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EXPANSIVE SOIL STABILIZATION BY SUGARE CANE MOLASSES

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CERTIFICATION

The thesis titled "Expansive Soil Stabilization by Sugar Cane Molasses" by Gadise Tesema meets the regulations governing the award of the degree of Master of Science (M.Sc.) in Civil Engineering Addis Ababa University and is approved for its contribution to knowledge and literary presentation.

Approved By the Board of Examiners

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DECLARATION

I hereby declare that the Thesis entitled *"Expansive Soil Stabilization by Sugar Cane Molasses"* has been carried out by me under the supervision of **Dr. Mesele Haile** during the year 2015 as fulfillment of Master of Science Program in Geotechnical engineering. I further declare that this work has not been submitted to any other University or institution for the award of any degree. All quotations and their sources are specifically acknowledged by means of references.

Place: Addis Ababa

Gadise Tesema

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List of Abbreviations

AASHTO	American Association Of Highway And Transportation Officials
ASTM	American Society For Testing And Materials
CBR	California Bearing Ratio
CEC	Cation Exchange Capacity
ERA	Ethiopian Roads Authority
IS	Indian Standard
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
SP	Swelling Pressure
TSA	Ton Of Sugar Per Annum
UCS	Unconfined Compressive Strength
USA	United States Of America

Units

gm	Gram
kg	Kilogram
km	Kilometer
kN	Kilo Newton
mm	Millimeter
meq	Milli equivalent
g/cm^3	Gram per centimeter cube
µm	Micrometer
kN/m^2	Kilo Newton per meter square
kPa	Kilo Pascal

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Abstract

Expansive soils are active clays that pose problem to civil engineering structures. This is caused by structural and volume instability in the soil mass due to swelling and shrinkage characteristics triggered by moisture variation. These soils are found in widespread areas in the world. Several researches have been done and various methods and techniques have been proposed and developed for stabilization of expansive soils to improve engineering properties. During construction, the removal of expansive soils and replacement with suitable fill material is an appropriate method in areas where abundant suitable fill materials are available nearby. However, at places of limited suitable fill material within economical distance and if large thickness of poor sub-grade soil to be replaced occurs, the method is not suitable. The most commonly used technique is chemical stabilization with cement and lime. These chemicals are most effective when used on site with very controlled moisture of hydration and site specific techniques. Other manufactured inorganic and organic compounds are used worldwide but most of them are not economically viable. Since most of them are import commodities they are very expensive. This is especially true for developing countries like Ethiopia.

The rising cost of traditional stabilizing agents and the need for economical utilization of industrial and agricultural wastes for valuable engineering purposes has driven an investigation into the stabilizing potential of molasses (a byproduct of sugar industry) in expansive clay soils.

The necessary laboratory tests, index tests, strength testes, swelling tests are incorporated for the natural as well as the stabilized soil. Chemical and physical testes to characterize the stabilizer molasses has also been carried out.

Analyses of the results show that slight improvement on the geotechnical properties of Molasses stabilized soil. Molasses reduces plasticity index, CEC, soil PH, swelling potentials and swelling pressure and OMC and increased MDD, CBR, UCS values as molasses content is increased up to certain percentage. On the other hand if the Molasses is increased beyond certain percentage the reverse properties are observed. Curing has an insignificant effect on the geotechnical properties of molasses stabilized soil. From this research work it was found out that molasses stabilized soil does not meet the minimum requirement of ERA pavement manual specification for use as a sub-grade material in road construction.

CHAPTER ONE: INTRODUCTION

1. Introduction

1.1. General Background

The problems caused by issues related to expansive soil in civil engineering structures were first identified in the late 1930's. Since then many countries have been reporting negative consequences of expansive soil. The method of construction, maintenance and overall performance of structures constructed on expansive soil is dependent on proper geotechnical investigations and result interpretation before any subsequent project design or construction work. Consequently the cost incurred and damages caused by construction works founded in expansive soil would be reduces. The fundamental problem associated with expansive soil is notable volume change of the soil mass. This is caused by alternate swelling and shrinkage characteristics as a result of changes in moisture content. The character change is amplified within the depth of moisture fluctuation. The behavior of expansive soils and extent of swelling – shrinkage varies from place to place due to the variation in climate, topography and type of parent material from which the expansive soil is formed. These factors determine the type of clay mineralogy and have great influence on soil water chemistry that is responsible and directly related to shrinkage - swell properties of expansive soils. The expansive clays of Ethiopia are residual, derived manly from the weathering of basic volcanic rocks and some trachytes. (S.M & Julius K., 2012) Due to the fact that the engineering properties of expansive soil of Ethiopia are different from the same soil in other localities, researches on the engineering properties of expansive soil is essentially done.

The prevailing stabilization related solutions to resolve problems associated with expansive soil during constructions of roads and building in Ethiopia are;

1) The use of traditional chemical stabilizers (lime and cement). They are moderately expensive.

2) To use imported manufactured chemical stabilizers, in most cases, most of them are not effective and proven not to improve engineering properties of expansive soil of our country. In addition they are highly expensive. (Tesfahun, 2010).
3) The use of horizontal and vertical moisture barriers, for e.g. Geo-membranes, which are expensive and can't be economical for the construction of long road sections.
4) The effectiveness of these mixed additives (soil stabilizers) towards improving engineering property and cost reduction depends on the soil conditions, stabilizer properties, type and importance of construction (i.e., houses, roads, etc.). The selection of a particular additive depends on costs, benefits, availability, and practicality of its application. The relative occurrence of expansive soil along the construction site and the extent depth/ thickness of expansive soil formation also control the choice of stabilization method.

Generally the above mentioned methods are not adequate and satisfactory result is not gained so far. This challenge made the issue to get due attention and triggered the need for investigation and introduction of innovative soil stabilization approaches which can improve engineering properties in cost effective way. To arrive at comprehensive solution, adoption and implementation of different technologies based on site specific conditions is also required. In this regard introducing technologies that enable the use of locally available marginal materials: - agricultural and industrial wastes contribute a lot to reduce construction as well as road maintenance costs especially for low traffic volume roads. The investigation of use of molasses as soil stabilizer is initiated from the above rational. Currently sugar factories are flourishing in Ethiopia and hence Molasses is expected to be found abundantly. If affirmative results are to be obtained from the research work, the use of molasses as a soil stabilizer has a double, geotechnical properties improvement of soil and reduction of disposal from existing and expanding sugar factories. Hence, it is essential to conduct scientific investigation on bulk utilization of such industrial by product in Geo-technical Engineering works.

In this research work the use of molasses as cost effective additive and effectiveness of molasses to improve some engineering properties of expansive soil is investigated.

In this research work the cost effectiveness of molasses as soil additive and its efficiency in improving engineering properties of expansive soil are assessed.

1.2. Research Justification

- Traditional chemical stabilizers are relatively expensive as compared to cost of molasses.
- There is relative abundance of molasses from the already established and expansion works of new factories.
- The use of Molasses results in the reduction of factories effluent and resolving issues related to other environmental concern and

cost of industrial waste disposal techniques

- Ease of application during construction, (since molasses is easily diluted in water it can be applied to the soil with the commonly used equipment eg. water truck.)
- Enhanced workability and uniform mixture for compaction during construction is easy
- Unlike manufactured products, the environmental impact of molasses is minimal.

1.3. Objectives

1.3.1. General Objective

- To determine potential use of molasses as expansive soil stabilizer and identify economical mixing proportion of the molasses with expansive soil.

1.3.2. Specific Objectives

- To reduce the swelling potential of the soil after stabilization
- To improve the strength and compaction property of the soil after stabilization.

- To characterize and determine Atterberg limits and indices, free swell, California Bearing Ratio, Compaction property (MDD and OMC), swelling pressure of the soil after stabilization.

1.4. Research Methodology

In this study both empirical and theoretical research methodologies were employed to attain the objectives of the research.

i. *Literature survey*: various academic sources; such as text books, academic journals, seminars and research papers were reviewed in order to have theoretical background pertaining to expansive soil, and different soil stabilization techniques.
ii. *Sampling and testing*: material sampling and testing methods are used to characterize material and physical properties of the soil. This is a critical stage of the study and the sample size of soil testing is optimized as it can potentially affect the performance of the roads.
iii. *Sample preparation of the soils*: involved air drying, pulverization and sieving of the natural soil sample to the required particle sizes. Classification of soil was made by running grain size distribution and Atterberg limit tests. Then Atterberg limit, free swell, free swell ratio, free swell index, compaction and California Bearing Ratio tests are carried out on natural soil as well as on soil-molasses mix to study the effect of the stabilizer (Molasses).
iv. *Analysis and discussion of test results*: considering theoretical backgrounds and outcomes of the laboratory testes; the results obtained have been analyzed and discussed thoroughly.
v. *Conclusions and recommendations*: are deduced based on the obtained results.

1.5. Scope Of The Research

This study is supported by different types of literatures and a series of laboratory experiments. However, the findings of the research are limited to one soil sample considered in this research which is expansive clay sampled from Addis Ababa Nifaselk Lafto sub city around Jamo condominium. The results are also specific to the type of additive /molasses /used and test procedures that have been adopted in the experimental work. Therefore, findings should be considered indicative rather than definitive for applications.

1.6. Organization of the Thesis

The presentation of this thesis work is organized in six Chapters. *The first Chapter* gives a brief description of the thesis background, objectives, scope and methodology employed. *Chapter two* presents literature review on expansive soils, the material molasses and soil stabilization respectively. Important details from previous studies are also included in this Chapter. *Chapter three*, briefly discuses about the study area . *The fourth Chapter* deals with the characterization of materials used for the study and laboratory testing procedures followed. *The fifth Chapter* consists the test results obtained; analysis of results and discussions of results with respect to the theoretical background and findings of previous studies. *Chapter six* presents conclusions and recommendations drawn from this research.

CHAPTER TWO: LITRATURE REVIEW

2. Literature Review

Expansive soil is defined as plastic clay soil that exhibits high volume change when subjected to moisture variations due to seasonal climatic conditions or artificial causes. The degree of expansiveness depends on whether the soil mass contain active clay minerals or not. The most common active clay mineral is Montmorillonite. Alternate expansion and shrinkage cause deformation in the soil mass and result in the damage of engineering structures founded on this soil. The cost incurred due to maintenance of already damaged structures is remarkable. Prior to construction of engineering structures to reduce the problems associated with expansive soils, so many techniques: removal and replacement with non expansive fill, ponding or prewetting, the adoption of better design approaches i.e the use of moisture barriers or membranes and soil stabilization methods were known so far (Nelson & Miller, 1992). Stabilization is the dominant means of soil improvement. Stabilizers help to modify the geotechnical properties of the soil thereby improving their engineering performance and suitability for various construction purposes. Extensive researches done on soil improvement techniques have categorized stabilizing methods based on soil processing mechanisms: mechanical stabilization, chemical stabilization, thermal stabilization and electrical stabilization.(Nelson & Miller, 1992). Among these, mechanical and chemical are the most widely used techniques due the provision of fast, efficient, repeatable and reliable improvements on raw soil properties. Chemical improvement is a time saving method that enables sub-grade or sub-base layer and otherwise unsatisfactory materials in-situ to obtain higher density and strength, obviating the need for costly excavation and replacement with borrow material. Practitioners often design and select chemical stabilizers to reduce the plastic nature of expansive soils from problematic levels (high PI values) to non problematic levels (close to zero PI values) (Chen, 1975). The three most commonly used traditional chemical stabilizer for expansive clays are: bitumen, lime and cement. These stabilizers have been successful in enhancing soil properties to requisite levels. However, these stabilizers have their individual limitations and consequently do not provide effectual solutions in all soil types. Unfortunately, the costs of these stabilizers are on the high side making them economically unattractive as stabilizing agents. The use of nontraditional chemicals; Polymers Based Products, Copolymer Based Products , Fiber Reinforcement ,Calcium Chloride, Sodium Chloride and other stabilizers are becoming popular due to their relatively low cost, ease of application, and short curing time(Halik, Sunghwan, & Asthurirangan, 2010).

Recent trend in research works in the field of geotechnical engineering and construction materials have evolved innovative techniques that focuses more on the search for cheap and locally available materials such as industrial and agricultural wastes, etc. as stabilizing agents for the purpose of full or partially replacement of traditional stabilizers. During the process of soil stabilization and modification the emphasis is on maximum utilization of local material considering significant reduction in cost of construction. The use of industrial and agricultural wastes to stabilize local expansive soil sub-grade may achieve the double objective of reducing the problems of this type of soil, and also of providing alternative use for the additives, thus eliminating the economic and environmental cost, waste disposal cost involved in managing them.

2.1. Expansive Soil In General

Expansive soils can be found anywhere in the world where climatic, geological and topographic conditions favored their formation. These soils are abundant in semi – arid regions of tropical and temperate climate zones where the annual evaporation exceeds the precipitation. Climatic condition coupled with environmental factors facilitates weathering of the parent rock and formation of residual soil in restricted leaching condition .As a result, magnesium, calcium, sodium, iron cations may accumulate in the system to form Montimorillonite which is the dominant mineral in expansive soil. It is formed from stacks of sheets built from two basic units, the tetrahedral unit of silica and the octahedral unit of hydroxide of aluminum, iron or magnesium .The weak Vander wall force and exchangeable cataions between sheets of crystalline alumino silicates is responsible for shrinkage swell characteristics of expansive soils when moisture fluctuation in the soil mass is prevalent.

Desiccated cracks of expansive soil deposits in dry season is commonly seen , cracks measuring 70 mm wide and over 1 m deep have been observed and may extend up to 3m or more in case of high deposits(S.M, D.C, A.J.M.S., & I.B.H., 2014). Heaving ground due to swelling of expansive soil in rainy season or due any cause of moisture alteration in this soil mass could also be observed. Hence undesired engineering properties of expansive soil:-weakness of the foundation soil from volumetric instability, swelling pressures development due to swelling ground is responsible for many damages of engineering structures.

2.2. Identification And Classification Of Expansive Soils

2.2.1. Identification Tests

2.2.1.1. Field Identification

Expansive soil deposits can be recognized in the field through visual inspections. The method is simple and easy to use. Some of the important field identification method that indicate the potential for expansiveness of soil are the following:

- They usually have a color of black and gray
- Desiccated surfaces with open or closed fissures and heave of the ground due seasonal moisture variation.
- Wet samples of the soil are sticky causing low traffic ability.
- Slickenside, (highly polished or shiny fissure surface)
- Cracking appear in nearby structures (mainly on walls, foundations and grade beams of buildings and longitudinal cracks especially appear near road shoulders and around center line of high ways .Transversal crack emerge in minor drainage structures like culverts .

2.2.2. Laboratory Identification

In general there are three different methods of laboratorial identification of expansive soil namely; mineralogical identification, indirect and direct methods.

2.2.2.1. Mineralogical Identification

The basis of the method is that, the swelling potential of any clay can be evaluated by identification of the constituent mineral of that clay. This method is used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and change deficiency and surface activity of clay particle. These properties are fundamental factor controlling expansive soil behavior. The various techniques under these methods are:

-X-ray diffraction

-Differential thermal analysis

-Dye absorption

-Electron microscope

-Base exchange capacity, etc

However, these methods are not suitable for routine tests due to the fact that they require expensive test equipment and also demand trained technicians for the interpretation of test results. (Chen, 1975).

2.2.2.2. Indirect Methods

These methods consist of simple soil property tests that are easy and can be performed in most soil mechanics laboratory. The result form this tests yield an excellent indices of expansive properties. The various tests under these methods are: Atterberg limit tests, shrinkage tests, colloidal content tests and the CEC tests (Chen, 1975) strongly states that erroneous conclusion can be drawn if the indirect methods are used independently.

2.2.2.3. Direct Methods

These methods present the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Optimum sample size needs to be considered during testing to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional odometer. Standardized procedure that considers factors that affect the shrink swell potential as well as simulate the expected loading condition should be adopted.

2.3. Classification of Expansive Soils

2.3.1. General Classification

There are different classification schemes, which use different basics for the purpose. Among these, the Unified Soil Classification System (USCS) and the American Association of state Highway and Transport official (AASHTO) method makes use of index property for classification and are often used. Soils rated CL or CH by USCS, and A6 or A7 by AASHTO, may be considered potentially expansive (Nelson & Miller, 1992).

2.3.2. Classification Specific To Expansive Soils

The General classification system give clue that a soil may exhibit expansive character but it does not provide comprehensive information. The parameters determined from expansive soil identification tests have been combined in a number of different classification schemes to give qualitative rating on the expansiveness of the soil. Due to lack of standardization of classification procedures, different schemes are used in different localities. However the direct use of such schemes for design purpose do not give reliable results for the reason of some limitation during formulation of these schemes. Hence, it is very important to emphasize that design decision has to be based on predicting testing and analysis, which provide reliable information. Some of the classification methods discussed in literatures is given in the following sections.

2.3.3. Classification Based On Indirect Predictions Of Swell Potential

2.3.3.1. Skempton Method

This method classifies clays according to their activities which is developed by Skempton (1953) by combing Atterberg limits and clay content (% percent by weight finer than 2μ m) into a single parameter called activity. Skempton classified clays into three classes according to their activities as indicated in Table 2.1 Activity is defined as:

$$\textbf{Activity} = \frac{\textbf{PI}}{(\textbf{Percent of clay} < 0.002mm)} \quad (\mathbf{2.1})$$

Table 2. 1: Classification of Expansive soil based on Skempton Method

Potential of Expansion	Activity
Low/inactive	Ac < 0.75
Medium/Normal	0.75<Ac < 1.25
High/ Active	Ac > 1.25

Based on this classification, montmorillonitic clay (Expansive Clay) is defined as active, illitic clay as normal and Kaolinitic clay as inactive (Chen, 1975)(Nelson & Miller, 1992).

2.3.3.2. Method of Chen

Chen (1975) presented a single index method for identifying expansive soils using only plasticity index. Chen suggested four classes of clays according to their plasticity indices shown in Table 2.2

Table 2. 2: Relation between the swelling potential of clays and the plasticity index(Chen, 1975)

Swelling potential	Plasticity index
Low	0-15
Medium	10-35
High	20-55
Very high	35 and above

2.3.3.3. USBR Method

This method is developed by Holtz and Gibbs; it is based on direct correlation of observed volume change with colloid content, plastic index and shrinkage limit. The classification is as given in Table 2.3

Table 2. 3Classification based on bureau of reclamation method

Colloid content, (%)	Plasticity index, (%)	Shrinkage limit, (%)	Probable expansion, (%)	Degree of expansion
<15	<18	>15	<10	Low
13-23	15-28	10-16	10-20	Medium
20-31	25-41	7-12	20-30	High
>28	>35	<11	>30	Very high

2.3.4. Classification Based On The Odometer Swell Potential Values

Based on the odometer swell potential values, (H.B, R.G, & R., 1962) and (Holtz & Gibbs, 1956) have classified the relative expansiveness of the swelling soils. The expansiveness categories proposed by these workers are shown in Table 2.4 and Figure 2.1.

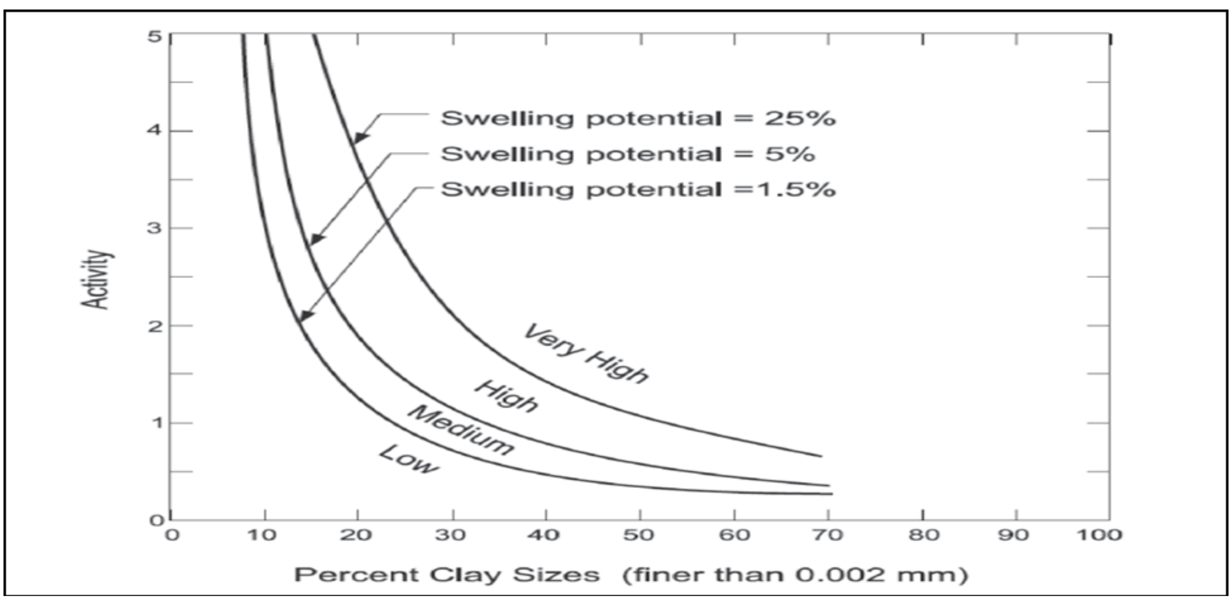


Figure 2. 1: *Classification Chart for Swelling Potential* **(H.B, R.G, & R., 1962)**

Table 2. 4: classification based on Odometer Swell Potential Values

Holtz and Gibbs (1956) classification of percent swell*	Seed et al's (1962) classification of percent swell**	Degree of Expansion
0-10	0-1.5	Low
10-20	1.5-5	Medium
20-35	5-25	High
>35	>25	Very high

* (Holtz & Gibbs, 1956) *classified degree of expansion from the volume change on undisturbed and remolded samples (air-dry to saturated under a load of 1 pound per square inch).*
** (H.B, R.G, & R., 1962) *classified degree of expansion from volume change measured as percentage of swell on soaking from 100% maximum density and optimum moisture content in a standard AASHTO compaction test under a surcharge of 1 psi on remolded, artificially prepared samples*

2.4. Sugar Cane Molasses

Sugar Cane Molasses is a very thick dark brown syrupy liquid, byproduct of sugar industry. Its constituent composition is influenced by factors such as sugar cane cultivation, soil type, ambient temperature, moisture, season of production, variety, production practices at a particular processing plant, and by storage variables. Consequently, considerable variation may be found in nutrient content, flavor, color, viscosity and total sugar content. (S.S & S.S, 2010; Julius K., 2011).

The physical and chemical properties of black strap molasses obtained from one of the sugar industries of India are summarized in the following tables (S.S & S.S, 2010).

Table 2. 5: Physical Properties of Molasses(S.S & S.S, 2010)

Sr.No.	Physical properties	Molasses
1	Colour	Dark brown
2	Specific gravity	1.4
3	Viscosity(cp at 200C)	1500
4	PH	4.5
5	Litres/tonne	714
6	Appearance	syrupy liquid
7	Gallons/tonne	157

Table 2. 6: Chemical Composition of Molasses(S.S & S.S, 2010)

Sr.No.	chemical compoitions	Molasses
1	Dry matter	
2	Crude Protein	4.40%
3	Sugars (as sucrose)	45%
4	Fiber	Nil
6	Ash	12%
7	SiO2	0.5
8	K2O	3.5
9	CaO	1.5
10	MgO	0.1
11	P2O5	0.2
12	Na2O	0.07
13	Fe2O3	0.07
14	Al2O3	0.07
15	SO3	1.6
16	Chlorides	0.4

Generally molasses from sugar industries are graded based on the remaining sugar contained after crystallization process as ; integral or un clarified molasses, high-test molasses ; A molasses, B molasses, C (final) molasses and syrup-off. (Rena) ."A" molasses is an intermediate product. Approximately 77% of the total, available, raw sugar in clarified/concentrated sugarcane juice is extracted during first centrifugation process.

"B" molasses is also known as "second" molasses. It, too, is an intermediate product, At this point; approximately 89% of the total recoverable raw sugar in the processed cane has been extracted.

The last molasses is known as "C", "final" or "black strap" molasses and in some countries as "treacle". It is the end product. Even though C molasses is considered the end or final product in a raw sugar factory, it still contains considerable amounts of sucrose (approximately 32 to 42%) which to date has not been recovered by an economically viable method.

2.4.1. Use Of Molasses

Molasses is traditionally used in fermentation technologies to produce ethanol. Fermentation treatment of molasses to produce baker´s yeast or proteins is also tightly connected with ethanol production. The molasses produced in Kenya is mainly used in manufacture of gasohol, production of alcoholic drinks, and also used as animal feeds(Julius K., 2011).

Molasses is applied in many food or non-food processes because of high content of nitrogenous compounds, carbohydrates and its sweet taste (E., Z.Bubnika, & A., 2012) the use of molasses in road sector is as (i) dust palliative on the footpaths around sugar factories (Julius K., 2011) and (ii) to make molasses-based material for de-icing of roads (E., Z.Bubnika, & A., 2012) Also research which was done to replace bitumen in certain amount for low traffic pavement roads has showed encouraging result. (SAMMY.M, 2009)

2.5. Molasses Production In Ethiopia

According to the report from sugar corporation of Ethiopia; the current aggregated national Sugar production capacity from Wonji Shoa , Methehara , FIncha and tendaho sugar factories is estimated to be 1.24 million tons of sugar per annum(TSA). The aggregated ethanol production from the same sugar factories is also estimated to be 1.08 million meter cube per annum (Cm3) See table 5.1. The Government of Ethiopia is undergoing mega Sugar Development projects to boost the in-house sugar production capacity to a significant level. Kessem, Kuraz, Wolkayit , Arjo Didessa and Belles sugar development projects collectively are expected to have production of 2.7 million TSA and 0.3 million Cm3 of Sugar and ethanol respectively See table 5.1. When these sugar development projects attain maximum production capacity; the total national sugar and ethanol production capacity will be 4 million TSA and 1.4 million Cm3 respectively. Therefore there will be significant supply of Molasses in the recent years. However, since Molasses is a multi-functional by product of sugar process, it is currently used for production of ethanol, bakery yeast, rectified and technical alcohol and as animal feedstock. This intern could create supply and demand constraint. Nevertheless, using Molasses for soil stabilization have significant socio-economic benefits namely; reducing industrial process wastes and cost minimization of road construction projects. The Molasses used for this study is sourced from Methara Sugar factory and based on a study conducted by Ethiopian sugar industry support center; the indicative Molasses availability of the factory is estimated to be 4000 ton/year for local sale and 33000 ton/year for available stock use. At present; the ethanol processing unit of Wonji shoa and Tendhao sugar factories is not functional, as a result molasses supply for the use of soil stabilization will favor the factories west removal activities.

Table 2. 7: Annual Production Capacities of Sugar Factories

Name	Location	Year of Establishment (G.C)	Tons Of Sugar Per Annum (TSA)		Ethanol Meter Cube Per Annum (Cm3)	
			2010	**2015**	**2010**	**2015**
Wonji Shoa Sugar Facory	Oromia , Nazeret	1954	174,946	220,700	10,000	12,800
Metehara Sugar Factory	Oromia	1970	136,692	136,692	12,500	12,500
Finchaa Sugar Factory	Oromia , Horro Guderru	1998	110,000	270,000	8,000	20,000
Tendaho Sugar Factory	Afar , Awash Basin	2006		619,000		63,000
		Total		**1,246,392**		**108,300**

Source: Ethiopian Sugar corporation

Table 2. 8: Annual maximum Planned Production capacity of sugar Development Projects

No	sugar Development Project	Location	Tons Of Sugar Per Annum (TSA)	Ethanol Meter Cube Per Annum (Cm3)
1	Kessem	Afar ,Fentallie andDulecha	260,000	30,000
2	Kuraz	South Omo Zone	1,946,000	183,134
3	Wolkayit	Tigray,Wolkayit	484,000	41,654
4	Arjo Didessa	Oromia, Wollega	240, 000	20,827
5	Belles	Amahara and benishangul	242,000	20,827
	Total		**2,690,000**	**296,442**

Source: Ethiopian Sugar corporation

2.6. Stabilization

Soil stabilization is the alteration of one or more soil properties to create an improved soil material possessing the desired engineering properties. There are three purposes for soil stabilization. These include; increasing the shear strength of an existing ground condition to enhance its load-bearing capacity (i), achieve a desired improved permeability (ii) and enhance the durability of the soil (iii) (S.M, D.C, A.J.M.S., & I.B.H., 2014).

According to the technical manual of the U.S. Departments of the Army and Air Force (JDAAF 1994) "Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil.

The two broad categories of stabilization are Mechanical stabilization and chemical stabilization. Mechanical stabilization refers to process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil (e.g Modifying expansive soil by blending with non-expansive soil). Mechanical stabilization is best suited for coarse grained soils However; clayey soils are more effective if chemically stabilized.

2.6.1. Chemical Stabilization

Chemical Stabilization is one of the methods which is widely used to stabilize the soil sub grade .It involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime , fly ash , calcium or sodium chloride or with viscous-elastic material such as bitumen. Chemical stabilization involves three basic reactions cation exchange, flocculation-agglomeration pozzolanic reactions.

2.6.1.1. Ion Exchange And Flocculation

Clay particles carry exchangeable ions that are held weakly on the particle surface that can be readily replaced by others in moist medium. The exchangeable cations may be present in the surrounding water or be gain from the stabilizers. The most common exchangeable cations are Ca++,Mg++, H+, K+, NH4+, Na+, often in about that order of general relative abundance . Chemical in balance with the negative charged clay surface and the positive cations in the solution adjacent to the clay are referred to as the double diffusion layer (DDL). When these DDL's occur there is a repulsion force generated between the clay particles due to the concentration of negative and positive charge. This contributes to the swell pressure. The replacement of univalent ions by divalent ions provides a strong attraction between particles as this reactions take place thickness of the diffused double layer decreases .Hence, swelling potential decreases.

Cation exchange reactions result in the flocculation and agglomeration of the soil particles due reduction in the diffused double layer.

2.6.1.2. Pozzolanic Reaction

Pozzolans are finely divided siliceous or aluminous material that in the presence of water react with lime to produce the cementing effect / pozzolanic reactions/. Since it is time dependent curing of samples for certain duration, for further strength gain is essential.

i) Chemical Reactions In Lime Treated Soils

Several reactions occur when lime is added to clay in the presence of water. The major reactions are cation exchange, flocculation-agglomeration, carbonation, and pozzolanic reaction.(Ehitabezahu, 2011) Cation exchange and flocculation-agglomeration reaction occur immediately after mixing and these reactions cause immediate changes in strength, plasticity index, and workability of the soils. Carbonation is reaction of carbon dioxide in the open air or voids in the ground with lime, which forms a relatively weak cementing agent. Cementation caused by carbonation on the clay surface results rapid initial increase in strength. Pozzolanic reaction occurs between lime and silica and alumina of the clay mineral and produces cementing material including calcium-silicate-hydrates and calcium alumina hydrates.

The long term result of pozzolanic reactions (Equations, i) and ii)) is solidification of the soil (Ehitabezahu, 2011) Rate of the pozzolanic reactions depends on time and temperature.

$$Ca(OH)_2 + SiO_2 \longrightarrow CaO - SiO_2 - H20 \quad (i)$$

$$Ca(OH)_2 + Al_2O_3 \longrightarrow CaO - Al_2O_3 - H20 \quad (ii)$$

ii) Chemical Reactions In Cement Treated Soils

This method immediately reduces the plasticity characteristics of the soil which are caused by calcium ions released during the initial hydration reactions. It is noticed that a small addition of cement stabilizer increases the aggregation reactions rapidly which in turn decreases the Plasticity Index value.The hydration reactions of Portland cements are due to the production of different compounds and gels that increase the soil strength through complex pozzolanic activity (Chen, 1975)(Nelson & Miller, 1992)This bonding not only serves to protect aggregates but also prevents them from swelling and softening from absorption of moisture

The reactions that occur during cement chemical process can be listed as

2 (3CaO.SiO2) + 6H2O _ 3CaO.2SiO2.3H20 + 3Ca (OH)2 (1.1)
(tricalcium silicate) (water) (tobermorite gel) (calcium hydroxide)

2 (2CaO.SiO2) + 4H20 _ 3CaO.2SiO2.3H2O + Ca (OH)2 (1.2)
(bicalcium silicate) (water) (tobermorite gel) (calcium hydroxide)

3CaO.Al2O3 + 2H2O+ Ca (OH)2 _ 3CaO.Al2O3.Ca(OH)2.12H2O. (1.3)
(tricalcium aluminate) (water) (calcium hydroxide) (tetracalcium aluminate hydrate

iii) Stabilization mechanism in molasses treated soils

Chemical oxides and elements contained in molasses and other elements imbibed from the soil by the sugar cane as nutrients to support growth are the ones, which probably interacted with expansive soil to change its characteristics during stabilization.(S.M & Julius K., 2012) Addition of cane molasses to expansive clay soil caused cation exchange that led to reduction of double layer thickness. Reduction in double layer thickness caused flocculation of clay particles and eventually aggregation.(S.M & Julius K., 2012) The cation that caused flocculation reduced also the amount of adsorbed water in clay and consequently caused reduction of water content of liquid limit of clay. But water content of plastic limit increases. Reduction in liquid limit and increase in plastic limit resulted in reduction of plasticity index. Aggregation increased effective grain sizes. Aggregation/ agglomeration changed textural condition of clay soil and reduced the specific surface of soil particles.(Julius K., 2011) Further Adhesive Mechanism is through electrochemical attraction between aggregated soil particles which was enhanced by the adhesive molasses which bound the particles together. Adhesive properties of molasses were derived from Hydrogen bonds attributed to Hydroxyl group found in sucrose of molasses.(S.M & Julius K., 2012) The clay soil particles were then held together by molasses and they formed larger particles than clay size grains which caused reduction in clay content of soil.

2.7. Results From Previous Research Works

Several research works related to expansive soil of Ethiopia were done so fare. Some of them which are related to this research work are worth mentioning.

Danel Nebro evaluated lime and liquid stabilizer called Con-Aid for stabilization of potentially expansive sub grade soil on samples collected form Addis-Jimma road which had indicated different pavement damages aggravated by the presence of expansive soils. He pointed out that addition of lime reduces the swelling potential but no significant improvement in the engineering properties of the soil was attained by addition of Con-Aid (Danel, 2002).

Sertse Tadese evaluated soil stabilization For Road Works on Highly Expansive soils of Ethiopia. Soil samples collected form Robe –Seru Road project was blended with clay, volcanic cinder and mixed with lime and cement at different proportions (Sertse, 2003). The effects of each mix was investigated in laboratory by performing Consistency, swell and strength tests. The findings and conclusions of the study can be summarized as:-

- Consistency limiting values of the highly expansive soils were decreased by the addition of red clay soil and cinder material.
- Addition of red clay soil and cinder increased the CBR value but not to satisfactory level. The UCS values decreased with the addition of blending soil.

Yohannes Argu studied stabilization of light grey and red clay sub grade soil collected from Addis Ababa using SA-44/LS-40 chemical and lime. He found out that the applications of SA-44/LS-40 chemical alone are ineffective in improving the soaked CBR value of the red clay and light grey soils (Yohannes, 2008).

Tesfahun Ashuro has studied Performance of Unconventional Soil stabilizers in Stabilization of Substandard Materials for Road Sub grade and Sub base.

The two unconventional manufactured stabilizers were used: PURE CRETE (liquid enzyme product) and Anyway Natural Soil Stabilizer ANSS (powder product). The stabilizers were combined with a total of five different soils with classifications

According to AASHTO as A-7-5, A-7-6, A-2-7, A-2-4, and A-2-6. ANSS stabilization induced the most improvement on engineering properties of all soils tested at manufacturer recommended dosages and PURE CRETE failed to show any improvement at manufacturer recommended application rate (Tesfahun, 2010).

Habtamu Solomon has evaluated the performance of chemically stabilized expansive sub grade soil of Selected Road section in north eastern Addis Ababa (Habtamu, 2011) .

The performance of a locally manufactured hydrated lime and an imported industry product Anyway Natural Soil Stabilizer (ANSS) were evaluated based on laboratory test results of expansive sub-grade, soils collected from Gerji area. Two soil layers on color variations were observed in the field the upper dark gray clay soil and the lower light gray clay soil. The effects of the chemicals were then evaluated on two soil samples after the necessary laboratory tests.

- The improvement of the sub-grade soil samples increased with increasing both dosages as well as curing periods.
- In general terms, increasing the dosage has more significant effect than that of increasing the curing period and 4% of either chemical has resulted in adequate improvements of the sub-grade soil.
- The performance of hydrated lime is better than that of ANSS and the improvement of the dark gray clay soil is better than the light gray clay soil.

Ehitabezahu Nigusse evaluated the effect of sodium silicate and its combination with cement/lime for soil stabilization collected from Addis Ababa. Montmorillonitic clay was treated using 2%, 4% and 6% lime, 1%, 2.5% and 6% liquid sodium silicate and the respective combinations of the additives by dry weight of the soil (Ehitabezahu, 2011). She concluded that;

- Sodium silicate is not a suitable additive for montmorillonitic clay (expansive soil) stabilization.
- Mixing sodium silicate with lime is not a viable option for montmorillonitic clay (expansive soil) stabilization.

Meron Wubeshet bagasse ash as a sub-grade soil stabilizing material was assessed. Bagasse is one of the by products from the sugar Industry (Meron, 2013).

The stabilizer (5%,10%, 15%, 20%,25% and30%) by dry weight of the soil was used. lime was supplementary added to the (5%,15%,30%) bagasse ash stabilized extra soil samples . All the stabilized soil samples were also cured for 7-days for Atterberg limits, compaction and CBR tests. Analysis of the results shows that Slight improvement on the geotechnical properties of bagasse ash as summarized bellow;

- Baggasse ash reduces plasticity index, swelling and MDD with an increase in OMC and CBR with all higher bagasse ash contents.
- Curing has an insignificant effect on the geotechnical properties of bagasse ash stabilized soil
- The plasticity index significantly decreased with addition of bagasse ash combined with lime and increased curing period. However, the addition of bagasse ash alone has a minor effect on the plasticity index of expansive soil.
- The addition of lime and bagasse ash together led to a more decrease of the maximum dry density and increase in optimum moisture content compared to the addition of lime and bagasse ash separately.

  The addition of bagasse ash in combination with lime improved the CBR value. The improvement is more significant when the sample is cured. Hence, combination of bagasse ash and lime can strongly improve the strength of the expansive soil.

Based on Reshid Museums 'study on Stabilization of expansive soils with lime (A Case Study on the Adura-Burbey DS6 Road Segment) (Reshid, 2014). In this study, hydrated lime, of percent varying from 2 to 12 percent (by dry weight of the soil) was used for stabilization of expansive soils. Atterberg limits, Shrinkage limits, Linear shrinkage, Specific gravity, Free swell, Moisture density relationships, California bearing ratio (Soaked CBR) CBR Swell, Unconfined Compressive strength(immediate and 7 days cured) tests were conducted and the following conclusion were drawn.

- Addition of lime has resulted in a reduction of the free swell of the soil. As the percentage of stabilizer increased, free swell ratio decreased.
- Addition of lime to the tested samples led to the reduction in liquid limit, plasticity index plastic limit of the blended samples has not shown a clear trend as it increases from 0 to 2% and starts decreasing from 2% to 12%.
- The addition of lime for the studied soil has resulted in an increase in optimum moisture content and reduction of maximum dry density for the same compaction effort.
- The optimum lime content in improving the CBR of the soil from its poor sub grade quality to poor to fair class is found out as 12 percent.

Previous works done worldwide on stabilization of expansive soil by sugar Cain molasses is limited. Also literatures on this issues are barely found . some geotechnical experiments conducted on soft soils of India , Nigeria and expansive soils of Kenya indicated the reduction of plasticity index of soils and strength increment when stabilized with molasses(SAMMY.M, 2009; Julius K., 2011; S.S & S.S, 2010)(Julius K., 2011)(S.S & S.S, 2010).

1. Terrazyme

Recently Bio-Enzymes have emerged as a new chemical for soil stabilization. Bio-enzymes are eco-friendly, liquid additives. Many Civil Engineering Company involved in the construction of roads use an innovative technology called a bio enzymatic, Terrazyme (molasses) soil stabilizer. (S.S & S.S, 2010). An enzyme TerraZyme Also referred to as TZ, by the manufacturer is a natural, non-toxic liquid, formulated from sugar molasses. Terrazyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application. (S.M, D.C, A.J.M.S., & I.B.H., 2014) Terrazyme is a surfactant (an ionic surface active agent) which changes the hydrophilic nature of lime material and clay to hydrophobic(Greeshma, Lamanto, & S., 2014) .Additionally it helps the lubrication of soil particles and increases the compatibility of many soils. The reaction of Terrazyme on the soil is effective due to the ion-exchange capacity of clay minerals. Terrazyme also changes the plastic characteristics of these materials due to a reduction in its water absorbing capacity. The effect of Terrazyme on these materials is permanent(S.M, D.C, A.J.M.S., & I.B.H., 2014). They act on the soil to reduce the voids between soil particles and minimize absorbed water in the soil for maximum compaction(Greeshma, Lamanto, & S., 2014). Literature confirms that TZ improves the engineering qualities of the soil like CBR values and dry density. This in turn also decreases the OMC and plasticity index of soil. Stabilizer (Greeshma, Lamanto, & S., 2014) .The application of Terrazyme to fine-grained soils enhances weathering resistances.(Greeshma, Lamanto, & S., 2014).

2. Plasticity

High Plasticity is indirect clue of the expansion nature of soil. A soil with a low plasticity index requires only a small reduction in moisture content to bring about a substantial increase in shear strength. Conversely, a soil with a high plasticity index would not stabilize under load until large moisture content changes have taken place. This implies that highly plastic soils are less stable and, if they are used in the construction of a road pavement, they may need to be stabilized in order to increase their shear strength and even their bearing capacity.(S.M & Julius K., 2012)

Research work on soil molasses mixture was conducted in Kenya on expansive soil sampled from Kano plains of from ten test pits. The soil used was heavy clay (clay content was > 60%) and the cation exchange capacity was high typical of heavy clay soil containing (Na+) as its major cation . The result from the research showed that molasses reduced the plasticity index of the soil from an average of 39% for untreated soil to an average of 26% for treated soil at molasses content of 8% by weight of dry soil cured for 7 days. Also the result indicates that cane molasses reduced plasticity index through aggregation of soil particles and binding of the same by molasses. It was concluded that molasses could reduce the plasticity of expansive clay soil if molasses content in the soil did not exceed 8% by weight of dry soil(S.M & Julius K., 2012). The evaluation of some physical test results gave promising indication, when the soil was treated with molasses, the pH value changed and the soil became slightly acidic. This means that the addition of molasses resulted in a cation exchange reaction (S.M & Julius K., 2012)

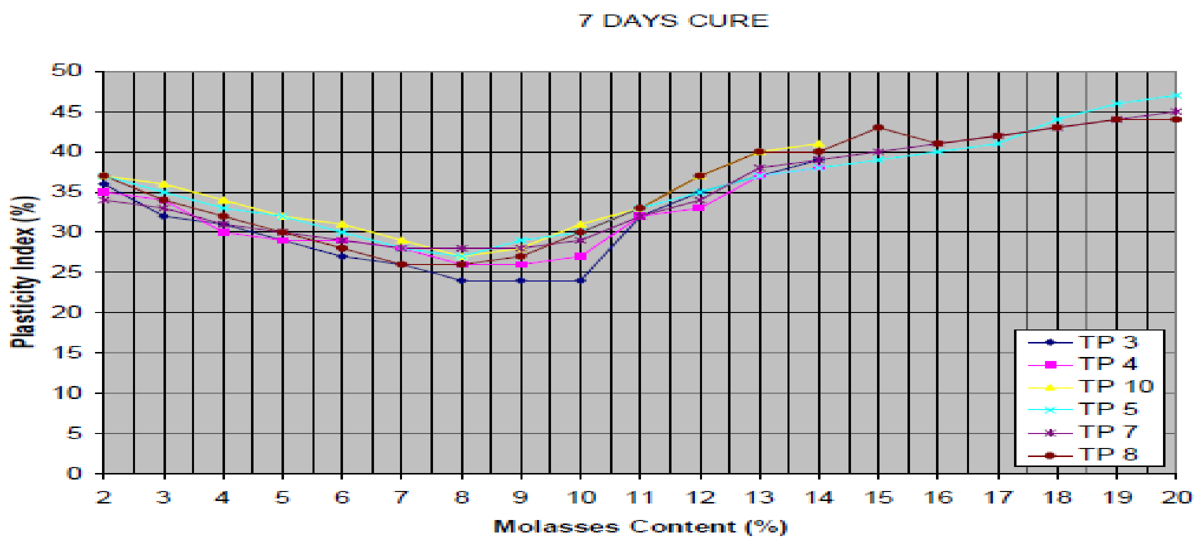


Figure 2. 2: Plasticity Index versus Molasses Content **(S.M & Julius K., 2012)**.

3. Soil Strength

Moisture has a significant effect on the shear strength property of expansive soil. Generally the shear strength of expansive soil reduces when the moisture content is increased. When the shear strength of expansive soil is mentioned it should always be referenced with the moisture content .Also the shear strength of the soil should be stated at the specific conditions (unsaturated and saturated state) .The stress history of expansive soils have a great influence on the shearing strength of soils. Most expansive soils behave as over consolidated soils .The reduction in strength is caused do to volume instability from alternate shrink swell characteristics. The research work on expansive soils of Kenya cover molasses content in the soil ranging from 4 to 14 % by weight of air dried soil each proportions evaluated for : 7DC- 7 days cure; 7DC+7DS – 7 days cure + 7days soak; 28DC – 28 days cure; 28DC +7DS – 28 days cure +7 days soak for each soils sampled from four test pits .Results from research work conducted in Kenya on expansive soil (CH) containing (Na+) as its major cation showed that 8% cane molasses by weight of dry soil was the maximum for effective stabilization of expansive clay soil. The un- soaked CBR values ranged from 3- 4%. But the values for the soil specimens stabilized with molasses were generally higher than those of neat soil under similar conditions. However, CBR values for14% molasses content, cured for 7days and capillary soaked for the same period were more or less equal to those of un soaked neat soil. It was also observed that the molasses content and curing durations of the specimens before testing had an effect on CBR value. Increasing the curing duration led to increased CBR value. Increasing the molasses content in the soil also resulted in increased CBR value of the soil. However further increase beyond 8% molasses content resulted in reduction of CBR values(S.M & Julius K., 2012).

The reduction of CBR values with increasing molasses content beyond a certain limit can also be attributed to coating of individual soil grains with molasses. As molasses coated the soil grains, its thickness around each grain increased with increase of molasses content in the soil and led to increase in the distances between individual soil grains. Beyond certain molasses content in the soil the distances between individual soil grains reaches an extent that electrostatic attraction forces which keep the soil particles together due to relatively short distances between them become ineffective.

Molasses mixed with expansive clay soil reduced its swelling tendencies as well (S.M & Julius K., 2012).

The CBR Values for 8% molasses are summarized in table 2 .9 below.

Table 2. 9: CBR (%) Values Of Molasses Stabilized Soil Samples (Julius K., 2011)

CBR (%) for Molasses Stabilized Soil						
8% Molasses						
S/no	**7DC**	**7DC+7DS**	**Swell (%)**	**28DC**	**28DC+7DS**	**Swell (%)**
TP1	42	23	0.48	45	24	0.47
TP3	52	25	0.57	53	29	0.56
TP5	53	25	0.56	51	27	0.56
TP8	51	24	0.56	52	25	0.55

A study with the aim to substantiate the effectiveness of unconventional liquid soil stabilizer, Molasses for improving the shear strength and CBR value of two types of fine grained soils (CI and CH) was done on soil samples obtained from Guduvancheri (Chennai) . The soil sample was treated with varying proportions of Molasses which was brought from Jalgaon, Maharashtra. Concentration of dosage was varied by dry soil weight. Since the Molasses used had syrupy liquid appearance was slightly viscous than water , it was directly added in dry soil at required proportions and samples were uniformly and homogeneously mixed.(E., Animesh, A.T, G., & A.Abdul, 2015)

Soil sample being Intermediate compressible clay (CI), was varied with 5-8% of molasses, while second soil sample was highly compressible clay (CH) which had relatively high optimum moisture content was varied with 9-12% molasses by dry soil weight.

The results from this research showed that use of molasses increased the unconfined Compressive strength. The highest increment was observed on addition of 6% Molasses to soil sample 1, UCC strength increased by 94%. The highest strength increment was obtained by addition of 10% Molasses to soil sample 2, UCC strength increased by 85%. The graphs are indicated below for both soil types.

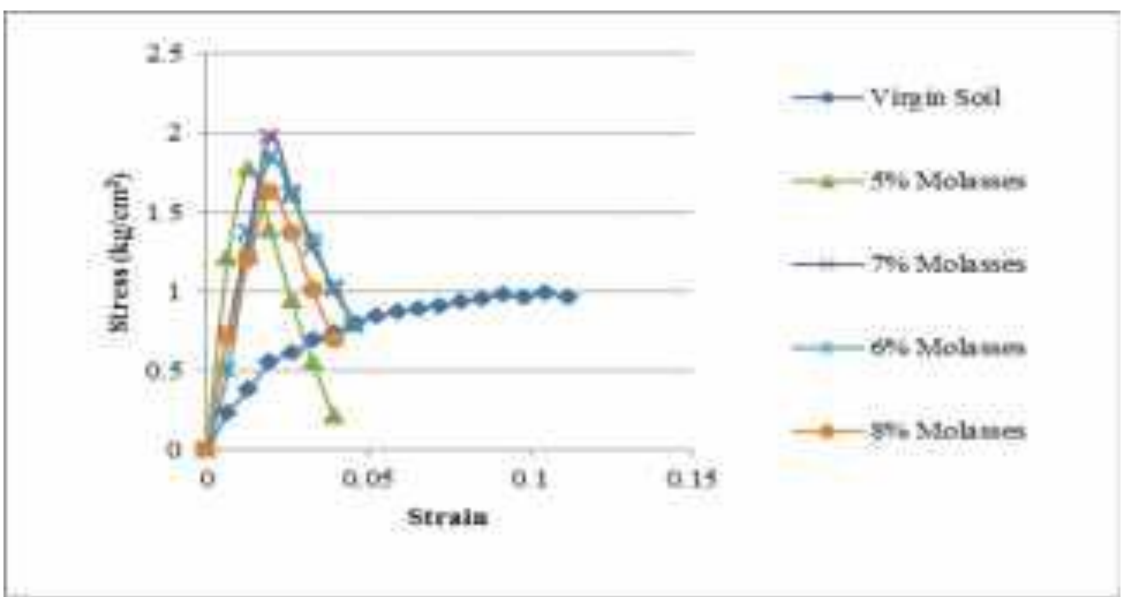


***Figure 2. 3: UCS value for varied % of molasses for soil sample 1 (CI)*(E., Animesh, A.T, G., & A.Abdul, 2015)**

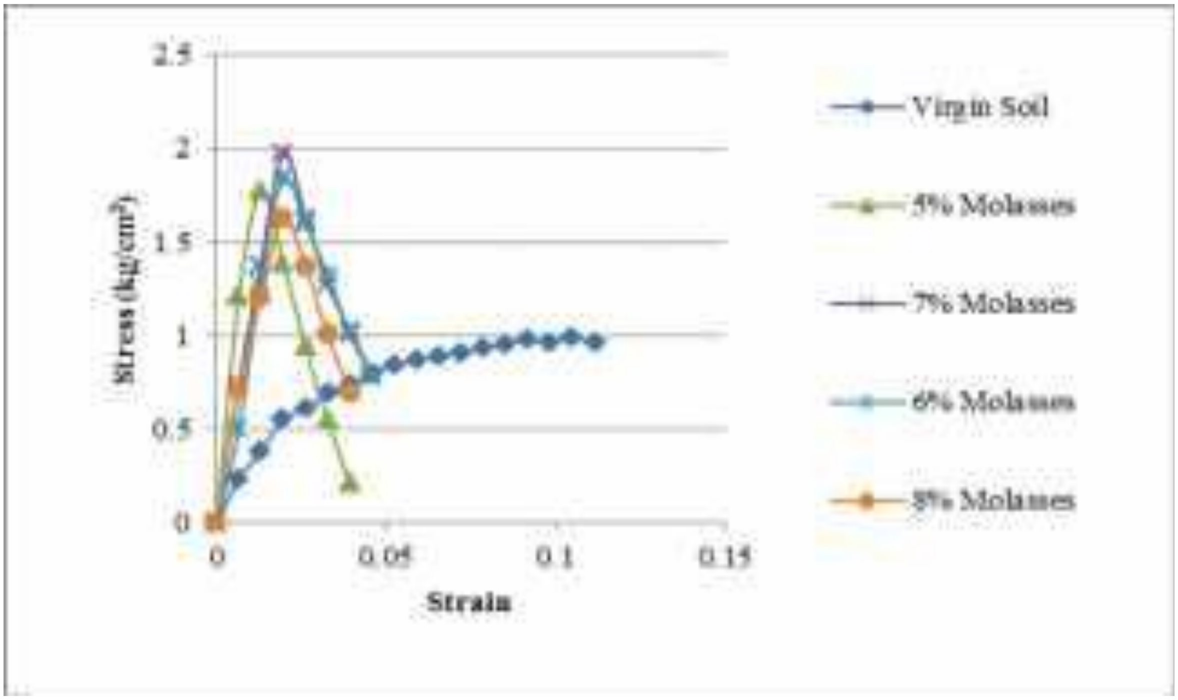


Figure 2. 4: UCS value for varied % of molasses for soil sample** 2 **(CH)**(E., Animesh, A.T, G., & A.Abdul, 2015)**

CBR value of both soils have showed increment .The variation in their value for cured, soaked and un soaked values are given in Table 2.10 below .From the above finding the researchers concluded that. Molasses enhanced soil cohesion (shear strength parameter) which leads to strong cementation of soil particles and hence strength increment of the stabilized soil. (E., Animesh, A.T, G., & A.Abdul, 2015).

Table 2. 10:CBR values of Cl and CH soil for varied molasses content (E., Animesh, A.T, G., & A.Abdul, 2015)

	Molasses	**CBR un soaked**	**CBR curing (3days)**	**CBR soaked (4days)**
Soil Sample 1 (CI)	5%	13.41%	18.01%	2.07%
	6%	13.48%	19.60%	2.16%
	7%	13.90%	20.39%	2.21%
	8%	14.08%	20.98%	2.17%
Soil Sample 2 (CH)	9%	10.60%	14.83%	3.07%
	10%	10.76%	16.01%	3.30%
	11%	11.62%	16.95%	3.48%
	12%	11.21%	16.15%	2.59%

Another research work was done in India to explore binding material which basically prevents dust in road construction and besides improves the strength characteristic of weaker soil. Murem   soft non plastic soil was used. The Atterberg limit test and CBR tests were conducted for the soft –soil treated with molasses proportion of (5%, 5.5%, 6%, 6.5%, 7%, 7.5%) (S.S & S.S, 2010).

Test results from un socked CBR values were evaluated and found to increase by 5.12%, 22.67%, 24.68%, 34.00% 23.12% and 22.02% for the respective increasing molasses content. The maximum increase in CBR is by addition of 6.5% molasses. The compaction curve of the molasses treated soli also shifted to the left of the curve for the soft soil only . The dry densities of the molasses treated sols are greater than the untreated soil. By addition of 6.5% of molasses in soil, the value of maximum dry density of modified soil is increased due to proper rearrangement of modified soil mix and due to improved binding capacity (S.S & S.S, 2010)

Sammy M.Asiago has conducted comparative Study on sub-base road pavement layer in Kenya using molasses and cement as soil stabilizing additives. (SAMMY.M, 2009). The study indicated Molasses, being a sugar, retards the setting of cement by about 4 hours. The results from this study have shown that addition of 1.0% molasses has an improving quality on the strength of cement improved gravel, improving the CBR by about 8.2%. The combination of the increase in strength and delay in setting can be a welcome relief in road construction where there would be a reduction in cost and shorter construction periods respectively (SAMMY.M, 2009).

CHAPTER THREE: DISCRIPTION OF THE STUDY AREA

3. Description Of The Study Area

3.1. Location, Topography And Population Size

Addis Ababa, the capital of Ethiopia, is located in the central highlands of Ethiopia. With an elevation ranging from 2000-2800masl. It is the highest capital in Africa. Its topography is constituted by hills, rivers and streams.

The city is bounded by 9° 00'N and 10° 00'N Latitudes, 37° 30'E and 39° 00'E Longitudes. It is the seat of International Organization (UNDP, UNICEF, ECA, AU, etc.), high level of governmental and Non-governmental organizations.

The city is expanding from time to time horizontally in the expansion areas to the east, south, west, and to a limited extent to the north. The population of the city have been grown from 443,728 in 1961 to 1,167,315 in 1978 and 2,112,737 in 1994 (CSA, 1999).

The Authority publishes regular abstracts, the latest one, The 2007 Population and Housing Census of Ethiopia: Statistical Report for Addis Ababa City Administration in December 2008 estimates population of the city to be 2,739,551 . The study area is located in Nefasilk lafto Sub-city of Addis Ababa city commonly named as "Jemo condominium " which is the third highly populated sub-city with population of 316,283,(CSA, 2008) . The study area is in a close premises to Anbessa Garage. (Figure 3.1 and 3.2). The area is covered by extensive formation of expansive soil. Hence the soil sampling for this study is used from this area. About 300 kg of soil is used for the laboratory test.

Figure3. 1 *:Study area (Jemo Condominium one1) Google Earth Map*

Figure3. 2: Study area (Jemo Condominium one1) Addis Ababa City base Map

3.2. Climate

The Climate of Addis Ababa is WoinaDega type (Daniel, 1977).The Rainfall has unimodal pattern, one distinct rainy and dry season. The dry season is October through May and the wet one is from June to September. The rainfall peak is in August. The long-term mean annual rainfall observed at Addis Ababa Observatory is 1254mm (Berhanu, 2002).
The maximum temperature of Addis Ababa ranges between 20^0c (in wet season) to 25^0c (in dry season), while the minimum falls between 7 - 12^0c in the year. This indicates that daily variation of temperature is highly pronounced.
Wind speed is generally moderate, ranging between 0.5 to 0.9 m/s. The average daily sunshine hours are 9.5 hours in November and December, and far low, 3 hours, in July and August. Pan-evaporation records at Addis Ababa Observatory showed that the average monthly pan-evaporation during dry season (November) is about 180mm and in wet season (July) falls to 75mm(Habtamu, 2011).

3.3. Geology And Geo-Structures

Addis Ababa generally lies in the western margin of the Ethiopian rift and consists of different volcanic rocks that range from basic to acidic composition, belonging to the trap series (Tamiru, Tenalem, Dagnachew, Yirga, Solomon, & Nuri, 2006).
The North and North Eastern area (the Entoto Mountain, the northern and north eastern Addis Ababa) is covered with trachytes, rhyolites, basalts and several episodes of pyroclastic materials of older volcanism occur in the upper part and foothill sides of Entoto ridge. Overlying these, younger basaltic rocks (Addis Ababa Basalt) are found covering the central and Southern part of the city.
Outcrops of ignimbrites north of Bole area (Eastern Addis) and Lideta area (Central Addis) have been observed underlying the Addis Ababa basalt. Younger volcanic of trachy-basalt, trachytes, ignimbrites and tuff belonging to the Wochecha, Furi and Yerer volcanoes are recognized overlying un-conformably on the Addis Ababa basalt in the

western, South-Western and eastern part. The lacustrine formations covers Bole, Lideta, Mekanisa, Akaki-Aba Samuel area .Some alluvial deposit also occur along Akaki river in the southern and south-western part of Addis and minor deposit also occur along Kebena river in the area North-West of Bole.

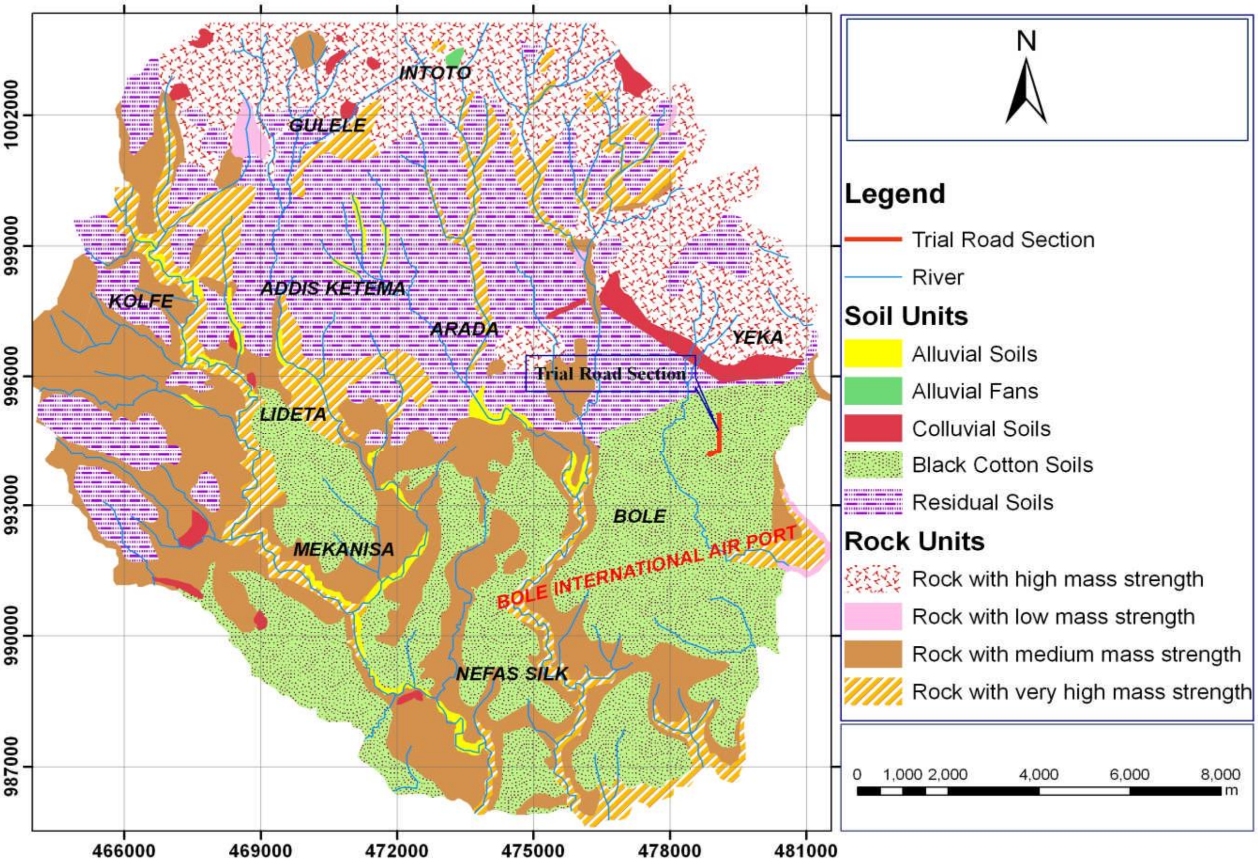


Figure3. 3: Engineering Geological Map of Addis Ababa(**Kebede & Tadesse, 1990)**

CHAPTER FOUR: MATERIAL DISCRIPTION AND LABORATORY METHODS

4. Introduction

4.1. Materials

A. Expansive Soil

The Expansive soil sample used for this research work is collected from Addis Ababa, Nifasilk Lafto Sub City around Jumo Condominium at 9911103.4656N and 469225.9766E from one test pit. The soil is grayish black in color highly plastic clay. Disturbed and undisturbed sample were collected from the test pit at a depth of 3m. Soil sampling from the test pit is shown in Figure 4.1.

Figure 4. 1: soil sampling collected from the test pit

B. Molasses

Molasses was obtained from Metehara sugar factory which is found in Oromia Regional State at 200 Km distance from Addis Ababa. Samples were taken from the containers of black strap molasses connected to the direct production pipe line which leads to the ethanol plant. To avoid spoil and contamination due atmospheric air and water, the cover of the plastic containers are tightly closed and placed under cool shelter.

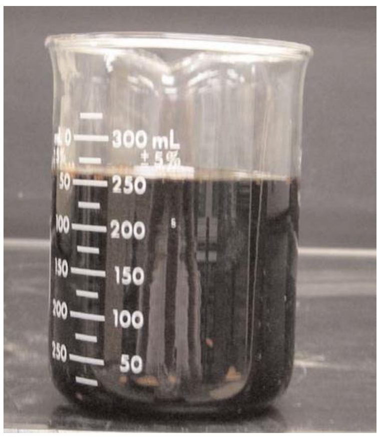


Figure 4. 2: Molasses sampled from Metehara Sugar factory

4.2. Sample Preparation

Prior to any laboratory tests and sample treatment with the molasses; the samples were prepared in accordance with the method described in AASHTO T87-86. The moist samples were properly air dried then soil boulders were pulverized using rubber covered mallet and quartered to get representative samples. For the uniform soil samples, samples were prepared by :- No 40 sieve (0.425mm) for Atterberg limits and indices and free swell tests; No 4 sieve (4.75mm) for compaction , Unconfined Compressive Strength (UCS) , California Bearing Ratio (CBR) and the swell-consolidation test ; for specific gravity , PH and CEC tests No 10 sieve (2.00 mm). Molasses treated samples were covered in plastic bags and properly cured. In this document, the term curing refers to maintaining sample moisture for certain period or air curing.

4.3. Mixing of Soil and Stabilizers

I) **Percentage Rates**

Percentage rates can be specified in many different ways. Traditionally used powder stabilizers are proportioned by weight, commercially available liquid stabilizers are proportioned by volume and some are specified by the manufacturer as DMR and AMR (Alan, Jacqueline, Lynn, & Howard) Dilution mass ratio (DMR) is the mass ratio of concentrated chemical product to water, used to express the product dilution in water prior to soil application. Application mass ratio (AMR) is the mass ratio of concentrated chemical product to oven-dry material in the treated soil.

The most common way to define the percentage rate is based on the dry weight of soil to be treated. For the stabilizers used in this research dosage rates are given as a percentage of the dry weight of the untreated soil. Accordingly, the amount of stabilizer to be used was calculated as follows

$$M_{ST} = p_{ST} * w_S\,(\mathbf{1} - \mathrm{I}\boldsymbol{MC}) \qquad \textbf{\textit{(4.1)}}$$

Where; M_{ST} =mass of stabilizer required in gm
p_{ST} =percentage of stabilizers required
w_S =mass of air-dry soil in gm
IMC=Initial moisture Content of the soil in fraction

II) **Mixing Procedures**

After the necessary soil samples are prepared passing the corresponding sieve No then the molasses to be add is prepared. The molasses is very thick and viscous, calculated amount of molasses based on the dry weight of soil was diluted with measured amount of water. Then the solution is added to the pre-determined amount of soil. Samples were thoroughly hand mixed before further steps. (Fig. 4.3)

Figure 4. 3: Water dilution of the molasses

III) Sample Curing

Molasses treated samples were covered in plastic bags to avoid moisture loss and cured in room temperature to maintain uniform condition. Atterberg limit and free swell samples were covered in plastic and placed in desiccators for 7 and 14 days curing period. Samples for all other testes are properly sealed in plastic bags and left for 7-days for curing.

4.4. Standard Laboratory Testes

i) Grain size analysis

The grain-size analysis is carried out to determine the relative proportions of different grain sizes which makes up a given soil mass. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles larger than 75 μm (retained on the No.200 sieve). Sedimentation process using hydrometer analysis method is carried out to determine the distribution of the finer particle size smaller than 75 μ m (usually silt and clay). After complete grain size analysis of both, the relative proportion of different size groups in each soil sample can be determined. The ranges of size especially the proportion of clay faction is very important in case of expansive soils. The test was conducted according to AASHTO T-11 96(2000).

Soil samples that pass 2mm sieve size have been taken for analysis, after air drying and pulverizing. The analysis is done by wet sieving for analysis of both sieve and hydrometer tests. The sieve and hydrometer analysis test results showed that on average the natural soil contained 1.56% gravel, 1.84% sand, 30.22% silt and 66.38% clay by weight.

Both AASHTO and USCS define grain size ranges (Bowles, 1992) as:

Gravel > 2mm as AASHTO and >4.75mm as per USCS

Sand 0.075-2mm as per AASHTO and 0.075-4.75mm as per USCS

Silt 0.002-0.075mm as per both AASHTO and USCS

Clay < 0.002 mm as per both AASHTO and USCS

After molasses is add to the soil and thoroughly mixed, aggregated /agglomerated soil particles are visually observed. Washing as well as pulverization process will damage the bonding that might be developed by the soil-molasses mix. Hence the grain size analysis with additives was not tested as the washing as well as pulverization process will damage the bonding that might be developed in the soil-molasses mix.

ii) Initial Moisture Content of the Soil (AASHTO T-265)

This test was conducted according to (AASHTO T-256). The oven-drying method was used to determine the moisture contents of the disturbed and undisturbed soil samples. Small representative natural soil specimens obtained from large bulk samples from the site are placed in plastic bags. The samples were then weighed as received and placed in moisture can, oven-dried at 105°C for 24 hours. Final dry weight is determent and the difference in weight was assumed to be the weight of the water driven off during drying,. The difference in weight was divided by the weight of the dry soil, recorded as the initial moisture content for the disturbed natural soil as 58%. Since undisturbed soils are obtained from the side pit , the moisture content is also determent with the same procedure and recorded a natural moisture content of the soil as 60% .

iii) Atterberg Limits Testing

The test is a consistency Limit identification test on the basis of moisture content. It include, the determination of; the liquid limits, plastic limits and the plasticity index for the natural soil and the soil-molasses mixtures. The tests are conducted for uncured, 7 and 14 days cured stabilized soil samples in accordance with AASHTO T89-90 and T90-96 testing procedures.

a. Liquid Limit

The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. Soil sample for liquid limit was air dried and 200g of the material passing through No. 40 sieve (425µm aperture) was obtained and thoroughly mixed on a flat glass plate with water to form a homogeneous paste. A portion of the soil water mixture was then placed in the cup of the Casagrande apparatus leveled off parallel to the base, The liquid limit (LL) is arbitrarily defined as the water content in percent at which pat of soil in Cassagrande's cup cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 blows from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two blows per second. The test is performed for well–spaced out moisture content from the drier to the wetter states. The values of the moisture content determined and the corresponding number of blows is then plotted on a semi–logarithmic graph .The liquid limit is determined as the moisture content corresponding to 25 blows from the graph. The same procedure is also carried out for the soil treated with varied contents of molasses for two curing durations (7 and 14 days).

b. Plastic Limit

The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. It is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling. A portion of the natural soil used for the liquid limit test is retained for the determination of plastic limit. The ball of soil sample is molded between the fingers and rolled between the palms of the hand until it dried adequately. The sample is then approximately divided into two equal parts. Each of the parts is rolled into a thread between the first finger and the thumb. The thread is then rolled between the tip of the fingers of one hand and the glass until the diameter of the thread is reduced to about 3mm and crumbled. The crumbled sample is put in container and the moisture content is determined. The same procedure is also followed for the molasses treated soil samples with and without curing periods.

c. Plasticity Index

The plasticity index of the natural soil and the soil–Molasses mixture is the difference between the liquid limits and their corresponding plastic limits. The plasticity indexes of the samples are calculated as:

PI =LL –PL **(4.2)**

(i) (ii)

Figure 4. 4: sample curing (i), Atterberg limit testing

iv) Shrinkage limit

Shrinkage limit is the maximum water content at which a reduction in water content will not cause decrease in the volume of the soil mass. The samples are first air dried and placed in oven for complete drying. On further drying the water begins to withdraw from the interior of the soil , whose color then changes from dark to light. The surface of the desiccating soil shows a characteristics pattern of shrinkage crack. The finer the particle of the soil, the greater is the amount of shrinkage.

a. **Linear Shrinkages**

Linear shrinkage is a measure of how a sample will reduce in length upon complete drying expressed as a percentage of the original length. A linear shrinkage test was carried out to determine the linear shrinkage characteristics of the natural as well as the stabilized soil, when various percentages of molasses were used and cured for 7- days.

The test was conducted according to Indian standard IS 2718

The linear shrinkage (LS) was calculated as a percentage of the original specimen from the equation,

$$\boldsymbol{Ls}=(\boldsymbol{Lo}-\boldsymbol{LD})/\boldsymbol{LD}*\mathbf{100} \qquad (\mathbf{4}.3).$$

Where; Lo=Original length of the mold and LD=length of dry specimen

(i) (ii) (iii)

Figure 4. 5: linear shrinkage samples before oven drying (i and ii) after oven drying (iii)

b. Volumetric shrinkage

A more accurate method of determination of the shrinkage limit involves measuring the volume of the sample. It represents the amount of water required just to fill all of the voids of a given cohesive soil at its minimum void ratio. It is used to evaluate the shrinkage potential, crack development and swell potential of cohesive soil. The test was conducted as per to **ASTM D 4943)/AASHTO** method**.** A representative sample passing through a 425 μm (No. 40) sieve was obtained and mixed with moisture nearly equal to the liquid limit. Then sample is placed in small pat for 2-days, air dried before oven drying. The moisture-content loss due to drying the soil to a constant volume is determined and subtracted from the initial moisture content to calculate the shrinkage limit. The volume of the dry soil pat is determined from its mass in air and its indicated mass when submerged in mercury. A coating of wax is used to prevent water absorption by the dry soil pat. The test is repeated for 7-day cured molasses treated samples and the corresponding volumetric shrinkages were computed accordingly. (Fig 4.6)

(i)

(ii)

(iii)

(iv)

Figure 4. 6 *Volumetric Shrinkage samples are drying (i and ii) oven dried (iii) and mercury displaced*

v) Free Swell Index Test

Some soils, particularly those clays containing Montmorillonite, tend to increase their volume when their moisture content increases. The free swell test is one of the most frequently used simple tests to estimate the swelling Potential of expansive clay. It is beneficial to carry out this test before further laboratory tests are conducted. Free swell test may be considered as a measurement of volume change in clay upon saturation. This test includes the determination of the free swell index of the natural soil and molasses treated samples in accordance with IS: 2720 (Part 40) 1977 testing procedure.

The test is performed by pouring, 10cc of oven dry soil passing a sieve size of 0.425mm (No. 40), into a 100cc graduated jar filled with water. Samples are left undisturbed for 24 hours. Then the swelled Volume of the soil after the material settles (24hr) is measured. Soils having a free swell value greater than 100% are expansive soils.

Free swell index is computed using Equation (4.4) shown below. The same procedure was followed for the treated cured and uncured soil samples with increment of Molasses content.

$$FS = ((V_f - V_o)/V_o)*100\% \qquad (4.4)$$

Where FS= free swell, %

V_f= soil volume after swelling, cm^3

V_o=volume of dry soil, $10cm^3$

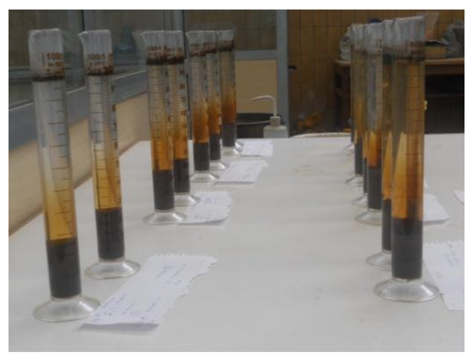


***Figure 4. 7**: (i) oven dried sample before test (ii) samples after final swelling*

vi) Specific gravity

The specific gravity (Gs) of soil is the measure of heaviness of the soil particles. It is defined as the ratio of the mass in air of a given volume of soil particles to the mass in air of an equal volume of gas free distilled water at a stated temperature (20°C). This test was conducted in accordance with AASHTO T100-93 testing procedure. Specific gravity is determined by means of a calibrated pycnometer, by which the mass and temperature of a de-aired soil/distilled water sample is measured. Determination of the specific gravity for the natural soil and the soil molasses mixtures were done. The specific gravity of the soil grains have value in computing the void ratio, degree of saturation and particle size by wet analysis when the unit weight and water content are known. typical values of specific gravity from other works is also presented in Table 4.1 below.

Table 4. 1 Typical values of Addis Ababa expansive soil**(Mesfin, 2005)**

Clay Type	**Range of specific gravity**
Silty clay	2.70-2.88
Black clay	2.77-2.81
Grey Clay	2.80-2.82

vii) Cation exchange capacity tests

Cation Exchange Capacity (CEC) The CEC is the quantity of exchangeable cations required to balance the negative charge on the surface of the clay particles. CEC is expressed in Milli-equivalents per 100 grams of dry clay. CEC is related to clay mineralogy. High CEC values indicate a high surface activity. In general, swell potential increases as the CEC increases.

Mostly the method specified by Bache (Suat & Seracettin, 2010) is used because of its simplicity. The soil samples, which dried at 105 ^{0} C and weighed 45 gm, were saturated to Na + with sodium acetate ($CH_3COONa._3H_2O$) solution (1 N) at PH 8.2. When the samples were fully saturated with Na +, ethanol (95%) was used to wash out excess salt and the Na + cations were replaced with NH_4^+ by using ammonium acetate (CH_3COONH_4) solution (1 N) at pH 7.0. Then, the amount of sodium in the solution was determined by the atomic adsorption method and the cation exchange capacity of the samples was calculate with below equation:

$$CEC\ (meq/100) = \frac{10^4}{W} N_f x D \qquad (4.5)$$

Where; N_f is concentration of sodium ion in extract, D is density coefficient of ammonium acetate solution, and W is oven dry sample weight (g).

In this study, natural and molasses treated soil samples were prepared and brought to Water Works Design and Supervision Enterprise laboratory for the CEC tests .The tests were conducted by well trained experts .The flow chat which summarizes the test procedures followed in the laboratory Appendiex-1 and the values for exchangeable cations, CEC and PH are summarized and attached in Appendix -1 Table-A-3. Although in this research work the mineralogical identification test XRD, X- Ray diffraction was not conducted due to high cost, the CEC values obtained can be used as indication of the type of clay mineral present in the soil. (Water Works laboratory manual)

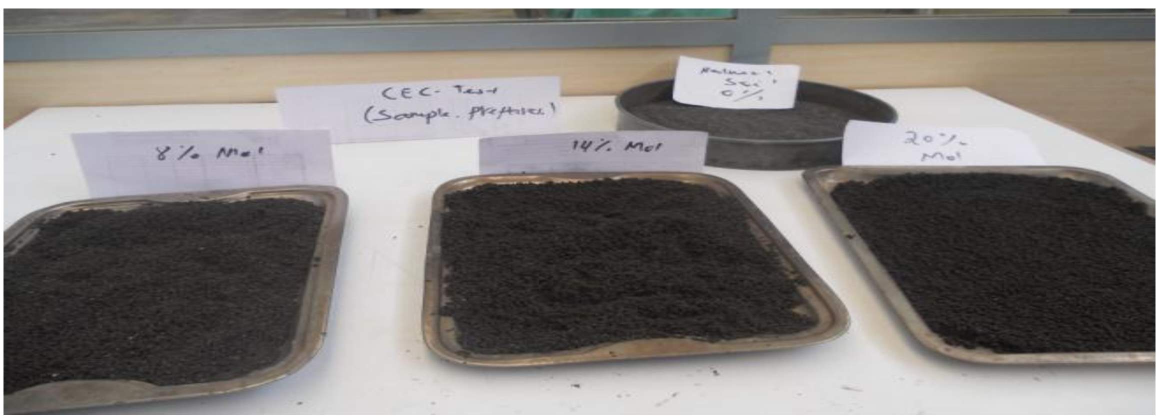


Figure 4. 8 *Sample preparation For CEC test*

viii) Compaction

This test includes the determination of the maximum dry density and the optimum moisture content in accordance with AASHTO T99-94 testing procedures. The test is conducted for both the natural and soil-Molasses mixture. By varying the moisture content for each trial, air dried fresh soil sample of about 2.0 kg are used . Every sample is then compacted into the 944 cubic centimeters of mass; in three layers of approximately equal mass with each layer receiving 25 blows. The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample leveled off at the top of the mould with a straight edge. The mould containing the leveled sample is then weighed to the nearest 1g. One small representative sample is then taken from the middle of compacted soil for the determination of moisture content. The same procedure is repeated until minimum of five sets of samples are taken for moisture content determination. The bulk and dry densities are then calculated for each compacted specimen. The values of the dry densities are plotted against their respective moisture contents; MDD is deduced as the maximum point on the resulting curves. The corresponding value of moisture contents at maximum dry densities, which is deduced from the graph of dry density against moisture content, gives the optimum moisture content OMC.


(i)


(ii)


(iii)


(iv)

Figure 4. 9*Curing of molasses treated compaction sample (i) Testing (ii , iii, iv)*

ix) Unconfined Compression Test

The Unconfined Compression Test determines approximate undrained shear strengths due to the slightly relaxed in situ pressures of the sample. This test is a fast and economical means of approximating the shear strength at shallow depths. A cylindrical soil sample diameter 38mm and height of which is 76mm without any confining pressure, is subjected to an axial compressive load until failure occur.

Tests are performed in accordance with AASHTO T 208 for the natural as well as molasses treated soils. Remolded samples were prepared after the required quantity of soil is determent from previously calculated values of the bulk density and moisture content of the Proctor Tests.

Equation to determine the unconfined compressive strength is given as follows:

$$q_u/A = P \qquad (4.6)$$

q_u = unconfined compressive strength (kPa)
P = Compressive force (kN)
A = cross section area (m^2)
Typical values for cohesive soils of the specified soil types are cited by (Sertse, 2003) and presented here in under.

Very soft: <0.25kg/cm^2 (24kPa)
Soft: 0.25kg/cm^2 to 0.5 kg/cm^2 (24-50kPa)
Medium: 0.5kg/cm^2 to 1.0 kg/cm^2 (50-98kPa)
Stiff: 1.0kg/cm^2 to 2.0 kg/cm^2 (98-196kPa)
Very Stiff : 2.0kg/cm^2 to 4.0 kg/cm^2 (196-392kPa)
Extremely stiff: >4.0kg/cm^2 (329kPa)

The changed average cross sectional area at a particular deformation during the test was calculated using the following equation

$$A = Ao \ / \ 1-\varepsilon \qquad (4.7)$$

Where; A = corrected cross sectional area (m2)
Ao= original cross sectional area (m2)
ε = axial strain (mm/mm), $\varepsilon = \Delta L/L$

The shear strength is defined as half the compressive strength:

$$c= q_u/2 \qquad (4.8)$$

The total quantity of each needed to prepare the required number of test specimens at each prescribed stabilizers percentage of maximum dry unit weight and water content is specified in the Appendices.

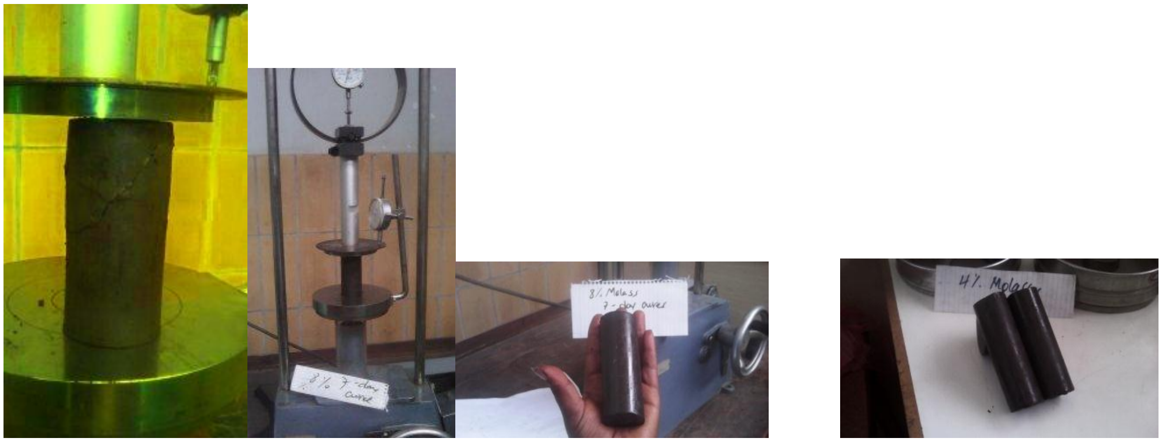


Figure 4. 10 *UCS Test*

x) California Bearing Ratio (CBR) Test

The CBR test measures the Penetration resistance of a soil under controlled moisture and density conditions. The CBR number is used to rate the performance of soils primarily for use as bases and sub grades beneath pavements for roads and air fields. In order to compare the results with previous studies, one point CBR tests were carried according to AASHTO T193-93. To investigate the effect of the additive molasses on the specimens, compacted specimens were given 7 days curing in CBR molds at room temperature as shown in Fig 4.10. During curing period the compacted specimens were subjected to surcharge loads to simulate the overlying load in the actual pavement section. The test is done for soaked and un soaked samples for the natural and molasses treated soils .CBR samples were remolded based on the optimum moisture content value, as determined from proctors test using standard compaction. All CBR test samples are compacted in the molds with standard hammer.

The un soaked CBR molds are directly penetrated after 7 days of curing. But half of the compacted soil samples are soaked for 4 days (96 hours) in a water bath to get the soaked CBR value and the CBR swell of the soil. The CBR swell of the soil is measured by placing the tripod with the dial indicator on the top of the soaked CBR mold in the bath. The initial dial reading of the dial indicator on the soaked CBR mold is taken just after soaking the sample. At the end of 96 hours the final dial reading of the dial indicator is taken hence the swell percentage of the initial sample is given by:

$$Percent\ Swell\ (\text{CBR Swell}) = \frac{Change\ in\ Length\ in\ mm\ during\ soaking\ x100\%}{116.43mm} \quad (4.9)$$

The CBR is obtained as the ratio of load required to protrude a certain depth of penetration of a standard penetration piston into a compacted specimen of the soil at some water content and density of the standard load required to obtain the same depth of penetration on a standard sample of crushed stone. i.e

$$\text{CBR \%} = \frac{\text{Test Load on the sample x 100\%}}{\text{Standard Load on curshed stone}} \quad (4.10)$$

The details of the test are provided in annex 3.

(ı)

(ıı)

(ııı)

Figure 4. 11*: CBR Test ,sample curing (i) , sample soaking (ii) , sample penetration(iii)*

xi) Swell consolidation test/swelling Pressure Tests

The test is done to measure the swelling pressure and swelling potential of the natural as well as the molasses treated soil sample. Swelling pressure is the pressure, which prevents the soil specimen from swelling or that pressure which is necessary to retain the specimen back to its original state (Void ratio, height) after swelling(S.M & Julius K., 2012).

Remolded samples of the natural and soil molasses mixture were prepared by using the corresponding OMC and compacting samples to get the respective MDD of the soil samples as obtained from the proctor tests. The compacted sample is placed in the consolidation ring of diameter 50mm, and height of 20mm, then it is subjected to a vertical pressure of 6.9 kPa water is added to the sample. When swelling of the sample has ceased the vertical stress is increased in increments until it has compressed to its original height .This is commonly termed the zero-volume-change swelling pressure.

The above testing procedure was followed for the evaluation of swelling pressure. The swelling pressure tests were conducted on the treated and natural samples. The corresponding swelling potential of all samples is also computed and specified in % swell. The details of the tests are given in the Annex-2.

Figure 4. 12 *Consolidometer/odometer for swelling pressure measurement.*

CHAPTER FIVE: TEST RESULTS AND DISCUSSIONS

5. Introduction

This chapter presents the laboratory test results and discusses underlying issues with results obtained. The relevant engineering property of the soil is evaluated both for natural and treated/stabilized soil samples separately. The tests include Consistency test :- Atterberg limits (uncured, 7-days cured , 14 days cured The test results of Atterberg limit for the 7 and 14 days cured samples did not show major variations. Hence, only 7 days of curing for other tests is adopted .i.e, , free swell (uncured, 7-days cured) , moisture density relationship /compaction test , the strength tests :-unconfined compressive strength UCS test (uncured, 7-days cured) and California bearing ratio (CBR) , 7- days cured for both Soaked and un-soaked soil samples . In addition, using one dimensional Odometer, swell consolidation test is run on the 7-days cured samples and the natural soil .

5.1. Properties Of Materials Used In The Research Work

5.1.1. Natural Soil

The results of the tests conducted for identification and/or determination of properties of the natural soil pre-Molasses applications are presented in Table 5.1. The soil is grayish black in color. As shown in Figure 5.1 in the particle size distribution curve almost 96.6% of the soil is passing through No. 200 sieve; it exhibits a liquid limit of 108%, a plastic limit of 35% and plasticity index of 73 %. According to Daksan and Rama (1973) Liquid limit less than 35% is low , between 35% and 50% *medium*, between 50% and 70% *high* and greater than 70% *very high* . Therefore, the value for the soil under consideration is 108%, which is *very high*. Based on the USCS soil classification system the soil is CH (high plastic clay) .According to AASHTO the soil falls under the A-7-5 soil class. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material. Results that are related to swelling characteristics of the soil also indicate that the soil is highly expansive clay with a free swell of about 150%. The soil has a maximum dry density of 1.24g/cm^3, optimum moisture content of 35.4%. The UCS value for the remolded sample is 142 (kPa) un-soaked CBR value of 17.5% and soaked CBR value of 0.77%. The swelling pressure and the Swelling potential from the swell consolidation test are 325kPa and 14.1 % respectively.

Table 5. 1: Geotechnical properties of the natural soil

Property	Quantity
Percentage passing No. 200 sieve %	**96.6**
Liquid limit %	**108**
Plastic limit %	**35**
Plasticity index %	**73**
Linear shrinkage %	**11**
Volumetric shrinkage %	**14**
AASHTO soil classification	**A-7-5**
USCS	**CH**
Natural moisture content %	**60.59**
Specific gravity	**2.73**
Free swell %	**150**
Maximum dry density g/cm3	**1.24**
Optimum moisture content %	**35.4**
UCS (kPa)	**142**
Soaked CBR value %	**0.77**
Unsoaked CBR value %	**17.5**
CBR-swell %	**0.08**
Swelling pressure Ps (KPa)	**325**
Swelling potential %	**14.1**
Color **grayish black**	

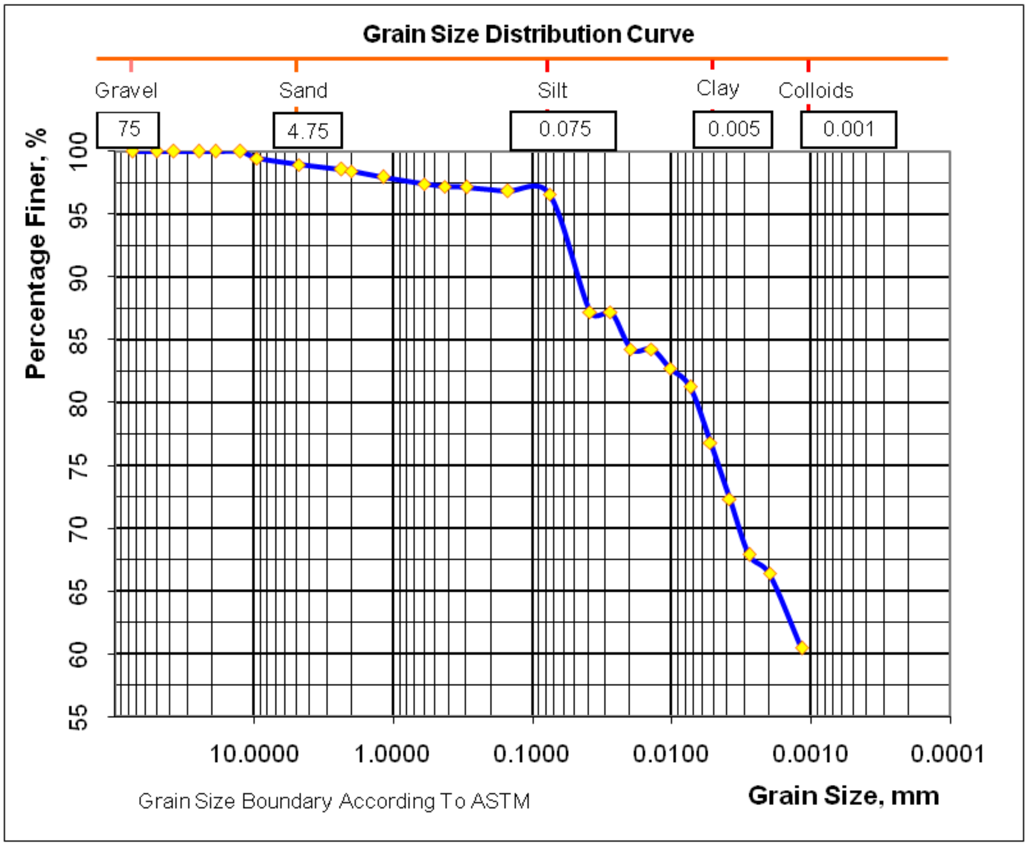


Figure 5. 1particle size Distribution curve of the natural expansive soil

5.1.2. Characteristics of Molasses used.

The quality of Molasses/Black strap is tested in the quality control lab of Methara sugar factory before it is feed in to Ethanol plant. Samples are taken at certain time interval and average values of the 24hr samples result is reported daily. According to the reported values of the molasses sampled for this research (Brix=92 ,Pol= 34.5 , Purity=37.5).This parameters are indicative of the sucrose content and set limitations for sugar contents that should not be passed to the ethanol plant . Chemical and physical tests were conducted in Wenji Agricultural research center to characterize the stabilizer and to identify constituent elements as it is presented in Table 5.2 below. The CaO which is valuable oxide for stabilization is in higher presence than other Oxides this is probably due to the addition of lime to obtain white crystallized Sugar during milling stage of sugar processing . Also as pointed out by (Teshale, 2012), the scale formed in the distillation column of ethanol plant is 63.87% composed of CaO. To assess cause of this scaling, the raw molasses has been characterized for their composition and pH. The result shows that the molasses of Metahara sugar factory is with an average of 2.41% CaO which is abnormally high when compared to world average of 1.5% CaO % molasses.(Teshale, 2012). Other compositions are also cited in the annex part of this document which was done during factory inspection period on feasibility study regarding the production of Ethanol from Molasses and the more recently done researches by Abiy. T and Girma A.2015.

Table 5. 2 Chemical composition of final Molasses samples at Metahara .

Parameter	**Fresh sample/from the production line**
PH	5.48
EC (ms)	32.3
Ash content (%)	20.6
Ca^{+2}(me/l)	32
Mg^{+2}(me/l)	12
Brix (%)	91.1
Rs(%)	10.13

5.2. Effect Of Molasses on stabilized soil

5.2.1. Effect of Molasses on Soil PH and CEC

When Molasses is added to the soil the alkaline media is slightly converted to acidic. The highest reduction is obtained for 8% molasses –soil mixture.

The CEC of the soil is decreased as molasses is added. The highest reduction is obtained for 8% molasses. Most of the researchers state that there is a decrease in CEC of soils treated with additives such as fly ash (Suat & Seracettin, 2010). The reduction of CEC in soil samples was explained by the formation of new phases and flocculated fabric that results in less water absorption potential (Suat & Seracettin, 2010) . Also there is a direct relation between soil CEC values and Liquid limit it can be deduced form the following chart, figure 5.2 developed by the imperial equations relating CEC with LL (Yilmaz, 2001).Since the stabilization mechanism is likely from the cation exchange reactions, CEC test is conducted in water works design supervision soil section laboratory results are summarized here . Details for the results are attached in the annex of this document.

Table 5. 3 CEC and PH results of the natural and the stabilized soil

	(Natural soil)	**Stabilized soil %molasses**		
Parameter	**0%**	**8%**	**14%**	**20%**
PH(H2O)(1;2.5)	7.98	6.68	6.45	6.31
EC(ms/cm)(1;2.5)	0.43	4.23	5.74	7.09
CEC(meq/100gm of soil)	71.79	61.18	63.97	65.49
Sum of cations (meq/100gm of soil)	68.63	55.07	60.31	64.92

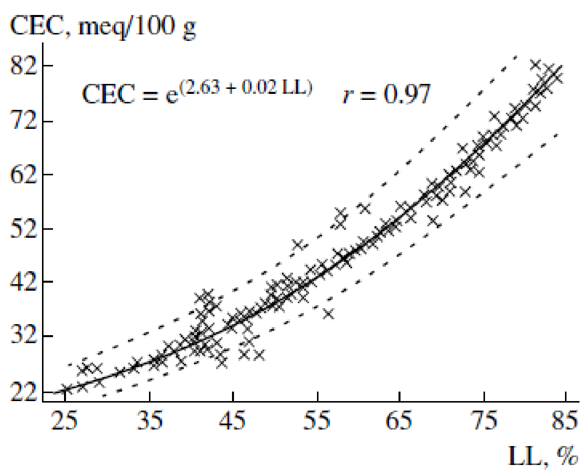


Figure 5. 2 Relationship between CEC and LL values of clayey soils.(Yilmaz, 2001)

5.2.2. Effect Of Molasses On Atterberg Limits

The effect of molasses on the plasticity index of the soil is shown in Figure 5.3 for un cured, 7-days cured and 14 –days cured samples. Generally very slight decrease with increment of molasses content is observed. The variation between cured and uncured samples is insignificant.

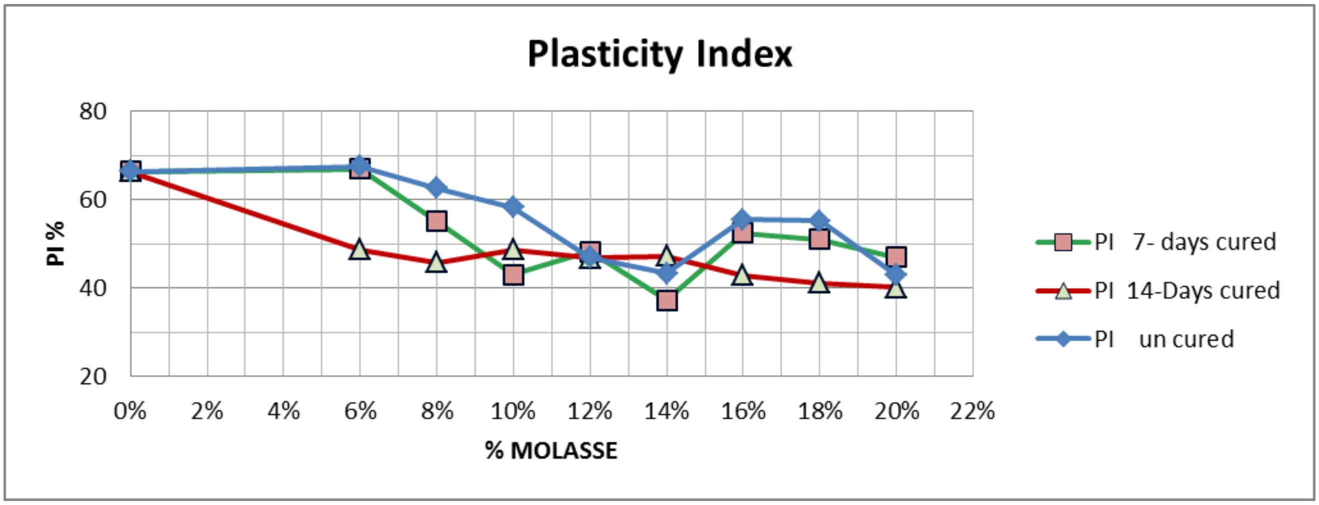


Figure 5. 3:Variation of plasticity index with different molasses content

The slight decrease in plasticity indices are probably due to the reduced surface activites i.e due to floculation and agglomeration of clay particles caused by cation exchange . Details of the Atterberg limit test results are shown in Appendix 3 .

5.2.3. Effect of Molasses on Free index

The effect of molasses on the free swell of the expansive soil both for the cured and uncured samples is insignificant. This is because since the molasses is readily dissolved or diluted in water the agglomerated soil-stabilizer mixture is dispersed and leads to increased specific surface area which facilitates swelling. The results for both cured and uncured stabilized samples are nearly 150% which is the averaged value for the natural expansive soil.

5.2.4. Effect Of Molasses On Soil Compaction Properties

All molasses treated soil samples compaction curve fail to the dry side of the natural soils compaction curve .This is more pronounced for higher percentages. When molasses is added to the soil aggregation and agglomeration takes place which leads more coarse aggregate formation and reduction in clay colloidal content which reduces the moisture uptake of the mix. The treated soil dry densities are also higher than the natural due to adhesive property of molasses. Compaction curve for all samples is summarized in Figure 5.4 below.

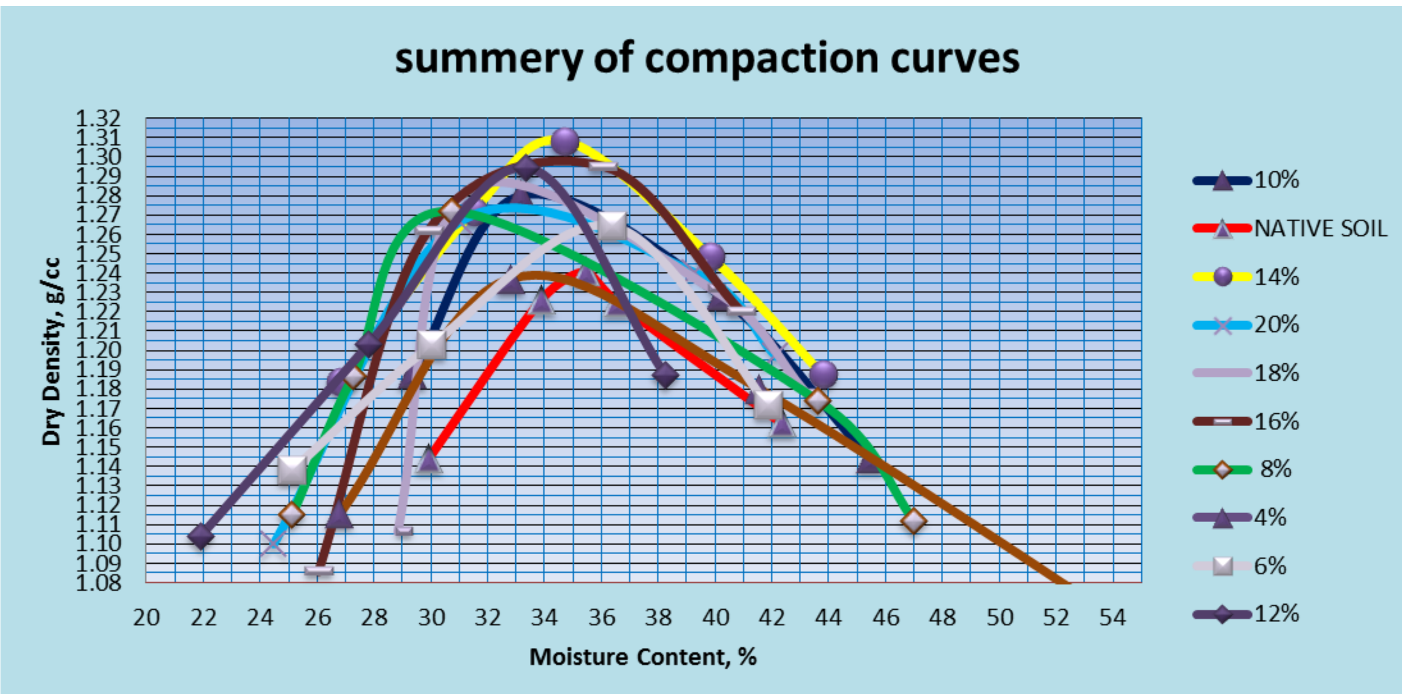


Figure 5. 4 summery of compacted curves.

5.2.4.1. Maximum Dry Densities

Generally, for all percentages of molasses used (from 4% to 20%, at every 2% increment) the dry densities of all compacted samples showed slight increment than for the natural soil dry density .Values of MDD with varied molasses contents is summarized in Figure 5.5. The observed increment is probably due to the fact that:

- As molasses exhibit sticking nature, it adhere soil particles together this gives rise to density increment.
- Since molasses contains resinous substance and other organic constituents the specific gravity is high.

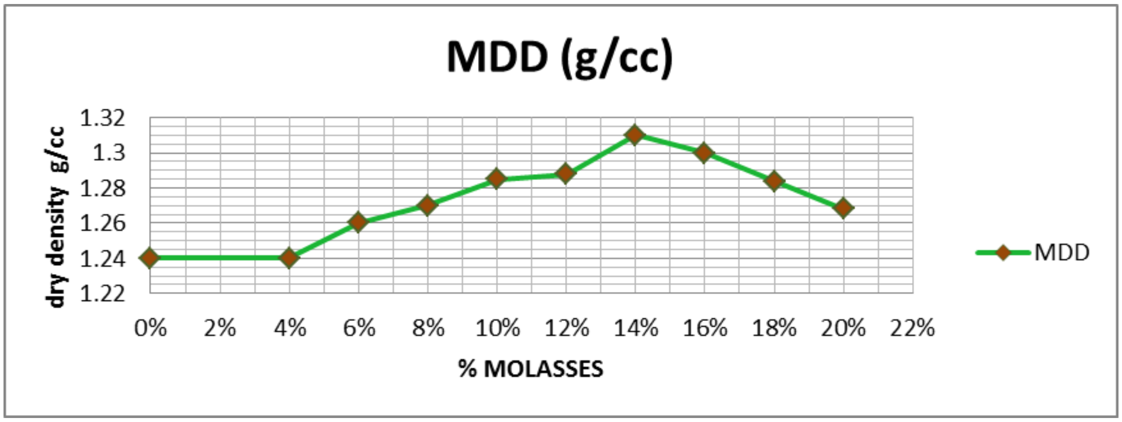


Figure 5. 5:Dry density values for varied contents of molasses.

5.2.4.2. Optimum Moisture Content

Generally, for all percentages of molasses used (from 4% to 20%, at every 2% increment) the optimum moisture contents' of all compacted samples fall to the dry side of compaction curve of the natural soil. This may be attributed to the aggregation of clay particles to form coarser size as molasses is added to the soil. Especially for higher percentages the difference is significant (3.4% and 2.9% for 18% and 20% molasses contents respectively. It was observed that the 8% molasses contents result in reduced OMC values than other percentages. As Molasses is liquid stabilizer the moisture content of the higher percentages molasses itself is nearly adequate to lubricate soil particles and facilitate water intrusion in the soils pore space resulting in higher OMC values. The results are summarized in Figure 5.6 bellow.

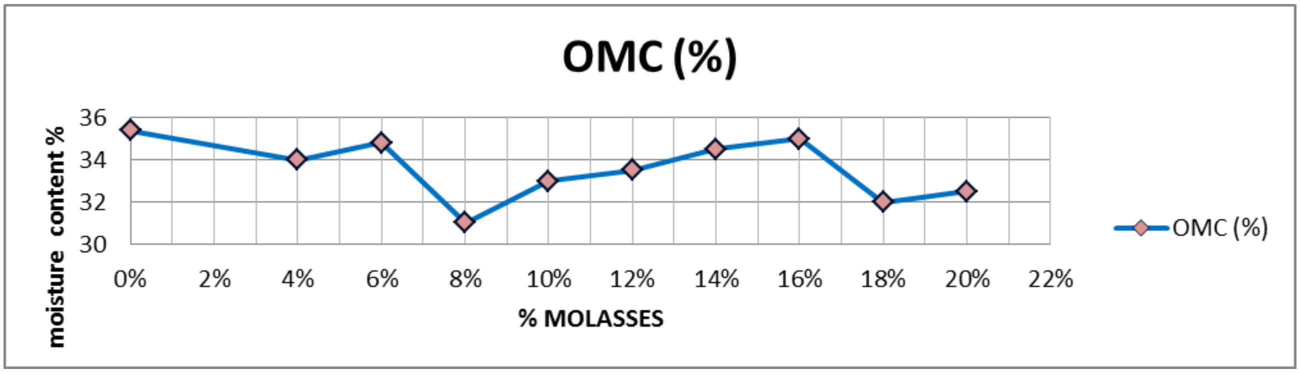


Figure 5. 6: Optimum moisture contents varied percentages of molasses.

5.2.5. Effect Of Molasses On Unconfined Compressive Strength

The variation between the UCS values of the cured and uncured soil samples is insignificant. For the uncured samples, it started with 182 kPa for the 4% molasses and increased to its pick value, 245kPa for the 8% molasses then drops to 109kPa for the 20% molasses contents.

For the cured samples, it started with 150 kPa for the 4% molasses and increased to its pick value, 289 kPa for the 8% molasses then drops to 118kPa for the 20% molasses contents. The values are summarized in figure 5.7 below. The soil treated with molasses exhibit ductile mode of failure. This is markedly observed for higher molasses contents, beyond 12% molasses. The natural soil sample has the lowest strain 3.68% and the treated samples strain value ranges from 5.26% to 8.16% for the un-cured samples and it ranges from 4.87% to 8.16% for the 7-day cured samples. As molasses content increase it tends to coat soil particles and put them apart rather than adhering to each other. This lubrication effect lead to strength decrement for higher percent molasses beyond 8% as can be observed in figure 5.8 and table 5.4 for uncured samples and figure 5.9 and table 5.5 for 7-day cured soil samples.

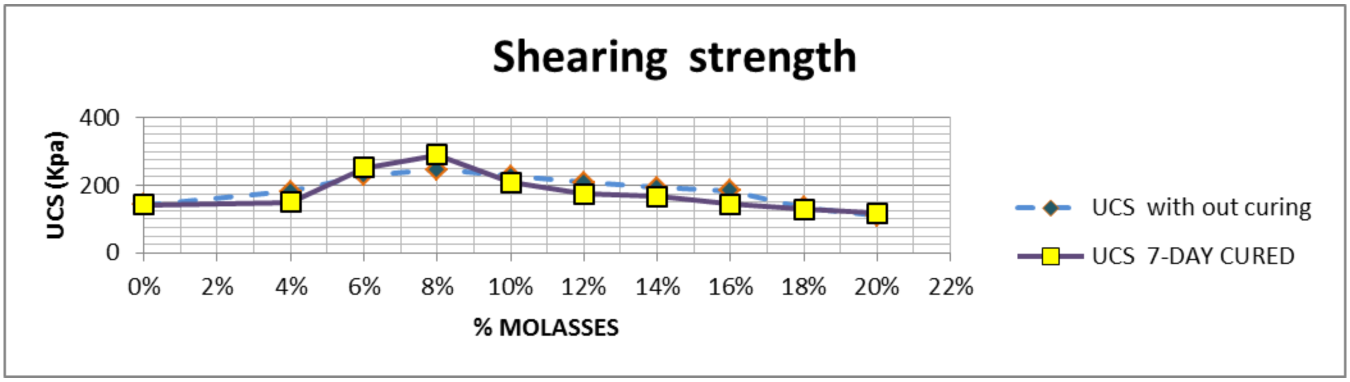


Figure 5. 7 :Summarized UCS values for varied percentages of molasses

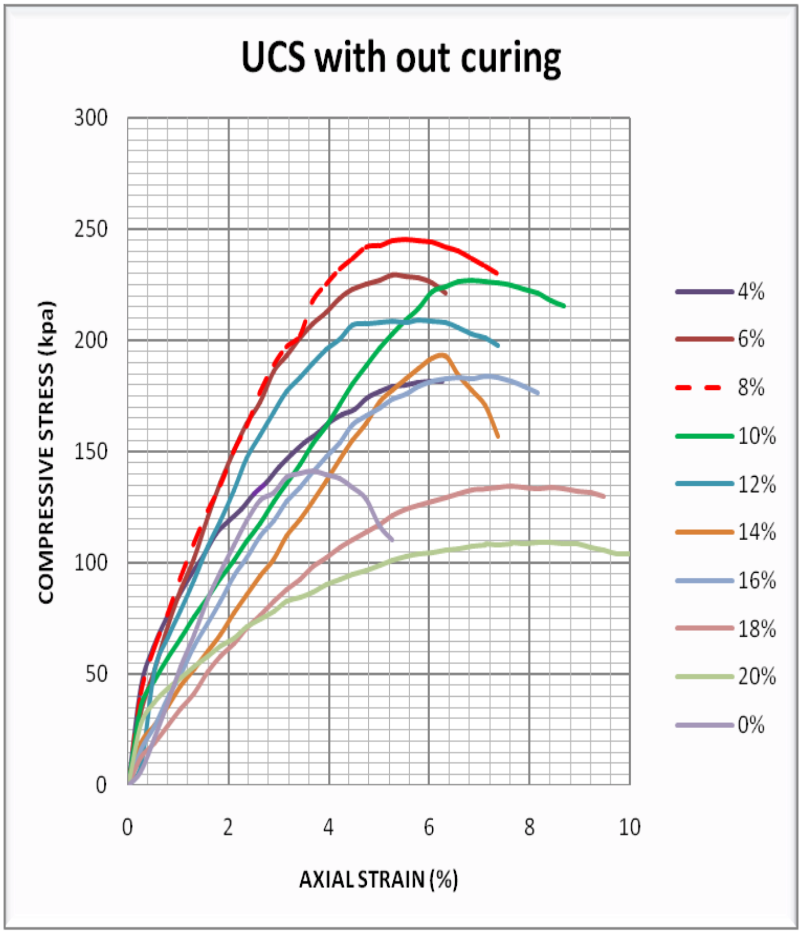
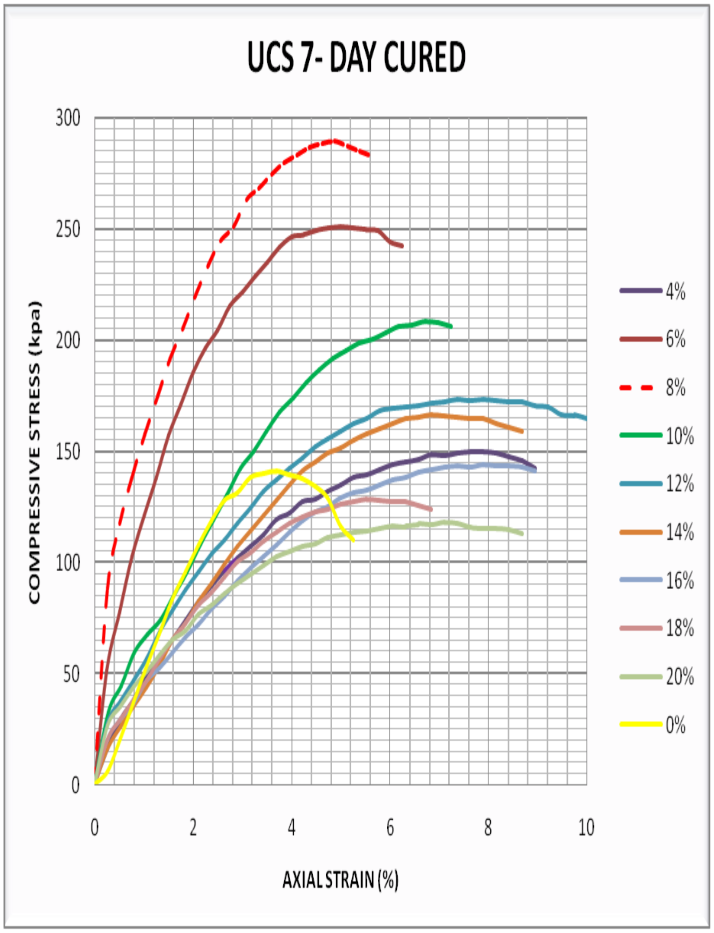


Figure 5. 8 *UCS curves for un-cured soil samples*

% Stabilizer	Unconfined Compressive Strength (qu) : kPa
4	**182**
6	**229**
8	**245**
10	**227**
12	**209**
14	**193**
16	**184**
18	**134**
20	**109**

Table 5. 4 UCS values for un cured soil samples



% Stabilizer	Unconfined Compressive Strength (qu) : kPa
4	**150**
6	**251**
8	**289**
10	**208**
12	**173**
14	**166**
16	**144**
18	**128**
20	**118**

Table 5. 5 UCS values for cured soil samples

Figure 5. 9 UCS curves for 7- day cured soil samples

5.2.6. Effect Of Molasses On California Bearing Ratio

Effect of molasses on CBR values has showed reasonable variation unlike the strength test UCS. This is especially true for the un-soaked soil samples .The smallest soaked CBR value is 0.77% which is for the natural soil and the largest value is 6.93% which is the value for 8% Stabilized soil. Similarly the pick value for the un-soaked CBR is 26.19 % for the 8% molasses treated sample. Detailed information is included in Fig 5.10 and Table 5.6 and Appendix 3.0.

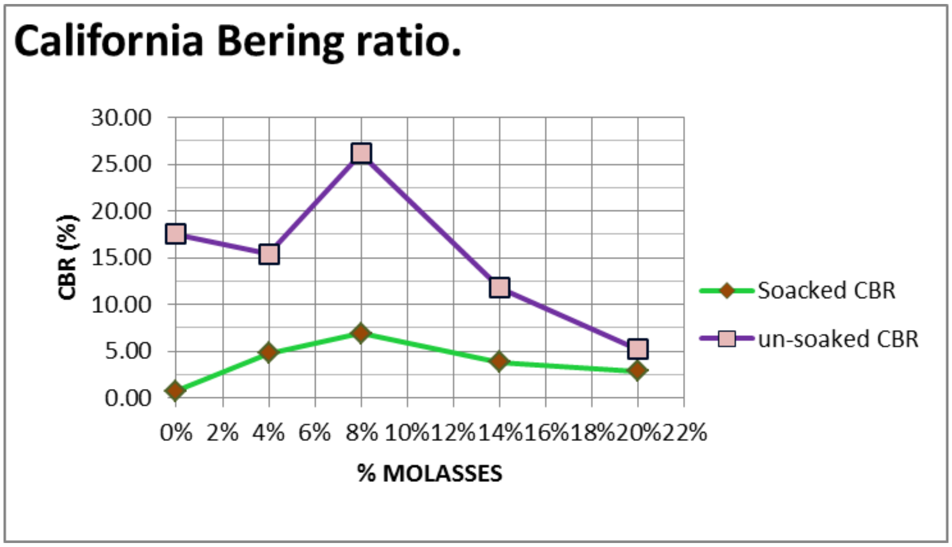


Figure 5. 10: Summery of California bearing ratio for different molasses content

Table 5. 6 summery of swell CBR values for varied molasses content

Soacked CBR Tests		un-Soacked CBR Tests
CBR Value (%)	**CBR Swell (%)**	**CBR Value (%)**
0.77	0.08	17.52
4.81	0.01	15.4
6.93	0.01	26.19
3.85	0.03	11.74
2.89	0.01	5.2

Table 5. 7: Summery Of Soaked CBR Value

Stabilizer	STANDARD LOAD(kN)		LOAD (kN)		CBR (%)		Swell CBR (%)
%	2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
0%	13.35	20	0.10	0.15	0.77	0.77	0.08
4%	13.35	20	0.64	7.20	4.81	3.61	0.01
8%	13.35	20	0.93	1.08	6.93	5.42	0.01
14%	13.35	20	0.51	0.75	3.85	3.74	0.03
20%	13.35	20	0.39	0.51	2.89	3.74	0.01

Table 5. 8: Summery of un -soaked CBR value

Stabilizer	STANDARD LOAD(kN)		LOAD (kN)		CBR (%)	
%	2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm
0%	13.35	20	2.34	2.44	17.52	12.25
4%	13.35	20	2.06	2.37	15.40	11.87
8%	13.35	20	3.50	3.91	26.19	19.61
14%	13.35	20	1.57	2.08	11.74	10.45
20%	13.35	20	0.69	0.90	5.20	4.51

5.2.7. Effect Of Molasses On Swelling Pressure and Swelling Potentials

5.2.7.1. Effect Of Molasses On Swelling Pressure

The swelling pressure for the natural soil is 325 kPa. For the molasses treated samples it varies from 87.5kPa to 300kPa for different molasses contents for nearly similar moisture contents and dry densities. The drop in swelling pressure indicates chemical reaction, cation exchange reaction took place during curing, compaction prior to consolidation in the odometer.

5.2.7.2. Effect Of Molasses On Swelling Potentials

As mentioned above, the free swell values for molasses treated soils didn't show significant variation this is because as molasses is moisture sensitive the molasses is washed out by water and is seen de coloring the suspension in the 100ml free swell bottle

.But for the Swell –Consolidation test slight reduction in the swelling potential is observed for all molasses treated 7-day cured and compacted soil samples during swelling duration(3-days) .detailed information is included in the Appendix 3.

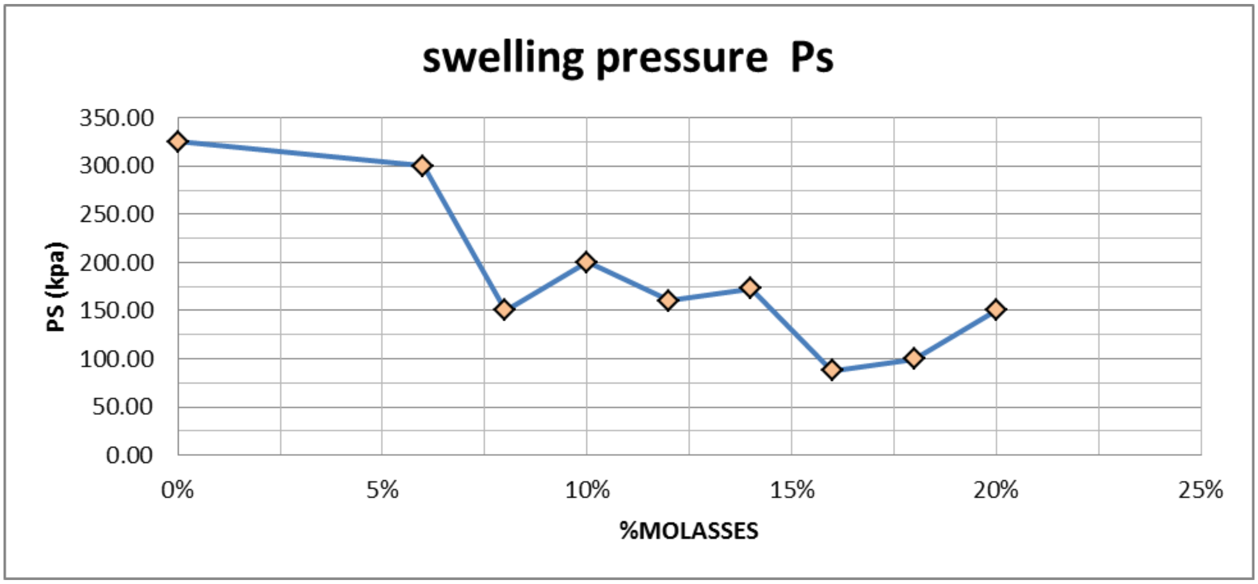


Figure 5. 11 Swelling pressures for varied content of molasses

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6. Conclusion And Recommendation

6.1. Conclusion

The following conclusions are drawn on the basis of the test results and synthesis of the research work within the scope of the study.

- As it can be deduced from the geotechnical test results of the natural soil, the engineering properties of the expansive clay soil under study are not suitable to be used as a sub-grade and/or embankment fill material unless its undesirable properties are improved.
- The inorganic elements especially the CaO which is present in the sugar cane molasses used for the study is active in causing a chemical reaction involving cation exchange with the expansive clay soil during stabilization.
- Addition of molasses changes the slightly alkaline soil to slightly acidic as could be observed from the PH results.
- The CEC values are reduced up on addition of molasses to soil. This is also true for LL value as there is direct relation b/n CEC and the soil LL.
- In soils treated with molasses, 8% by dry weight of the soil was found to be optimum stabilizer content. The pick values for strength tests: UCS, CBR are at this percentage. The minimum values or the decrease in swelling potentials and swelling pressures is also obtained for soils mixtures prepared at 12% molasses by dry weight of the soil.
- Results obtained from the strength tests; UCS and CBR of molasses treated samples vary because: for the UCS tests, molasses treated soils are cured in plastic bag for 7-dayes in loosen state and then compacted before subsequent tests. During compaction the molasses soil aggregation and agglomeration is disturbed and reduced the strength result. This is also the reason for UCS test results not showing much variation for the cured and uncured samples. But for the CBR testes, after soil is mixed with molasses it is immediately compacted in CBR mold, covered in plastic bag and left for 7-dayes in compacted state before testing. Since the molasses –soil aggregation is not disturbed higher strength results were obtained.
- The above incident shows that the usual laboratory test procedures that disturbed molasses – soil aggregation could not directly be applied to molasses treated soils

if best result is to be obtained. Hence more refined test procedures should be devised.

- Generally curing has low effect on engineering properties of the stabilized soil.
- The plasticity index is slightly reduced with increase in Molasses content but increased beyond 14% molasses.
- The optimum moisture content reduced and the maximum dry densities values increased with increment of molasses content.
- Molasses readily dilute in water, this simplifies application of the stabilizer during constriction. But, since it is easily washed by water, soil particles that were flocculated and agglomerated due to an adhesive property of molasses got disintegrated. Since agglomerated /coarser particles which reduced the colloidal content of the soil are reduced to finer particle, losses in strength came to effect ..

- From the above scenario, Molasses could be used as standalone soil stabilizer, provided the necessary protection form water intrusion is made. For example it could be used to improve poor expansive subgrade .underlying sub-base with properly shield shoulders.

6.2. Recommendation

- Since slight modification and minor improvement in the engineering properties of the natural expansive soil is observed, molasses might be used along with other stabilizers. Also as it is supported by some literatures molasses retards the immediate setting of cement .This facilitates through mixing with the soil resulting in improved workability. So molasses can be used as an admixture to cement during soil stabilization.
- To study the effect of seasonal variation on molasses and or molasses –cement stabilized soil, Filed geotechnical tasted on carefully identified locations of expansive soil trial section should be carried out.

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Appendices

Appendix- 1: Chemical And Physical Tests

Table A. 1.1:Chemical composition of final molasses samples at Metehara

Parameter	Fresh	Pit
PH $_{(H2O)}$(1:10)	5.9	4.9
EC(dS/m)(1:10)	15.8	17.6
Ash content (%)	13.2	6.54
Total P(%) as P_2O_5	0.3	0.1
Total N(%)	0.68	0.15
Ca (%) as CaO	1.36	0.69
Mg (%) as MgO	0.64	0.32
Na (%) as Na_2O	0.1	0.1
K(%) as K_2O	5.13	2.65
Other parameters		
Brix (%)	81.1	61.3
Mc (%)	18.89	38.08
Rs (%)	16.19	48.52
S (%)	37.05	1.02

**Abiy Tesfaye and Girma Abiyehu (2005 E.C) Composition and uses of byproduct of methara Sugar factory .Ethiopian Sugar development Agency, Research Directorate, Wenji.

Table A. 2.1:Chemical composition of final molasses samples at Metehara

SI/ETH/79/803

ANNEX 10

ANALYSES OF MOLASSES FROM METEHARA, WONJI AND SHOA SUGAR FACTORIES

The cane molasses samples were obtained from the sugar factories through Ethiopian Sugar Corporation's main office in Addis Ababa, Ethiopia.

The analyses were performed by Oy Alko Abis Central Laboratory, Fermentation Dept. in Helsinki, Finland.

RESULTS

	Metehara (5.3.1980)	Wonji (March 1980)	Shoa (13.3.1980)
Brix, °	90	90	90
pH	5,5	5,8	5,6
Invert sugar (Bertrand), %	18,3	14,2	12,9
Total sugar as sucrose (Clerget + Bertrand), %	55,6	51,2	52,9
of which sucrose, %	38,2	37,7	40,6
invert sugar (as sucrose), %	17,4	13,5	12,3
Nonfermentable sugars, %	5,1	2,9	2,4
Volatile acide as acetic acid, %	0,33	0,36	0,34
Nitrogen, N, %	0,47	0,35	0,37
Phosphorus, P, %	0,02	0,03	0,03
Sodium, Na, mg/kg	226	2 000	870
Potassium, K, mg/kg	44 600	58 800	55700
Calcium, Ca, mg/kg	9 725	8 575	8825
Magnesium, Mg, mg/kg	1 210	1 920	1750
Nitrite, NO_2, mg/kg	less than 3	less than 3	less than 3
Ash (sulphated), %	14,0	17,7	16,5
Water (Fisher), %	20,9	21,5	21,5

***source : Feasibility study on the production of ethanol from molasses in Ethiopia (UNIDO contract no 80/33.

Table A. 3: Chemical and Physical test results of the molasses for ethanol production

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Sample type	Parameters (%)								
	Brix	Pol	Sucrose %	Ash %	Ca+2 me/l	Mg+2 me/l	Red. Sugar %	PH	Ec ms
Molasses	91.10	14.29	4.18	20.60	32	12	10.13	5.48	32.3
Vinasse	-	-	-	2.63	90	76	-	4.14	37.2

Conducted by

Checked by

Approved by

Table A. 4: CEC test procedures followed at water works laboratory

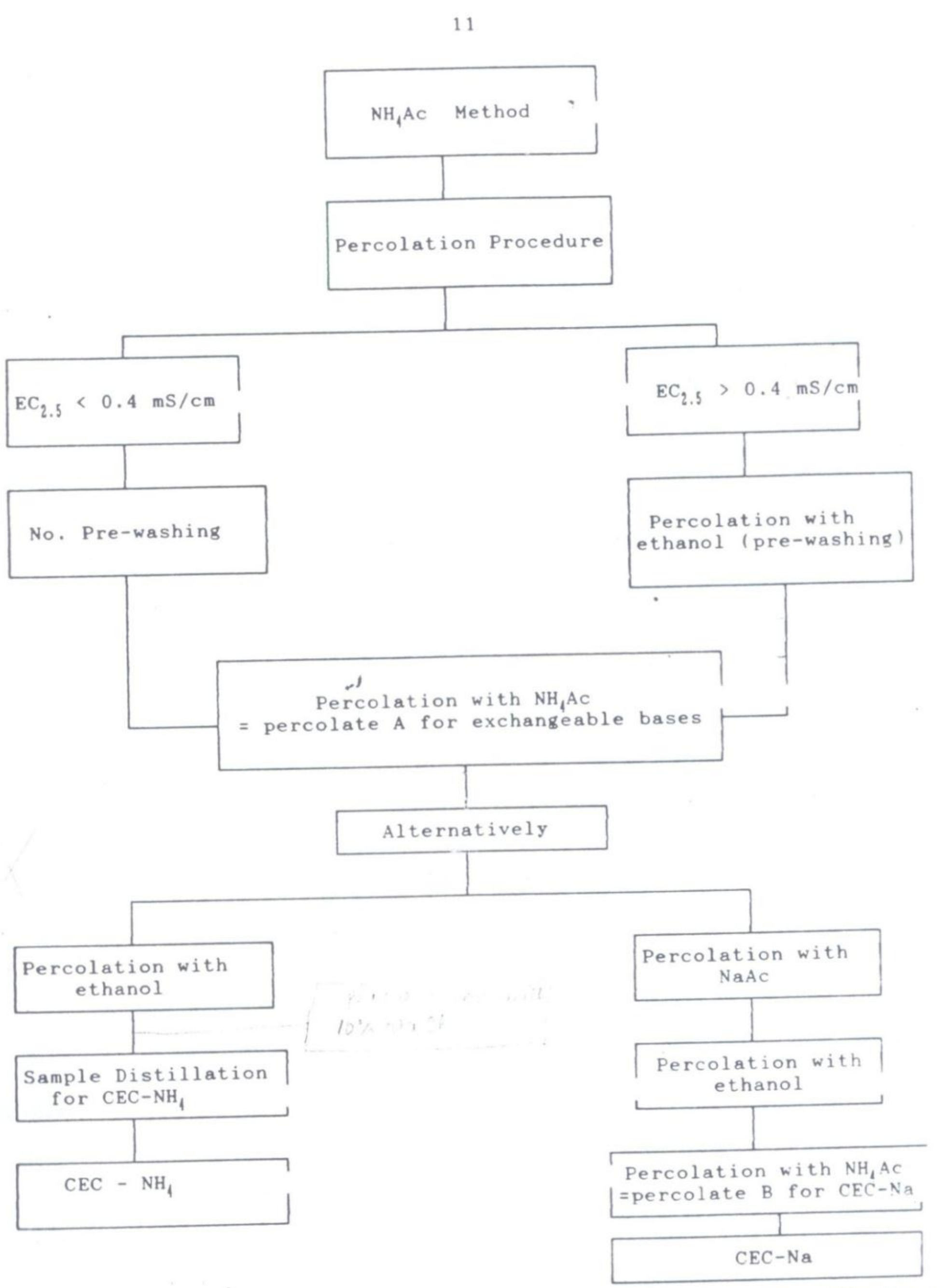

Fig. 9-1 Flow diagram of ammonium acetate method for exchangeable bases and CEC.

Table A. 5: CEC and PH test results for the treated and natural soil samples

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Water Works Design and Supervision Enterprise
Laboratory Service Sub Process

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Soil Fertility Section

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Client:- Gadise Tesma

Test Method: **Ammonium Acetate & Instrumental**

LABORATORY NUMBER	331/08	332/08	333/08	334/08			
Project	Soil Stabilization	Soil Stabilization	Soil Stabilization	Soil Stabilization			
% Stabilization	0 (Natural Soil)	8	14	20			
Received Date	15/10/15	15/10/15	15/10/15	15/10/15			
P^H-H_2O (1:2.5)	7.98	6.68	6.45	6.31			
P^H-KCL (1:2.5)	7.20	6.00	5.91	5.85			
EC(ms/cm) (1:2.5)	0.43	4.23	5.74	7.09			
Exch.Na(meq/100gm of soil)	1.68	1.41	1.54	1.64			
Exch.K(meq/100 gm of soil))	0.45	4.24	6.27	8.54			
Exch.Ca(meq/100 gm of soil)	49.65	36.95	39.37	41.16			
Exch.Mg(meq/100 gm of soil)	16.85	12.46	13.12	13.58			
CEC(meq/100 gm of soil)	71.79	61.18	63.97	65.49			
Sum of Cations (meq/100gm of soil)	68.63	55.07	60.31	64.92			
Exchangeable Sodium %(ESP)	2.34	2.31	2.40	2.51			

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Appendixes-2: Mix Proportion

Table B. 1 : Mix-Design for consistency limits of Soil-Molasses Mixtures (ATTERBERG Tests)

Test (Atterberg)	Mass of air-dry material (passing through sieve No.40 (0.425mm)in (gm)	Initial moisture (IMC %)	Mass of oven-dry material (passing through sieve No.40(0.425mm) in (gm)	OMC(%)	Percentage of Stabilizer Required	Mass of Stabilizers Required in gm	Volume of Water to dilute the viscose molasses (ml)
					Molasses (%)	Molasses (gm)	
	A	B	C=A*B		E	F=C*E	G=10%A
6% Molasses	500.00	8.00	460.00	34.80	6.00%	**27.60**	50.00
8% Molasses	500.00	8.00	460.00	31.0	8.00%	**36.80**	50.00
10% Molasses	500.00	8.00	460.00	33.0	10.00%	**46.00**	50.00
12% Molasses	500.00	8.00	460.00	33.5	12.00%	**55.20**	50.00
14% Molasses	500.00	8.00	460.00	34.5	14.00%	**64.40**	50.00
16% Molasses	500.00	8.00	460.00	35.0	16.00%	**73.60**	50.00
18% Molasses	500.00	8.00	460.00	32.0	18.00%	**82.80**	50.00
20% Molasses	500.00	8.00	460.00	32.5	20.00%	**92.00**	50.00

1

Table B. 2 Mix-Design for Moisture Density Relations of Soil-Molasses Mixtures (Proctor Tests)

Test (PROCTOR)	Amount of Air Dried Soil Required in Kg passed through sieve No.4 (4.75mm)	Initial moisture (IMC %)	Mass of Water in Air Dried Soil in Kg	Amount of Oven Dried Soil Required in Kg	Molasses % (% of Oven Dried Soil)	Molasses Required in kg	Molasses required in gm	Volume of Water to dilute the viscose molasses (ml)
	A	B	C=A*B	D=A-C	E	F=D*E	G=F*1000	H=10%A
6% Molasses	12.00	8.05%	0.97	11.03	6.00%	0.66	**662.04**	1,200.00
8% Molasses	12.00	8.05%	0.97	11.03	8.00%	0.88	**882.72**	1,200.00
10% Molasses	12.00	8.05%	0.97	11.03	10.00%	1.10	**1,103.40**	1,200.00
12% Molasses	12.00	8.05%	0.97	11.03	12.00%	1.32	**1,324.08**	1,200.00
14% Molasses	12.00	8.05%	0.97	11.03	14.00%	1.54	**1,544.76**	1,200.00
16% Molasses	12.00	8.05%	0.97	11.03	16.00%	1.77	**1,765.44**	1,200.00
18% Molasses	12.00	8.05%	0.97	11.03	18.00%	1.99	**1,986.12**	1,200.00
20% Molasses	12.00	8.05%	0.97	11.03	20.00%	2.21	**2,206.80**	1,200.00

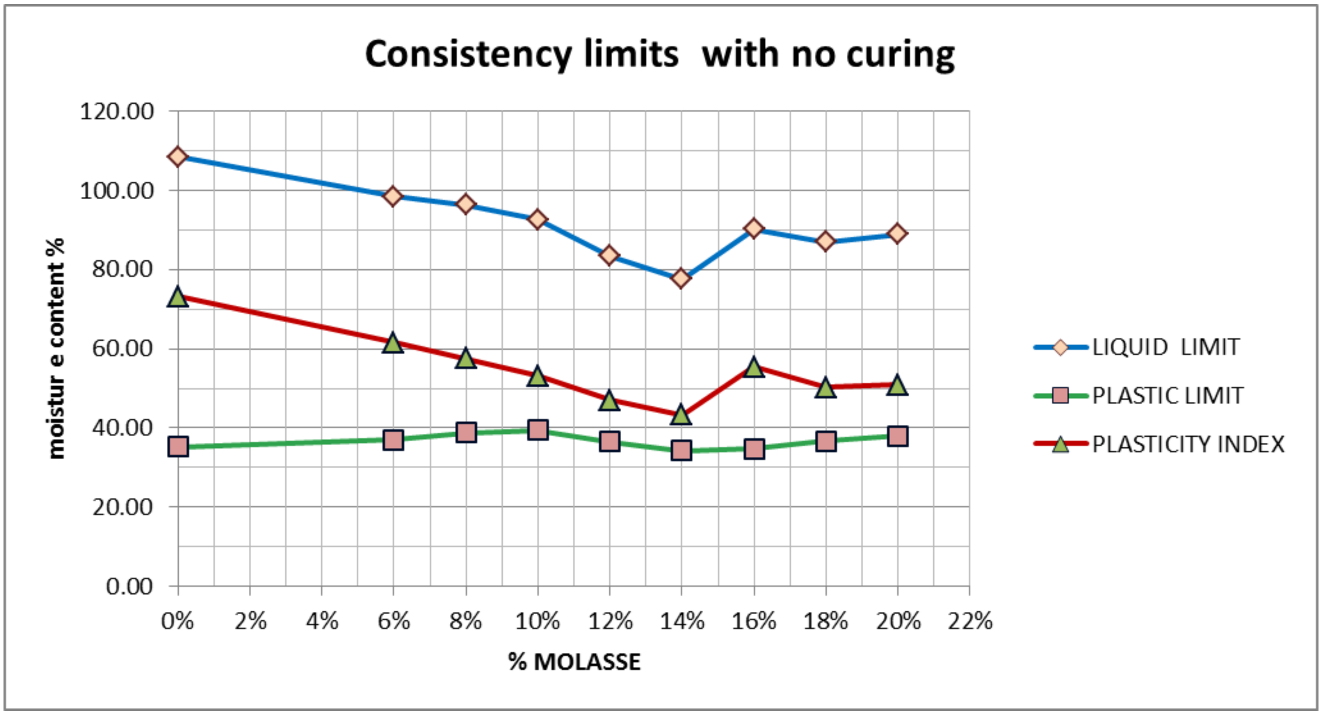
Table B. 3 Mix-Design for Unconfined Compressive Strength of Soil-Molasses Mixtures (UCS Tests)

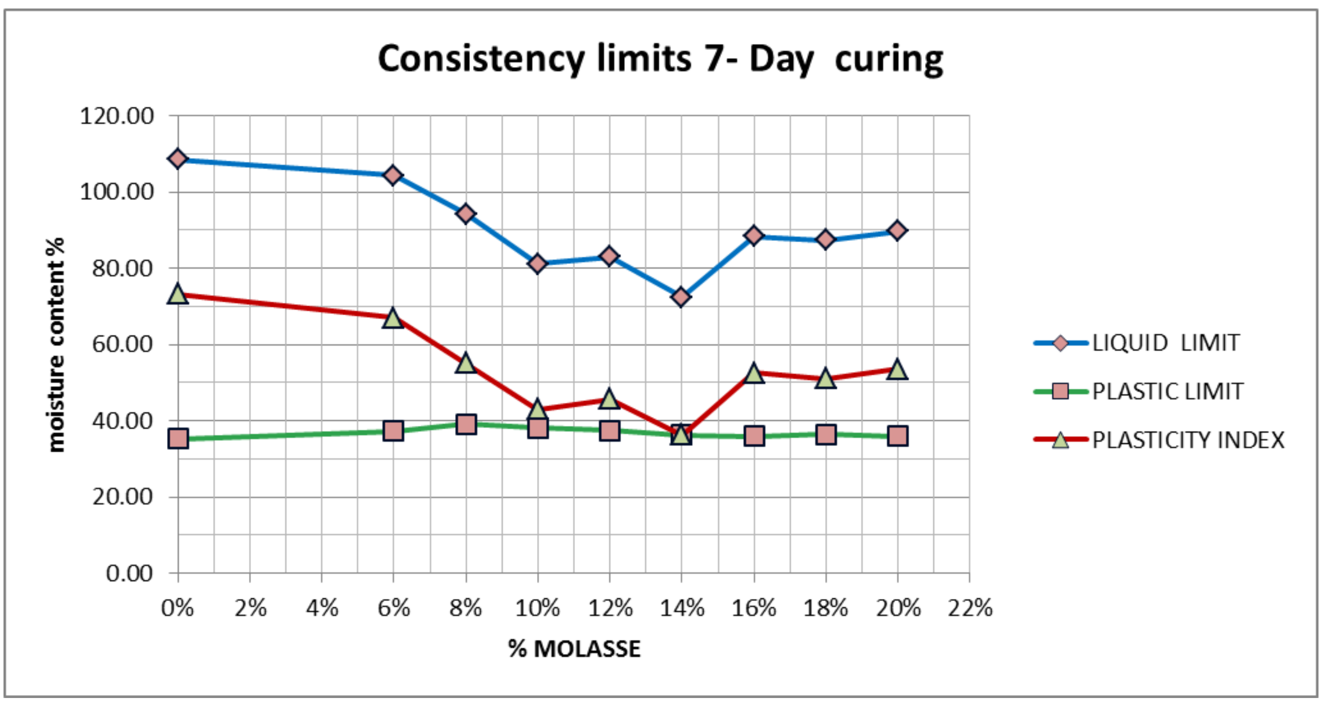
Test (UCS)	Mass of air-dry material (passing through sieve No.4 (4.75mm) in (gm)	Initial moisture (IMC %)	Mass of oven-dry material (passing through sieve No.4(4.75mm) in (gm)	OMC(%)	Percentage of Stabilizer Required	Mass of Stabilizers Required in gm	Volume of Water to dilute the viscose molasses (ml)
					Molasses (%)	Molasses (gm)	
	A	B	C=A*B		E	F=C*E	G=10%A
4% Molasses	2,000.00	8.00	1,840.00	34.00	4.00%	**73.60**	200.00
6% Molasses	2,000.00	8.00	1,840.00	34.80	6.00%	**110.40**	200.00
8% Molasses	2,000.00	8.00	1,840.00	31.0	8.00%	**147.20**	200.00
10% Molasses	2,000.00	8.00	1,840.00	33.0	10.00%	**184.00**	200.00
12% Molasses	2,000.00	8.00	1,840.00	33.5	12.00%	**220.80**	200.00
14% Molasses	2,000.00	8.00	1,840.00	34.5	14.00%	**257.60**	200.00
16% Molasses	2,000.00	8.00	1,840.00	35.0	16.00%	**294.40**	200.00
18% Molasses	2,000.00	8.00	1,840.00	32.0	18.00%	**331.20**	200.00
20% Molasses	2,000.00	8.00	1,840.00	32.5	20.00%	**368.00**	200.00

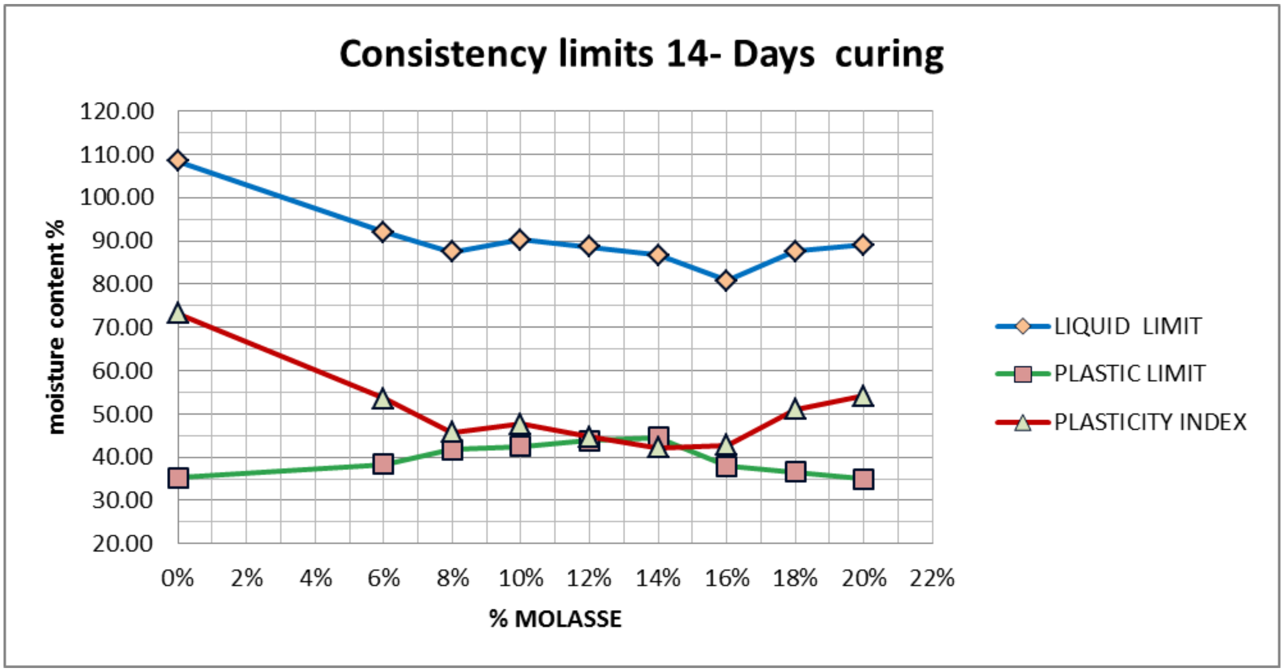
Appendix 3: Geotechnical Test results

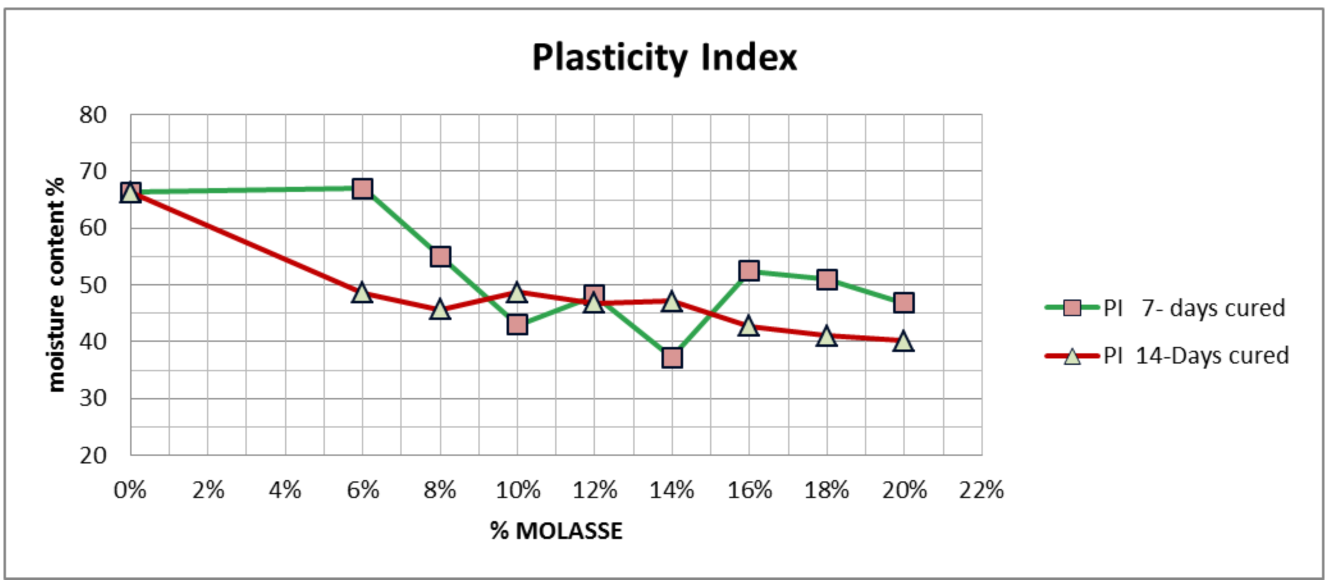
Table C. 1:Summary of test result for Atterberg limits

No	Sample Type	Consistency limits with no curing (%)			Consistency limits 7- Day curing (%)			Consistency limits 14- Day curing (%)			Shrinkage limits (%)		Remark
		LL	PL	PI	LL	PL	PI	LL	PL	PI	linear shrinkage	volumetric shrinkage	
1	ES	108	35	73	108	35	73	108	35	73	11.50	14.00	
3	ES+6%	98	37	62	104	37	67	92	38	54	11.33	-	
4	ES+8%	96	39	58	94	39	55	87	42	46	10.80	12.00	
5	ES+10%	93	39	53	81	38	43	90	43	48	11.20	-	
6	ES+12%	83	36	47	83	37	46	89	44	45	11.80	-	
7	ES+14%	78	34	43	72	36	36	87	45	42	-	13.00	
8	ES+16%	90	35	55	88	36	52	81	38	43	-	-	
9	ES+18%	87	37	50	87	36	51	88	37	51	-	-	
10	ES+20%	89	38	51	90	36	54	89	35	54	-	15.00	


Consistency limits with no curing
120.00
100.00
80.00
60.00
40.00
20.00
0.00
moistur e content %
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
20%
22%
% MOLASSE
LIQUID LIMIT
PLASTIC LIMIT
PLASTICITY INDEX


Consistency limits 7- Day curing
120.00
100.00
80.00
60.00
40.00
20.00
0.00
moisture content %
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
20%
22%
% MOLASSE
LIQUID LIMIT
PLASTIC LIMIT
PLASTICITY INDEX

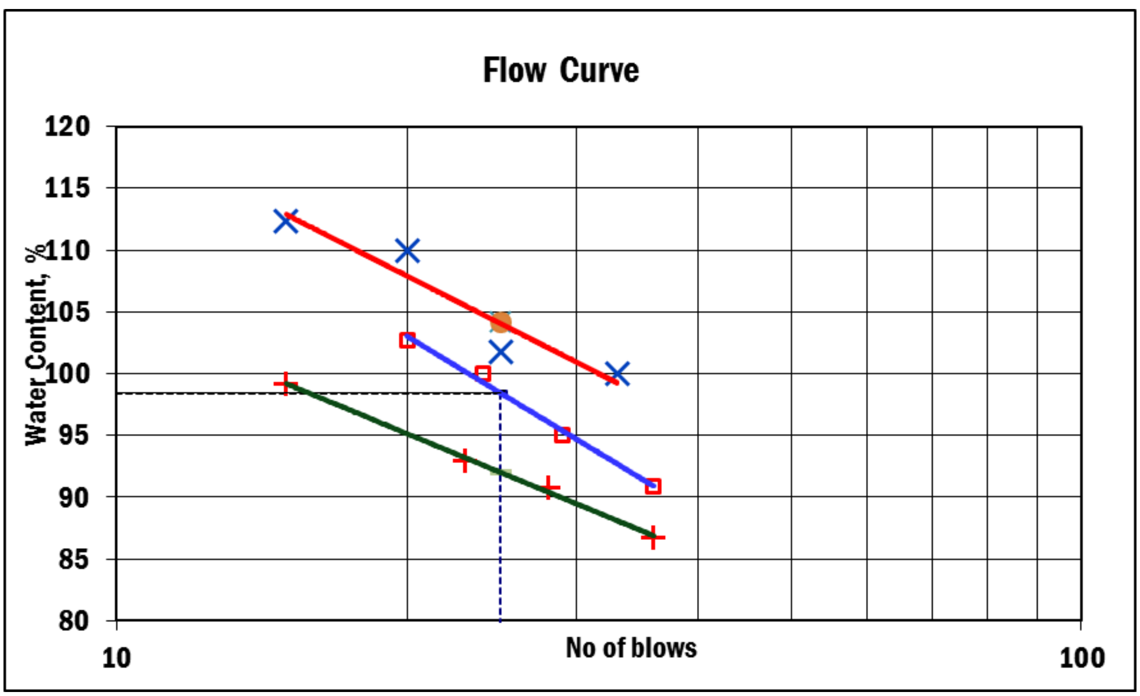

Consistency limits 14- Days curing
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
moisture content %
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
20%
22%
% MOLASSE
LIQUID LIMIT
PLASTIC LIMIT
PLASTICITY INDEX


Plasticity Index
80
70
60
50
40
30
20
moisture content %
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
20%
22%
% MOLASSE
PI 7- days cured
PI 14-Days cured

Appendix 3.1 Atterberg limits for varied percent molasses.

I) 6% Molasses -Soil mixture

6% 0 day cured						
Water content, %	90.91	95.04	100.00	102.65	36.32	37.50
No of blows	36	29	24	20	------	------
6% 7 day cured						
Water content, %	100.00	101.75	110.00	112.35	35.71	38.81
No of blows	33	25	20	15	------	------
6% 14 day cured						
Water content, %	86.76	90.77	92.97	99.19	37.07	39.77
No of blows	36	28	23	15	------	------



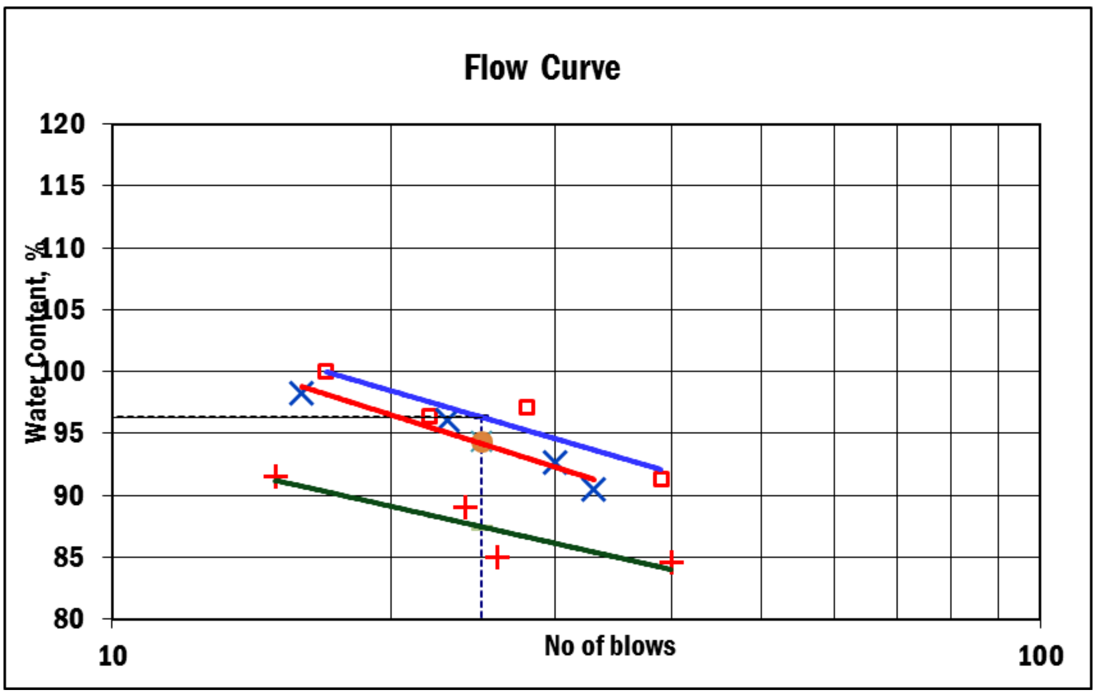
0 Day
LL 98
PL 37
PI 62

7 Day
LL 104
PL 37
PI 67

14 Day
LL 92
PL 38
PI 54

II) 8% Molasses -Soil mixture

8% 0 day cured						
Water content, %	91.30	97.09	96.40	100.00	37.61	39.78
No of blows	39	28	22	17	------	------
8% 7 day cured						
Water content, %	90.43	92.63	96.12	98.20	40.74	37.50
No of blows	33	30	23	16	------	------
8% 14 day cured						
Water content, %	84.62	84.93	89.06	91.49	42.42	41.11
No of blows	40	26	24	15	------	------



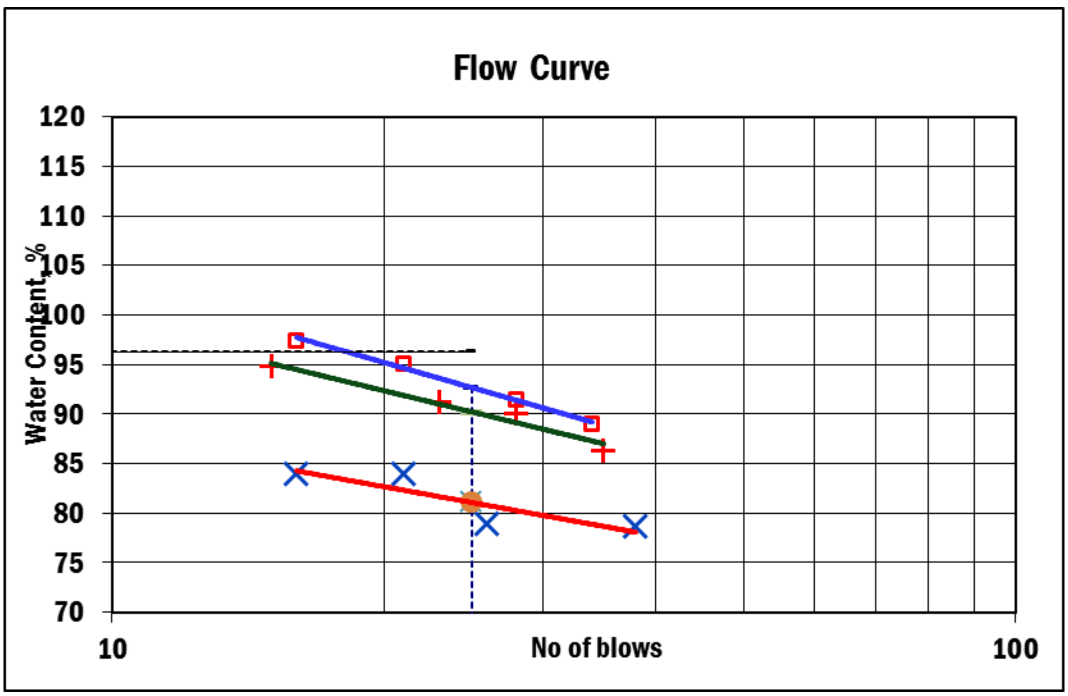
0 Day
LL 96
PL 39
PI 58

7 Day
LL 94
PL 39
PI 55

14 Day
LL 87
PL 42
PI 46

III) 10% Molasses -Soil mixture

10 % 0 day cured						
Water content, %	88.99	91.49	95.04	97.46	40.05	38.84
No of blows	34	28	21	16	------	------
10% 7 day cured						
Water content, %	78.64	78.90	83.93	84.00	38.24	38.03
No of blows	38	26	21	16	------	------
10% 14 day cured						
Water content, %	86.24	90.09	91.15	94.78	41.34	43.70
No of blows	35	28	23	15	------	------



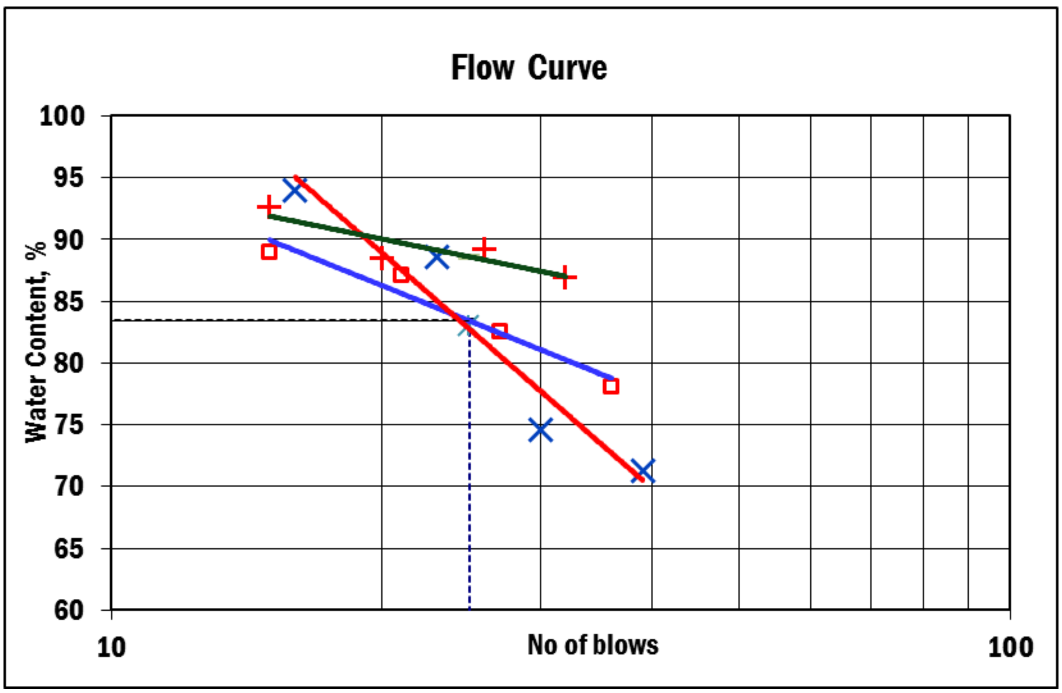
0 Day
LL 93
PL 39
PI 53

7 Day
LL 81
PL 38
PI 43

14 Day
LL 90
PL 43
PI 48

IV) 12% Molasses -Soil mixture

12 % 0 day cured						
Water content, %	78.13	82.56	87.10	89.00	36.84	36.05
No of blows	36	27	21	15	------	------
12% 7 day cured						
Water content, %	71.32	74.60	88.57	93.94	39.13	35.63
No of blows	39	30	23	16	------	------
12% 14 day cured						
Water content, %	86.96	89.22	88.51	92.59	44.92	42.78
No of blows	32	26	20	15	------	------



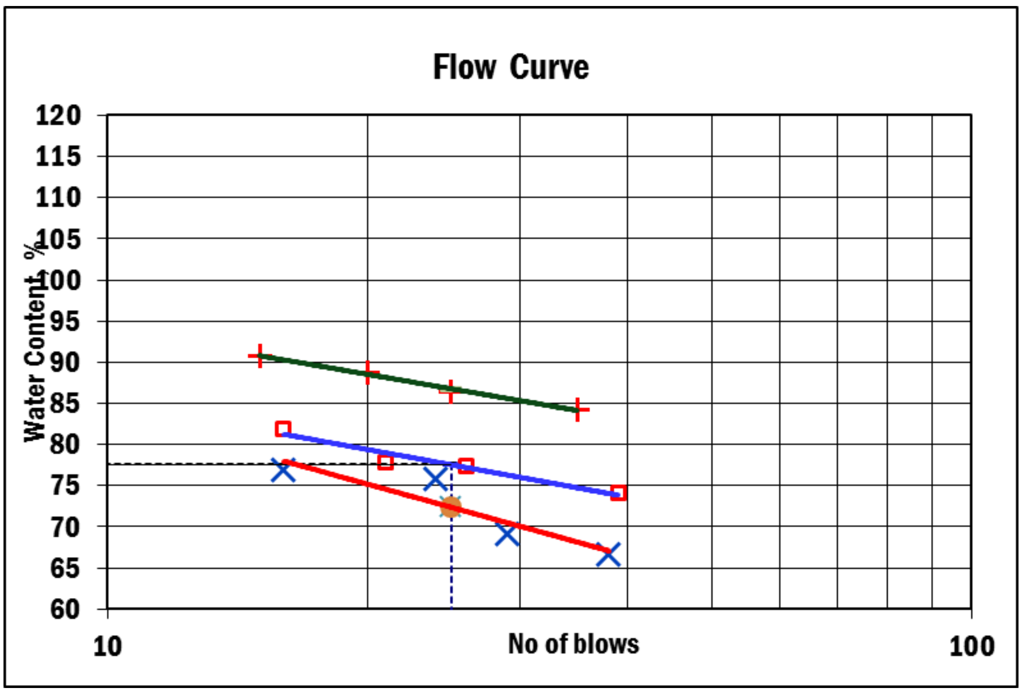
0 Day
LL 83
PL 36
PI 47

7 Day
LL 83
PL 37
PI 46

14Day
LL 89
PL 44
PI 45

V) 14 % Molasses -Soil mixture

	14 % 0 day cured					
Water content, %	74.05	77.45	77.88	81.90	35.14	33.33
No of blows	39	26	21	16	------	------
	14% 7 day cured					
Water content, %	66.67	69.11	75.86	76.85	33.67	38.71
No of blows	38	29	24	16	------	------
	14% 14 day cured					
Water content, %	84.24	86.46	88.72	90.78	40.91	48.34
No of blows	35	25	20	15	------	------



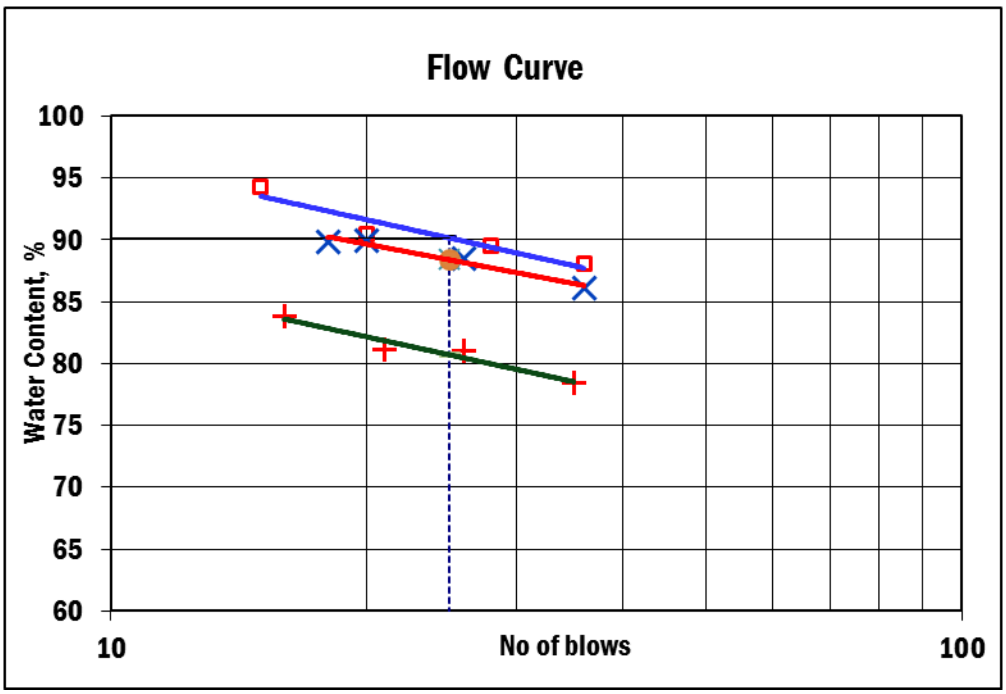
0 Day
LL 78
PL 34
PI 43

7 Day
LL 72
PL 36
PI 36

14 Day
LL 87
PL 45
PI 42

VI) 16 % Molasses -Soil mixture

	16 % 0 day cured					
Water content, %	88.04	89.47	90.43	94.29	34.38	35.05
No of blows	36	28	20	15	------	------
	16% 7 day cured					
Water content, %	86.09	88.46	89.93	89.86	36.11	35.71
No of blows	36	26	20	18	------	------
	16% 14 day cured					
Water content, %	78.40	81.03	81.12	83.82	38.10	37.70
No of blows	35	26	21	16	------	------



0 Day
LL 90
PL 35
PI 55

7 Day
LL 88
PL 36
PI 52

14 Day
LL 81
PL 38
PI 43

VII) 18 % Molasses -Soil mixture

18 % 0 day cured						
Water content, %	77.39	86.90	87.50	92.45	38.61	34.76
No of blows	38	27	25	18	------	------
18% 7 day cured						
Water content, %	82.14	87.62	89.13	89.76	37.10	35.65
No of blows	38	28	23	17	------	------
18 % 14 day cured						
Water content, %	81.43	86.92	89.40	95.80	35.51	37.50
No of blows	36	28	21	16	------	------

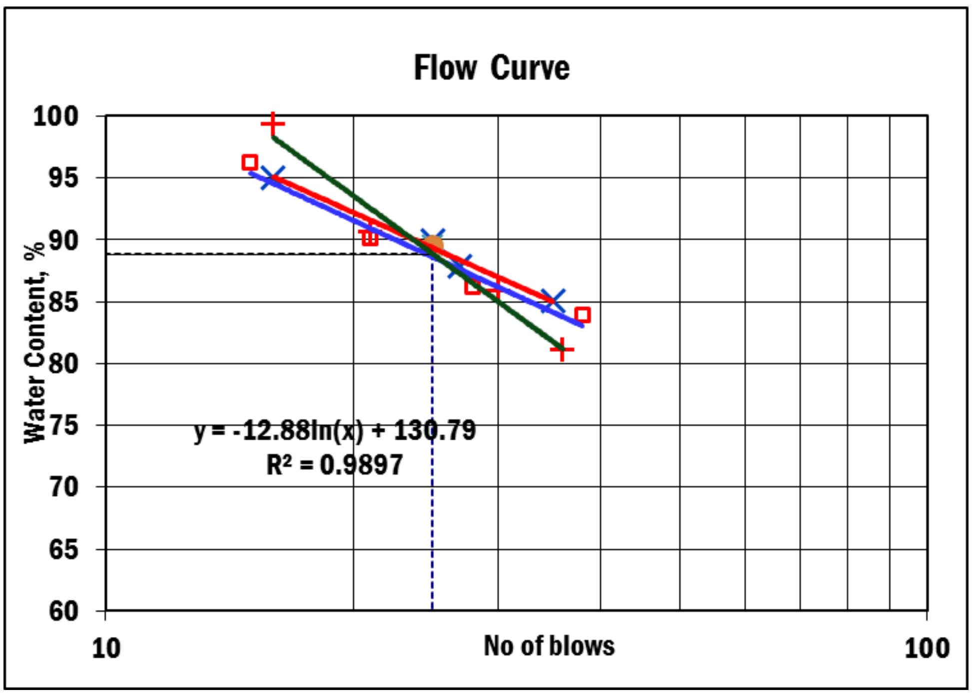
0 Day
LL 87
PL 37
PI 50

7 Day
LL 87
PL 36
PI 51

14 Day
LL 88
PL 37
PI 51

VIII) 20% Molasses -Soil mixture

			20 % 0 day cured			
Water content, %	83.96	86.21	90.12	96.21	37.68	38.27
No of blows	38	28	21	15	------	------
			20% 7 day cured			
Water content, %	85.03	87.86	89.89	95.02	35.94	35.82
No of blows	35	27	25	16	------	------
			20 % 14 day cured			
Water content, %	81.15	85.92	90.61	99.34	34.41	35.35
No of blows	36	30	21	16	------	------



0 Day
LL 89
PL 38
PI 51

7 Day
LL 90
PL 36
PI 54

14 Day
LL 89
PL 35
PI 54

Appendix 3.2

Table C. 2: Summary of Values for Strength tests

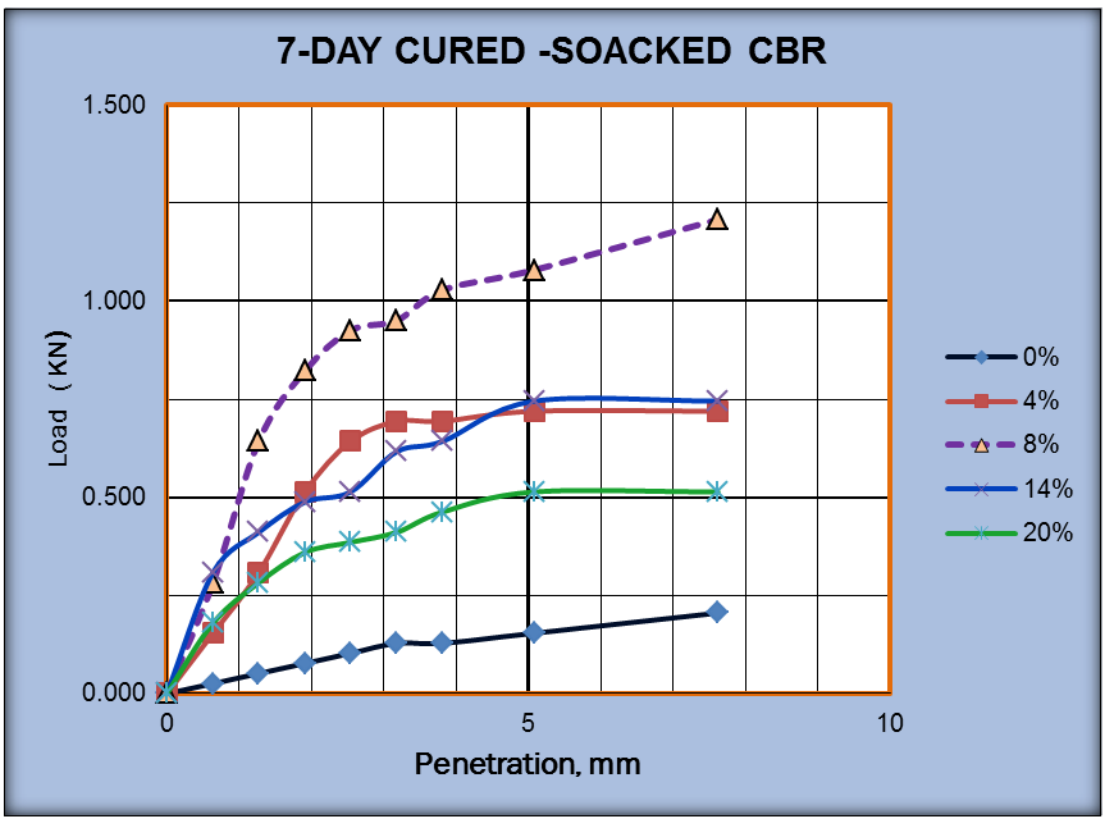
No	Sample Type	Moisture Density Relations with no curing		UCS (KPa)		Soacked CBR Tests		un-Soacked CBR Tests	Remark
		OMC (%)	MDD (g/cc)	With out curing	7-days curing	CBR Value (%)	CBR Swell (%)	CBR Value (%)	
1	ES	35.4	1.24	142		0.77	0.08	17.52	
2	ES+4%	34	1.24	182	150	4.81	0.01	15.40	
3	ES+6%	34.8	1.26	229	251	-	-	-	
4	ES+8%	31	1.27	245	289	6.93	0.01	26.19	
5	ES+10%	33	1.285	227	208	-	-	-	
6	ES+12%	33.5	1.288	209	173	-	-	-	
7	ES+14%	34.5	1.31	193	166	3.85	0.03	11.74	
8	ES+16%	35	1.3	184	144	-	-	-	
9	ES+18%	32	1.284	134	128	-	-	-	
10	ES+20%	32.5	1.268	109	118	2.89	0.01	5.20	

Appendix 3.3.

CBR values for varied percent molasses.

7-Day Cured, 4-Day soaked CBR

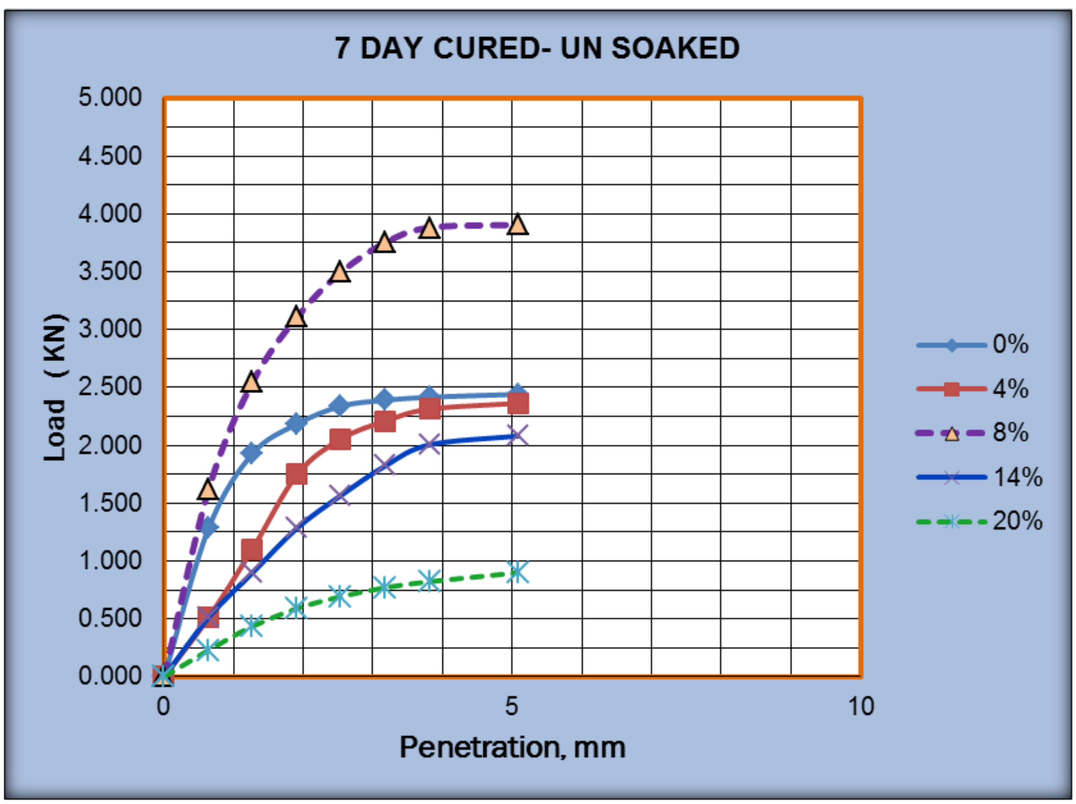
0%		4%		8%		14%		20%	
Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)
0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
0.026	0.64	0.154	0.64	0.283	0.64	0.308	0.64	0.180	0.64
0.051	1.27	0.308	1.27	0.643	1.27	0.411	1.27	0.283	1.27
0.077	1.91	0.514	1.91	0.823	1.91	0.488	1.91	0.360	1.91
0.103	2.54	0.643	2.54	0.925	2.54	0.514	2.54	0.386	2.54
0.129	3.18	0.694	3.18	0.951	3.18	0.617	3.18	0.411	3.18
0.129	3.81	0.694	3.81	1.028	3.81	0.643	3.81	0.463	3.81
0.154	5.08	0.720	5.08	1.080	5.08	0.746	5.08	0.514	5.08
0.206	7.62	0.720	7.62	1.208	7.62	0.746	7.62	0.514	7.62
	10.16		10.16		10.16			0.514	
	12.70		12.70		12.70			0.514	
CBR	**0.77**		**4.81**		**6.93**		**3.85**		**2.89**
%SWELL	**0.08**		**0.01**		**0.01**		**0.03**		**0.01**



CBR values for varied percent molasses.

7-Day Cured, un- Soaked CBR

0%		4%		8%		14%		20%	
Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)	Load (KN)	Penet. (mm)
0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
1.285	0.64	0.514	0.64	1.620	0.64	0.514	0.64	0.231	0.64
1.928	1.27	1.105	1.27	2.545	1.27	0.900	1.27	0.437	1.27
2.185	1.91	1.748	1.91	3.111	1.91	1.285	1.91	0.591	1.91
2.339	2.54	2.057	2.54	3.496	2.54	1.568	2.54	0.694	2.54
2.391	3.18	2.211	3.18	3.753	3.18	1.825	3.18	0.771	3.18
2.416	3.81	2.314	3.81	3.882	3.81	2.005	3.81	0.823	3.81
2.442	5.08	2.365	5.08	3.907	5.08	2.082	5.08	0.900	5.08
	7.62	2.365	7.62	3.907	7.62	2.108	7.62	1.003	7.62
	10.16		10.16	3.907		2.108	10.16		10.16
	12.70		12.70	3.907		2.108	12.70		12.70
CBR	**17.52**		**15.40**		**26.19**		**11.74**		**5.20**

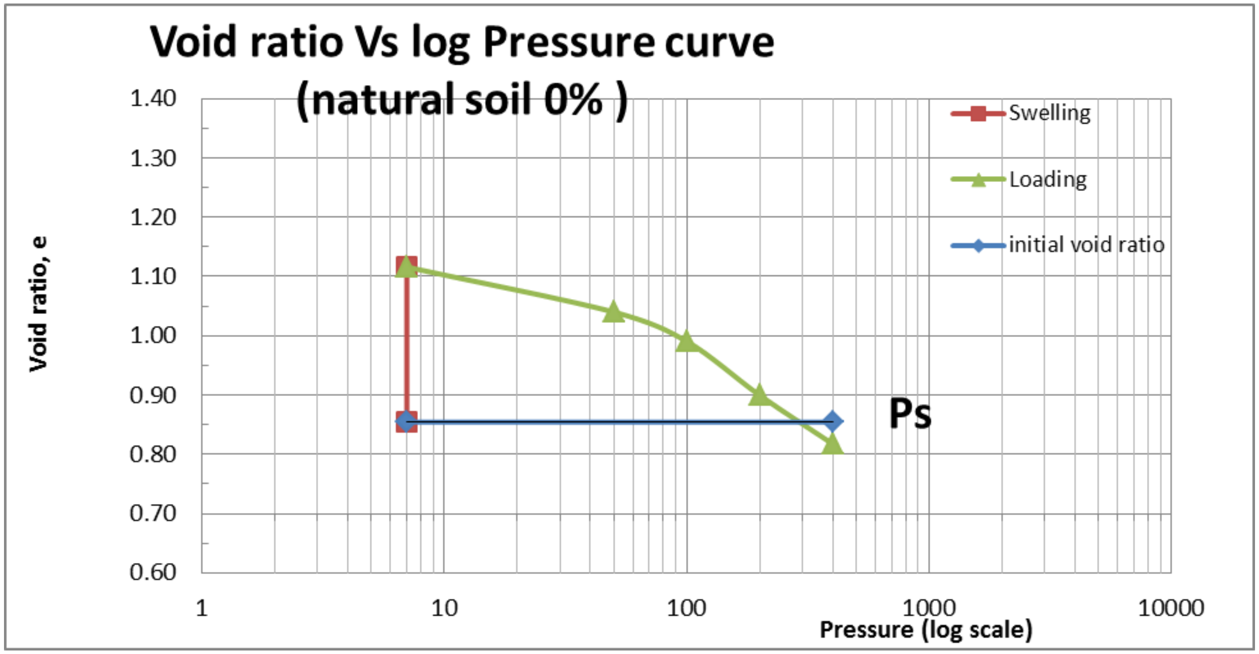


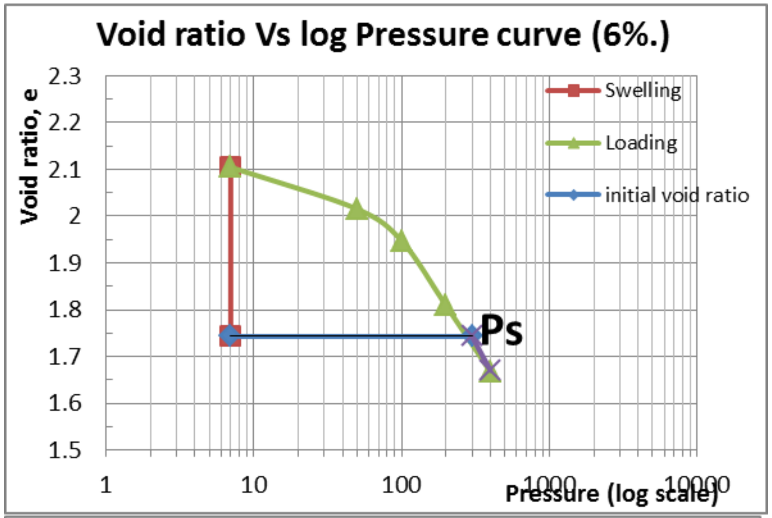
Appendixes 3.1

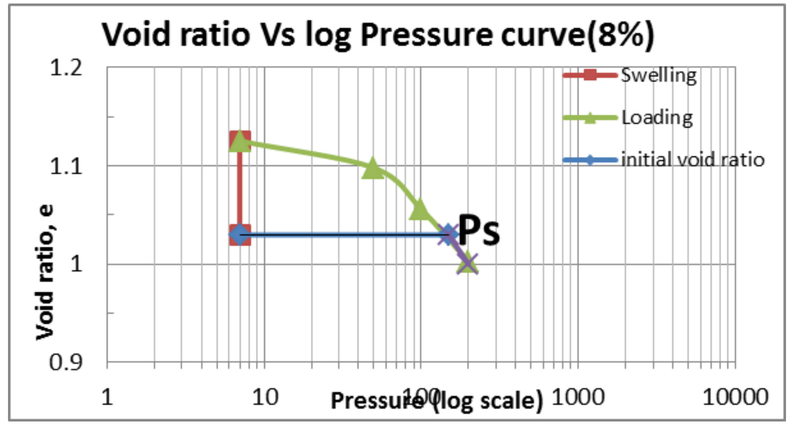
Table C. 3: Swell consolidation and Free swell tests Summary

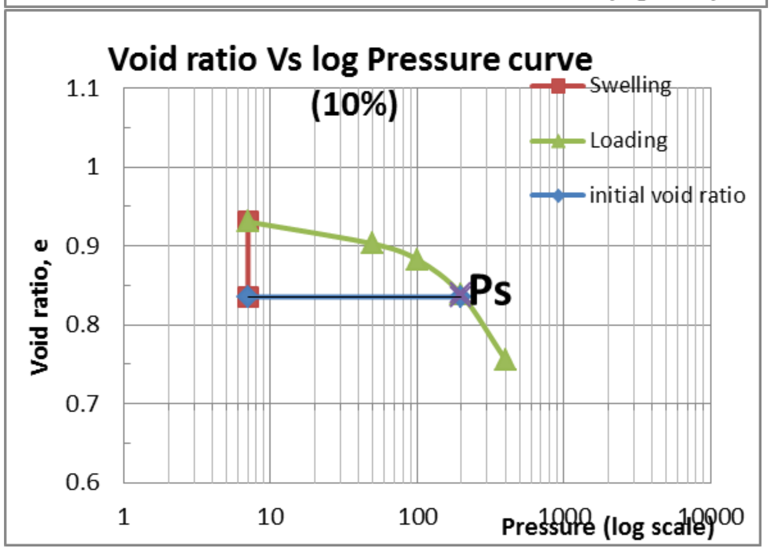
No	Sample Type	specific gravity	Moisture Density Relations with no curing		Swell Test (1Psi Load) (%)				Free swell (%)		Remark
			OMC (%)	MDD (g/cc)	Initial moisture content (%)	Initial Dry density (g/cc)	Swell (%)	Swell pressure (KPa)	With out curing	7-days curing	
1	**ES**	2.73	35.4	1.24	38.64	1.85	14.10	325.00	150	145	
3	**ES+6%**	2.48	34.8	1.26	28.60	1.91	13.20	300.00	145	146	
4	**ES+8%**	2.70	31	1.27	36.94	1.86	4.71	150.00	140	142	
5	**ES+10%**	2.72	33	1.285	40.59	1.91	5.20	200.00	146.5	144.5	
6	**ES+12%**	2.69	33.5	1.288	43.71	1.95	3.41	160.00	144	143.5	
7	**ES+14%**	2.60	34.5	1.31	37.55	1.83	5.46	172.73	146	145	
8	**ES+16%**	2.71	35	1.3	35.33	2.07	5.18	87.50	147.5	144	
9	**ES+18%**	2.44	32	1.284	34.35	1.85	4.56	100.00	142.5	143	
10	**ES+20%**	2.44	32.5	1.268	26.63	1.66	5.14	150.00	140	138	

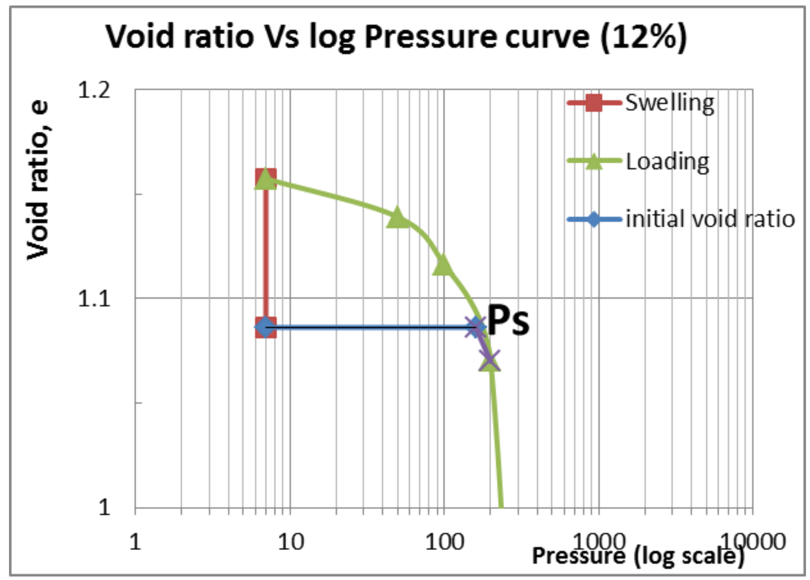
Appendix 3. 3 Void ratio vs log pressure curves for varied percent molasses.

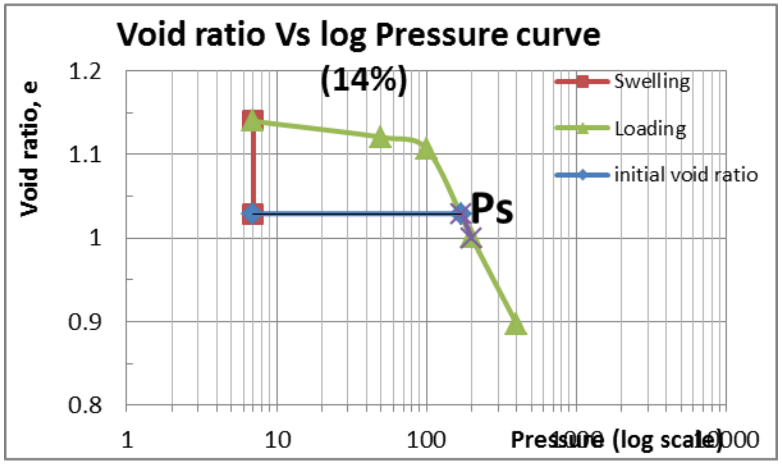

Void ratio Vs log Pressure curve
(natural soil 0%)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
Void ratio, e
1
10
100
1000
10000
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps

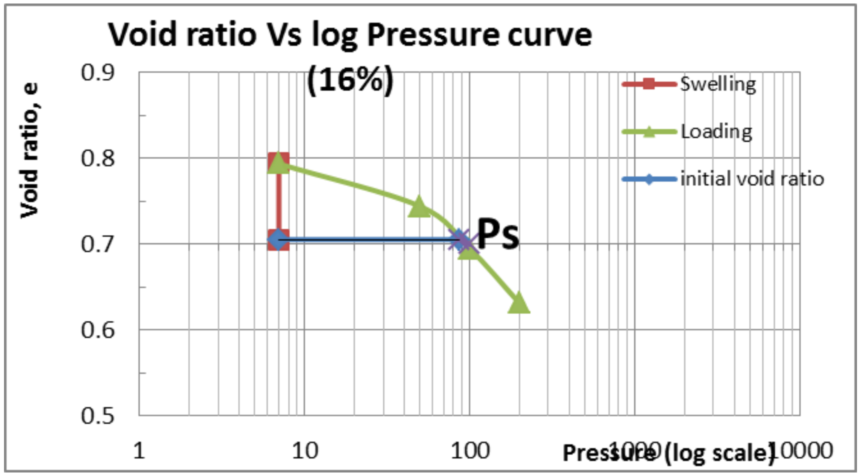

Void ratio Vs log Pressure curve (6%.)
Void ratio, e
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1
10
100
1000
10000
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps

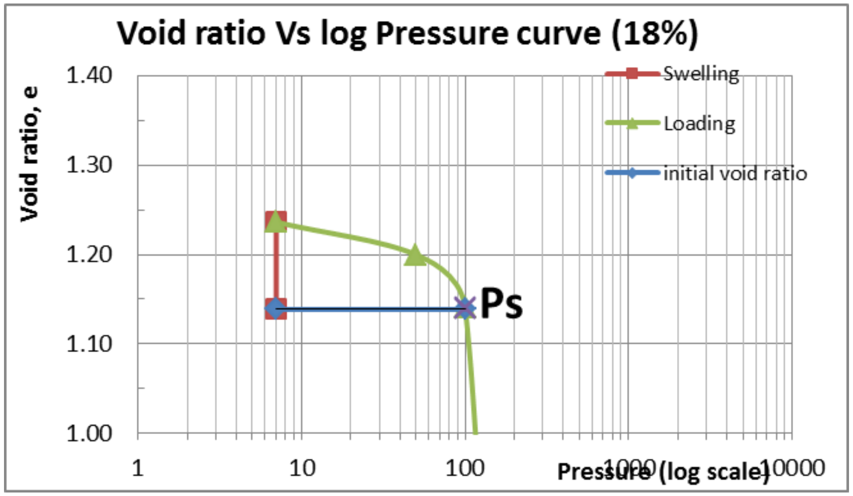

Void ratio Vs log Pressure curve(8%)
Void ratio, e
1.2
1.1
1
0.9
1
10
100
1000
10000
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps

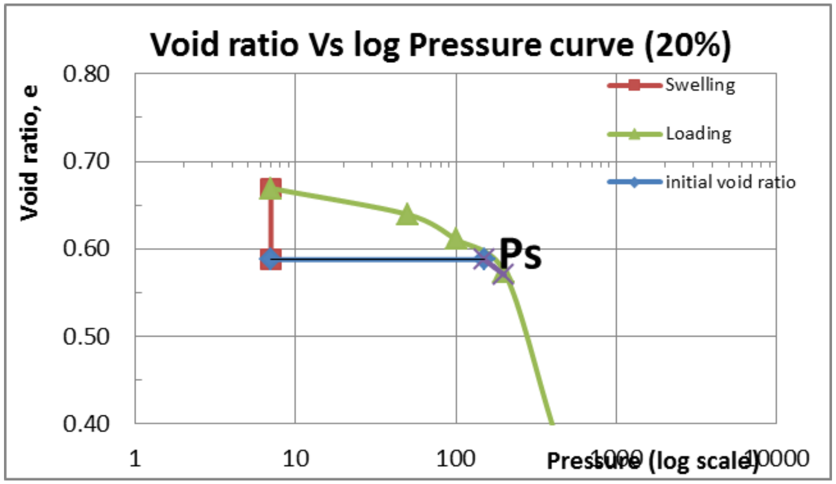

Void ratio Vs log Pressure curve (10%)
Void ratio, e
1.1
1
0.9
0.8
0.7
0.6
1
10
100
1000
10000
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps


Void ratio Vs log Pressure curve (12%)
Void ratio, e
1.2
1.1
1
1
10
100
1000
10000
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps


Void ratio Vs log Pressure curve (14%)
Void ratio, e
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps
1.2
1.1
1
0.9
0.8
1
10
100
1000
10000


Void ratio Vs log Pressure curve (16%)
Void ratio, e
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps
0.9
0.8
0.7
0.6
0.5
1
10
100
1000
10000


Void ratio Vs log Pressure curve (18%)
Void ratio, e
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps
1.40
1.30
1.20
1.10
1.00
1
10
100
1000
10000


Void ratio Vs log Pressure curve (20%)
Void ratio, e
Pressure (log scale)
Swelling
Loading
initial void ratio
Ps
0.80
0.70
0.60
0.50
0.40
1
10
100
1000
10000