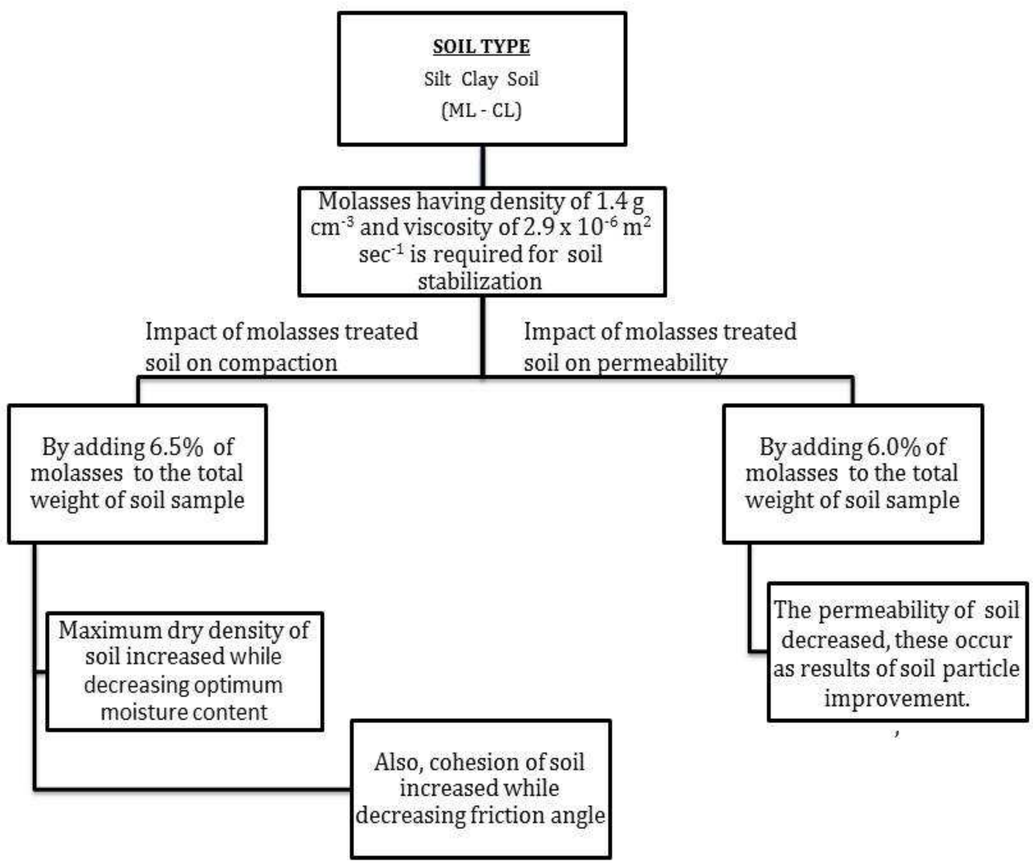

Figure 4 17 Developed protocol for stabilizing silt clay soil for use in earth-fill dam

4.6 Cost-benefit analysis of using molasses as soil stabilizer

The costs of eathfill dam embankment treated with molasses are much lower than those of a conventionally built embankment. In fact, molasses can lower embankment overall construction cost by 23.68% as shown in Table 4.4. Molasses as stabilizer improves engineering properties of soil and thus, increases strength of the soil.

Using molasses as soil stabilizer does not require a significant amount of additional knowledge during construction, however, understanding of stabilization process is simple, and no special tools are needed to carryout construction process. The quality of dam embankment constructed using molasses as soil stabilizer can be measured by conducting field and laboratory tests.

Table 4.4 Cost-benefit analysis of using molasses as soil stabilizer

S/N	Descriptions	Cost-Benefit Analysis of Molasses (Tsh/Ton)	Cost-Benefit Analysis of Cement (Tsh/Ton)
i)	Cost of purchasing molasses at factory (TPC)-Moshi	155,760	0
ii)	Transportation cost including loading and unloading	200,000	0
iii)	Cost of ordinary Portland cement already at site	0	440,000
	Total	**355,750**	**440,000**

Net saving in cost = 440,000 – 355,750 = 84,250/=

Percentage of saving = (84,250/355,750)*100 = 23.68%

Note:
Transportation cost of molasses and cement from factory to Tabora was developed based on distance and roughness of road surface.

Source: *Surface and Marine Transport Regulatory Authority (SUMATRA)-Tanzania*

CHAPTER 5: CONCLUSIONS

5.1 Optimized soil engineering properties pertinent to stabilization

This search was conducted to study the effect of adding molasses to silty clay soil. The soil was tested for consolidated-undrained triaxial test, soil permeability and compaction. By adding 6.5% of molasses to a soil sample, cohesion of soil was increased from 6.0kPa to 43.8kPa, while decreasing friction angle of soil from 22.1^{o} to 8.6^{o}. At 6.5% molasses treatment, maximum dry unit weight of soil was increased from 18.5kN/m^3 to 19.40kN/m^3. Unit bulk weight of soil increased from 20.72kN/m^3 to 21.34kN/m^3 at 6.0% molasses treatment. The optimum moisture content of soil decreased from 12.0% to 10.0% with the increased in molasses percentage. The permeability of the soil decreased from 6.062×10^{-5} mm sec^{-1} to 2.105×10^{-5} mm sec^{-1} with increase of molasses up to 6%. These results showed that, stabilization of silt clay soil with molasses, increased strength properties of soil.

5.2 Assessed potential of molasses as a soil stabilizer

Based on laboratory results, soil was tested for consolidated-undrained triaxial test, soil permeability and compaction. Laboratory experiment reveal that, by adding 6.5% of molasses to a soil sample, cohesion of soil was increased from 6.0kN/m^2 to 43.85kN/m^2, while decreasing friction angle of soil from 22.1^{o} to 8.6^{o}. Also, at 6.5% molasses treatment, maximum dry unit weight of soil increased from 18.5kN/m^3 to 19.40kN/m^3. Unit bulk weight of soil increased from 20.72kN/m^3 to 21.34kN/m^3 at 6.0% molasses treatment. The optimum moisture content of soil decreased from 12.0% to 10.0% with the increased in molasses percentage. The permeability of the soil decreased from 6.062 x 10^{-5} mm sec^{-1} to 2.105 x 10^{-5} mm sec^{-1} with increase of molasses up to 6%. These results showed that, stabilization of silt clay soil with molasses increase strength properties of soil, therefore molasses can be used as stabilizing agent for silt clay soil.

5.3 Developed protocol for stabilizing silt clay soil for use in earth-fill dam

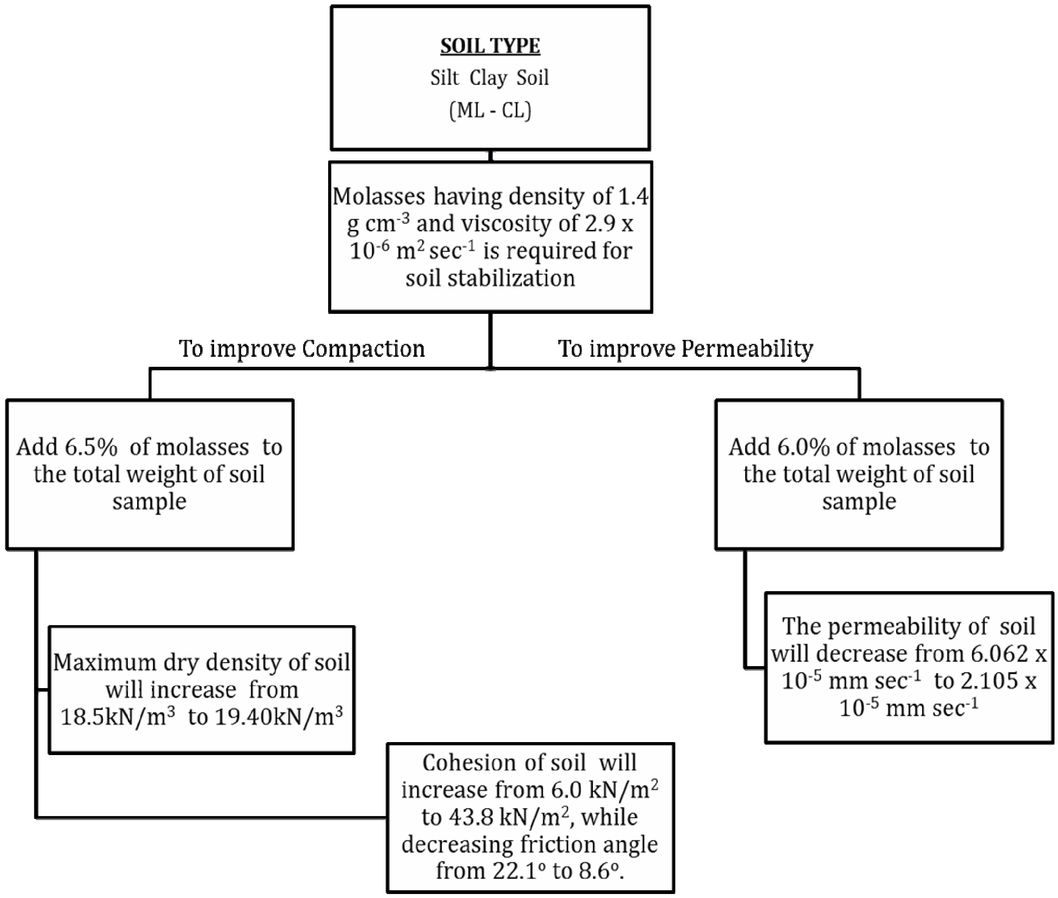

Figure 5.1 Protocol for stabilizing silt clay soil for use in earth-fill dam

CHAPTER 6: RECOMMENDATIONS

This investigation was conducted to study the effect of adding molasses on the properties of silty clay soil. The soil was tested for compaction, permeability and consolidated undrained triaxial test. Soil treated by adding 6.5% molasses show greater improvement of maximum dry density, cohesion and internal friction angle of soil. Also, minimum permeability of soil was attained at 6.0% molasses treatment. For satisfactory performance of silt clay soil stabilized using molasses it is recommended that, 6 to 6.5% of molasses can be used to stabilize soil for dam embankment construction. Also, dam embankment stabilized with molasses must meet the following criteria;

- The dam embankment and its foundation must be stable against sinking, overturning and sliding during construction, earthquake and flood and during all conditions of reservoir operation.

- Seepage through the embankment, foundation, and abutments must be controlled and collected to prevent excessive uplift pressures, piping and erosion of material into cracks, joints and cavities.

- Freeboard of dam embankment must be sufficient to prevent overtopping by wave action. An allowance for post-construction settlement of the dam and its foundation, and deformation caused by earthquake must be included. Spillways and outlets must be designed with sufficient capacity such that overtopping of the dam does not occur.

- Outer slope protection on both the upstream and downstream slopes must prevent erosion by wave action, reservoir water level fluctuations, rainfall and wind. Materials must be durable and resistant to wet-dry cycles. Materials must resist weather and erosion over long periods of time.

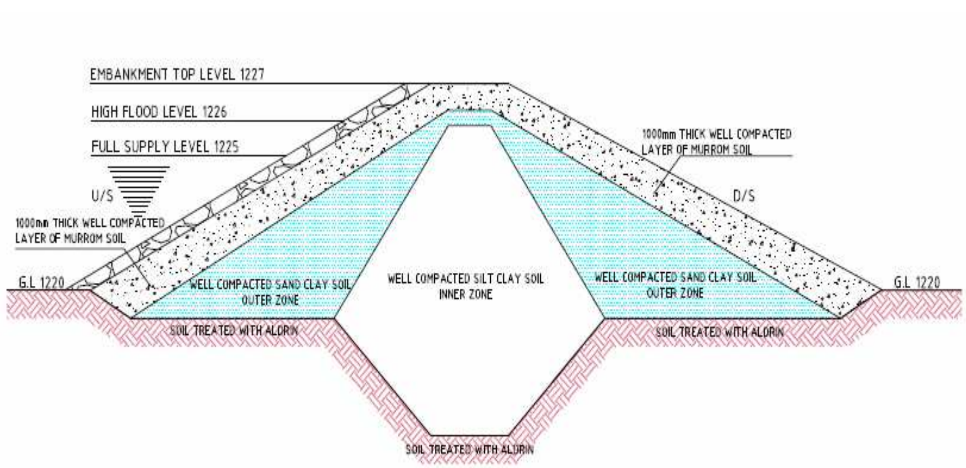

Figure 6.1 Typical cross-section of dam embankment showing layout of materials for inner zone, outer zone and upstream and downstream protection

- The dam must be constructed using appropriate quality control and quality assurance procedures. The ultimate performance of the dam depends on careful construction especially regarding foundation treatment, moisture and density control of the fill, and the design and construction of filters and drains.
- During reservoir filling and project operation, routine inspections of the dam embankment and its foundation and the evaluation of abnormal behavior and the necessity for remedial treatment are required.

Lastly, further studies are recommended to determine duration molasses as stabilizing agent will last in soil while maintaining the same strength of compacted soil. Furthermore, field trials must be done to assess the performance of dam embankment constructed with soil stabilized with molasses.

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Appendix A - SOIL CLASSIFICATION

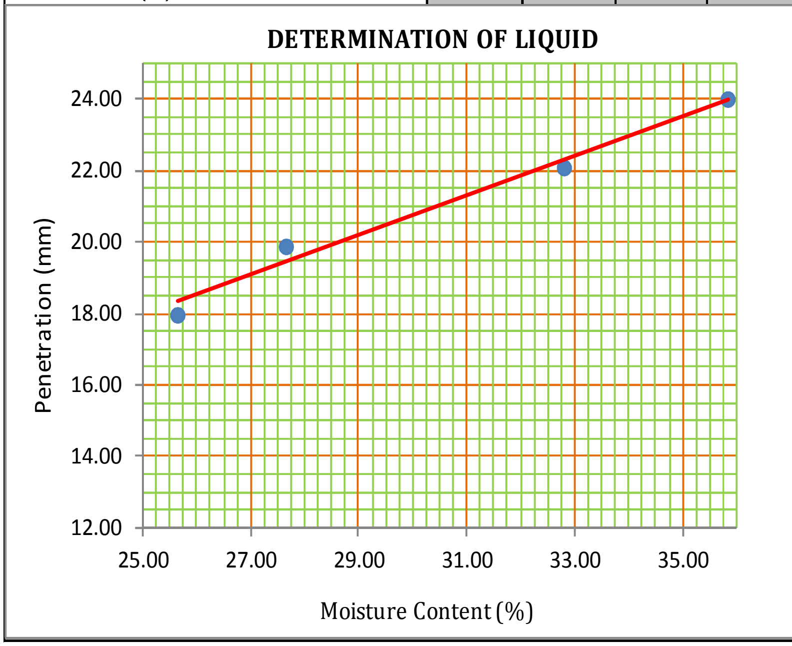
TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

ATTERBERG LIMITS DETERMINATION

Project : …………………………...……………………….....Stabilization of silt Clay soil using Molasses
Description of Soil:……..……………………………………………………………………...Silt Clay soil
Location: ……………………………………………………………………………………
Test Performed By:………Dotto & Mwanga E.W………………………….. **Date Of test:** ………….....…

TEST METHOD: CML TESTS 1.2, 1.3, and 1.4, ref. BS 1377: Part 2: 1990							
Determination of Liquid limit & Plastic limit							
Test No	**LIQUID LIMIT**				**PLASTIC LIMIT**		
Type of test	1	2	3	4	1	2	Average
Initial dial gauge reading(mm)	2.50	2.50	2.50	2.50			
Final dial gauge reading (mm)	20.50	22.40	24.60	26.50			
Cone penetration	18.00	19.90	22.10	24.00			
Moisture Can No	AA	AB	AC	AD	AE	AF	
Mass of can +Wet soil	44.90	39.50	43.30	50.10	16.35	16.50	
Mass of can + dry soil	37.90	33.50	35.20	40.10	15.61	15.55	
Mass of can (gms)	10.60	11.80	10.50	12.20	12.60	10.60	
Mass of Water (gms)	7.00	6.00	8.10	10.00	0.74	0.95	
Mass of dry soil (gms)	27.30	21.70	24.70	27.90	3.01	4.95	
water content(%)	25.64	27.65	32.79	35.84	24.58	19.19	21.89



Sample Preparation	
(a) As received	V
(b) Air Dried	℃
(c) Washed on 0.425mm	
(iii) Oven dried	°C
(iv) Unknown	
Proportion of material passing 0.425µm sieve %	
Liquid (%):	28.68
Plastic Limit(%):	21.89
Plasticity index(%):	6.79
Linear Shrinkage(%):	

Appendix B - COMPACTION TEST

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

COMPACTION TEST (Heavy)

TEST METHOD: CML TEST 1.9, ref BS 1377:Part4:1990

Project : ……………………………………………………………………………………….

Description of Soil:…5% molasses added

Location: ……………………………………………………………………………………

Test Performed By:……Dotto & Mwanga E.W…… **Date Of test:** ……………………………….

No of Blows:27 No of Layers 5 Masss of Rammer 4.5Kg

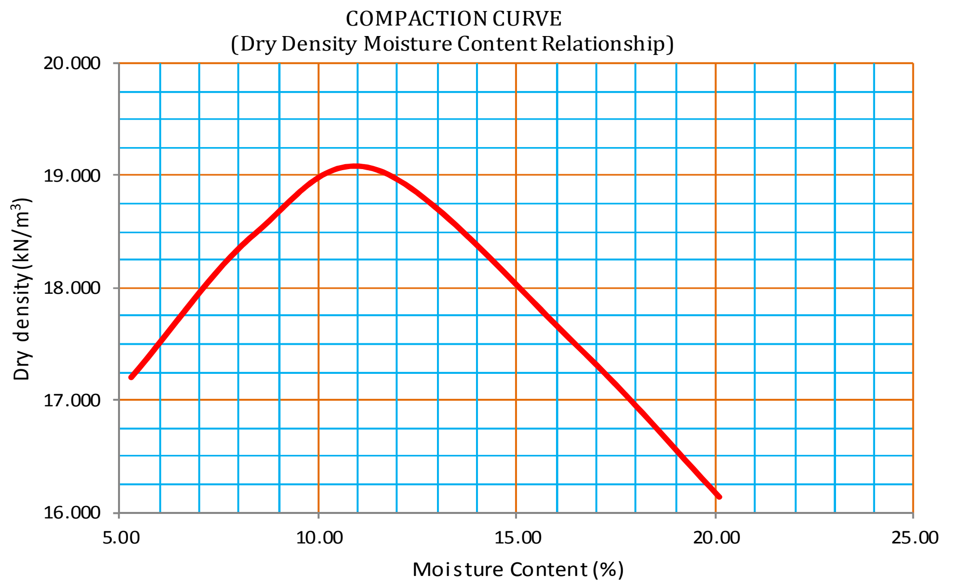
Mould dimmensions: Diameter 0.102m Hight 0.117m Volume 9.56x10^{-4}m^{3}

Water Content determination

Test No	1	2	3	4	5
Moisture Can No	F	G	B	C	D
Mass of can +Wet soil	78.00	69.10	83	80.70	89.20
Mass of can + dry soil	74.90	65.00	76.1	71.60	77.00
Mass of water (gm)	3.10	4.10	6.90	9.10	12.20
Mass of can (gm)	16.30	16.10	16.1	16.40	16.30
Mass of dry soil (gm)	58.60	48.90	60.00	55.20	60.70
water content(%)	5.29	8.38	11.50	16.49	20.10

Dry density determination

Assumed water content (%)	6	8	10	12	
Mass of Mould + Wet Soil (gm)	3479.5	3662.2	3778.3	3696.1	3600.7
Mass of Mould(gms)	1748.0	1748.0	1748.0	1748.0	1748.0
Mass of soil sample(kg)	1.7315	1.9142	2.0303	1.9481	1.8527
Bulk Density(kN/m^3)	18.112	20.023	21.237	20.378	19.380
Dry Density (kN/m^3)	17.202	18.474	19.047	17.494	16.136



Optimum Moisture Content 11.00 (%) Maximum dry density 19.063 (kN/m^3)

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

COMPACTION TEST (Heavy)

TEST METHOD: CML TEST 1.9, ref BS 1377:Part4:1990

Project : ………………………………………………………………………………………

Description of Soil:…5.5% molasses added

Location: ……………………………………………………………………………………

Test Performed By:……Dotto & Mwanga E.W…… **Date Of test:** ………………………………

No of Blows:27 No of Layers 5 Masss of Rammer 4.5Kg

Mould dimmensions: Diameter 0.102m Hight 0.117m Volume 9.56x10^{-4}m^3

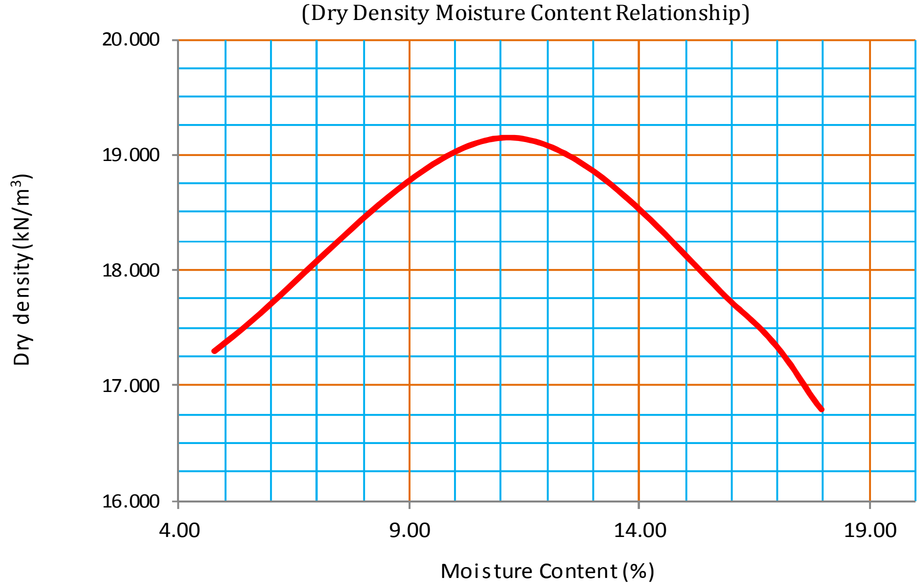
Water Content determination

Test No	1	2	3	4	5
Moisture Can No	2A	2B	1C	9D	
Mass of can +Wet soil	91.10	61.14	79.2	91.30	
Mass of can + dry soil	87.70	56.70	70.4	79.90	
Mass of water (gm)	3.40	4.44	8.76	11.40	
Mass of can (gm)	16.40	16.40	16.4	16.40	
Mass of dry soil (gm)	71.30	40.30	54.00	63.50	
water content(%)	4.77	11.02	16.22	17.95	

Dry density determination

Assumed water content (%)	6	8	10	12	
Mass of Mould + Wet Soil (gm)	3480.5	3780	3708.1	3641.5	
Mass of Mould(gms)	1748.0	1748.0	1748.0	1748.0	
Mass of soil sample(kg)	1.7325	2.032	1.9601	1.8935	
Bulk Density(kN/m^3)	18.122	21.255	20.503	19.806	
Dry Density (kN/m^3)	17.298	19.146	17.641	16.792	

COMPACTION CURVE
(Dry Density Moisture Content Relationship)



Optimum Moisture Content 11.02 (%) Maximum dry density 19.15(kN/m^3)

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

COMPACTION TEST (Heavy)

TEST METHOD: CML TEST 1.9, ref BS 1377:Part4:1990

Project : ……………………………………………………………………………………….

Description of Soil:…6.0% molasses added

Location: ……………………………………………………………………………………

Test Performed By:……Dotto & Mwanga E.W…… **Date Of test:** ………………………………

No of Blows:27 No of Layers 5 Masss of Rammer 4.5Kg

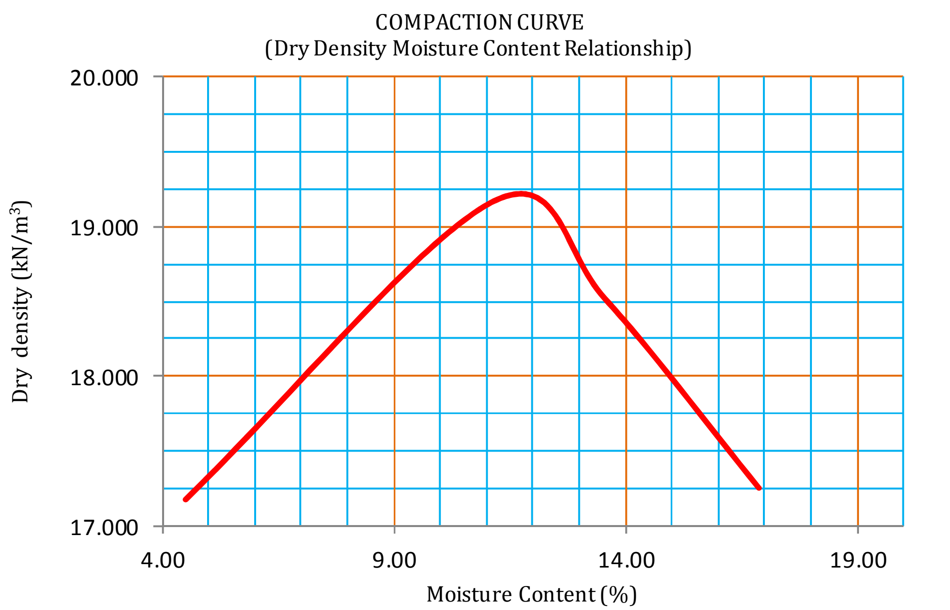
Mould dimmensions: Diameter 0.102m Hight 0.117m Volume 9.56x10^{-4}m^3

Water Content determination

Test No	1	2	3	4	5
Moisture Can No	6A	6B	6C	6D	
Mass of can +Wet soil	74.10	78.00	82.6	80.70	
Mass of can + dry soil	71.60	71.80	74.7	71.40	
Mass of water (gm)	2.50	6.20	7.90	9.30	
Mass of can (gm)	16.10	16.30	16.4	16.30	
Mass of dry soil (gm)	55.50	55.50	58.30	55.10	
water content(%)	4.50	11.17	13.55	16.88	

Dry density determination

Assumed water content (%)	6	8	10	12	
Mass of Mould + Wet Soil (gm)	3464.2	3785.5	3758.4	3676.0	
Mass of Mould(gms)	1748.0	1748.0	1748.0	1748.0	
Mass of soil sample(kg)	1.7162	2.0375	2.0104	1.928	
Bulk Density(kN/m^3)	17.952	21.313	21.029	20.167	
Dry Density (kN/m^3)	17.178	19.171	18.520	17.255	



Optimum Moisture Content 11.80 (%) Maximum dry density 19.25 (kN/m^3)

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

COMPACTION TEST (Heavy)

TEST METHOD: CML TEST 1.9, ref BS 1377:Part4:1990

Project : ……………………………………………………………………………………....……….....…..

Description of Soil:…6.5% molasses added

Location: ……………………………………………………………………………………………..…..

Test Performed By:……Dotto & Mwanga E.W…… **Date Of test:** ………………………………

No of Blows:27 No of Layers 5 Masss of Rammer 4.5Kg

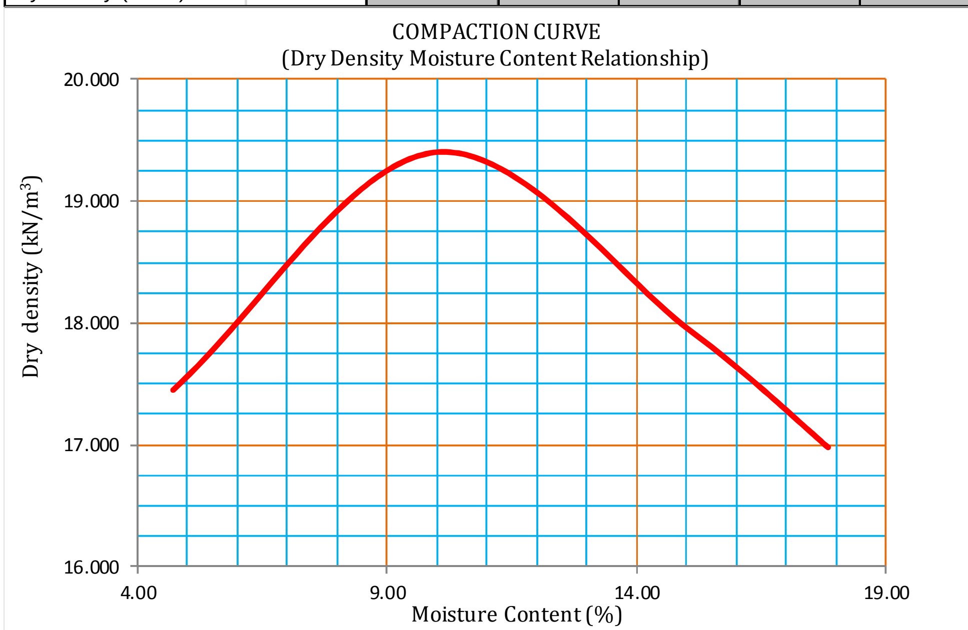
Mould dimmensions: Diameter 0.102m Hight 0.117m Volume 9.56x10^{-4}m^3

Water Content determination

Test No	1	2	3	4	5
Moisture Can No	7A	7B	7C	7D	
Mass of can +Wet soil	71.80	59.40	87.5	86.30	
Mass of can + dry soil	69.30	55.50	78.2	75.70	
Mass of water (gm)	2.50	3.90	9.30	10.60	
Mass of can (gm)	16.30	16.30	16.3	16.30	
Mass of dry soil (gm)	53.00	39.20	61.90	59.40	
water content(%)	4.72	9.95	15.02	17.85	

Dry density determination

Assumed water content (%)	6	8	10	12	
Mass of Mould + Wet Soil (gm)	3495.0	3787.2	3722.6	3661.0	
Mass of Mould(gms)	1748.0	1748.0	1748.0	1748.0	
Mass of soil sample(kg)	1.747	2.0392	1.9746	1.913	
Bulk Density(kN/m^3)	18.274	21.331	20.655	20.010	
Dry Density (kN/m^3)	17.451	19.400	17.957	16.980	



Optimum Moisture Content 10.00 (%) Maximum dry density 19.40 (kN/m^3)

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

COMPACTION TEST (Heavy)

TEST METHOD: CML TEST 1.9, ref BS 1377:Part4:1990

Project : ……………………………………………………………………………………….………...……….

Description of Soil:…7.0% molasses added

Location: ……………………………………………………………………………………………………….

Test Performed By:……Dotto & Mwanga E.W…… **Date Of test:** ……………………………….

No of Blows:27 No of Layers 5 Masss of Rammer 4.5Kg

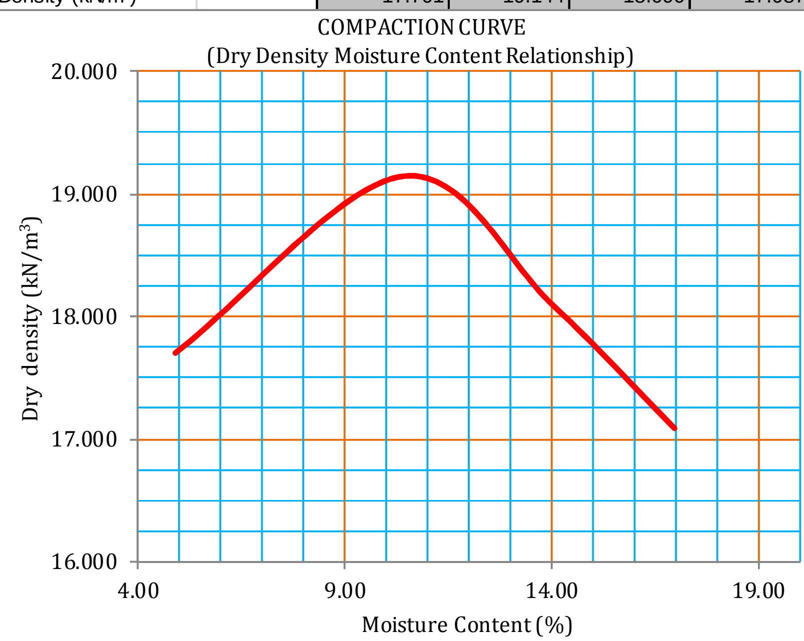
Mould dimmensions: Diameter 0.102m Hight 0.117m Volume 9.56x10^{-4}m^3

Water Content determination

Test No	1	2	3	4	5
Moisture Can No	8A	8B	8C	8D	
Mass of can +Wet soil	78.00	53.40	83.8	97.70	
Mass of can + dry soil	75.10	49.90	75.5	85.90	
Mass of water (gm)	2.90	3.50	8.30	11.80	
Mass of can (gm)	16.10	16.30	16.30	16.40	
Mass of dry soil (gm)	59.00	33.60	59.20	69.50	
water content(%)	4.92	10.42	14.02	16.98	

Dry density determination

Assumed water content (%)	6	8	10	12	
Mass of Mould + Wet Soil (gm)	3523.4	3768.8	3720.8	3658.9	
Mass of Mould(gms)	1748.0	1748.0	1748.0	1748.0	
Mass of soil sample(kg)	1.7754	2.0208	1.9728	1.9109	
Bulk Density(kN/m³)	18.571	21.138	20.636	19.988	
Dry Density (kN/m³)	17.701	19.144	18.099	17.087	



Optimum Moisture Content 10.50 (%) Maximum dry density 19.16 (kN/m³)

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

COMPACTION TEST (Heavy)

TEST METHOD: CML TEST 1.9, ref BS 1377:Part4:1990

Project : ………………………………………………………………………………………….

Description of Soil:…7.5% molasses added

Location: ………………………………………………………………………………………….

Test Performed By:……Dotto & Mwanga E.W…… **Date Of test:** ………………………………

No of Blows:27 No of Layers 5 Masss of Rammer 4.5Kg

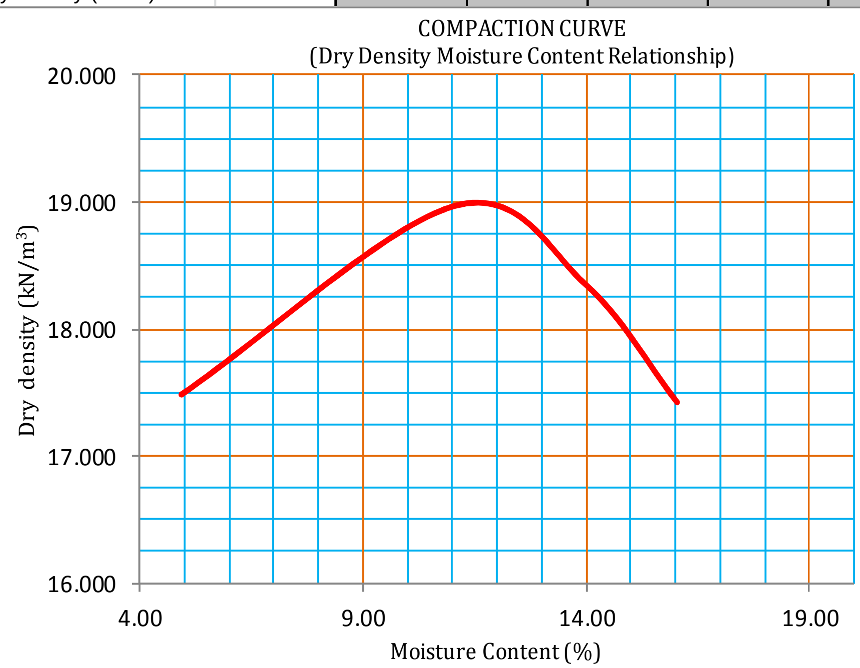
Mould dimmensions: Diameter 0.102m Hight 0.117m Volume $9.56x10^{-4}m^3$

Water Content determination

Test No	1	2	3	4	5
Moisture Can No	9A	9B	9C	9D	
Mass of can +Wet soil	65.20	62.50	81.3	77.60	
Mass of can + dry soil	62.90	57.90	73.3	69.10	
Mass of water (gm)	2.30	4.60	8.00	8.50	
Mass of can (gm)	16.30	16.30	16.10	16.10	
Mass of dry soil (gm)	46.60	41.60	57.20	53.00	
water content(%)	4.94	11.06	13.99	16.04	

Dry density determination

Assumed water content (%)	6	8	10	12	
Mass of Mould + Wet Soil (gm)	3502.0	3762.0	3747.7	3680.8	
Mass of Mould(gms)	1748.0	1748.0	1748.0	1748.0	
Mass of soil sample(kg)	1.754	2.014	1.9997	1.9328	
Bulk Density(kN/m^3)	18.347	21.067	20.917	20.218	
Dry Density (kN/m^3)	17.484	18.969	18.351	17.423	



Optimum Moisture Content 11.50 (%) Maximum dry density 19.00 (kN/m^3)

APPENDIX C - PERMEABILITY TEST

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ………………………………………………………………Stabilization of Silt Clay soil using Molasses

Description of Soil:………………………………………No Molasses added……………………..…….……….

Location: ………..

Test Performed By:…………………………*Dotto and Mwanga E.W* **Date Of test**: …………….....29/11/2013

A: Diameter of stand pipe……………... 5.50mm **B:** Cross section area of stand pipe ………......23.76mm^2

C: Diameter of Permeameter cell …....…101.30mm **D**: Cross section area of Permeameter cell ..…8,059.50mm^2

E: Length of sample …………………124.00mm **F:** Volume of permeameter …...…………..999.378cm^3

G: Average test temperature…………………... **H:** Specific gravity of soil particles (G)………………..…2.612

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	2		
Weight of can + wet soil (gms)	538.41		
Weight of can (gms)	97.38		
Weight of can + dry soil (gms)	458.23		
Weight of dry soil (gms)	360.85		
Weight of water (gms)	80.18		
Water content (%)	22.22		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	2,988.10		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	1,924.30		
Bulk density (gms/cm^3)	1.925		
Dry density (gms/cm^3) ………….. γ	1.575		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil $(e) = \left[\frac{H - \gamma}{\gamma}\right]$	0.658		
Porosity of the soil $(n) = \left[\frac{e}{1+e}\right]$	0.397		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	29/11/2013	
I. Final head of soil sample (cm) ………H_2	17.10	29/11/2013	
J. Starting time (T_1)	13:24	29/11/2013	
K. Finishing time (T_2)	16:21	29/11/2013	
L. Time duration (T_1 - T_2) in sec	10,651	29/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B*E}{D*L}\right] * \ln\left[\frac{H_1}{H_2}\right]$	6.062E-05	29/11/2013	

Average coefficient of permeability of soil	6.062×10^{-5}	mm/sec

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ……………………………………………………………….Stabilization of Silt Clay soil using Molasses

Description of Soil:……………………………………….5% Molasses added..………………….………..……….

Location: ……..

Test Performed By:………………………….*Dotto and Mwanga E.W* **Date Of test:** …………….....26/11/2013

A: Diameter of stand pipe……………... 5.50mm **B:** Cross section area of stand pipe ………....23.76mm^2

C: Diameter of Permeameter cell …....…101.30mm **D**: Cross section area of Permeameter cell ..…8,059.50mm^2

E: Length of sample …………………124.00mm **F:** Volume of permeameter …....………..999.378cm^3

G: Average test temperature…………………... **H:** Specific gravity of soil particles (G)………………..2.597

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	BB		
Weight of can + wet soil (gms)	226.72		
Weight of can (gms)	45.6		
Weight of can + dry soil (gms)	199.63		
Weight of dry soil (gms)	154.03		
Weight of water (gms)	27.09		
Water content (%)	17.59		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	2,949.80		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	1,886.00		
Bulk density (gms/cm^3)	1.887		
Dry density (gms/cm^3) …………. γ	1.605		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil $(e) = \left[\frac{H - \gamma}{\gamma}\right]$	0.618		
Porosity of the soil $(n) = \left[\frac{e}{1+e}\right]$	0.382		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	26/11/2013	
I.Final head of soil sample (cm) ………H_2	28.21	26/11/2013	
J. Starting time (T_1)	14:05	26/11/2013	
K. Finishing time (T_2)	16:53	26/11/2013	
L. Time duration (T_1 - T_2) in sec	10,131	26/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B \times E}{D \times L}\right] \times \ln\left[\frac{H_1}{H_2}\right]$	4.566E-05	26/11/2013	

Average coefficient of permeability of soil	4.566×10^{-5}	mm/sec

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ……………………………………………………………Stabilization of Silt Clay soil using Molasses

Description of Soil:……………………………………5.5% Molasses added…………………………………………

Location: ………

Test Performed By:………………………… *Dotto and Mwanga E.W* **Date Of test:** ……………...27/11/2013

A: Diameter of stand pipe……………... 5.50mm **B:** Cross section area of stand pipe ……..…...23.76mm²

C: Diameter of Permeameter cell …...…101.30mm **D:** Cross section area of Permeameter cell …..8,059.50mm²

E: Length of sample …………………124.00mm **F:** Volume of permeameter ……..………..999.378cm³

G: Average test temperature…………………... **H:** Specific gravity of soil particles (G)…………………2.570

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	Q		
Weight of can + wet soil (gms)	389.03		
Weight of can (gms)	75.19		
Weight of can + dry soil (gms)	343.3		
Weight of dry soil (gms)	268.11		
Weight of water (gms)	45.73		
Water content (%)	17.06		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	3,059.70		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	1,995.90		
Bulk density (gms/cm³)	1.997		
Dry density (gms/cm³) ………….. γ	1.706		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil $(e) = \left[\frac{H - \gamma}{\gamma}\right]$	0.506		
Porosity of the soil $(n) = \left[\frac{e}{1+e}\right]$	0.336		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	27/11/2013	
I.Final head of soil sample (cm) ………H_2	29.00	27/11/2013	
J. Starting time (T_1)	9:18	27/11/2013	
K. Finishing time (T_2)	13:23	27/11/2013	
L. Time duration (T_1 - T_2) in sec	14,742	27/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B * E}{D * L}\right] * \ln\left[\frac{H_1}{H_2}\right]$	3.070E-05	27/11/2013	

Average coefficient of permeability of soil 3.070 x 10^{-5} mm/sec

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ……………………………………………………………….Stabilization of Silt Clay soil using Molasses

Description of Soil:……………………………………..6.0% Molasses added..………………..……..………

Location: ……………………………………………………………………………………………………..

Test Performed By:………………………….*Dotto and Mwanga E.W* **Date Of test:** ……………....27/11/2013

A: Diameter of stand pipe…………….. 5.50mm **B:** Cross section area of stand pipe ……..….23.76mm^2

C: Diameter of Permeameter cell ….….101.30mm **D:** Cross section area of Permeameter cell ..…8,059.50mm^2

E: Length of sample ……………….…124.00mm **F:** Volume of permeameter …..…………..999.378cm^3

G: Average test temperature…………………... **H:** Specific gravity of soil particles (G)…………………2.528

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	275		
Weight of can + wet soil (gms)	411.3		
Weight of can (gms)	167.52		
Weight of can + dry soil (gms)	370.63		
Weight of dry soil (gms)	203.11		
Weight of water (gms)	40.67		
Water content (%)	20.02		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	3,100.60		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	2,036.80		
Bulk density (gms/cm^3)	2.038		
Dry density (gms/cm^3) …………. γ	1.698		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil $(e) = \left[\frac{H - \gamma}{\gamma}\right]$	0.489		
Porosity of the soil $(n) = \left[\frac{e}{1+e}\right]$	0.328		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	27/11/2013	
I.Final head of soil sample (cm) ………H_2	48.30	27/11/2013	
J. Starting time (T_1)	15:04	27/11/2013	
K. Finishing time (T_2)	18:34	27/11/2013	
L. Time duration (T_1 - T_2) in sec	12,641	27/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B \times E}{D \times L}\right] \times \ln\left[\frac{H_1}{H_2}\right]$	2.105E-05	27/11/2013	

Average coefficient of permeability of soil	2.105×10^{-5}	mm/sec

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ……………………………………………………………Stabilization of Silt Clay soil using Molasses

Description of Soil:…………………………………….6.5% Molasses added..…………………..………..………..

Location: ………..

Test Performed By:…………………………*Dotto and Mwanga E.W* **Date Of test:** …………....…28/11/2013

A: Diameter of stand pipe……………... 5.50mm **B:** Cross section area of stand pipe ……..…....23.76mm^2

C: Diameter of Permeameter cell …...…101.30mm **D**: Cross section area of Permeameter cell …..8,059.50mm^2

E: Length of sample …………………124.00mm **F:** Volume of permeameter …...………..999.378cm^3

G: Average test temperature…………………... **H**: Specific gravity of soil particles (G)………………..…2.509

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	17		
Weight of can + wet soil (gms)	415.37		
Weight of can (gms)	57.4		
Weight of can + dry soil (gms)	358.48		
Weight of dry soil (gms)	301.08		
Weight of water (gms)	56.89		
Water content (%)	18.90		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	3,065.10		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	2,001.30		
Bulk density (gms/cm^3)	2.003		
Dry density (gms/cm^3) ………….. γ	1.684		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil $(e) = \left[\frac{H - \gamma}{\gamma}\right]$	0.490		
Porosity of the soil $(n) = \left[\frac{e}{1+e}\right]$	0.329		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	28/11/2013	
I.Final head of soil sample (cm) ………H_2	58.70	28/11/2013	
J. Starting time (T_1)	16:05	28/11/2013	
K. Finishing time (T_2)	18:19	28/11/2013	
L. Time duration (T_1 - T_2) in sec	8,070	28/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B \cdot E}{D \cdot L}\right] \cdot \ln\left[\frac{H_1}{H_2}\right]$	2.413E-05	28/11/2013	

Average coefficient of permeability of soil	2.413×10^{-5}	mm/sec

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ……………………………………………………………Stabilization of Silt Clay soil using Molasses

Description of Soil:……………………………………7.0% Molasses added………………………………………

Location: ………………………………………………………………………………………………………

Test Performed By:…………………………*Dotto and Mwanga E.W* **Date Of test:** ……………....30/11/2013

A: Diameter of stand pipe……………... 5.50mm **B:** Cross section area of stand pipe ……..…...23.76mm^2

C: Diameter of Permeameter cell …...…101.30mm **D**: Cross section area of Permeameter cell …..8,059.50mm^2

E: Length of sample …………………124.00mm **F:** Volume of permeameter …...…………..999.378cm^3

G: Average test temperature…………………... **H:** Specific gravity of soil particles (G)………………..…2.537

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	3		
Weight of can + wet soil (gms)	514.30		
Weight of can (gms)	98.56		
Weight of can + dry soil (gms)	458.51		
Weight of dry soil (gms)	359.95		
Weight of water (gms)	55.79		
Water content (%)	15.50		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	3,006.10		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	1,942.30		
Bulk density (gms/cm^3)	1.944		
Dry density (gms/cm^3) …………. γ	1.683		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil $(e) = \left[\frac{H - \gamma}{\gamma}\right]$	0.508		
Porosity of the soil $(n) = \left[\frac{e}{1+e}\right]$	0.337		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	30/11/2013	
I.Final head of soil sample (cm) ………H_2	45.20	30/11/2013	
J. Starting time (T_1)	13:12	30/11/2013	
K. Finishing time (T_2)	16:22	30/11/2013	
L. Time duration (T_1 - T_2) in sec	11,342	30/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B*E}{D*L}\right] * \ln\left[\frac{H_1}{H_2}\right]$	2.559E-05	30/11/2013	

Average coefficient of permeability of soil 2.559 x 10^{-5} mm/sec

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

PERMEABILITY TEST

(FALLING HEAD PERMEAMETER)

Project : ……………………………………………………………Stabilization of Silt Clay soil using Molasses

Description of Soil:…………………………………..7.5% Molasses added..……………………..……………….

Location: ………………………………………………………………………………………………………..

Test Performed By:………………………..*Dotto and Mwanga E.W* **Date Of test**: ……………..29/11/2013

A: Diameter of stand pipe…………….. 5.50mm **B:** Cross section area of stand pipe ……….....23.76mm^2

C: Diameter of Permeameter cell …...…101.30mm **D:** Cross section area of Permeameter cell …..8,059.50mm^2

E: Length of sample ………………..124.00mm **F:** Volume of permeameter …...………..999.378cm^3

G: Average test temperature………………….. **H:** Specific gravity of soil particles (G)……………..….2.567

MOISTURE CONTENT AT THE END OF THE TEST

Test No.	1	2	Remarks
Can No.	576		
Weight of can + wet soil (gms)	393.00		
Weight of can (gms)	54.9		
Weight of can + dry soil (gms)	338.98		
Weight of dry soil (gms)	284.08		
Weight of water (gms)	54.02		
Water content (%)	19.02		

BULK DENSITY AND DRY DENSITY

Test No.	1	2	Remarks
Weight of cell+wet soil+filter paper (gms)	3,073.50		
Weight of cell (gms)	1,063.80		
Weight of filter paper (gms)			
Weight of wet soil (gms)	2,009.70		
Bulk density (gms/cm^3)	2.011		
Dry density (gms/cm^3) …………. γ	1.690		

POROSITY AND VOID RATIO

Property	1	2	Remarks
Void ratio of the soil (e) = $\left[\frac{H - \gamma}{\gamma}\right]$	0.519		
Porosity of the soil (n) = $\left[\frac{e}{1+e}\right]$	0.342		

COEFFICIENT OF PERMEABILITY

G. Test No.	1	Date	2
H. Initial head of soil sample (cm) …….H_1	100.00	29/11/2013	
I.Final head of soil sample (cm) ………H_2	43.00	29/11/2013	
J. Starting time (T_1)	9:48	29/11/2013	
K. Finishing time (T_2)	12:38	29/11/2013	
L. Time duration (T_1 - T_2) in sec	10,202	29/11/2013	
M. Coefficient of permeability (mm/sec.) $K = \left[\frac{B*E}{D*L}\right] * \ln\left[\frac{H_1}{H_2}\right]$	3.024E-05	29/11/2013	

Average coefficient of permeability of soil	3.024×10^{-5}	mm/sec

APPENDIX D - SPECIFIC GRAVITY TEST

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ……………………………………………………………....Stabilization of Silt Clay soil using Molasses

Description of Soil:…………………………………….No Molasses added..………………….……..…………..

Location: ………………………………………………………………………………………

Test Performed By:………………………..*Dotto and Mwanga E.W* **Date Of test:** ………………30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	7	10	12
3	Volume of pynometer ar 20^oC (cm^3)	50	50	50
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	29.14	26.65	26.26
6	Mass of pynometer + water (gms)	78.85	76.7	76.35
7	Temperature ^oC	20	20	20
8	Mass of pynometer + water +soil (gms)	83.38	81.29	80.85
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	28.09	28.14	28.06
12	Mass of oven dry soil (gms) $\mathbf{M_S}$ **= No.11 - No.10**	7.35	7.40	7.32
13	Mass of water equal to the volume of soil solids Mw =No.12 + No.6 – No.8	2.82	2.81	2.82
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.606	2.633	2.596

Note : α = (Density of water at temperature "t")/Density of water at 20^0C

Specific gravity of the soil is ………………………………… **2.612**

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ……………………………………………………………...Stabilization of Silt Clay soil using Molasses

Description of Soil:…………………………………….5.0% Molasses added..…………………..……..………..

Location: ……………………………………………………………………………………

Test Performed By:………………………..*Dotto and Mwanga E.W* **Date Of test:** ……………..30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	5	6	11
3	Volume of pynometer ar 20^{o}C (cm^{3})	50	50	50
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	29.06	28.88	24.86
6	Mass of pynometer + water (gms)	79.03	79.05	74.52
7	Temperature ^{o}C	20	20	20
8	Mass of pynometer + water +soil (gms)	82.76	82.9	78.41
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	26.94	27.00	26.94
12	Mass of oven dry soil (gms) **M_S = No.11 - No.10**	6.20	6.26	6.20
13	Mass of water equal to the volume of soil solids **Mw** =No.12 + No.6 – No.8	2.47	2.41	2.31
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.510	2.598	2.684

Note : α = (Density of water at tempera ture "t")/Density of water at 20^{0}C

Specific gravity of the soil is …………………………………… **2.597**

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ……………………………………………………………....Stabilization of Silt Clay soil using Molasses

Description of Soil:……………………………………..5.5% Molasses added..……………………..………..…………..

Location: ……………………………………………………………………………………………

Test Performed By:………………………...*Dotto and Mwanga E.W* **Date Of test**: ………………30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	11	12	10
3	Volume of pynometer ar 20°C (cm^3)	50	50	50
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	24.85	26.23	26.82
6	Mass of pynometer + water (gms)	74.57	76.43	76.81
7	Temperature °C	20	20	20
8	Mass of pynometer + water +soil (gms)	79.24	81.22	81.43
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	28.35	28.56	28.36
12	Mass of oven dry soil (gms) **M_S = No.11 - No.10**	7.61	7.82	7.62
13	Mass of water equal to the volume of soil solids **Mw** =No.12 + No.6 – No.8	2.94	3.03	3
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.588	2.581	2.540

Note : α = (Density of water at temperature "t")/Density of water at 20 °C

Specific gravity of the soil is ………………………………………… **2.570**

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ……………………………………………………………....Stabilization of Silt Clay soil using Molasses

Description of Soil:……………………………………..6.0% Molasses added..………………..………..……….…

Location: …………………………………………………………………………………………

Test Performed By:……………………….*Dotto and Mwanga E.W* **Date Of test:** ………………30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	9	85	46
3	Volume of pynometer ar 20^{o}C (cm^3)	25	25	25
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	19.29	19.92	19.62
6	Mass of pynometer + water (gms)	44.16	44.74	44.45
7	Temperature ^{o}C	20	20	20
8	Mass of pynometer + water +soil (gms)	47.49	48.03	47.76
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	26.28	26.18	26.19
12	Mass of oven dry soil (gms) **M_S = No.11 - No.10**	5.54	5.44	5.45
13	Mass of water equal to the volume of soil solids **Mw** =No.12 + No.6 – No.8	2.21	2.15	2.14
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.507	2.530	2.547

Note : α = (Density of water at tempera ture " t")/Density of water at 20^{0}C

Specific gravity of the soil is ………………………………………… **2.528**

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ………………………………………………………….....Stabilization of Silt Clay soil using Molasses

Description of Soil:…………………………………….6.5% Molasses added..…………………..……..…………..

Location: ……………………………………………………………………………………

Test Performed By:……………………...*Dotto and Mwanga E.W* **Date Of test:** ……………..30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	9	46	85
3	Volume of pynometer ar 20°C (cm³)	25	25	25
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	19.31	19.62	19.92
6	Mass of pynometer + water (gms)	44.11	44.41	44.7
7	Temperature °C	20	20	20
8	Mass of pynometer + water +soil (gms)	47.31	47.67	47.90
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	25.99	26.08	26.23
12	Mass of oven dry soil (gms) **M_S = No.11 - No.10**	5.25	5.34	5.49
13	Mass of water equal to the volume of soil solids **Mw** =No.12 + No.6 – No.8	2.05	2.08	2.29
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.561	2.567	2.397

Note : α = (Density of water at temperature "t")/Density of water at 20^0C

Specific gravity of the soil is ………………………………………… **2.509**

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ……………………………………………………………....Stabilization of Silt Clay soil using Molasses

Description of Soil:………………………………………7.0% Molasses added..…………………..………..…………...

Location: ………………………………………………………………………………………

Test Performed By:………………………...*Dotto and Mwanga E.W* **Date Of test:** ………………30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	7	6	5
3	Volume of pynometer ar 20°C (cm^3)	50	50	50
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	29.13	28.91	29.02
6	Mass of pynometer + water (gms)	78.94	79.15	79.12
7	Temperature °C	20	20	20
8	Mass of pynometer + water +soil (gms)	83.82	83.91	84.35
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	28.68	28.78	29.31
12	Mass of oven dry soil (gms) **M_S = No.11 - No.10**	7.94	8.04	8.57
13	Mass of water equal to the volume of soil solids **Mw** =No.12 + No.6 – No.8	3.06	3.28	3.34
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.595	2.451	2.566

Note : α = (Density of water at tempera ture "t")/Density of water at 20 ^{0}C

Specific gravity of the soil is ……………………………………… **2.537**

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

SPECIFIC GRAVITY TEST

TEST METHOD: CML TEST 1.5, ref BS 1377:Part2:1990

Project : ……………………………………………………………....Stabilization of Silt Clay soil using Molasses

Description of Soil:…………………………………….7.5% Molasses added……………………..……..…………...

Location: ………………………………………………………………………………………

Test Performed By:………………………..*Dotto and Mwanga E.W* **Date Of test:** ………………..30/11/2013

1	**Test No.**	**1**	**2**	**3**
2	Pynometer No.	7	6	11
3	Volume of pynometer ar 20°C (cm^3)	50	50	50
4	Method of air removal	Vaccum	Vaccum	Vaccum
5	Mass of empty pynometer (gms)	29.06	28.88	24.86
6	Mass of pynometer + water (gms)	79.03	79.05	74.52
7	Temperature °C	20	20	20
8	Mass of pynometer + water +soil (gms)	82.86	82.95	78.40
9	Evaporation dish No.	KY	KY	KY
10	Mass of evaporation dish (gms)	20.74	20.74	20.74
11	Mass of evaporation dish + dry soil (gms)	27.04	27.09	27.11
12	Mass of oven dry soil (gms) **M_S = No.11 - No.10**	6.30	6.35	6.37
13	Mass of water equal to the volume of soil solids **Mw** =No.12 + No.6 – No.8	2.47	2.45	2.49
14	Temperature correction factor (α)	1.000	1.000	1.000
15	Specific gravity of soil solids (Gs) $Gs = \left[\alpha \frac{Ms}{Mw}\right]$	2.551	2.592	2.558

Note : α = (Density of water at temperature "t")/Density of water at 20^0C

Specific gravity of the soil is ……………………………………… **2.567**

APPENDIX E - VISCOSITY TEST

TECHNICAL COLLEGE ARUSHA

SOILS & BITUMEN LABORATORY

VISCOSITY TEST

(Original Molasses from TPC -Moshi - Tanzania)

Project : ……………………………………………………………………………….Stabilization of Silt Clay soil using Molasses

Description of Material:……………………………………………..Molasses…………………………………………………………

Location: ……………………………………………………………………………………………………

Test Performed By:…………………………………..*Dotto and Mwanga E.W* **Date Of test:** …………… …30/11/2013

Orifice diameter of Viscometer (test Cup) ………4mm

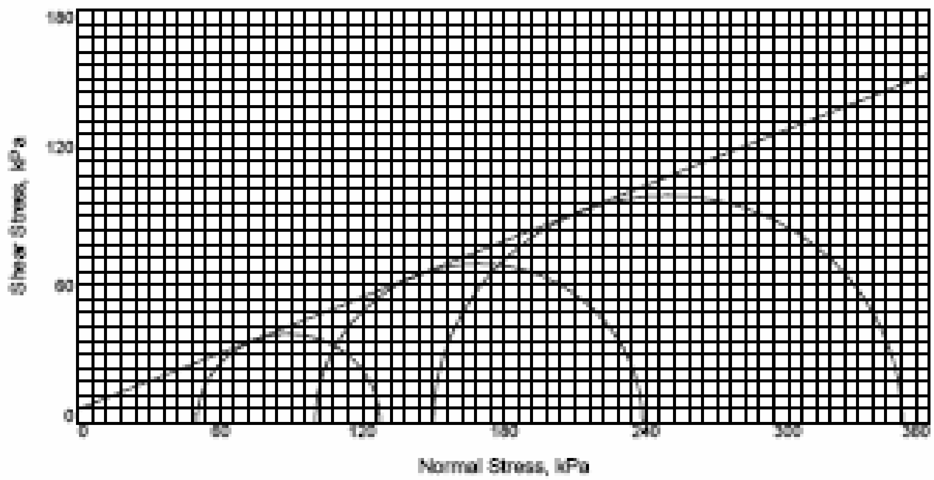
1	**Test No.**	**1**	**2**	**3**
2	Temperature ^{o}C	27.00	27.00	
3	Volume of molasses collected (cm^3)	50.00	50.00	
4	Height of molasses in measuring cylinder (cm)	5.00	5.00	
5	Cross section area of measuring cylinder (cm^2)	10.00	10.00	
6	Time of flow to fill 50cm^3 measuring cylinder (sec)	343.00	349.00	
9	Kinematic viscosity (m^2/sec)	0.000002915	0.000002865	
10	**Average kinematic viscosity (m^2/sec)**	**2.890 x10^{-6}**		

DETERMINATION OF DENSITY OF MOLASSES

Test No.	1	2	Remarks
Weight of empty measuring cylinder (gms)	129.68		
Weight of measuring cylinder + molasses (gms)	271.19		
Weight of molasses (gms)	141.51		
Volume of molasses (cm^3)	100.00		
Density of molasses (gms/cm^3)	**1.415**		

APPENDIX F - TRIAXIAL TEST

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained **Sample Type:** UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		Principal Stresses at Failure, kPa	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	77.6	4.0			127.6	50.0
2	100.0	0.0	138.6	4.4			238.6	100.0
3	150.0	0.0	198.5	6.0			348.5	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Saturation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	23.2	1640	100.0%	0.6580	70.0	140.0	1.4
2	23.2	1640	100.0%	0.6580	71.4	134.4	1.4
3	23.2	1640	100.0%	0.6580	73.1	128.5	1.4

Mohr-Coulomb Strength Parameters

Total

Strength Intercept, c= 6.0 kPa

Friction angle, ϕ = 22.1 deg

Tangent, ϕ = 0.41

Material Description

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

TRIAXIAL SHEAR TEST REPORT

GEOPROBE ENGINEERING LIMITED

Dar Es Salaam, Tanzania

Date Sampled: 13.12.2013

File: MWANGA

Remarks:

BOREHOLE No.01

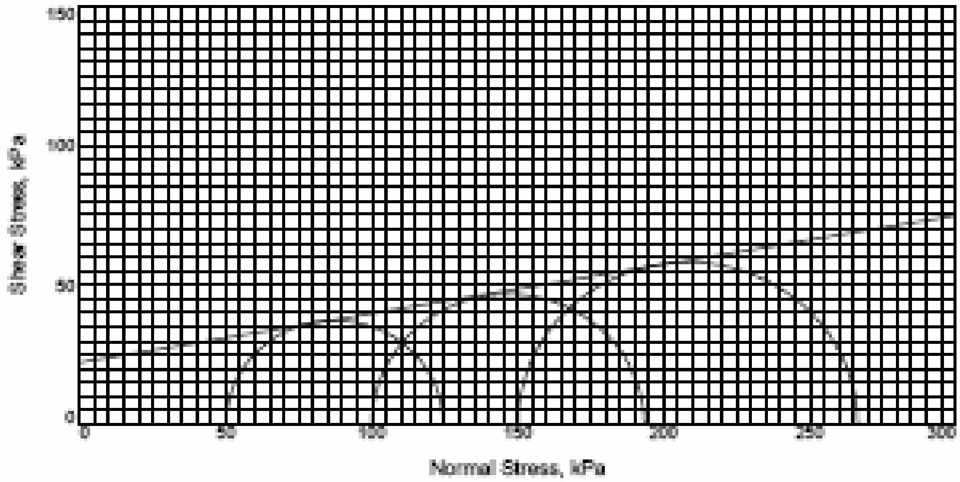
DEPTH (m): 1.5-2.5

Proj. No.: NO MOLASSES

Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained **Sample Type:** UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		Principal Stresses at Failure kPa	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	74.6	4.4			124.6	50.0
2	100.0	0.0	93.4	4.6			193.4	100.0
3	150.0	0.0	116.4	5.8			266.4	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Saturation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	20.4	1720	100.0%	0.6180	70.0	140.0	1.4
2	20.4	1720	100.0%	0.6180	71.6	133.9	1.4
3	20.4	1720	100.0%	0.6180	73.3	127.8	1.4

Mohr-Coulomb Strength Parameters		Material Description
	Total	
Strength intercept, c=	22.2 kPa	
Friction angle, ϕ =	10.0 deg	
Tangent, ϕ =	0.18	

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

Date Sampled: 13.12.2013

File: MWANGA

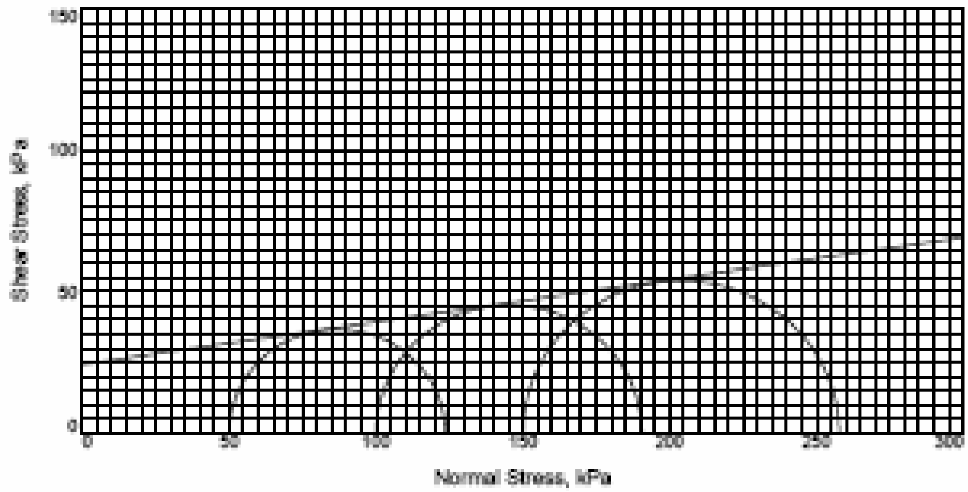
Remarks:
BOREHOLE No:1
DEPTH (m): 1.5-2.5

TRIAXIAL SHEAR TEST REPORT
GEOPROBE ENGINEERING LIMITED
Dar Es Salaam, Tanzania

Proj. No.: 5.0 % MOLASSES ADDED
Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained **Sample Type:** UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		Principal Stresses at Failure kPa	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	73.6	4.4			123.6	50.0
2	100.0	0.0	90.6	4.7			190.6	100.0
3	150.0	0.0	107.8	6.0			257.8	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Saturation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	19.5	1747	100.0%	0.5060	70.0	140.0	1.4
2	19.5	1747	100.0%	0.5060	71.6	133.9	1.4
3	19.5	1747	100.0%	0.5060	73.3	127.6	1.4

Mohr-Coulomb Strength Parameters		Material Description
	Total	
Strength intercept, c=	24.3 kPa	
Friction angle, ϕ =	8.5 deg	
Tangent, ϕ =	0.15	

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

TRIAXIAL SHEAR TEST REPORT
GEOPROBE ENGINEERING LIMITED
Dar Es Salaam, Tanzania

Date Sampled: 13.12.2013

File: MWANGA

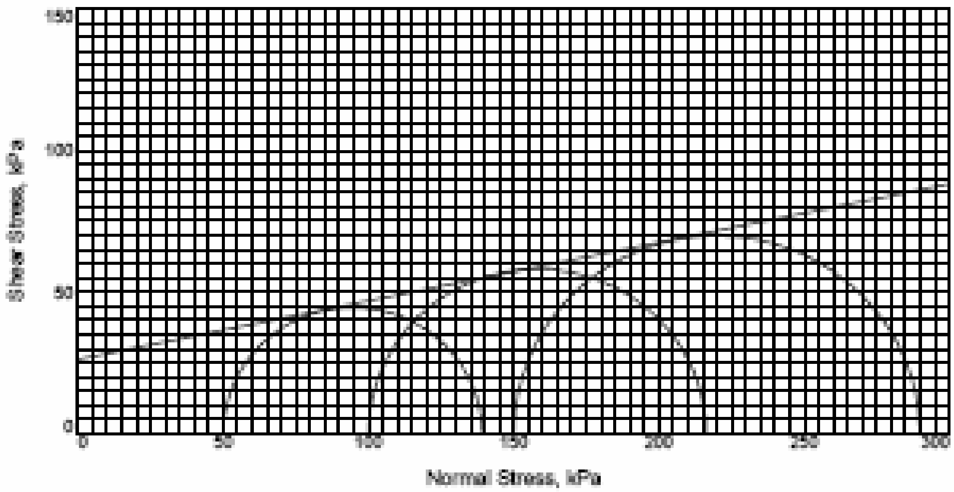
Remarks:
BOREHOLE No:1
DEPTH (m):1.5-2.5m

Proj. No.: 6.5% MOLASSES ADDED

Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained **Sample Type:** UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		Principal Stresses at Failure kPa	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	89.1	4.7			139.1	50.0
2	100.0	0.0	116.3	5.1			216.3	100.0
3	150.0	0.0	139.8	4.9			289.8	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Satur-ation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	19.3	1752	100.0%	0.4890	70.0	140.0	1.4
2	19.3	1752	100.0%	0.4890	71.7	133.4	1.4
3	19.3	1752	100.0%	0.4890	73.6	126.5	1.4

Mohr-Coulomb Strength Parameters		Material Description
	Total	
Strength intercept, c=	26.2 kPa	
Friction angle, ϕ =	11.7 deg	
Tangent, ϕ =	0.21	

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

Date Sampled: 13.12.2013

File: MWANGA

Remarks:

BOREHOLE No:1

DEPTH (m):1.5-2.5

TRIAXIAL SHEAR TEST REPORT

GEOPROBE ENGINEERING LIMITED

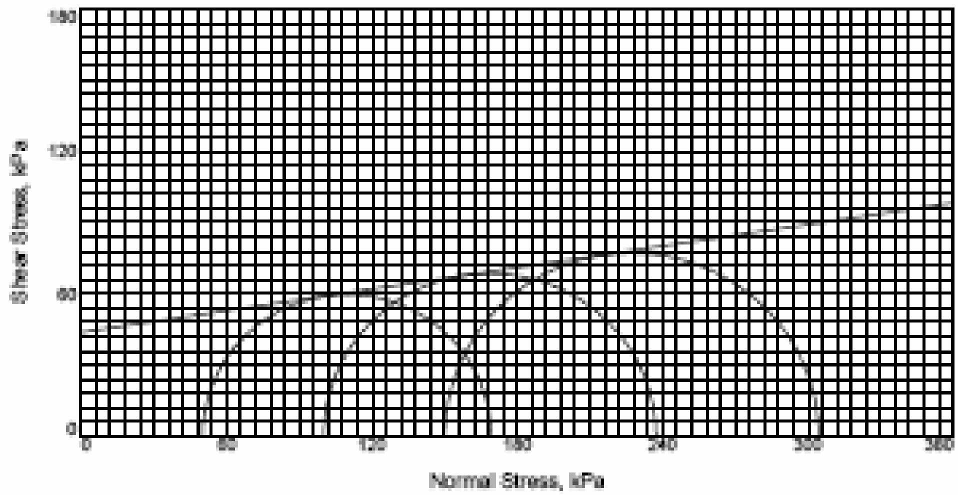
Dar Es Salaam, Tanzania

Proj. No.: 6.0% MOLASSES ADDED

Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained **Sample Type:** UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		[illegible]	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	119.3	4.4			169.3	50.0
2	100.0	0.0	137.3	5.0			237.3	100.0
3	150.0	0.0	154.5	7.2			304.5	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Saturation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	17.5	1810	100.0%	0.4900	70.0	140.0	1.4
2	17.5	1810	100.0%	0.4900	71.6	133.9	1.4
3	17.5	1810	100.0%	0.4900	73.4	127.3	1.4

Mohr-Coulomb Strength Parameters		Material Description
	Total	
Strength intercept, c=	43.8 kPa	
Friction angle, ϕ =	8.6 deg	
Tangent, ϕ =	0.15	

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

TRIAXIAL SHEAR TEST REPORT

GEOPROBE ENGINEERING LIMITED

Dar Es Salaam, Tanzania

Date Sampled: 13.12.2013

File: MWANGA

Remarks:

BOREHOLE No:1

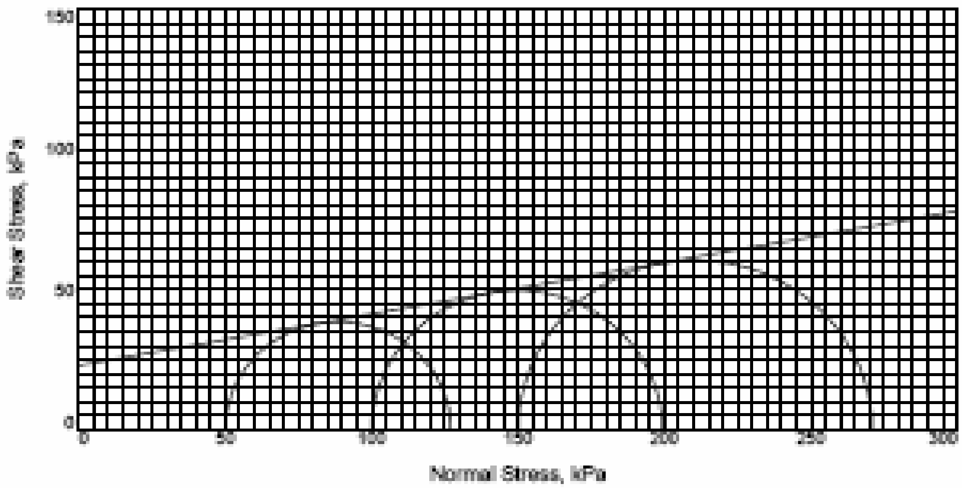
DEPTH (m): 1.5-2.5

Proj. No.: 6.5% MOLASSES ADDED

Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained **Sample Type:** UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		Principal Stresses at Failure kPa	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	77.1	4.7			127.1	50.0
2	100.0	0.0	99.3	5.3			199.3	100.0
3	150.0	0.0	121.0	5.1			271.0	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Saturation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	19.8	1737	100.0%	0.5080	70.0	140.0	1.4
2	19.8	1737	100.0%	0.5080	71.7	133.4	1.4
3	19.8	1737	100.0%	0.5080	73.7	126.3	1.4

Mohr-Coulomb Strength Parameters	Material Description
Total Strength Intercept, c= 23.0 kPa Friction angle, ϕ = 10.4 deg Tangent, ϕ = 0.18	

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

Date Sampled: 13.12.2013

File: MWANGA

Remarks:

BOREHOLE No:1

DEPTH (m): 1.5-2.5

TRIAXIAL SHEAR TEST REPORT

GEOPROBE ENGINEERING LIMITED

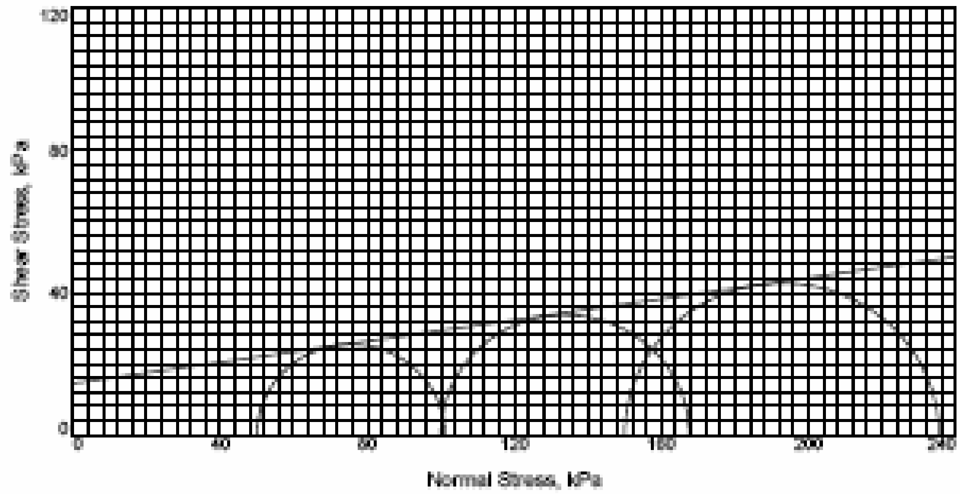
Dar Es Salaam, Tanzania

Proj. No.: 7.0% MOLASSES ADDED

Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

TRIAXIAL SHEAR TEST REPORT



Type of Test: Consolidated Undrained

Sample Type: UNSATURATED

No.	Fluid Press. kPa		Fail. Stress, kPa		Ult. Stress, kPa		Principal Stresses at Failure kPa	
	Cell	Back	Deviator	Strain, %	Deviator	Strain, %	σ_1	σ_3
1	50.0	0.0	51.1	4.7			101.1	50.0
2	100.0	0.0	67.6	4.2			167.6	100.0
3	150.0	0.0	85.5	5.7			235.5	150.0

No.	Consolidated Sample Parameters						
	% Water Content	Dry Dens. kg/m3	Saturation	Void Ratio	Diameter mm.	Height mm.	Strain Rate in/min.
1	19.9	1734	100.0%	0.5190	70.0	140.0	1.4
2	19.9	1734	100.0%	0.5190	71.7	133.4	1.4
3	19.9	1734	100.0%	0.5190	73.3	127.8	1.4

Mohr-Coulomb Strength Parameters		Material Description
	Total	
Strength Intercept, c=	14.5 kPa	
Friction angle, ϕ =	8.4 deg	
Tangent, ϕ =	0.15	

Client: RESEARCH

Project: Stabilization of Silt Clay using molasses for small earthfill dam embankment construction as inner zone

Location: GOWEKO

Sample Number: U4 **Depth:** 1.5-2.5m

TRIAXIAL SHEAR TEST REPORT

GEOPROBE ENGINEERING LIMITED

Dar Es Salaam, Tanzania

Date Sampled: 13.12.2013

File: MWANGA

Remarks:

BOREHOLE No:1

DEPTH (m): 1.5-2.5

Proj. No.:7.5% MOLASSES ADDED

Figure 1

Tested By: MWANGA E.W **Checked By:** CHARLES PETER

APPENDIX G – ABBREVIATIONS

PI	Plasticity Index
CBR	California Bearing Ratio
Psi	Pound per square inch
LL	Liquid limit
PL	Plastic limit
CML	Central material laboratory manual
Gs	Specific gravity
kPa	Kilo-newton per square meter
Pa	Newton per square meter
BS	British Standard
C	Cohesion
ϕ	Friction angle
OMC	Optimum moisture content
MDD	Maximum dry density
e	void ratio
n	porosity
CL	Clay of low plasticity
ML	Silt of low plasticity