ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)
SCHOOL OF GRADUATE STUDIES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Cost and Time Effect of Using Sub Grade ANSS Chemical Stabilizer in Road Construction

(A Case Study of Addis Ababa City, Road Construction on Expansive Soil)

By
Helen Hailu Degefa
January, 2016

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A Thesis Submitted to

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Master of Science in Geotechnical Engineering

By

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ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF GRADUATE STUDIES

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the Supervision of my research advisor **Dr. Samuel Tadesse a**nd has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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Symbols and Abbreviations

AASHTO - American Association of Highway and Transportation Officials

AACRA- Addis Ababa City Roads Authority

ANSS- Anyway Natural Soil Stabilizer

ASTM- American Society for testing and Materials

CBR- California Bearing Ratio

CS- Clayey sand

ERA- Ethiopian Road Authority

GI - Group Index of AASHTO soil classification

LGC- Light grey clay

LL - Liquid Limit

PL - Plastic Limit

PI - Plastic Index

MDD- Maximum Dry Density

OMC- Optimum Moisture Content

SAS- Sub Arterial Street

USCS - Unified Soil Classification System

UCS- Unconfined Compressive strength

Abstract

Road connectivity is one of the key components for development in a city as well as in a nation, as it promotes access to economic and social services, generating increased income and employment. However, the construction of such economically vital sector is the most expensive and time taking public project undertaken by the government. Conventional pavement design and construction practices require high quality materials to fulfill minimum construction standards which will be transported from long distances from the project site under construction which is costly. In addition, natural resources are degraded and environmentally affecting the quarry areas which has significant environmental effect, and this way of construction takes longer time to complete the project. In many of road projects it is very difficult to obtain suitable construction materials for sub grade with in economical hauling distances.

One of the proven technologies to reduce cost and time of road construction is enabling use of marginal materials by using stabilization of soil. Stabilization can be derived from chemical, electrical, mechanical or thermal means. In this study chemical stabilizer are considered. *Chemical stabilizers* can generally be categorized in to two broad categories: *conventional and unconventional* stabilizers. Conventional stabilizers such as cement lime, fly ash, and bituminous products have been intensely researched, and their fundamental stabilization mechanisms have been identified. Unconventional soil stabilizers are additives consist of a variety of chemical agents that are diverse in their composition and in the way they interact with the soil. In this research ANSS (Anyway Natural Soil Stabilizer) which is categorized as *unconventional chemical stabilizer*s used to analyze the effect of stabilizer on engineering properties of expansive soils. A case study has been made on Addis Ababa City roads which are constructed on expansive soils are taken.

In the laboratory, the native soil were combined with different dosages of the stabilizer 2%,4%, 6% and 8% to find out the optimum dosage of stabilizer. From the laboratory test results it is confirmed that 6%is an optimum dosage of stabilizer for the typical expansive soil in the study area. Using this optimum dosage of chemical stabilizer cost and time comparison have been made with the conventional way of construction.

As it has been observed from the analysis, treated expansive soil with 6% of the chemical stabilizer improves the bearing capacity and Plasticity of the soil to a required level and it saves around 30% of the cost and 42% of the time of road construction in a the city which is constructed in a conventional way, however the performance duration of the stabilizer shall be studied further in the future, as the road which have been done with same technology shall be evaluated after some service years.

Chapter One

Introduction

1.1 Background

Currently the number of population in Ethiopia is estimated around 95 million and it's assumed that the total population will be increased by 2.6% average growth rate per annum (CSA,2012). Accordingly, the urban areas of the country is growing by 6% and the number of cities will be increased dramatically until 2020 given increasing migrations from rural to urban areas (CSA, 2005). That in turn requires construction of well integrated infrastructures of Road Network, water supply, Electricity, Telecom etc. One of the main infrastructures is Road. Roads help a city to have integrated and accessible transport networks that connect people and places. Accordingly, the Government of Ethiopia invests a lot of money on road infrastructures considering the integrated plan among sectors and growing economy of the Country. In fact road construction needs a huge investment, so specific researches are required in this field to guarantee efficient transport, access and comfort with limited budgets.

According to Reporter News (2015), out of the total capital budget of the country, 35 billion Birr is allocated for federal Road Constructions. In addition to the federal road network budgets, other regional budgets are allocated to construct roads in urban areas/city roads; for example in 2014, 8 billion Birr of the total budget of Addis Ababa City Administration goes to road construction of the city, This indicates that the Lion Share of the capital budget of the country goes to construction of roads. Therefore, in order to deliver strategic and efficient system huge research is needed in the sector.

1.2 Statement of the problem

Like many developing cities, Addis Ababa is growing in highly unplanned fashion in the previous eras and the last 15 years were crucial to get the city back to a well-planned city and upgrading the city roads to a standard road network is one of the themes of the city government. Delivering the objective with a limited budget, time is one of the challenging agenda of the city and in relation to this and other factors transport problems has become the city's burning agenda.

The Addis Ababa City Government, in its part, is trying to solve the present traffic conjunction problem by way of reconstructing and upgrading of existing deteriorated roads and the reconstruction of new roads based on standard road network master Plan of the city, Highways, and Mass Transport Corridors.

The construction and maintenance of all demanded new roads and rehabilitation of deteriorated roads is very expensive in relation to the allocated budget, in addition there is limited natural resources of construction which is already degraded for the constructed roads, building and other infrastructures so far, since the roads need a suitable fill material for the pavement layer to meet the design of the roads. As a result of this problem, the city government can only build or rehabilitate limited road projects relative to the current demand of road infrastructure.

One of the reasons of longer construction time in urban areas is the conventional methodology of construction which needs transportation of selected sub grade material which is expensive and not existing within an economically feasible distance, it also requires to deploy heavy machineries at the quarry site to extract and crush the materials and haul to the project. In addition, it incurs traffic jams and damages on the built up road segments.

These problems require adaptation of different technologies based on site specific conditions. In this regard introducing technologies that enable the use of available material itself, without transportation, will contribute a lot to the time and cost of construction, and it can also avoid damaging of existing roads which are caused during transportation of selected material from quarry to project and unsuitable materials from projects to dumping areas.

One of the innovative technologies that enable use of soil and marginal aggregates along the road corridor is soil stabilization. In many part of the world many researches has been carried out following the scarcity of good road making materials in an effort to find a cheap magical chemical which when added in small quantities to a soil, result in the rapid formation of a highly-stable pavement mixtures.
In this thesis, an attempt was made to discuss one of the chemical stabilizer which are currently available in the city, determine the effective dosage of the stabilizer on a specific soil type and finally

analysis will be made to compare the cost and time difference of construction using traditional way with that of using the stabilizer, and recommendations are made according to the output of the study.

1.3. Objective

The main objective of this thesis is to analyze the cost and duration of construction of road projects using Sub grade Chemical Stabilization and compare them with that of Conventional way of Road construction.

This is achieved through the following specific objectives.

Specific objectives are;

- Finding the required optimum content of the stabilizer to improve the sub grade property
- Analyzing cost and time of construction using the stabilizer
- Analyzing cost and time of construction in a conventional way (current method)
- Comparing the cost and time of construction in conventional way and using chemical stabilizer

1.4. Methodology

In order to effectively achieve the objectives of this study the following approaches have been followed and a rational work program was conducted.

- A comprehensive desk study has been conducted to study the type and mechanism of stabilization, the city administration plan about road network and current projects has been studied using the data found at the city road authorities.
- Based on the desk study selection of study area of the project site has been made in accordance with the city administration physical plan. Based on the plan of the city administration, the site where the stabilizer happens to be tested is found to be the southern part of Addis Ababa city which is round Akaki. Kality sub city.
- A specific chemical stabilizer has been selected as per the availability and current pilot projects of the city administration.
- Literature review on the history and use of stabilizers, mechanical and chemical, conventional and unconventional chemical stabilizers have been discussed in detail.
- Investigation of the properties of the native soil before treatment are performed in accordance with the required specifications, all basic properties of the soil which are used for road construction has

been performed to examine the property of the native/untreated soil.

- Investigation of the property of the soil by a trial test of blending with different dosage of stabilizers by mass are performed to find out the effective dosage of stabilizer to improve the native soil property to a required strength.
- Using the effective dosage of stabilizer, analysis of cost of construction using the specific dosage of stabilizer has been performed
- Then Analysis of construction time of the project using the stabilizers performed.
- Finally, Comparison of cost and time with the conventional way of construction is performed ,

1.6. Organization of the Thesis

This thesis is structured as follows, the first chapter deals about Introduction. Chapter Two is review of literatures to support the study, followed by general description of the study area in chapter three and property of materials under chapter four. Chapter five deals with laboratory result and discussion of treated soil and guidelines of application in chapter six and comparison of cost and time is made at the seventh chapter finally, chapter eight presents conclusions and recommendations including future researchable areas.

Chapter Two

Literature Review

2.1 Overview

Long term performance of pavement structures often depends on the stability of the underlying soils. Engineering Design of these constructed facilities relies on the assumption that each layer in the pavement has the minimum specified structural quality to support and distribute the super imposed loads. These layers must resist excessive permanent deformation, resist shear and avoid excessive deflection that may result in fatigue cracking in overlaying layers. Available earth materials do not always meet these requirements and may require improvements to their engineering properties in order to transform this inexpensive earth material into effective construction materials. This is often accomplished by physical or chemical stabilization or modification of this problematic soil. Although the solution appears simple and straight forward, engineering property of individual soils may vary widely due to heterogeneity in soil composition, difference in micro and macro structure among soils, variability and heterogeneity of geologic deposits and due to different in physical and chemical interactions of air/water with soil particles. These differences necessitate the use of site specific treatment options of stabilization.

In its broad context "Soil Stabilization" is a process for developing full load support values of weak soils. Soil stabilization has been long recognized as the "art" of improving the behavior of roadbed materials through careful selection of moisture control and compaction.

The use of improvement of soil behavior, with expected results, is the best way to describe soil treatment methods. Often it is more economical to provide such treatments to in situ and borrow materials, rather than replacing them or somehow avoiding them [1].

A difficult problem in civil engineering work exists when the sub-grade is found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase [2]. Over the years, engineers have tried different methods to stabilize soil that are subjected to fluctuations in strength and stiffness properties as a function of fluctuation in moisture content. Stabilization can be derived from thermal, electrical, **mechanical** or **chemical** means. The first two options are rarely used. Therefore further study is reviewed on mechanical and chemical stabilizers.

2.2 Mechanical Stabilization, or Compaction

Mechanical stabilization, or compaction, is the densification of soil by application of mechanical energy. Densification occurs as air is expelled from soil voids without much change in water content. This method is particularly effective for **cohesion less** soils where compaction energy can cause particle rearrangements and particle interlocking. But the technique may not be effective if this soil is subjected to significant moisture fluctuation. The efficiency of compaction may also diminish with an increase of the fine content, fraction smaller that about 75µm, of the soil. This is because cohesion and inter particle bonding interferes with particle rearrangement during compaction.

Blending of two or more materials can be considered. This procedure involves the mixing of materials that have different properties, with individually unacceptable properties to produce a material with the required properties, (typically particle size distribution and/or plasticity) to form a material having improved characteristics, given the limitations of the source materials.

Altering the physiochemical properties of fine-grained soil by means of chemical stabilizer/modifiers is a more effective form of durable stabilization than densification in these fine grained soils. Chemical stabilization of non-cohesive, coarse grained soils, soils with particles greater than 50 percent by weight coarser than 75µm is also beneficial if a substantial stabilization reaction can be achieved in these soils. In this case the strength improvement can be much higher, greater than tenfold, when compared to the strength of the untreated material [4].

In this research the area of interest is cohesive soils and the detail discussions will be on chemical stabilizers.

2.3 Chemical Stabilization

Chemical stabilization is defined as any treatment or method whereby a chemical is used to either change the soil properties and thereby increase the bearing capacity of the soil layer or increase the strength and stiffness through cementation [3].

There is an increasing effort around the world towards introducing innovative and unconditional road construction approaches that aim at reducing costs of construction by enabling use of marginal materials found within the road route. One of proven technologies in connection to this effort is chemical stabilization of soil [5].

Chemical stabilizer can be categorized as **Conventional and unconventional** stabilizers. **Conventional** stabilizers are stabilizers such as cement, fly ash, and bituminous products have been intensely researched, and their fundamental stabilization mechanisms have been identified. **Unconventional** soil stabilization is additives consist of a variety of chemical agents that are diverse in their composition and in the way they interact with the soil. Unfortunately, relatively little is about their interaction with geotechnical materials or their fundamental stabilization mechanisms due to proprietary nature of commercial stabilization additives: their exact chemical compositions are not disclosed [5].

2.3.1 Role of Chemical Stabilization

In general Chemical stabilization is used for a wide range of purposes, some of them are to;

- dry out soil where the moisture content is too high for successful compaction,
- make the soil less permeable where it is necessary.
- reduce the plasticity of soils used in road construction and thereby to reduce the effect of moisture variations.
- improve the compatibility of clays by changing the clay to a more granular and workable material.
- reduce the swelling and shrinkage of clays.
- improve the bearing capacity and strength of pavement layers and temporary bypasses, especially during rainy periods to limit construction delays due to rain.
- delay certain chemical reactions such as the weathering of sulfides and other minerals that is detrimental to road soils.
- neutralize the sulfuric acid and to reduce the solubility of the highly soluble sulfate salts in gold and certain other mine waste rock crushed stone base materials etc.

The more commonly used chemical stabilizers are lime, cement, bitumen, slag (GGBS) and fly ash. All of these chemical stabilizers are marketed as a milled powder and are available in either bulk form or in paper bags. A wide range of dust palliatives and other proprietary products have appeared in the stabilization market, including calcium chloride, natural and synthetic polymers, sulfonated oils and enzymes and various other proprietary products of which little is known about their compositions. Many of these are not classified as true stabilizers but may have some soil modifying properties.

2.3.2 Type of Chemical Stabilization

This paper is focused on two common type of chemical stabilizers Lime and cement and since the chemical stabilizer which is used for this study is a basic mix of both lime and cement with a name Anyway Chemical stabilizer (ANSS) including a few additives [7].

2.3.2.1 Lime

Lime is one of the common chemical stabilizers. The use of lime as a building material dates back some 5,000 years when lime and clay were mixed and compacted to form bricks used in the construction of the pyramids of Shensi in Tibet. About 2, 000 years ago the Romans used lime to improve the quality of their roads. The Romans made mixtures of lime and volcanic ash called "Pozzolana" in which theprinciples of today's cement can be seen. The word "cement" is derived from the Latinword "Caementum" and was used by the Romans to describe aggregate particles in amortar‖. John Smeaton built the Eddystone lighthouse in 1756 using a mixture of blue lime and Pozzolanic clay. He was however not aware that he had discovered the basic principle of cement manufacture and this enabled Joseph Aspdin to patent the process, which he called "Portland cement" in 1824.In the United States, tests have been carried out with lime stabilization since 1930 but success was achieved only ten years thereafter. The development of the triaxial compression test in 1945 allowed stabilization methods to be compared directly with oneanother. Thereafter chemical stabilization of soils developed rapidly.The first cement manufactured in South Africa was produced in 1892 in the "EersteCement Fabrieken" at Daspoort, Pretoria. The first chemical stabilization trials werecarried out in the Transvaal in 1941 when 5 per cent of cement was mixed into a soil layer on the road between Pretoria and Delmas (P36/1) using the ripper teeth of graders and light ploughs. A year later cement stabilization was also carried out on the national route between Standerton and Volksrust with more effective mixing methods. Since then stabilization has increased to such an extent that on virtually every sealed road in Gauteng, one or more of the pavement layers is now stabilized [5].

There are generally two types of lime used for stabilization of soils, namely, hydrated and anhydrate. unhydrated (unslaked) lime is produced by heating lime stone or dolomite (calcium magnesium carbonate) to form calcium oxide (CaO) with varying percentages of magnesium oxide (MgO). This can be slaked by treatment with steam or water, and calcium hydroxide (Ca(OH)2) or calcium and magnesium hydroxide (Ca(OH)2 + Mg(OH)2) is formed. The hydration of calcium oxide is normally much faster than that of magnesium oxide. Has a strong chemical affinity to absorb water.

Hydrated lime, sometimes called slaked lime, is quicklime to which water has been added until all the oxides of calcium and magnesium have been converted to hydroxides, the water has slacked quicklime's thirst. Hydrated lime made from pure calcium oxide and 24percent chemically combined water. Hydrated lime is white and powdery.
Hydrated lime is most commonly used for the lime stabilization of soils, due to its plasticity nature it is used for road construction and hence avoids pothole formations.

Two basic through complex reaction apparently take place when lime is mixed with a soil, namely:

a) A fairly rapid and sometimes almost instantaneous amelioration that may involve the exchange of Ions: and

b) A pozzolanic reaction taking place over a period of time ranging from a few minutes to several months or longer. In both cases there is a chemical reaction between the lime and the soil.

Ion Exchange

This relatively rapid reaction involves both cations and anions and is accompanied by flocculation and the formation of agglomerations caused by clay particles adhering to one another, This increases the plastic limit and thus the plasticity Index (PI) is reduced, whereas the liquid limit may remain unchanged, decrease or decrease. But the material becomes more workable and the strength usually increased. Lime is often added to acidic, sulphate-contaminated crushed stone to prevent salt damage. This can be regarded as a type of ion exchange although clay minerals are not involved.

Pozzolanic reaction

If sufficient lime is added to a soil the PH is increased to about 12, 4, which is the PH of saturated lime water at 25 ˚C. At this high PH reactions take place between lime and clay minerals and other pozzolans, such as amorphous silica to produce cementations hydrated calcium silicate and aluminates gels similar to those presented in hydrated Portland cement. Crystallization and hardening of these gels are largely responsible for the strength developed.

Initial Consumption of lime

The amount of lime required to satisfy the soil-lime reaction varies considerably with different soils and a test for the initial consumption of lime (ICL) has been developed. This is a quick test to determine the amount of lime required by the soil-lime mixture to maintain the lime-saturated PH for one hour after the lime has been added (usually a PH of 12, 4 at 25°C). IF ICL of the soil fines is greater than 3.5 per cent, the lime demand is considered to be high. It has been found that most weathered basic igneous rocks have a high demand for lime although certain other materials derived from sedimentary rocks, for example, may also have a high lime demand. In an analysis of random samples from various parts of South Africa, about 25 per cent of the samples had a lime demand that would be regarded as high [1]. Sufficient lime should be added to satisfy the ICL and additional lime is necessary for the formation of cementing compounds (Pozzolanic Reaction). The amount of lime required for the development of a significant pozzolanic reaction is best determined by strength tests.

It should be noted that a high ICL is significant not only in lime stabilization but also in cement stabilization, since soils with a high ICL will consume part of the calcium in the cement stabilization, since soils with a high ICL will consume part of the calcium in the cement and thus the strength of the cement treated with material may be reduced. Sometimes this can explain why unexpectedly high cement contents are necessary to satisfy strength criteria. If soil with a high ICL is treated with cement it may be necessary to increase the cement content or the ICL of the formation of cementing Reactions, is also very high.

Choice of Strength Test

(a) Modified materials: the CBR is a useful test for estimating the strength of modified materials.
(b) Cemented material: the UCS test is easy to perform and it has been used extensively for mix design and quality control. Considerable experience has been grained with the UCS and criteria for strength in TRH14 are based on the UCS. However the tensile strength is important since it represents loading conditions in the field more closely, and attention should be given to the use of tensile tests for design and controlled purposes. The flexural test id particularly suitable for structural pavement design and should be used in central laboratories to study the properties of the cemented material and for mix design. At present relatively little experience has been gained with tensile tests and in the interpretation of test results, and it is recommended that greater use be made of tensile tests in practice.

2.3.2.2 Cement

Composition and property

Cement clinker is manufactured by heating together a mixture of raw materials, which provide sources of calcium, silica, alumina and iron. The clinker formed is then ground to a fine powder together with gypsum for set control, which is the basis of all the cements produced. The range of cements consists of clinker ground together or blended with various percentages of cement extenders (eg, slag, limestone, flyash, etc).

Hydration of the tricalcium aluminate results in the early set and hydration of the tricalcium silicate the strength development of cement-water pastes. The long-term strength is provided by hydration of the tricalcium and dicalcium silicates, which initially form calcium silicate hydrate gels. With time, these gels crystallise and form a strong Interlocking matrix, cementing the soil and aggregate particles together. The hardening of dicalcium silicate takes place slowly (only after about 28 days) and this material does not initially contribute much towards the early strength of the hydrated cement. The tri- and dicalcium silicates contribute about 95 per cent of the overall strength. Gypsum is ground together with the clinker to retard the rapid setting of the cement by coating the tricalcium aluminate early during the hydration process. Small quantities of free calcium oxide are present in clinker and additional slaked lime (about 20 per cent $Ca(OH)2$) is released as part of the calcium silicate hydration reactions. The properties of any cement are influenced by the amount and nature of the constituents and extenders present. The method of manufacture and source materials utilized have a large influence on the properties of cement, particularly the cooling method that is used in the manufacture of the clinker. The degree of grinding has a significant impact on the rate of setting of the cement, with finer cements setting much quicker than coarser cements. Research has shown that the hydration properties of two cement samples with identical compositions are not necessarily the same. For this reason the chemical composition of cement can only be regarded as an indication of its probable behavior. In addition to specific chemical properties, cement must also possess certain definite physical properties, e.g. soundness, setting times and time-strength requirements, which are specified in the EN 197-1 requirements [2].

Chemical reaction of cement with water:

Cement reacts with water to release hydrates of the constituent particles (mainly calcium-silicate hydrate: to bermorite). This reaction is known as the hydration of cement. It is, however, a complex process and will not be dealt with further. The calcium hydroxide released on the hydration of calcium silicates serves a number of useful Functions:

- It provides calcium ions for possible cation exchange reactions similar to those occurring during lime stabilization
- It reacts with any clays present in the soil or gravel as a pozzolan, which produces added strength and reduces the plasticity
- It maintains a high pH in the cemented material, which is necessary to ensure long-term durability of the cementations products. In stabilized soils, the additional calcium hydroxide is an advantage unlike its presence in concrete, where it reduces the durability of concrete.

Factors that influence the rate of hydration:

Hydration of cement commences as soon as the cement makes contact with the water. The rate of hydration and thereby the rate of strength development slows as it becomes more difficult for the unreacted cement to come into contact with water. Reference has already been made to the fineness of the cement particles. Cement particles that are more finely ground have an increased specific surface area, i.e. the total surface area of the particles. The hydration rate is increased because of the greater opportunity for contact between cement and water. Temperature plays an important role in all chemical reactions. As the temperature falls, the cement reaction is slowed down, and when the temperature is below 5°C, no reaction takes place. The opposite is also true: as the temperature rises the reaction speeds up and this can have serious implications when roads are stabilized in hot dry areas. Road surface temperatures in excess of 70°C have been measured in the western parts of South Africa – this can have an impact on the material under primes.

Setting time:

The time taken for the cement paste to set or to harden is known as the setting time. Two stages are recognized, namely, initial set and final set. There is no well-defined physical meaning to these terms, which arbitrarily describe the gradual setting taking place 13. However, after the initial set the cement-water paste is regarded as unworkable [5]. Generally, but not necessarily in every case, the setting time increases as the main cement type changes. This fact has been identified in Europe, where a pre standard on hydraulic road binders (ENV, 13282) has been released. This pre standard has strength classes in the range 5.0 to 35 MPa and a minimum initial setting time of 120 minutes [5].

2.3.2.3 Fly ash

Fly ash is a by-product of modern power stations. Fine material (fly ash) is collected by electrostatic or mechanical precipitation in the flues. Fly ash is not a stabilizer on its own, but is a pozzolan that reacts with lime on site as a stabilizer.

2.3.2.4. ANSS (Anyway Natural Soil Stabilizer)

General

The use of chemical additives for soil stabilization is a new area of research. Most of applications relate to military rapid construction of roads and highways [7].

Many researches have been done on the subject of soil stabilization using various additives: the most researched common methods of soil stabilization of clay soils in pavement works are cement and lime stabilization. This paper describes an investigation of the effect of addition Cement and Lime mixes with some additives which is already on trial application in Addis Ababa city with a readymade mix name ANSS. This stabilizer is a mix of Cement, lime, Pozzolans and rate governing additives and polypropylene fiber [7].

As Mentioned above lime and cement are the most researched hydraulic products. On the one side, cement stabilization is very good at non-plastic materials, while lime is well documented to reduce swell in highly plastic materials. There is a great deal of soil behavior in between these two soil types and this is where the lime and cement mix has the ability to contribute not only to strength increase, but also to reduce plasticity and swelling character of the soil. For the readymade mix (ANSS) to be able to do this, both cement and lime are part of the components. There are other materials, such as pozzolans, rate governing additives and other inorganic hydraulic products. It is for this reason that the mechanism of cement and lime form a great deal of the broader discussion in some of the documents.

Natural Soil Stabilizer **(**ANSS)claims to be an extremely cost effective method of converting poor quality soil into a strong impermeable layer [7].It permits construction of pavements, embankments and reinforced earth structures in areas where they were not previously economically viable.

However, it should be noted that, the general objective of this paper is to analyze the advantage of using stabilizers in road construction in terms of cost and time, not to endorse specific stabilizers like ANSS, this stabilizer is selected only because the current pilot projects of the city are liked with it and research is needed to be done in detail, which is not researched and documented yet. Otherwise mixing of local stabilizers like cement and lime and be done in other researches to find out the best mix design to have effective and efficient stabilizer to our interest.

Reaction Process

ANSS is calcium driven, inorganic soil stabilizer patented worldwide. Its specific formulation allows for stabilization of a broad range of materials without compromising the quality of the result.
The main components that are used to formulate ANSS are a series of inorganic hydration activated powders. It is composed of a specific type of cement, a lime, several pozzolans, rate governing additives, and a unique polypropylene fiber. The specific formulation allows for the individuality of the components to contribute to the reaction process, but also act holistically contributing of the stabilization process.

The theory behind their reactivity is quite simple, but the chemistry of each individual powder differs and the collaborative reaction is quite complex. Each component reacts individually while also contributing to the broader stabilization reaction. Each component contained in the stabilizer has its own series of reactions that occur at varying rates, which can be broken down into initial, short term and long term reactions.

ANSS is mixed with the soil as a dry powder. Initiation of hydration will commence immediately upon addition of water. The importance of achieving the desired water content is required not only for hydration of the components contained in ANSS, but also for wetting the reactive soil particles sufficiently to allow for exchange reactions to take place.

Dissolution of Ca (OH)2 will provide an excess of Ca-ions in the soil solution. These divalent ions will incorporate themselves into the clay structure, which provides a starting point for calcium silicate and calcium aluminate reaction products to form. Due to the cation effect, calcium is a difficult ion to replace on the exchangeable sites of clay. Therefore, it will remain in the clay structure. The presence of calcium in the crystal structure of clays allows for other clay particles to form bridging covalent bonds, forming insoluble calcium silicates and a starting point for aluminosilcate bridges. These bridges form an integral part of the inter-particle crystal matrix [7].

Due to the phases contained in the stabilizer, there is a considerable rise in the pH of the system. This increase in soil pH will activate the pH dependent sites on the surfaces and edges of clay particles. This will also provide a key site for combining with other soil particles creating a link between the micro and macro structure of the soil [7].

One of the first reactions to take place is flocculation of the clay particles, which is associated with an immediate reduction (or elimination) in the plasticity (PI) of the soil. The 'aggregation' of the fine fraction leads to stability within the layer. Following flocculation, medium to long term reactions begin and secondary reaction products form.

Summary of initial hydration reactions are also as follows:

- addition of water initiates the hydration of all components in the mix.
- lime mix dissolution creates excess ca-ions and OH-ions,
- OH-ions increase the PH of the soil solution, in so doing activating the PH dependent sites on clays,
- Ca-ions interact with exchangeable and PH dependent sites on clays, forming calcium silicates and calcium aluminate hydration products,
- hydration of calcium is very rapid,
- Calcium will form from nucleation sites to cast the soil particles in to an interconnected matrix,
- Ca-ions from the special cement mix hydration, along with ca-ions from from the lime mix hydration, will activate the slag components
- C3A hydration is initiated.
- Calcite formation will be limited due to the reduced nature of porosity
- the initial reaction will end with the final setting time of the lime mix, approximately 120 minutes from addition of water.

Chapter Three

General Description of the Study Area

3.1 Study Area

The study area is around southern part of Addis Ababa, Akaki Kality Sub city. Addis Ababa is the Capital of Ethiopia, lies at the foot of Entoto Mountains. From its lowest point, at 2,326 masl in the southern periphery. Addis Ababa, the capital and largest city of Ethiopia has an estimated population of over 3 million inhabitants in 2012 [12]. With 2.1% annual population growth (CSA, 2008) and constantly increasing industrial activities, the city is currently facing environmental pressure from urbanization and industrialization. The city covers an area of 500 km2 and harbours about 65.3% of all industrial and commercial activities of the country.

Akaki Kality is one of the 10 Sub cities of Addis Ababa, the capital of Ethiopia. The district is the southernmost suburb of the city and borders with the districts of Nifas Silk-Lafto and Bole subcities.

Akaki Kality Sub city is mostly covered by expansive black clay soils which are found to be substandard soil for sub grade construction. To analyze and compare the application of the stabilizer in the laboratory as well as on the field, the project location is selected in accordance with the Addis Ababa City Roads Authority programs who has a pilot project of the stabilizer in the sub city, the application of the stabilizer on the access road project of the industrial areas around Kality [ANNEX]. Field application data's has been collected which are later compared with the laboratory blending percentages.

The city roads authority selects the project site to make improvement on the conventional way of road construction, as the demand of roads is becoming high with urbanization: Roads are helping the city to have integrated and accessible transport networks that connect people and places. Accordingly, the Government of Ethiopia invests a lot of money on road infrastructures considering the integrated plan among sectors and growing economy of the Country. In fact road construction needs a huge investment, so specific researches are required in this field to guarantee efficient transport, access and comfort with limited budgets.

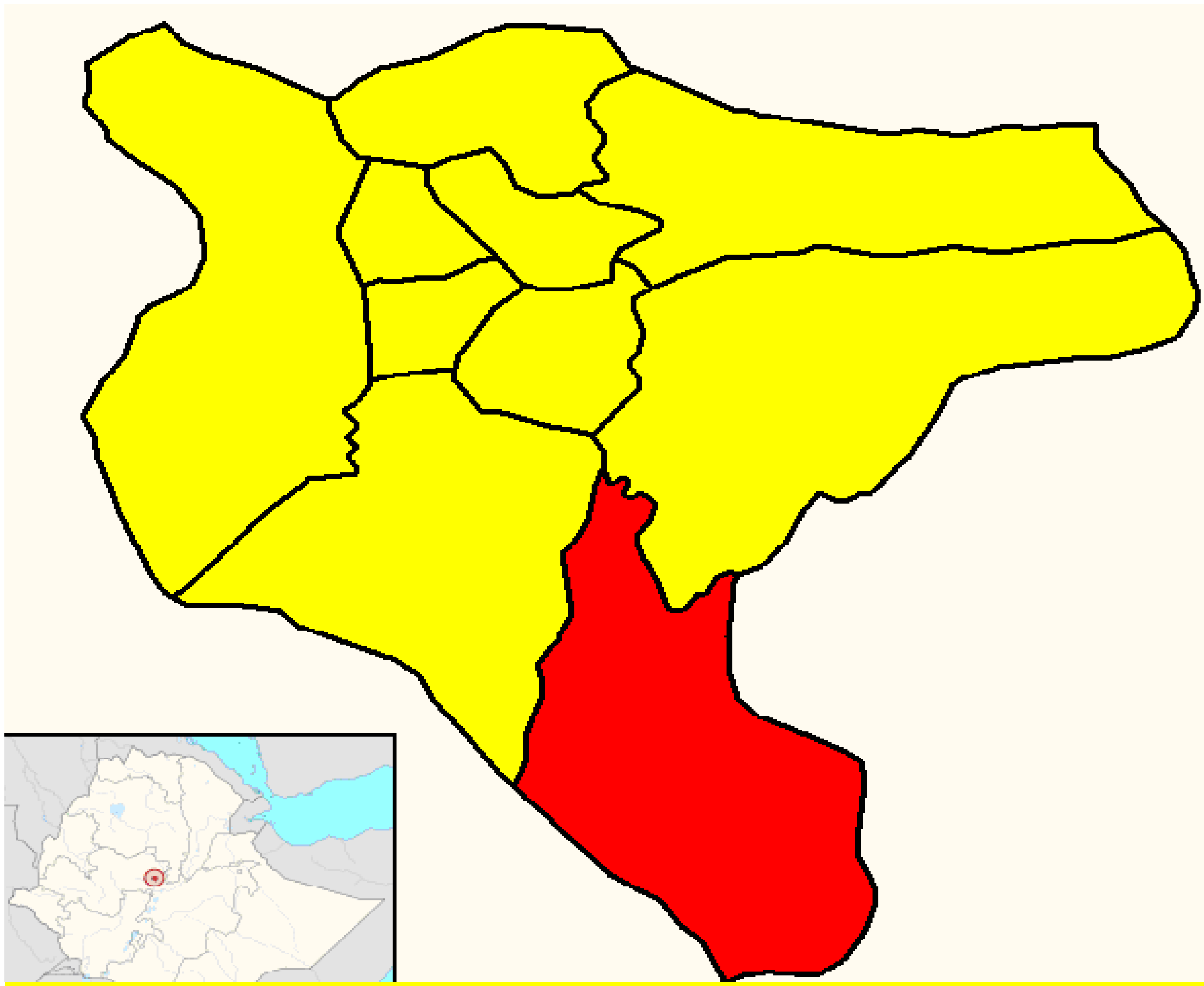

Figure 1: Map of the Study Area, Addis Ababa City, Akaki Kality Sub City

3.2 General Soil Property of the Study Area

Swelling Soils are common in southern part of Addis Ababa, especially in the study area, Akaki Kality. And are frequently encountered during highway construction. To minimize damage to roadways from swelling action, it is necessary that these soils be recognized, when encountered in the field and that the boundaries of the soils along the project be determined during preliminary soil survey [10].

In the city of Addis Ababa black cotton soil is usually found in most of the areas of the city, either as thin layer, with the darker color and are oriented parallel to the bedding. The bands range in thickness from, few centimeters to as much as ten meters from the existing ground surface.

If any of the characteristics of black cotton soil are noted during the soil survey (particularly in those area indicated on the map) if the possibility of swell is suspected for any other reason, notes should be made on the AACRA prescribed forms [10].

Even though soil content of a soil contains expansive clays, it may not swell if in place moisture is high enough. It is therefore important to know the actual moisture content of the soil in order to assess the possibility of problems due to swell. For this reason, if swelling soils are identified or suspected during the soil survey, moisture samples should be taken at or slightly below the elevation of the proposed grade line for those areas.

Chapter Four

Property of Materials

4.1 Property of Untreated/ Native Soil

The property of the native soil around Kality area is expansive. Which cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquake and floods [14]. The amount of damage caused by expansive soils is alarming. For example, in the United States, it has been estimated that losses from expansive soils exceed two billion dollars annually [15]. Unfortunately, expansive soil problems have not been recognized outside the area of their occurrence. In the underdeveloped nations, few people realize the magnitude of the damage caused by expansive soils.

Expansive soils are abundant in arid or semi-arid regions where annual evapotranspiration exceeds precipitation. The alkaline environment and lack of leaching favor the formation of montmorillonite minerals which have a very high swell potential. The origin of expansive soils is related to the composition of the parent material and the degree of physical and chemical weathering to which the materials are subjected [16]. The basic igneous rocks and the sedimentary rocks which contain montmorillonite as a constituent. The weak bonding force between the successive layers in montmorillonite allow water to enter between the individual sheets and cause swelling which lead to serious foundation problems. Compacted clays subjected to low pressures may show significant expansion when inundated. Swell potential by definition is the percent swell of a soil compacted as in the standard compaction test and subjected to 69 kPa surcharge before being immersed in water. A soil with a high swell potential usually exhibits a high swell pressure. The amount of swell is reduced by the overburden pressure. The higher the foundation pressure, the smaller the swell due to the inundation of the active supporting soil. The overburden pressure just sufficient to prevent swell upon inundation is termed the swell pressure [3].

Problems due to expansive soils usually occur in cut areas and in transition from cut to fill areas. They could also occur in fill areas where moderate to high swelling soils are used for fill. These soils are usually identified by Atterberg Limits (Liquid limit and Plasticity Index) and Swelling Pressure values and other related test values: According to AASHTO T 89 [9]native soil samples are taken to the lab and tested for the properties they have. This is analyzed in detail at chapter five.

a) Soil-Preparation

Sampling were taken during dry seasons using a sampling probe and shovel to a sample depth of an average 80cm from the natural ground level and the samples has been placed in a bags and labeled and transported to the laboratory. And as Per AASHTO testing Standards the following laboratory tests were performed.

b) Atterberg Limit

The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced.

A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system. Soil with a plasticity index of over 50% should be disposed from site. However, in this research it is stabilized to gain the required strength.

c) Classification of Soil

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles as per AASHTO system the classification of untreated soil is given below.

Table 1: Atterberg Limits, Grain Size Analysis and Classification of Untreated Soil

Liquid Limit (LL)	95
Plastic Limit (PL)	44
Plastisty Index (PI=LL-PL)	51
Linear Shrinkage	

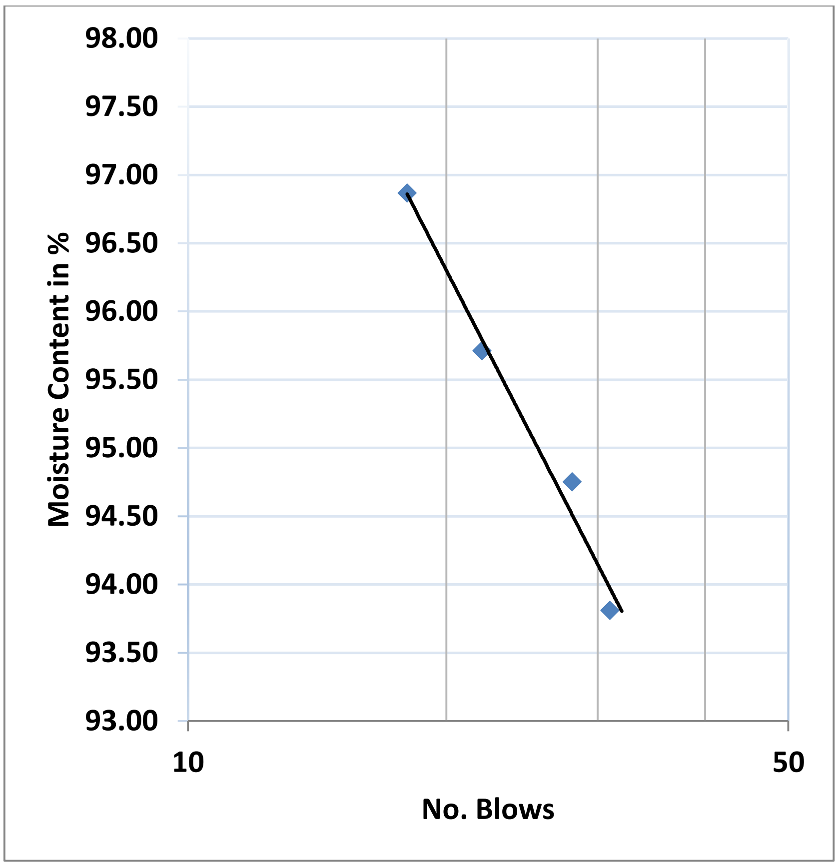

Figure 2: Flow Curve for Native Soil

d) Moisture- Density Relationships (Compaction Test)

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compaction effort. The compaction effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R.R. Proctor in 1933, therefore, the test is also known as the proctor test. Two types of compaction tests are routinely performed:

(1) The Standard Proctor Test, and
(2) The Modified Proctor Test.

In this case these tests can be performed in three different methods as outlined in the attached Table. In the standard proctor Test, the soil is compacted by a 5.5 lb hammer falling a distance of one foot into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer. The Modified Proctor Test is identical to the Standard Proctor Test except it employs a 10 lb hammer falling a distance of 18 inches, and uses five equal layers of soil instead of three. There are two types of compaction molds used for testing. The smaller type is 4 inches in diameter and has a volume of about 1/30 ft3 (944 cm3), and the larger type is 6 inches in diameter and has a volume of about 1/13.333 ft3 (2123 cm3). If the larger mold is used each soil layer must receive 56 blows instead of 25.

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test) and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density. The optimum water content is the water content that results in the greatest density for a specified compaction effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density. The summary moisture density relationship from the proctor test carried out in the laboratory for the native soil is as shown in the table below. Detail Laboratory tests and tables are shown in the ANNEX.

Table 2: Moisture Density Relation of Untreated Soil

MDD (g/cc)	1.36
OMC (%)	28.5

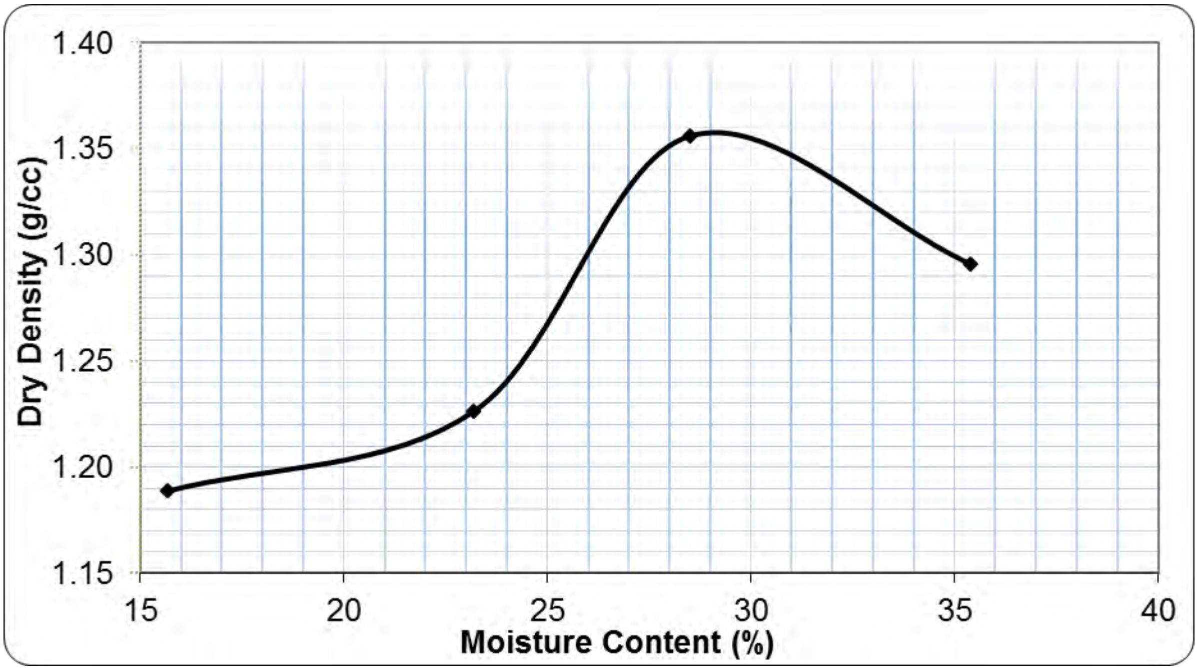

Figure 3: OMC versus MDD of Native Soil

e) *Swelling Pressure property*

Considerable research has been done in an attempt to characterize the swelling properties of expansive soils. It is well known that there is a relationship between the expansive-mineral content and the swell potential.

Expansive or swelling soils are abundant in arid or semi-arid regions where annual evapotranspiration exceeds precipitation. The alkaline environment and lack of leaching favor the formation of montmorillonite minerals which have a very high swell potential.

Swelling refers to the localized volume changes in expansive soil as they absorb moisture. Swelling or expansive soils are susceptible to volume change (Shrinkage and swell) with seasonal fluctuations in moisture content. The magnitude of this volume change is dependent on the type of soil (Shrink-Swell potential) and its change in moisture content. A loss of moisture will cause the soil to shrink, while an increase in moisture will cause it to expand or swell.

The tests, carried out under different loading conditions, are described and the summarized result is shown.

Table 3: Swelling Pressure of Untreated Soil (Undisturbed Sample)

Sr No	Source	Depth,cm	Swelling Pressure, Kpa
1	Akaki Site for Research	80.0	103.50

f) CBR (Californian Bearing Ratio)

The CBR test measures the shearing 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 subgrades beneath pavements for roads and airfields [19]. CBR tests were made on the specimens at the optimum moisture value for the soil as determined using standard compaction. In order to compare the results with previous studies both one point and multiple point CBR tests were carried according to AASHTO T193-93 and ASTM D1883-98. All CBR tests samples are compacted in the molds with standard hammer. To investigate the effect of additives on the specimens, compacted specimens were given 7 days curing in CBR molds at room temperature. During curing period the compacted specimens were subjected to surcharge loads to simulate the overlying load in the actual pavement section. At the start and end of curing period weight of specimens were measured to note effect of curing on the samples. Samples under curing at room temperature in CBR molds Summary of normalized CBR results for untreated soil is 1% and the test result is presented on the ANNEX.

g) UCS (Unconfined Compressive Strength)

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated untrained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test.

For soils, the un drained shear strength (su) is necessary for the determination of the bearing capacity of foundations, dams, etc. The un drained shear strength (su) of clays is commonly determined from an un confined compression test. The un drained shear strength (su) of a cohesive soil is equal toone-half the unconfined compressive strength (qu) when the soil is under the f = 0condition (f = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents un drained conditions, when the un drained shear strength is basically equal to the cohesion(c). This is expressed as:
su = c =2/qu Then, as time passes, the pore water in the soil slowly dissipates, and the intergranular stress increases, so that the drained shear strength (s), given by s = c+ s'tan f , must be used. Where s'= intergranular pressure acting perpendicular to the shear plane: ands'= (s - u), s = total pressure, and u = pore water pressure: c'and f' are drained shear strength parameters.
The laboratory test results of unconfined compressive strength is given in table 4 below.

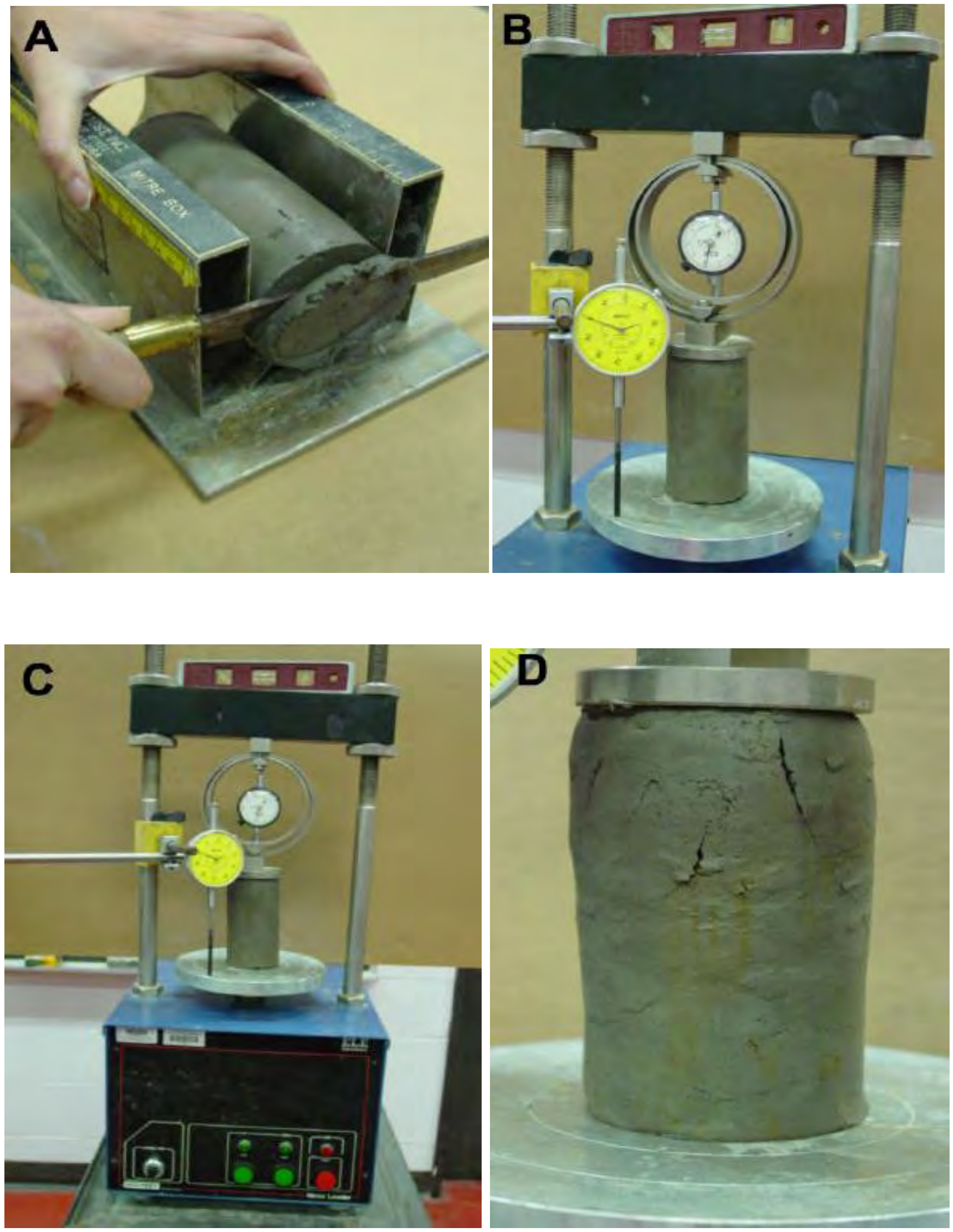

Figure 4: Unconfined Compressive Strength Test in the laboratory

h) *Summary of Laboratory results of Native Soil*

Summary of all the laboratory results of the native soils are presented in the table below for ease of reference.

Table 4: Summary of laboratory results of untreated soil

Item	Native Soil
Liquid Limit	95
Plastic Limit	44
Plastic Index	51
Classification of Soil	A-7-6 (59) (Expansive Soil)
Maximum Dry Density (MDD)(g/cc)	1.55
Optimum Moisture Content (OMC) (%)	24
Free Swell (%)	90
Californian Bearing Ratio at 95% MDD (Soaked)	1
Swelling Pressure (Kpa)	103.5
Unconfined Compressive Strength (Kpa)	q=112.6 ,c=56.3

4.2 Property of chemical Stabilizer (Anyway Natural Soil Stabilizer, ANSS)

4.2.1 General

The general chemical composition of anyway natural soil stabilizer, ANSS, is Cement, Lime, Pozzolanas, rate governing additives and a unique polypropylene fiber. Many researches have been done on the subject of soil stabilization using various additives: the most researched common methods of soil stabilization of clay soils in pavement work are cement and lime stabilization. The high strengths obtained from cement and lime stabilization may not always be required, however, there is justification for seeking cheaper additives which may be used to alter the soil properties. This paper and laboratory investigation is to analyze the effect of addition of ANSS which is a mix of cement and lime with some additives which is used here in Addis Ababa as a pilot project [7, 11].

4.2.2 Chemical Reaction Process during stabilization with ANSS

The main components that are used to formulate ANSS are a series of inorganic hydration activated powders. It is composed of a specific type of cement, lime and several pozzolans, rate governing additives, and a unique polypropylene fiber. The specific formulation allows for the individuality of the components to contribute to the reaction process, but also act holistically contributing of the stabilization process.

The theory behind their reactivity is quite simple, but thechemistry of each individual powder differs and the collaborative reaction is quite complex. Each component reacts individually while also contributing to the broader stabilization reaction. Each component contained in ANSS has its own series of reactions that occur at varying rates, which can be broken down into initial, short term and long term reactions [7].

A summary of initial hydration reactions are as follows:

- addition of water initiates the hydration of all components of ANSS (cement, Lime and others).
- lime mix dissolution creates excess ca-ions and OH-ions,
- OH-ions increase the PH of the soil solution, in so doing activating the PH dependent sites on clays, Ca-ions interact with exchangeable and PH dependent sites on clays, forming calcium silicates and calcium aluminate hydration products,
- hydration of calcium is very rapid,
- calcium will form from nucleation sites to cast the soil particles in to an interconnected matrix,
- Ca-ions from the special cement mix hydration, along with ca-ions from the lime mix hydration, will activate the slag components.
- C3A hydration is initiated.
- calcite formation will be limited due to the reduced nature of porosity
- the initial reaction will end with the final setting time of the lime mix, approximately 120 minutes from addition of water.

4.3 Prior to Stabilization

Prior to the application of the stabilizer there are several aspects that need to be addressed. Firstly, a data survey needs to be established, which should include the climatic conditions, traffic requirements, loads, and a natural soil property survey. Based on the results an appropriate road design cross sections shall be created. Then, the weak layers under the required cross section should be stabilized or replaced to obtain a required strength of sub grade. In this thesis, the unsuitable layer will be stabilized on site instead of hauling and replacing by other suitable material.

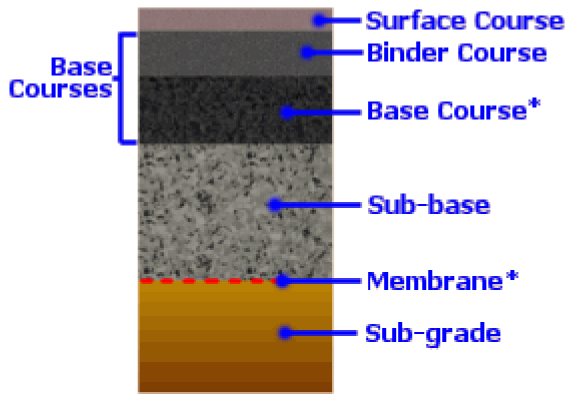

Figure 5: Typical Cross Section of Urban Roads

4.4 Sampling and testing

By mixing the natural soil with different dosage of stabilizer tests should be conducted to identify the optimum content of the stabilizer to be used during implementation, to ensure compliance of the strength with the requirement of the project specification outlined as per the pavement layer design.

All samples of soil should be taken in accordance with the standard methods specified on the design. The standard methods that should be utilized for testing include:

(a) The specifications of the American Society of Testing and Materials (ASTM).

(b) The specifications of the American Association of State Highway and Transportation officials (AASHTO).

(c) British Standards Institute Specifications (BS)

(d) Standard methods for testing road construction materials (TMH1 and TMH6) and for calibration (TMH2), compiled by the Committee of Land Transport Officials (COLTO)

Accordingly to The specifications of the American Association of State Highway and Transportation Officials (AASHTO) the following tests were made with different dosage of chemicals to analyze the optimum content of the stabilizer to stabilize soil to the required strength of subgrade soil, check the laboratory results on strength improvement of the native soil which is taken from the pilot project study area around Kality Industrial zone and finally analysis of cost and time will be made based on the optimum stabilization amount.

4.4.1 Preparation of the specimens

The calculated amount of ANSS stabilizer additive should be admixed with the raw or untreated material thoroughly to a uniform color before the optimum water is added

4.4.2 Modified Curing method of the treated Soil in the Laboratory

Curing of the stabilized soil is a little bit different from the standard curing system of the untreated soil because the chemical stabilizer needs some reaction time with the soil before applying load or before socking.

After completion of the compaction effort, the specimens should be cured for seven (7) days in a suitable curing room, exposed to air. At no stage whatsoever during the seven (7) day period should the compacted specimens is submerged under water.

The compacted specimens can either be placed under damp hessian bags or wood chipping to prevent the compacted specimens from drying out too quickly and thus preventing adequate strength gains from taking place.

After the seven (7) day curing period, the specimens should be removed from the curing room and submerged in water for the four (4) day soaking period, for the determination of the CBR. The compacted UCS specimens shall be immediately crushed to total failure on removing the compacted specimens from the curing room.

4.4.3 Curing methods of the stabilization on site

The stabilized layer should be protected against rapid drying out for 3 days following completion of the layer.

Advanced setting and hardening of the layer can be reduced through continuously keeping the layer wet or damp by watering at frequent intervals. During this period the application of water should be controlled so that it will not unduly wet the layer but, at the same time, will not allow the layer to dry out. Layers allowed to dry out too quickly may adversely affect the stabilization mechanism.

During the curing period the stabilized layer should be protected against heavy rain and flooding. While a moderate amount of gentle rain on the stabilized is good, a heavier rainfall or flooding will erode the layer before it has an opportunity to cure, and may otherwise interfere with the reaction.

Chapter Five

Laboratory Test Results of Treated Soil and Discussion of Results

5.1 Moisture Density Relationship of treated soil with different percentage of stabilizer

*5.1.*1 General

The determination of the relationship between water content and density of soils is used in determining the compaction of the material. The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density for the layer with minimum voids.

By achieving high densities, not only is the shear strength and elastic modules improved but also the ingress of water is reduced or eliminated.

5.1.2. Effect of the stabilizer ANSS on Maximum Dry Density (MDD) of the Soil

Moisture density tests have been carried out with 2%, 4%, 6% and 8% of stabilize to determine the optimum quantity/ percentage of stabilizer to get the maximum density of soil, and the following results has been obtained. (Refer the detail laboratory results from Annex).

Table 5: Percentage of stabilize and MDD

Percentage of stabilizer	OMC (%)	MDD (g/cc)
0	28.5	1.36
2	29	1.44
4	26	1.53
6	26	1.54
8	29.5	1.47

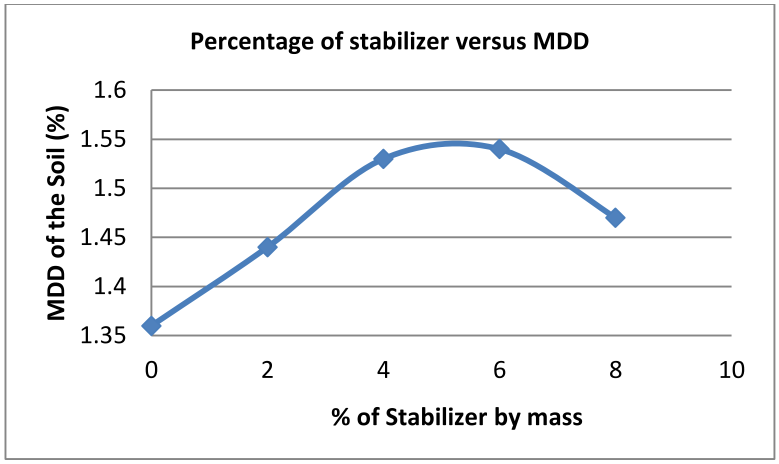

Figure 6: Percentage of Stabilizer versus MDD

As observed from the results above, with increment of percentage of stabilizer the maximum dry density increases to a maximum saturated pointof around 5.5 to 6 % at 26% OMC, adding more stabilizer will not increase the density of the soil, this is assumed to be theoptimum dosage of stabilizer to add on the natural soil, in this case since the laboratory tests have been performed within 2% interval, and price of the manufacturer is the same for 5.5 and 6% of dosages, 6 % at 26% of moisture content has been taken as optimum dosage to stabilize the soil, since the objective of this paper is to analyze cost and time savings.

5.2 Atterberg Limits with different dosage of stabilizer

5.2.2 Effect of stabilizer on the Atterberg Limits

According to the manufacturer, dosage to be applied for stabilization depends on the type of soil. In this research so much effort has been made to find appropriate dosage rate and a trial dosage of 2%, 4% and 6% doses by dry weight sample has been performed, and different results have been found as shown in the table and the detail lab analysis is attached from Annex C to F.

Table 6: Atterberg Limits (LL, PL and PI) of treated Soil with different dosage of Stabilizer

Dosage of ANSS On Native Soil (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0	95	44	51
2	86	49	37
4	78	52	26
6	68	49	19

Table 11 shows the effect of ANSS treatment on plasticity index values, from the table it can be seen that the plasticity index of the treated soil decreases with increasing of ANSS (the stabilizer)
The lowest plasticity index obtained is 19 with 6% content of ANSS.

5.3 Californian Bearing Ratio and Unconfined Comprehensive Strength (UCS) determination of treated soil for strength test

5.3.1 General

The strength of soils or cohesive materials can be assessed by the determination of the CBR and/or UCS.

- CBR test: used to evaluate the potential strength of sub-grade, sub-base and base-course material.
- UCS test: used to provide an approximate value of the strength of cohesive soils in terms of total stresses and is used to quickly obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state.

5.3.2 Effect of stabilizer on the Californian Bearing Ratio (CBR)

In order to establish the required stabilizer content required to produce a mixture conforming to either a specific CBR or UCS, specimens shall be prepared at three (3) different stabilizer contents, and CBR or UCS determinations shall be made for each specimen. The three contents are usually in increments of two (2) percentage points e.g. 2%, 4% and 6% by mass of the total oven-dried material.

The CBR and UCS tests shall be conducted in accordance with the methods described in the Standard Methods as specified, subject to the following additional provisions.

As detailed discussed on the Laboratory Procedures Above the Californian bearing ratioresults general view has been given below for different dosages of the Chemical Stabilizer ANSS (the detail test results has been given from in the ANNEX .

Table 7: CBR of treated Soil with different dosage of stabilizer

Dosage of ANSS On Native Soil	Californian Bearing Ratio at 95% MDD (Soaked)	Remark
Native Soil	1	Standard curing method
2%	3	Standard curing method
4%	7	Standard curing method
6%	11	Standard curing method
6%	*17	*Modified curing method (allowing time for bonding of soil with the chemical prior to soaking for four days)

- As it is observed from the table, the dosage of the native soil CBR is very weak which is not suitable for subgrade construction but with 2% mix application of the stabilizer it is suitable for replacement of swampy material under subgrade undercuts and 6% mix is optimum for capping material replacement above the subgrade as per the optimum strength of soil according to ASHTO and AACRA manuals which is a minimum of 15% [10].

- For the first 3 sequence of laboratory tests of CBR 2%, 4% and 6% mixes has been tested using standard curing method and the result were not satisfactory to the required level, even with the 6% but as we learnt later the curing method shall be modified to give time for the soil particles and the chemical to acquire enough bonding time (3 days air-dry)to obtain strength before socking [7].

Accordingly, it is observed that with 6% of modified curing the required result has been obtained and due to the limitation of availability of the chemical modified curing method has not been performed for the other dosages.

5.3.3 Effect of Stabilizer on Unconfined Comprehensive Strength (UCS)

Table 8: Unconfined Comprehensive Strength of treated Soil at 6%

Dosage of ANSS On Native Soil	**UCS(kpa)**
Native Soil (0%)	q=112.6 and c=112.6
6%	q=365.20 and c=182.60

- Due to limited availability of the stabilizer, unconfined comprehensive strength (UCS) is only performed for effective dosage, which is 6%.

  Therefore, as we have seen from the table, the effect of the stabilizer on UCS shows a significant increment of native soil from q=112.6, c=112.6 to q=365.20, c=182.60 at 6% doze which is the optimum dosage of stabilizer.

5.4 Swelling Pressure of the treated Soil

5.4.1 General

Swelling refers to the localized volume changes in expansive soil as they absorb moisture. Swelling or expansive soils are susceptible to volume change (shrinkage and swell) with seasonal fluctuations in moisture content. The magnitude of this volume change is dependent on the type of soil (Shrink-Swell potential) and its change in moisture content. A loss of moisture will cause the soil to shrink, while an increase in moisture will cause it to expand or swell.

5.4.2 Effect of stabilizer on Swelling Pressure of Soil

Same as UCS swelling pressure test is also performed for 6 % of dosage after it is found that the appropriate dosage is 6% for capping layer replacement. And as it is observed from the test the swelling pressure has also a significant reduction from 103.5 to 3.5 Kpa, which is very significant, it should be noted that, this test has been made with a modified curing systems, that is the main reason to get this higher value, as the mix of sample gets enough time to create a bond between soil particles and the chemical stabilizer during the air dry curing time.

Table 9: Swelling Pressure property of treated Soil with Different Dosage of Stabilizer

Dosage of ANSS On Native Soil (%)	**Swelling Pressure KPa**
Native soil	103.5
6%	3.5

Chapter Six

Guidelines of Construction Using the Stabilizer

6.1 General

The following project specifications have been written to cover all phases of work normally required for the stabilization of materials or pavement layers using anyway natural soil stabilizer (ANSS). The document has been structured in such a way as to present the three phases of any project: **pre-application, the application itself and post-application** procedures. The objective of this guideline is to produce manual for the road authorities to be able to produce uniform results throughout all the project document is intended as a guide for practicing engineers and leaves room for engineering judgment to be administered [7].

6.2 Pre-Application

A) Prior to stabilization

Prior to the application beginning there are several aspects that need to be addressed. Firstly, a survey needs to be established, which should include the climatic conditions, traffic requirements, loads, and a soil survey. Based on the results an appropriate road design should be created [7].

B) Sampling and testing

Tests should be conducted by the party carrying out the application, both before and during the progress of the work, to ensure compliance with the requirements of the project specification outlined by a reputable consulting engineering firm experienced in the aspects of pavement layer design. Results of the testing are the responsibility of the client's lab and the client's consulting engineer.

All samples of soil and general materials should be taken in accordance with the standard methods specified. The standard methods that should be utilized for testing include:

- The specification of the city roads authority
- The specifications of the American Society of Testing and Materials (ASTM)
- The specifications of the American Association of State Highway and Transportation Officials (AASHTO)
- British Standards Institute Specifications (BS)

- Any other standard that might be applicable for the client

In addition to the above standard methods of testing, standard specifications or test methods of other bodies may also be referred to in these specifications, or test methods may be described where no acceptable standard method exists.

C) Untreated material

The following tests should be conducted on the natural or untreated soil/material before construction of any pavement layer proceeds. The results should be forwarded to a consulting engineer or engineering firm to the house consulting team.

- Gradation, particle size distribution and particle size analysis
- Plasticity (Atterberg Limits)
- Group Classification
- Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)
- California Bearing Ratio (CBR) and/or Unconfined Compressive Strength (UCS)

D) Mix test of untreated material with stabilizer

The following tests should be conducted on the soil/material to be stabilized with ANSS before construction of any pavement layer proceeds (i.e. prior to project initiation):

- MDD (Modified) and OMC at varying dosages
- Evaluation of strength (CBR and/or UCS) versus ANSS stabilizer content at differing dosages
- Atterberg limits at varying dosages (Atterberg Limits)

6.2.1 Properties tested

A) Particle size distribution

The particular packing arrangement for a material is normally represented by the particle size distribution (gradation) curve based on proportions (by mass) assign successive sieves. A lack of coarse or finer particles would produce an unbalanced gradation or distorted gradation curve resulting in poor mechanical stability and unsatisfactory compaction. Therefore, an improvement in gradation and in the reduction of oversized material will result in more uniform strength development, uniform mixing and compaction. It is preferable to have a gradation with a continuously smooth curve from the maximum particle size to the smallest particle size with no excess or lack in certain particle fractions [7].

B) Particle size analysis

The particle distribution of the finer material passing the 2 mm sieve has a marked effect on the compatibility and bearing strength of the material.

C) Atterberg limits

Plasticity gives an indication of the materials' clay reactivity (active clay content) and affinity to water (moisture content), which will affect the variability in strength development and the possible need for increasing the stabilizer content.

D) Group classification

The group classification is useful in determining the relative quality of the soil material for use in earthwork structures, embankments, sub-grades, sub-bases and bases.

The classification is based on laboratory determinations of particle size distribution, liquid limit and plasticity index.

E) Moisture-density relationships

The determination of the relationship between water content and density of soils is used in determining the compaction of the material. The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density for the layer with minimum voids.

By achieving high densities, not only is the shear strength and elastic modules improved but also the ingress of water is reduced or eliminated.

F) Strength / CBR and UCS determinations: additional Provisions

The strength of soils or cohesive materials can be assessed by the determination of the CBR and/or UCS.

- CBR test: used to evaluate the potential strength of sub-grade, sub-base and base-course material.
- UCS test: used to provide an approximate value of the strength of cohesive soils in terms of total stresses and is used to quickly obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state.

In order to establish the required stabilizer content required to produce a mixture conforming to either a specific CBR or UCS, specimens shall be prepared at three (3) different stabilizer contents, and CBR or UCS determinations shall be made for each specimen. The three contents are usually in increments of two (2) percentage points e.g. 2%, 4% and 6% by mass of the total oven-dried material.

The CBR and UCS tests shall be conducted in accordance with the methods described in the Standard Methods as specified below, subject to the following additional provisions.
The purpose is to facilitate conditions in the field and to allow sufficient strength gain to take place.

F.1) Preparation of the Specimens

The calculated amount of ANSS stabilizer additive should be admixed with the untreated material thoroughly to a uniform color before the optimum water or moisture content is added.

F.2) Curing of the specimens in the Laboratory

After completion of the compaction effort, the specimens should be cured for seven (3 to 7) days in a suitable curing room, exposed to air. At no stage whatsoever during the seven (3 to 7) day period should the compacted specimens be submerged under water.

The compacted specimens can either be placed under damp hessian bags or wood chipping to prevent the compacted specimens from drying out too quickly and thus preventing adequate strength gains from taking place.

After the seven (3 or 7) day curing period, the specimens should be removed from the curing room and submerged in water for the four (4) day soaking period, for the determination of the CBR. The compacted UCS specimens shall be immediately crushed to total failure on removing the compacted specimens from the curing room.

F.3) Curing the stabilized work on site

The stabilized layer should be protected against rapid drying out for 3 days following completion of the layer.

Advanced setting and hardening of the layer can be reduced through continuously keeping the layer wet or damp by watering at frequent intervals. During this period the application of water should be controlled so that it will not unduly wet the layer but, at the same time, will not allow the layer to dry out. Layers allowed to dry out too quickly may adversely affect the stabilization mechanism.

During the curing period the stabilized layer should be protected against heavy rain and flooding. While a moderate amount of gentle rain on the stabilized, compacted surface will not harm the layer (and may in fact assist in the reaction), a heavier rainfall or flooding will erode the layer before it has had an opportunity to cure, and may otherwise interfere with the reaction.

F.4) Provision for traffic

Traffic may be allowed onto the surface (pavement layer or sub-grade) provided that strict speed controls are posted and there is no likelihood of rain. The provision of traffic signs and flag-persons during construction should be established by the party carrying out the application so that signs and procedures do not hinder the safety of the construction crew and the road users. Insome instances the road may require full closure to expedite work.

Typically the work is executed so that each section of roadway is completed to full width at the end of the days' work.

6.3 Foundation and Drainage

Before commencement of stabilization of materials or pavement layers, assessment of the foundation and drainage should be carried out.

6.3.1 Foundation

The stabilized layer should be constructed on a stable, durable, adequately compacted foundation layer or underlying pavement structures, depending on the type and amount of traffic load. The following problems should be addressed and eliminated before any stabilization of a material or pavement layer is initiated:

- Excessive volume changes which occur in some soils as a result of moisture change (eg. expansive soils and soils with a collapsible structure).
- Flaws in structural support (eg. sinkholes and slope stability).
- Non-uniform support that results from wide variations in soil types or states.
- Biological activity (eg. moles, termites etc.).
- Organic material (eg. humus, vegetation etc.).
- Non-compaction of underlying layers.
- Low and insufficient bearing capacity of the underlying layers.

6.3.2 Drainage

The compacted layers should be adequately drained and shaped (design specification) to prevent standing water from scouring the completed work. Open drains should be excavated within the road prism (medium drains and side drains) either by hand or special excavating equipment (excavators or similar equipment's) to control the free water by effective drainage.

Open drains will prevent the damage of the stabilized layer and its foundation from free water. All existing open drains shall be cleared out, and where necessary, shaped by removing the sediment and turning the floors and sides. All backfilling that is required for excavation of open drains and concrete linings, should be of suitable material and compacted to at least 90% of Mod. AASHTO density or higher.

All reasonable precautions should be implemented to prevent the material or the road from becoming excessively wet as a result of rain and groundwater. Groundwater or storm-water drains can also be done using underground storm water pipe installation in urban areas.

Where material or existing layers are too wet to comply with the requirements in regard to moisture content during construction, the material shall be dried out until it is adequately suitable for compaction, stabilization, and all other aspects associated with ANSS application.

6.4 Construction limitations

ANSS should be applied to an area of such size that all operations, dry mixing through cutting final grade, to be completed within 6 hours. Perform all operations in a continuous manner and complete all operations during daylight hours. Any rain falling on the working area during the process of stabilization may be sufficient cause to require re-commencement of the process.

No material for the stabilized layer may be placed if the underlying layer has been softened by excessive moisture.

Depths in excess of 150 mm can be compacted provided that the correct equipment and compactor is utilized that can achieve an effort large enough to compact the lower regions of the layer. Commonly, depths of more than the maximum of 150 mm should be constructed in two separate layers in order to ensure that the minimum compaction requirement is obtained.

Only apply stabilizer when the ambient air temperature is at least 5°C (41°F) in the shade and rising. Do not mix stabilizer with frozen soils or with soil containing frost.

6.5 Stabilization Procedures

Stabilization using ANSS (the process of improving the engineering properties of a material by means of the addition of ANSS) is subject to the quality of materials available and the impact of the environment (traffic, climate, etc.) on the structural design.

Stabilization with ANSS endeavors to increase the quality of the project and reduce construction costs by improving the properties of substandard, readily available material to comply with the relevant specifications [7].

A) Material/ ANSS Natural Soil Stabilizer

ANSS should be kept under cover and protected from moisture from the time of purchase to the time of use. If ANSS has been left exposed to environmental elements, consult an ANSS representative. ANSS is manufactured under ISO 9001:2000 Standard. Documentation or other acceptable evidence of the quality of ANSS shall be provided upon request.

B) Soil

It is preferable to stabilize a soil with a continuously smooth gradation curve from the maximum particle size to the smallest particle size with no excess or lack in certain particles. All soil should be tested prior to the project or application to determine the dosage of ANSS to produce the designed strength.

C) Water

The characteristics of the water that is sought for stabilization are that it is soft, reasonably clean, and free from oil, acid, alkali, organic and other impurities. Water that is thought to encourage adverse reactions should be approved for compatibility with ANSS.

6.6 Construction procedure of projects

A) Prior to the construction of the stabilized layer

Stabilized layers should be constructed only where the underlying layer or foundation meets all specified requirements. Before construction of any stabilized layer and before any transported material for stabilization is dumped on the road, the underlying layer should be investigated to establish whether there is any damage, wet spots or other defects. Any defects to the layer should be rectified before the stabilized layer is constructed.

Where the stabilized layer is constructed on the floor of a pavement excavation or on the top of an existing pavement layer i.e. where the underlying layer has not been reworked or reconstructed, the floor of the excavation or the top of the existing pavement layer should first be watered and the compaction of the layer should be verified.

B) Applying ANSS

A) Preparing the layer

The material to be stabilized should be placed, or in the case of an existing pavement layer, scarified to the full depth specified, broken down, watered if necessary and mixed to achieve a homogenous layer. Any oversize material (> 1/3 the thickness of the layer to be stabilized) should be removed.

Figure 7: Scarifying

Figure 8: Creating Drainage

Dosage determination should be performed prior to product application. After the layer of soil or stabilized material has been prepared the product should be spread uniformly over the full area of the layer by means of an approved type of mechanical spreader or by hand. Material that has been exposed to the open air for a period of 4 hours or more should not be used.

If application is administered by hand, pockets or bags of the product should be accurately spaced at equal intervals along the section to be stabilized so that the specified rate of application can be achieved. The stabilizing agent should be spread as evenly as possible over the entire surface.

Marking and spreading products (as per the dosage requirement)

Figure 9: Marking

Figure 10: placing product as per the spacing (the markings)

Figure 11: Spreading Product

It is no advisable to apply ANSS when wind conditions, as determined by the on-site engineer or project manager, are such that the stabilizer becomes airborne in such a manner as to become hazardous to traffic, workmen, adjacent workers, adjacent property, or results in adverse impact upon the public.

B) Dry-mixing ANSS

Immediately after the product has been spread it should be mixed with the soil/material to the full depth of treatment. Special attention should be taken not to disturb the compacted layer underneath and especially not to mix the stabilizing agent in below the desired depth. Mixing should continue for as long as necessary and repeated as often as required to ensure homogeneity and thorough mixing of the soil/material with ANSS over the full area of the application site.

Mixing should be done using a rotovator (soil recycler or agricultural), grader or equivalent equipment over successive passes of the layer. Specific attention should be made to ensure that the mixing device does not cycle ANSS and relocate the majority of the powder on the bottom of the layer to be constructed.

Figure 12: Dry Mixing

C) Watering

The water supply and watering equipment should be adequate to ensure that all the water required is added and mixed with the soil/material being treated within the prescribed period to enable compaction to be completed.

Uniform mixing of the product and water is paramount to the success of the stabilized layer. The number of passes required for ANSS stabilization to obtain adequate mixing is based on the type of soil and experience of the contractor.

Immediately after ANSS has been properly mixed into the layer, the pre-determined moisture content (OMC) should be administered.

Each application or increment of water should be well mixed with the material so as to avoid concentration of water near the surface or in pockets within the layer.

Particular care should be taken to ensure satisfactory moisture distribution over the full depth, width and length of the section being stabilized and to prevent any portion of the work from getting excessively wet after the stabilizing agent has been added. Ensure that the moisture content of the mixture is not below the specified optimum moisture or more than 2 percent above the specified optimum moisture content, and less than the quantity that causes the roadbed to become unstable during compaction and finishing.

If any portion of the work becomes too wet after the stabilizing agent has been added and before the mixture has been compacted, as during rain or downpour, the application shall be rejected. These portions should be allowed to dry out to the required moisture content and then be scarified, re-stabilized, re-compacted and finished off.

Figure 13: Watering

D) Shaping and Compaction

Initiation and completion of compaction of the material in the pavement layer should be carried out within 4 hours. In colder climates, a cool soil may slow the setting of ANSS and this should be taken into consideration in the design stage.

The type of compaction equipment to be used and the amount of rolling to be done should be such as to ensure that specified densities are obtained without damage being done to lower layer structures. Selecting the right compaction equipment is typically carried out by the contractor.

The compacted layers should be adequately shaped (design specification) to prevent standing water from scouring the completed work. The process of shaping should be completed by an experienced grader operator and should be facilitated by shaping the road to reflect the required camber without excessive removal from or addition to the thickness of the layer.

Compaction should be carried out in a series of continuous operations covering the full width of the layer concerned. The length of any section of a layer being compacted shall, wherever possible, not be more than can be properly compacted with the available equipment. During compaction, the layer should be maintained to the required shape and cross-section, and holes, ruts and laminations should be removed.

During compaction, loss of moisture from evaporation should be corrected by further light applications of water over the surface.

The minimum compaction required shall be $98% of Mod AASHTO density for the stabilized layer and the sub-base or immediate underlying layers.

During final compaction, field density determinations should be done to determine accurately the applied compaction effort and to ensure the minimum compaction requirement has been obtained. Density testing should be carried out within 24-hours of compaction having been completed.

Figure 14: Shaping

Figure 15: Compaction

E) Road Completed and Asphalt Seal

Figure 16: Road completed

Figure 17: Asphalt Seal

6.3 Post-Application sampling and testing

The following tests should be completed after the application has been completed:

- Layer densities ; The layer density's should be controlled by means of nuclear density and moisture gauge, operated by a suitably trained technician complying with the statutory regulations governing the use of the gauge. The gauge should be certified to be suitably calibrated.
- Layer thickness and long term strength; the stabilized layer thickness will be controlled by random test holes or core sampling. Core samples are to be taken 56 days after completion of the project unless otherwise specified. The average thickness will be the design depth with a tolerance of 10%.

6.4 Field Performance of the Stabilization

It's difficult to evaluate the field performance of the pilot project at Kality industrial area, because there was no sealing pavement layer and drainage system is constructed yet, and the procedures of application and the critical issues of drainage and sealing layer has not been observed closely by the client due to knowledge gap and researches on the area.

Chapter Seven

Comparison of Construction Cost and Time

7.1 Types of Construction Cost Estimates

The required levels of accuracy of construction cost estimates vary at different stages of project development, ranging from ball park figures in the early stage to fairly reliable figures for budget control prior to construction. Since design decisions made at the beginning stage of a project life cycle are more tentative than those made at a later stage, the cost estimates made at the earlier stage are expected to be less accurate. Generally, the accuracy of a cost estimate will reflect the information available at the time of estimation.

Construction cost estimates may be viewed from different perspectives because of different institutional requirements. In spite of the many types of cost estimates used at different stages of a project, cost estimates can best be classified into three major categories according to their functions. A construction cost estimate serves one of the three basic functions: design, bid and control. For establishing the financing of a project, either a design estimate or a bid estimate is used.

Design Estimates; For the owner or its designated design professionals, the types of cost estimates encountered run parallel with the planning and design as follows:

- Screening estimates
- Preliminary estimates (conceptual estimates)
- Detailed estimates (definitive estimates)
- Engineer's estimates based on plans and specifications

For each of these different estimates, the amount of design information available typically increases.

Bid Estimates; For the contractor, a bid estimate submitted to the owner either for competitive bidding or negotiation consists of direct construction cost (material, labor and equipment) including field supervision, plus a markup to cover general overhead and profits. The direct cost of construction for bid estimates is usually derived from a combination of the following approaches.

- Construction material, labor and equipment
- Subcontractor quotations
- Quantity takeoffs/ cost breakdown
- Construction procedures

Control Estimate; for monitoring the project during construction, a control estimate is derived from available information to establish:

- Budgeted cost after contracting but prior to construction
- Estimated cost to completion during the progress of construction.

7.1.1 Design Estimates

In the planning and design stages of a project, various design estimates reflect the progress of the design. At the very early stage, the *screening estimate* or *order of magnitude* estimate is usually made before the facility is designed, and must therefore rely on the cost data of similar facilities built in the past. The design professional will include expected amounts for contractors' overhead and profits.

The costs associated with a facility may be decomposed into a hierarchy of levels that are appropriate for the purpose of cost estimation. The level of detail in decomposing the facility into tasks depends on the type of cost estimate to be prepared. For conceptual estimates, for example, the level of detail in defining tasks is quite coarse; for detailed estimates, the level of detail can be quite fine.

When the detailed design has progressed to a point when the essential details are known, a detailed estimate is made on the basis of the well-defined scope of the project. When the detailed plans and specifications are completed, an engineer's estimate can be made on the basis of items and quantities of work.

7.1.2 Bid Estimates

The contractor's bid estimates often reflect the desire of the contractor to secure the job as well as the estimating tools at its disposal. Since only the lowest bidder will be the winner of the contract in most bidding contests as per the procurement low of Ethiopian Federal Government, any effort devoted to cost estimating is a loss to the contractor who is not a successful bidder. Consequently, the contractor may put in the least amount of possible effort for making a cost estimate if it believes that its chance of success is not high [10].

If a general contractor intends to use subcontractors in the construction of infrastructure, it may solicit price quotations for various tasks to be subcontracted to specialty subcontractors. Thus, the general subcontractor will shift the burden of cost estimating to subcontractors. If all or part of the construction is to be undertaken by the general contractor, a bid estimate may be prepared on the basis of the quantity takeoffs from the plans.

In general, as it is mentioned above, the direct cost of construction for bid estimates is usually derived from a combination of the following approaches.

- Construction material, labor and equipment
- Subcontractor quotations
- Quantity takeoffs
- Construction procedures/methodology

In this thesis ***bid estimate*** is used around the study area Akaki kality for cost comparison purpose since most of the projects in the city are outsourced (executed by contractors using open bid tenders) and project cost data of the city administration is based on the current bid price.

7.2 Cost comparison, Conventional way of construction versus construction using the stabilizer

Cost of construction of the conventional way and unconventional way is taken from the current bid price of the cost around the study area which included construction material, labor, equipment, overhead and profit. In case of the unconventional way there was not enough competitive bidders to supply the stabilizer and the contract cost has been fixed based on negotiation with the supplier [11].

In order to construct, rehabilitate or upgrade any road network in urban areas, large quantity of gravel and capping material is needed, but most of the time, in cities, the location of suitable materials are far from the project site. Which make the transportation and construction cost high.
One of the reasons of longer construction time in urban areas is that the conventional methodology of construction which needs transportation of suitable sub grade material which is expensive to find within economically feasible distance from the construction site, and it also requires to deploy heavy machineries at the quarry site for the production of suitable materials and hauling the material to the project sites.
In addition, it incurs traffic jams, high fuel consumption and causes damage to the buildup road segments.

This is a common challenge in most of the road construction projects [11]. Therefore as a result of this, urban road construction becomes very expensive. Which is getting nearly 24 million Birr per km and 7 m width of Asphalt road construction in the city [11].

One of the innovative technologies that enable use of soil and marginal aggregates along the road corridor is soil stabilization. Adding in small quantities of a chemical stabilizer to a native soil, results in the rapid formation of highly-stable pavement mixtures [3]. Use of available materials itself without transportation and waste of the natural material significantly decreases cost of cut to waste and production and hauling of selected materials from lengthy distances to replace the removed materials.

When the cost comparison is made the following basic common assumption were taken to make the comparisons in similar podium. And based on the following assumptions cost comparison is shown on table 10.

- location of selected materials are the same for the study area.
- material cost above the subgrade layer (surface layer) is the same in both cases, therefore, the surfacing layer cost is not considered during the comparison.
- Current prices are taken from addis ababa city roads authority for all cases.
- similar master plan road width of 30 meter and 5 kilometer length road is used for the quantity tabulation.

- the stabilizer cost of 6% mix by mass is taken from the contract document of Addis Ababa city roads authority which is entered with the suppliers of ANSS for the pilot project of the city [11].
- during the application of the stabilizer, only the subgrade depth is scraped, stabilized and compacted.
- Similar design cross sections and quantities are used to calculate the cost which is a design cross section of 60 cm capping layer, 27 cm subgrade, 17 cm base layer and 10 cm Asphalt Layers, where only the subgrade cost is analyzed for comparison since the remaining layers base layer and asphalt are the same in both cases.

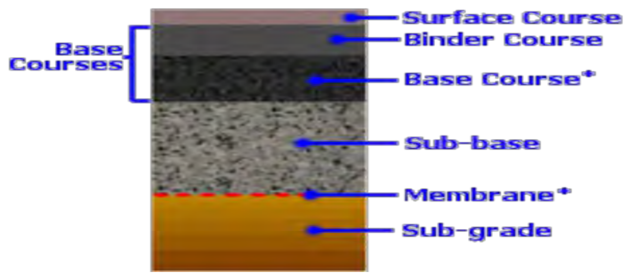

Figure 18: Typical Asphalt Road Cross Section

Table 10: Cost comparison of construction for Earth works and subgrade in the two methods of construction [11].

Item	unit	Quantity		Unit Price (Birr)		Total Price (Birr)	
		Conv.	Stab.	Conv.	Stab.	Conv.	Stabilized
Excavation (in case of stabilizer no excavation of subgrade)	M3	231,000	81,000	90	90	20,790,000	7,290,000
Selected Material subgrade	M3	90,000	-	210	-	18,900,000	-
Replacement of materials (undercut)	M3	9,000	-	190	-	1,710,000	-
Stabilization of subgrade	M3	-	150,000	-	150.50	-	22,575,000
Total Cost						**41,400,000**	**29,865,000**

Note; the cost is made as per AACRA's current bid and contract price, this indicates that to construct 1(one) kilometer Road with 7 meter width it costs around 24,150,000 Birr.

7.3 Time comparison of conventional way of construction versus that of using the stabilizer

Since our case study is Addis Ababa City Roads, the current data of the city administration is used for comparison of cost and time. As per the current road construction duration of Addis Ababa city it takes an average of 365 days to construct 5 kilometer road with 30 meter width of Asphalt Road in a conventional way of construction [11].

When this technology is used travel time to transport excavated and unsuitable materials from and to the project will be eliminated and time to transport selected materials from far areas will be minimizes, in addition, to get a selected material takes time to identify proper quarry site.
Referring our case study of Addis Ababa city again, the average time of completion using the stabilizer is as follows
Time for the construction of 100 meter with seven meter with is one day, therefore for 5000 meter and 30 meter width it will take : (5000*4.28/100)=214 days means 7months therefore it is a total of 210 days. This data of project duration is calculated from the input data of the current pilot project of stabilization, the case study of Kality Indestrial zone road project, which is a pilot project of the city Administration using a stabilizer.

7.4 Comparison of Time and Cost of the two methods of Construction

After all the above researches to find effective dosage for the worst substandard soil to stabilize to a required level and comparing the cost there is a saving of around **30%** ((41,400,000-29,865,000)/41,400,000) and time saving of construction as shows above is **42%**. In addition to this quantified costs there are other environmental cost savings like degradation of land for quarry site, dumping areas, avoiding damages on existing Asphalt layers during transportation of subgrade materials etc.

Chapter Eight

Conclusions and Recommendations

8.1 Conclusions

In road construction, especially in urban areas, the modification of engineering properties of Expansive soils becomes very important to geotechnical engineers as borrow materials for the foundation soils are becoming less and less available and very costly.

Following that from the present study of using chemical stabilizer to stabilize and reuse the natural material of the natural soil for a sub grade, the following conclusions can be derived:

1) As it has been observed from the several laboratory tests, treating expansive soil with 6% of the chemical stabilizer ANSS improves the CBR and the Plasticity of the soil to a required level and this saves around 30% of the cost and 42% time of road construction in the city. However the performance duration of the stabilizers shall be studied further in the future as the roads which have been done with same technology shall be evaluated after some service year periods.

2) Unmeasured benefits related to environmental protections like avoiding degradation of natural resources surrounding urban and suburban areas.

3) Stabilization of natural soil will also eliminate damages of existing roads due to mobility of heavy trucks during construction period to transport selected materials and to avoid unsuitable materials.

8.2 Recommendations

Using new Technologies by evaluating through researches is a very important action for the construction sector, since the construction sector has a lion share of the capital budget of the country, Ethiopia.

This research is one of the platforms to recommend that using qualified stabilizers in road construction is useful technology to save time and cost of construction. In addition, the following specific recommendations have been made for future conduction of researches.

1) The field performance of the Road which has been constructed using the stabilizer has to be evaluated against the service year and traffic loading. As pavement performance is related to the stiffness of the underlying base and sub grade.

2) Anyway natural soil stabilizer (ANSS) is basically a mix of lime and cement which is produced in our country, researches can be made to mix these two chemicals with trial proportions to a specific strength requirement, and some additives can be added to accelerate the reaction process which were not disclosed from the suppliers of ANSS.

3) Other uncountable benefits of using soil stabilizers on native soil related to environmental protections, like avoiding degradation of natural resources to replace removed materials, avoid damaging of existing roads through transportation of materials, saving spoiling areas for other land uses etc., all can be studied and researched in a quantifiable manner for using some indicative parameters.

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Annexes (Laboratory Analysis, Results and Pictures)

Annex A: Native Soil Lab Results

Table 11: Atterberg Limits, Grain Size Analysis and Classification of Untreated Soil

	LIQUID LIMIT				PLASTIC LIMIT		
Test No.							
No. Blows	31	28	22	18			
Container No.	27	30	12	18	11	13	
Wet soil + Container,g	79.95	72.59	79.06	77.13	63.37	62.72	
Dry Soil + Container,g	67.37	63.38	67.45	65.69	59.76	59.15	
Mass Container, g	53.96	53.66	55.32	53.88	51.55	51.14	
Mass of Moisture, g A	12.58	9.21	11.61	11.44	3.61	3.57	
Mass of Dry Soil, g B	13.41	9.72	12.13	11.81	8.21	8.01	
Moisture Content % (A/B)*100	93.81	94.75	95.71	96.87	44	45	

Group Index (GI) = 0.2A + 0.005AC + 0.01BD =	**59**
Where A = > 35% < 75% , B = > 15% < 55% Passing on #200	
C = > 40% < 60% L.L. , D = > 10 < 30 P.I.	
AASTHO Classification A-7-6 [56]	

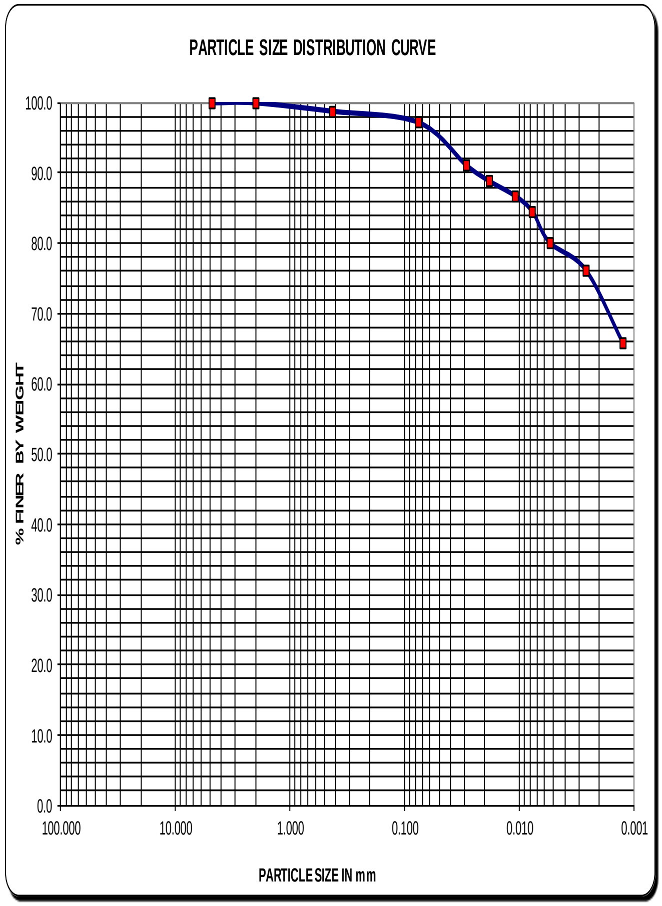
Liquid Limit (LL)	**95**
Plastic Limit (PL)	**44**
Plastisty Index (PI=LL-PL)	**51**
Linear Shrinkage	

Sieve Analysis

Sieve (mm)	% PASSED
9.50	-
4.750	-
2.000	100.0
0.425	98.9
0.075	97.2

Hydrometer Analysis

Smaller than (mm)	Percent
0.020	89.0
0.002	73.0
0.001	65.0



Grain size	% Passed
4.75	100.0
2.00	100.0
0.425	98.8
0.075	97.2
0.0286	91.1
0.0183	88.9
0.0107	86.7
0.0076	84.5
0.0054	80.1
0.0026	76.1
0.0012	65.7

SIZE PROPORTIONS

Particle larger than 2.00 mm, % 0.0

Sand (2.00mm-0.075mm), % **2.8**

Silt (0.075mm-0.002mm), % **24.2**

Clay (less than 0.002), % **73.0**

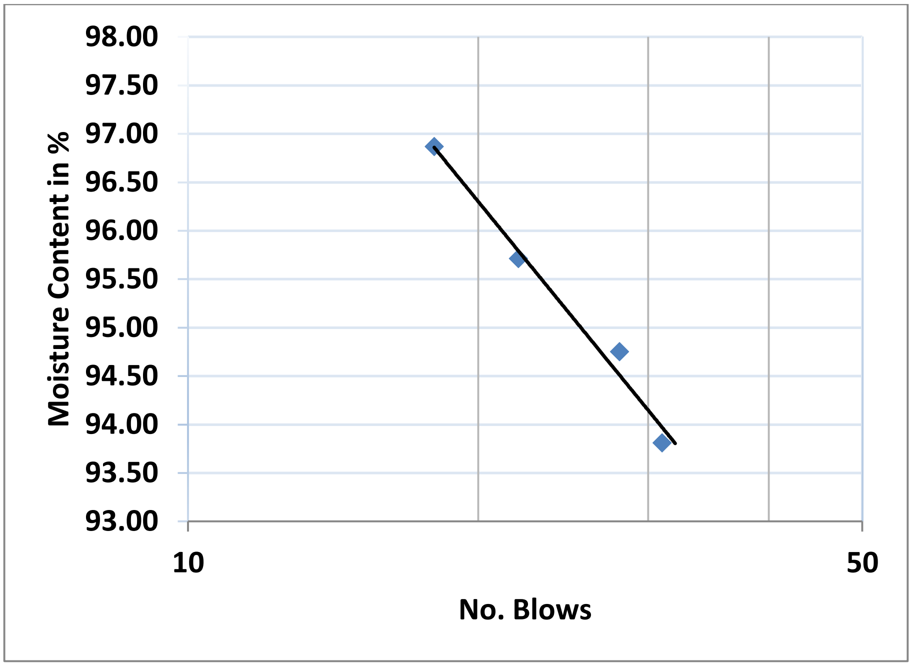
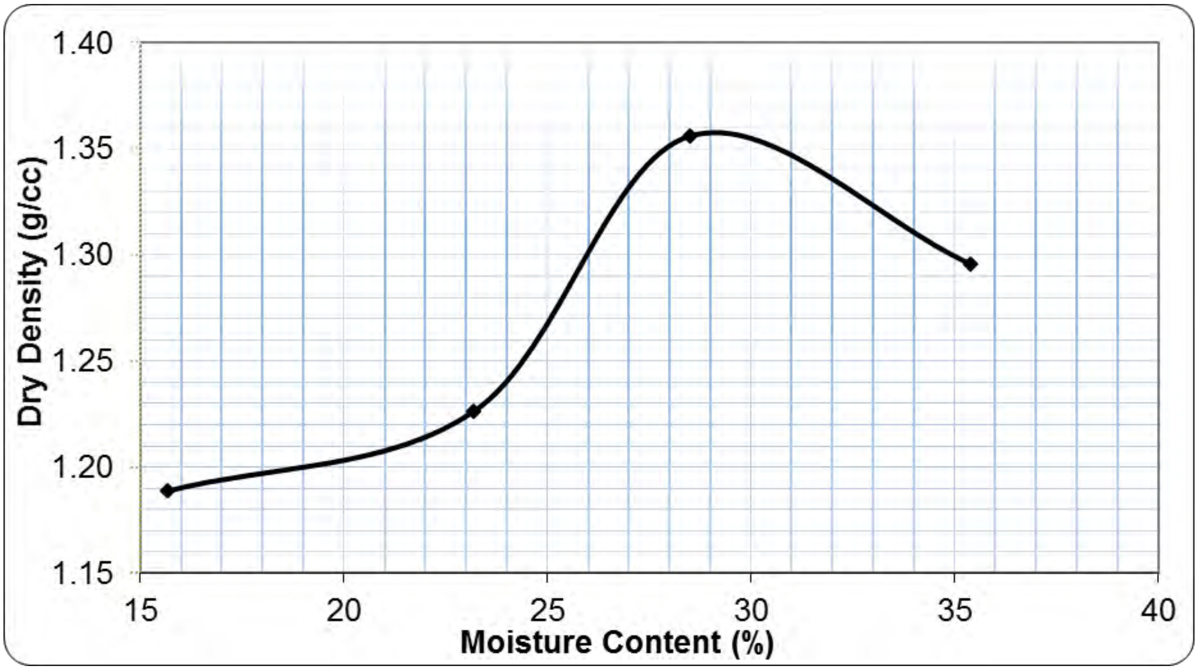


Table 12:Moisture Density Relationship ofUntreated Soil(AASHTO: T-180)

Trial No	1	2	3	4	5
Mold weight + sample (gm)	5647	5775	5994	6005	
Mold weight (gm)	4349	4349	4349	4349	
Sample weight (gm)	1298	1426	1645	1656	
Mold volume (Cm3)	944	944	944	944	
Bulk density(g/cm3)	1.38	1.51	1.74	1.75	
Wet weight +can	194.10	214.40	191.40	193.60	
Dry weight + can	171.00	177.90	152.90	147.80	
Weight of can	23.60	20.50	17.80	18.40	
Weight of moisture	23.10	36.50	38.50	45.80	
Weight of dry soil	147.40	157.40	135.10	129.40	
Moisture content (%)	15.67	23.19	28.50	35.39	
Dry density (g/cm3)	1.19	1.23	1.36	1.30	



MDD (g/cc)	1.36
OMC (%)	28.5

Table 13: CBR of Untreated Soil (which is 1%)

		10 Blows		30 Blows		65 Blows	
		Before	After	Before	After	Before	After
Moulder No.				2		18	
Weight of Soil + Mold, g	a			11522.5	11730.0	11687.0	11950.0
Weight of Mold, g	b			7775.0	7775.0	7786.0	7786.0
Weight of Soil, g	d=a-b			3747.5	3955.0	3901.0	4164.0
Volume of Mold, cc	e			2120.0	2120.0	2120.0	2120.0
Wet Density of Soil, g/cc	f =d/e			1.77	1.87	1.84	1.96
Dry Density of Soil, g/cc	=f/(1+w) **			1.53	1.67	1.73	1.84

** w is moisture content in fraction

MOISTURE DETERMINATION

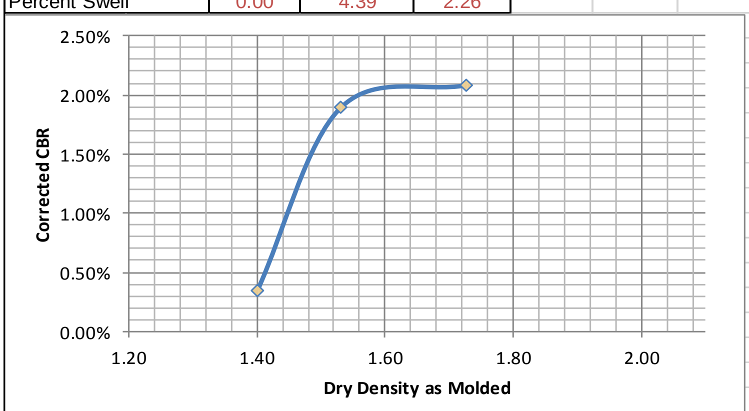
		30 Blows			65 Blows		
		Before	After		Before	After	
			Top	middle		Top	middle
Container No.		4	10	8	14	24	33
Wet Soil + Container, g	A	460	480	470	495.0	550.0	496.0
Dry Soil + Container, g	B	410	430	440	470.0	520.0	470.0
Weight of Water, g	C=A-B	50.0	50.0	30.0	25.0	30.0	26.0
Weight of Container, g	D	87	86	89	86.5	86.5	87.0
Weight of Dry Soil,g	E=B-D	323.0	344.0	351.0	383.5	433.5	383.0
Moisture Content, %	w=C/E*100	15.48	14.53	8.55	6.52	6.92	6.79
Average Moisture Content	%	15.48	11.54		6.52	6.85	

PENETRATION TEST DATA

Penetration	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg.	Load,KN	COR.Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %
0	0	0.00			0	0.00			0	0.00		
0.64	0.5	0.02			1	0.05			3	0.15		
1.27	1	0.04			2	0.10			4	0.20		
1.91	1	0.04			4	0.20			4.5	0.23		
2.54	**1.1**	**0.05**	**0.05**	**0.35%**	**5**	0.25	**0.25**	**1.89%**	**5.5**	0.28	**0.28**	**2.08%**
3.18	2	0.09			6	0.30			6.5	0.33		
3.81	2.1	0.09			6.5	0.33			7	0.35		
4.45	2.5	0.11			7	0.35			8	0.40		
5.08	**2.5**	0.11	0.11	**0.53%**	**7.5**	0.38	0.38	**1.88%**	**8.5**	0.43	**0.43**	**2.13%**
7.62	3	0.13			9	0.45			10	0.50		
10.16												
12.7												

SWELL

No. of Blows	10	30	65
RDG. (Before Soaking)	0	0	0
RDG. (After Soaking)	0	5.1	2.63
Percent Swell	0.00	4.39	2.26



At 95% AASHTO Modified Maximum Dry Density, CBR =1%

`CBR= 1%

Table 14:Swelling Property of Untreated Soil (Undisturbed Sample)

Sr No	Source	Depth,cm	Swelling Pressure, Kpa
1	Akaki Site for Research	80.0	103.50

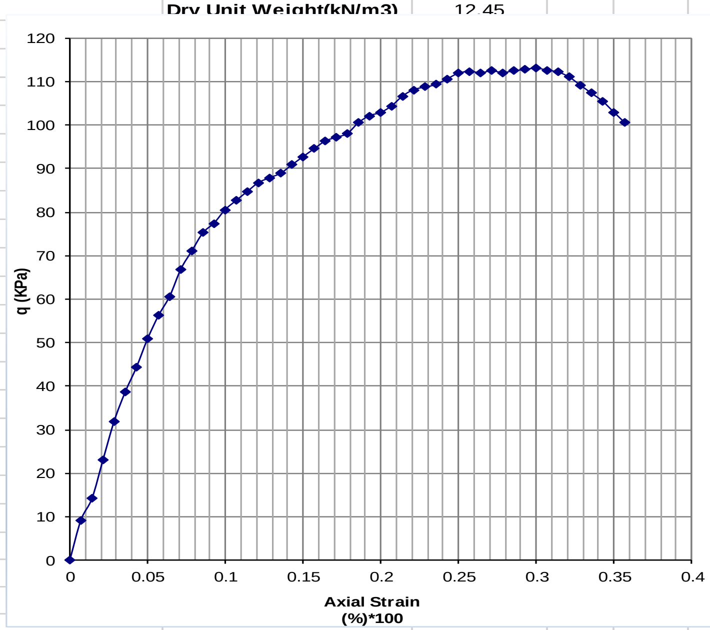
Table 15: UCS of Untreated Soil

Unconfind Compressive Strength Test, ASTM D2166

Source	Akaki Site for Research
Depth(cm):	80
Sample :	Undisturbed Sample

Unit Weight	
Diameter (m)	0.07
Hieght (m)	0.14
Mass (Kg)	0.907
Area (m^2)	0.00385
Volume,m3	0.0005
Bulk density (kg/m3)	1683.7
Bulk Unit Weight(kN/m3)	16.52
NMC %	32.68
Dry Density (kg/m3)	1268.95
Dry Unit Weight(kN/m3)	12.45

Axial Strain	**Comp. Str (q,kpa)**
0	0
0.0071	9.19
0.0143	14.20
0.0214	23.16
0.0286	31.99
0.0357	38.70
0.0429	44.32
0.0500	50.83
0.0571	56.27
0.0643	60.66
0.0714	66.88
0.0786	71.11
0.0857	75.26
0.0929	77.48
0.1000	80.57
0.1071	82.69
0.1143	84.76
0.1214	86.79
0.1286	87.88
0.1357	88.93
0.1429	90.84
0.1500	92.71
0.1571	94.53
0.1643	96.31
0.1714	97.20
0.1786	98.05
0.1857	100.55
0.1929	102.16
0.2000	102.90
0.2071	104.43
0.2143	106.72
0.2214	108.15
0.2286	108.75
0.2357	109.32
0.2429	110.63
0.2500	111.90
0.2571	112.37
0.2643	112.04
0.2714	112.45
0.2786	112.09
0.2857	112.45
0.2929	112.78
0.3000	113.09
0.3071	112.64
0.3143	112.19
0.3214	111.02
0.3286	109.16
0.3357	107.32
0.3429	105.49
0.3500	103.00
0.3571	100.55



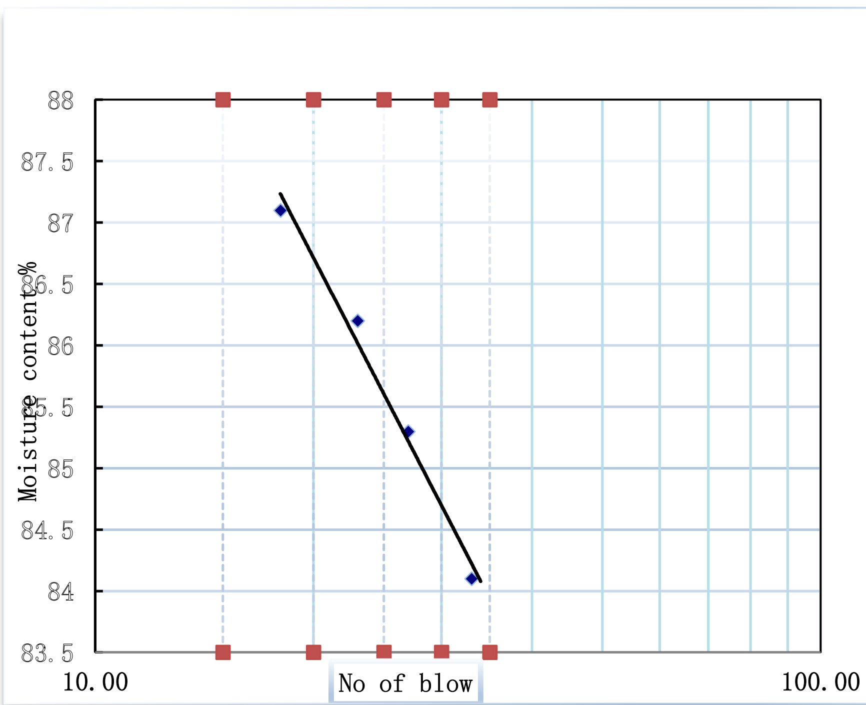
q (Kpa)	112.60
C(Kpa)	56.30

Wt of Wet Soil(gr.)=	907.15
Wt of Dry Soil(gr.)=	683.69
NMC(%)=	32.68

Annex B: Blended Soil in Laboratory (2% of ANSS +Native Soil)

Table 16:Atterberg Limits, Sieve analysis and Classification of Soil (with 2% dosage of Stabilizer)

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	4	6	8	27	20	11
Number of blows	33	27	23	18		
Wt.of Container +Wet soil(g)	70.77	65.27	70.67	68.75	66.18	65.24
Wt.of Container +Dry soil(g)	62.11	57.77	62.83	61.35	61.48	60.73
Wt.of water (g)	8.66	7.5	7.84	7.4	4.7	4.51
Wt.of Container weight (g)	51.81	48.98	53.74	52.85	51.86	51.43
Wt.of Dry soil (g)	10.3	8.79	9.09	8.5	9.62	9.3
Moisture content %	84.1	85.3	86.2	87.1	48.9	48.5
				Average %	49	



Liquid Limit :	86
Plasticity Limit:	49
Plasticity Index:	37

Table 17: CBR of treated Soil (with 2% dosage of Stabilizer)

		10 Blows		30 Blows		65 Blows	
		Before	After	Before	After	Before	After
Moulder No.				8		11	
Weight of Soil + Mold, g	a			11497.0	11916.0	11687.0	12114.0
Weight of Mold, g	b			7751.0	7751.0	7767.0	7767.0
Weight of Soil, g	d=a-b			3746.0	4165.0	3920.0	4347.0
Volume of Mold, cc	e			2120.0	2120.0	2120.0	2120.0
Wet Density of Soil, g/cc	f =d/e			1.77	1.96	1.85	2.05
Dry Density of Soil, g/cc	=f/(1+w) **			1.39	1.51	1.44	1.43

** w is moisture content in fraction

MOISTURE DETERMINATION

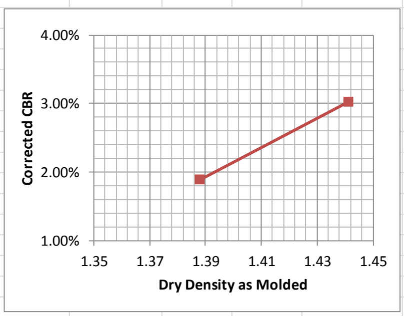
	10 Blows			30 Blows			65 Blows		
	Before	After		Before	After		Before	After	
		Top	middle		Top	middle		Top	middle
Container No.				6	3	8	7	90	14
Wet Soil + Container, g A				560.0	458.5	481.0	436.5	493.0	577.0
Dry Soil + Container, g B				462.0	337.0	449.0	362.5	360.0	453.5
Weight of Water, g C=A-B				98.0	121.5	32.0	74.0	133.0	123.5
Weight of Container, g D				103.0	98.0	94.5	101.0	101.5	106.0
Weight of Dry Soil,g E=B-D				359.0	239.0	354.5	261.5	258.5	347.5
Moisture Content, % w=C/E*100				27.3	50.8	9.0	28.3	51.5	35.5
Average Moisture Content %				27.3	29.9		28.3	43.5	

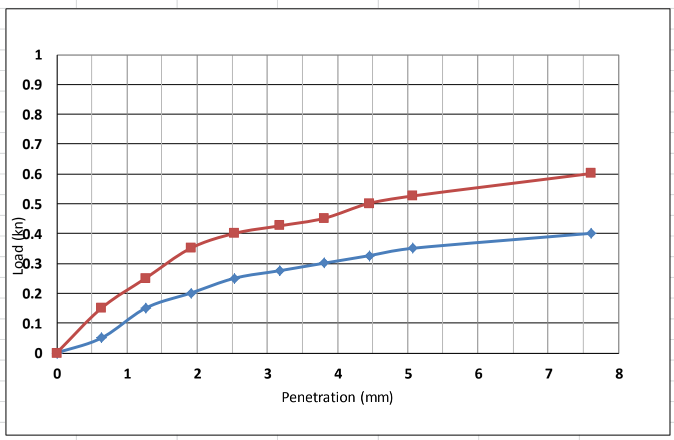
PENETRATION TEST DATA

Penetration	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg.	Load,KN	COR.Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %
0					0	0.00			0	0.00		
0.64					1	0.05			3	0.15		
1.27					3	0.15			5	0.25		
1.91					4	0.20			7	0.35		
2.54					5	0.25	0.25	1.89%	8	0.40	0.40	3.02%
3.18					5.5	0.28			8.5	0.43		
3.81					6	0.30			9	0.45		
4.45					6.5	0.33			10	0.50		
5.08					7	0.35	0.35	1.76%	10.5	0.53	0.53	2.63%
7.62					8	0.40			12	0.60		
10.16												
12.7												

SWELL

No. of Blows		30	60
RDG. (Before Soaking)		0	0
RDG. (After Soaking)		16	13.01
Percent Swell		13.76	11.19





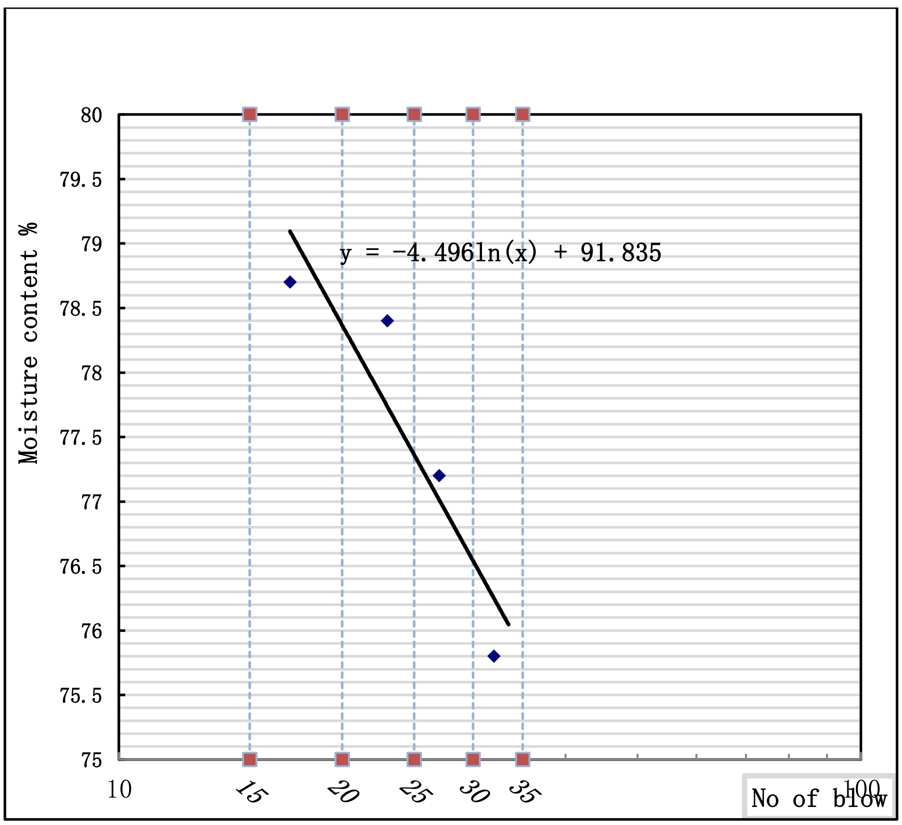
At 93% AASHTO Modified Maximum Dry Density, CBR = 2.8%

CBR Value Should Be Grater than or Quall To 30%

Annex C: Blended Soil in Lab at (4% of ANSS+Native Soil)

Table 18:Atterberg Limits, Sieve analysis and Classification of Soil (with 4 % dosage of Stabilizer)

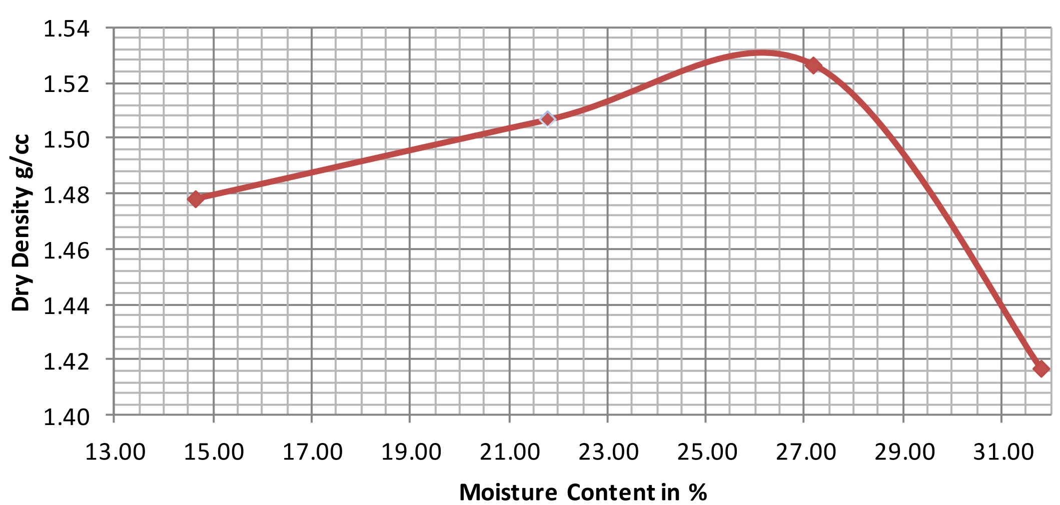
	LIQUID LIMIT				PLASTIC LIMIT	
Container number	14	15	13	30	1	12
Number of blows	32	27	23	17		
Wt.of Container +Wet soil(g)	61.68	65.59	69.12	70.16	63.12	64.86
Wt.of Container +Dry soil(g)	54.68	58.94	61.17	62.85	59.72	61.56
Wt.of water (g)	7	6.65	7.95	7.31	3.4	3.3
Wt.of Container weight (g)	45.45	50.33	51.03	53.56	53.18	55.19
Wt.of Dry soil (g)	9.23	8.61	10.14	9.29	6.54	6.37
Moisture content %	75.8	77.2	78.4	78.7	52.0	51.8
				Average %	52	



Liquid Limit :	78
Plasticity Limit:	52
Plasticity Index:	26

Table 19: Moisture Density Relationship of treated Soil (With 4% dosage of Stabilizer)

TEST DATA					
Target Moisture Content					
Mass of Wet soil + Mould A(g)	11803.5	12125.5	12371.5	12201.0	
Mass of Mould B(g)	7899.0	7899.0	7899.0	7899.0	
Mass of Wet soil C=A-B(g)	3904.5	4226.5	4472.5	4302.0	
Bulk Density B=C/V	1.69	1.83	1.94	1.87	
Container No.	7	2	5.0	3.0	
Mass of Container +Wet soil a(g)	336.0	361.6	337.1	347.3	
Mass of Container +Dry soil b(g)	307.5	316.1	287.5	289.4	
Mass of Container d(g)	113.0	107.5	105.4	107.4	
Mass of Dry soil e=b-d(g)	194.5	208.6	182.2	182.0	
Mass of Moisture f=a-b(g)	28.5	45.4	49.5	57.9	
Moisture Content w=f/e*100(%)	14.65	21.77	27.19	31.79	
Dry Density B/(100+w)*100(g/cm3)	1.48	1.51	1.53	1.42	



Maximum Dry Density (MDD)=	1.53
Optimum Moisture Content(OMC)=	26.0%

Table 20: CBR of treated Soil (With 4% dosage of Stabilizer)

		10 Blows		30 Blows		65 Blows	
		Before	After	Before	After	Before	After
Moulder No.				11		8	
Weight of Soil + Mold, g	a			11441.0	11775.5	11690.0	12013.5
Weight of Mold, g	b			7706.5	7706.5	7779.0	7779.0
Weight of Soil, g	d=a-b			3734.5	4069.0	3911.0	4234.5
Volume of Mold, cc	e			2120.0	2120.0	2120.0	2120.0
Wet Density of Soil, g/cc	f =d/e			1.76	1.92	1.84	2.00
Dry Density of Soil, g/cc	=f/(1+w) **			1.37	1.40	1.45	1.50

** w is moisture content in fraction

MOISTURE DETERMINATION

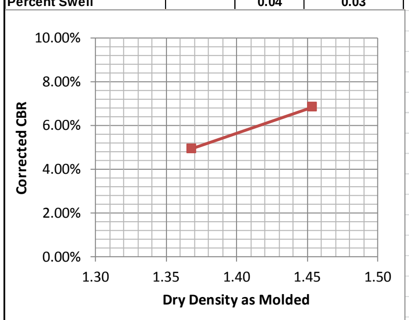
	10 Blows			30 Blows			65 Blows		
	Before	After		Before	After		Before	After	
		Top	middle		Top	middle		Top	middle
Container No.				5	1	7	7	10	12
Wet Soil + Container, g A				526.5	546.0	612.0	520.5	582.0	613.0
Dry Soil + Container, g B				431.0	406.0	505.5	431.5	457.0	489.0
Weight of Water, g C=A-B				95.5	140.0	106.5	89.0	125.0	124.0
Weight of Container, g D				99.0	108.0	100.5	101.0	100.5	100.0
Weight of Dry Soil,g E=B-D				332.0	298.0	405.0	330.5	356.5	389.0
Moisture Content, % w=C/E*100				28.8	47.0	26.3	26.9	35.1	31.9
Average Moisture Content %				28.8	36.6		26.9	33.5	

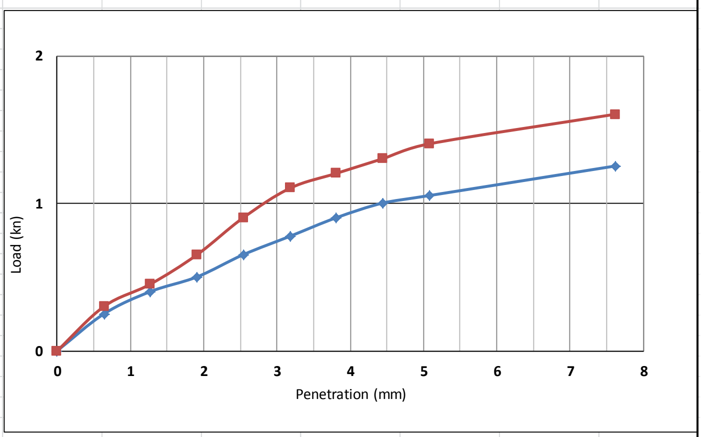
PENETRATION TEST DATA

Penetration	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg.	Load,KN	COR.Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %
0					0.0	0.00			0	0.00		
0.64					5.0	0.25			6	0.30		
1.27					8.0	0.40			9	0.45		
1.91					10.0	0.50			13	0.65		
2.54					13.0	0.65	0.65	4.91%	18	0.90	0.90	6.80%
3.18					15.5	0.78			22	1.10		
3.81					18.0	0.90			24	1.20		
4.45					20.0	1.00			26	1.30		
5.08					21.0	1.05	1.05	5.27%	28	1.40	1.40	7.02%
7.62					25.0	1.25			32	1.60		
10.16												
12.7												

SWELL

No. of Blows		30	60
RDG. (Before Soaking)		0	0
RDG. (After Soaking)		0.05	0.03
Percent Swell		0.04	0.03





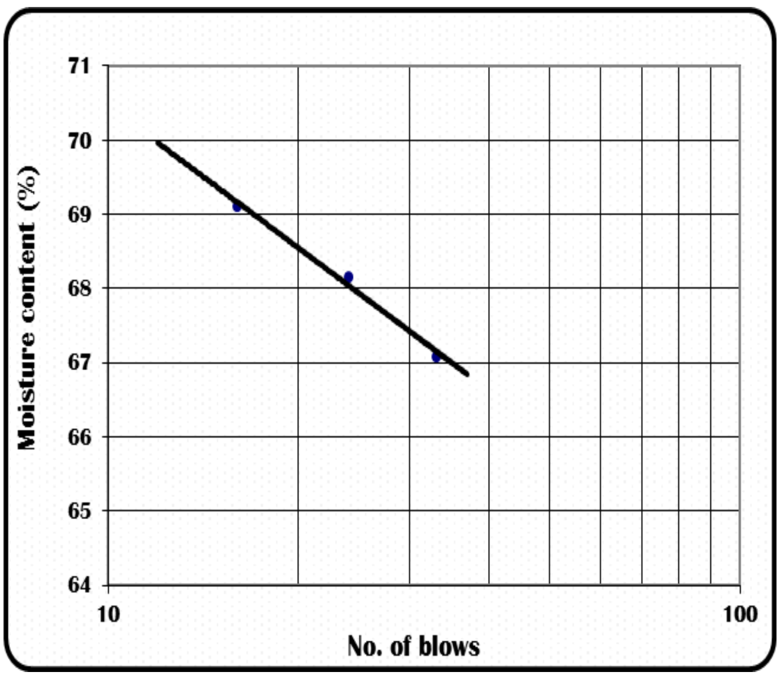
At 93% AASHTO Modified Maximum Dry Density, CBR = 7%

CBR Value Should Be Grater than or Quall To 30%

Annex D: Blended Soil in Lab at(6% of ANSS +Native Soil)

Table 21:Atterberg Limits of Soil (With 6% dosage of Stabilizer)

	Liquid Limit			Plastic Limit	
No. of blows	33	24	16		
Wt. of wet soil + Can (gm)	43.66	44.49	43.27	26.78	26.64
Wt.of dry soil + Can (gm)	34.20	34.94	33.85	24.73	24.53
Wt. of Water (gm)	9.46	9.55	9.42	2.05	2.11
Wt. of Can (gm)	20.10	20.93	20.22	20.54	20.17
Wt. of dry soil (gm)	14.10	14.01	13.63	4.19	4.36
Moisture Content(%)	67.09	68.17	69.11	48.93	48.39
			Average PL(%)=	48.66	



Liquid Limit (%)	68
Plastic Limit (%)	49
Plasticity Index (%)	19

Table 22:Moisture Density Relationship of treated Soil (With 6% dosage of Stabilizer)

Wet mold+sample(g)	12060	12290	12149			
Wet of mold(g)	7874	7874	7874			
Wet of sample(g)	4186	4416	4275			
Volume of mold(cm)^3	2275	2275	2275			
Wet density (g/cc)	1.84	1.94	1.88			
tare No	90	9	6			
Wet tare+sample(g)	475.0	446.5	483.0			
Wet tare+dry sample(g)	410.0	374.0	390.0			
Wet of water(g)	65.0	72.5	93			
Wet of tare(g)	101.5	95.5	103			
Wet of dry sample(g)	308.5	278.5	287			
Moisture content(g/cc)	21.1	26.0	32.4			
Dry density(g/cc)	1.52	1.54	1.42			

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.54	26.0	5

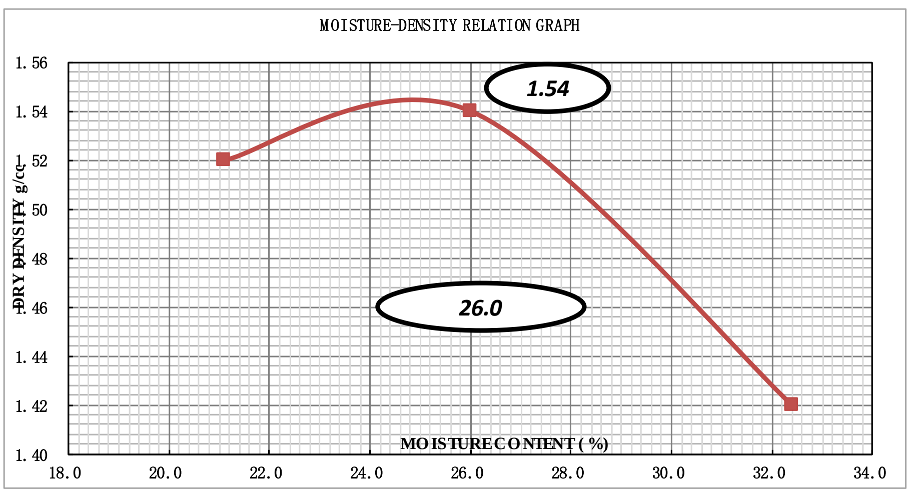


Table 23: Californian Bearing Ratio of treated Soil (With 6% dosage of Stabilizer with standard curing method)

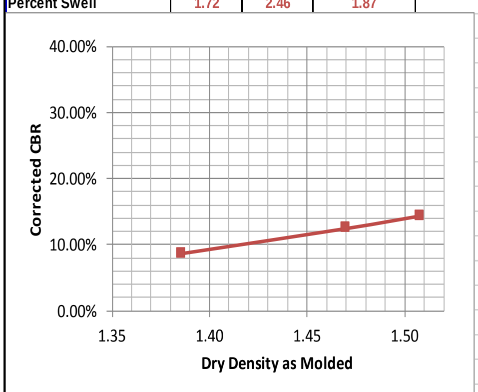
	10 Blows			30 Blows			65 Blows		
	Before	After		Before	After		Before	After	
		Top	middle		Top	middle		Top	middle
Container No.	5	1	7	6	9	10	9	11	12
Wet Soil + Container, g A	526.5	560.5	612.0	611.5	504.0	569.0	619.0	527.5	651.0
Dry Soil + Container, g B	431.0	460.0	505.5	514.5	373.5	457.0	523.0	387.0	531.0
Weight of Water, g C=A-B	95.5	100.5	106.5	97.0	130.5	112.0	96.0	140.5	120.0
Weight of Container, g D	99.0	100.0	100.5	103.0	95.5	101.0	96.0	101.0	99.5
Weight of Dry Soil,g E=B-D	332.0	360.0	405.0	411.5	278.0	356.0	427.0	286.0	431.5
Moisture Content, % w=C/E*100	28.8	27.9	26.3	23.6	46.9	31.5	22.5	49.1	27.8
Average Moisture Content %	28.8	27.1		23.6	39.2		22.5	38.5	

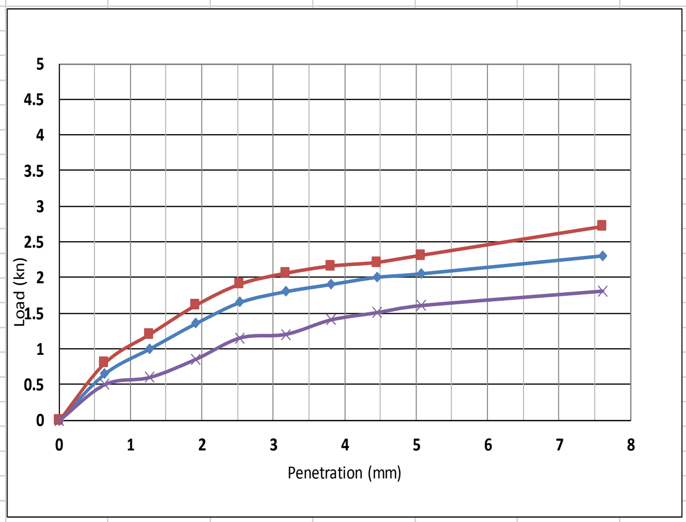
PENETRATION TEST DATA

Penetration	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg.	Load,KN	COR.Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %	Dial Rdg	Load,kn	COR Load	CBR %
0	0	0.00			0	0.00			0	0.00		
0.64	10	0.50			13	0.65			16	0.80		
1.27	12	0.60			20	1.00			24	1.20		
1.91	17	0.85			27	1.35			32	1.60		
2.54	23	1.15	1.15	8.69%	33	1.65	1.65	12.47%	38	1.90	1.90	14.36%
3.18	24	1.20			36	1.80			41	2.05		
3.81	28	1.40			38	1.90			43	2.16		
4.45	30	1.50			40	2.00			44	2.21		
5.08	32	1.60	1.60	8.03%	41	2.05	2.05	10.28%	46	2.31	2.31	11.54%
7.62	36	1.80			46	2.31			54	2.71		
10.16												
12.7												

SWELL

No. of Blows	10	30	60
RDG. (Before Soaking)	0	0	0
RDG. (After Soaking)	2	2.86	2.17
Percent Swell	1.72	2.46	1.87



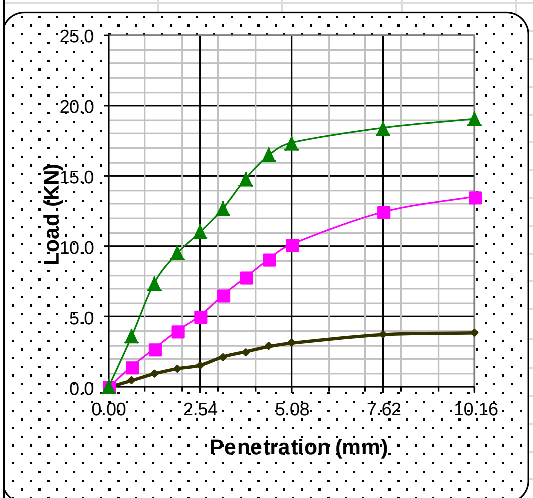


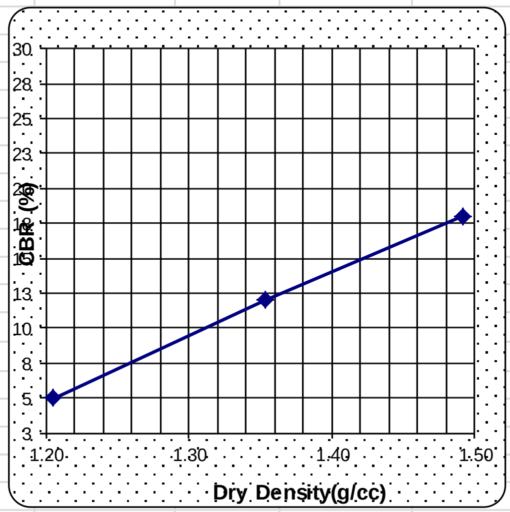
At 95% AASHTO Modified Maximum Dry Density, CBR = 11%

CBR Value Should Be Grater than or Quall To 15%

Table 24: Californian Bearing Ratio of treated Soil (With 6% dosage of Stabilizer with Modified curing method)

	Before Soaking			After Soaking		
Number of Blows	**10blows**	**30blows**	**65blows**	**10blows**	**30blows**	**65blows**
Weight of wet soil + mould (gm)	9848	10085	10364	10021	10215	10449
Weight of mould (gm)	6335	6175	6031	6335	6175	6031
Weight of wet soil (gm)	3513	3910	4333	3686	4040	4418
Volume of mould ($cm^{3)}$	2124	2124	2124	2124	2124	2124
Wet density of soil (gm/cm^3)	1.65	1.84	2.04	1.74	1.90	2.08
Dry density of soil (gm/cm^3)	1.21	1.35	1.49	1.20	1.34	1.46
Moisture Content						
Weight of wet soil + container (gm)	145.60	156.50	183.00	123.00	131.59	143.62
Weight of dry soil + container (gm)	112.04	120.66	139.65	91.60	98.58	106.89
Weight of container (gm)	21.80	21.10	21.60	21.10	20.61	20.36
Weight of moisture (gm)	33.56	35.84	43.35	31.40	33.01	36.73
Weight of dry soil (gm)	90.24	99.56	118.05	70.50	77.97	86.53
Moisture Content, % (m)	37.19	36.00	36.72	44.54	42.34	42.45





No. of Blows	DD (g/cm3)	CBR %	
		2.54mm	5.08mm
10	1.21	5	4
30	1.35	12	10
65	1.49	18	15

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.55	1.96	0.35
30	1.10	1.36	0.22
65	1.39	1.6	0.18

Remarks: CBR@95%MDD = 17%

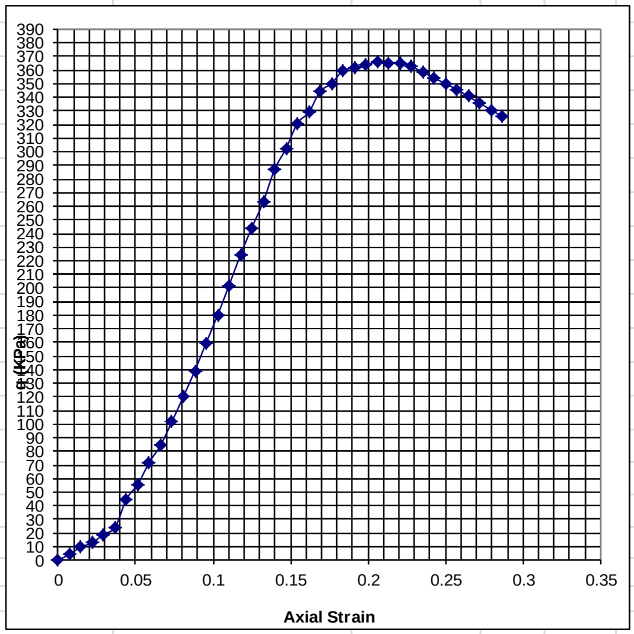
Table 25: Swelling Pressure of Treated Soil (With 6% Dosage of Stabilizer)

Sr No	Source	Depth,cm	Swelling Pressure, Kpa
1	Akaki Site for Research	-	3.50

Table 26: UCS of treated Soil (With 6% dosage of Stabilizer)

Axial Strain	Comp. Str (q,kpa)
0	0
0.0074	4.33
0.0147	9.67
0.0221	12.80
0.0294	19.05
0.0368	24.16
0.0441	44.82
0.0515	55.85
0.0588	71.84
0.0662	84.51
0.0735	102.03
0.0809	120.27
0.0882	139.19
0.0956	159.76
0.1029	179.98
0.1103	201.79
0.1176	224.17
0.1250	244.25
0.1324	263.01
0.1397	287.05
0.1471	302.27
0.1544	320.87
0.1618	329.05
0.1691	344.28
0.1765	350.21
0.1838	359.54
0.1912	361.60
0.1985	363.55
0.2059	366.28
0.2132	365.46
0.2206	365.45
0.2279	362.84
0.2353	358.55
0.2426	354.28
0.2500	350.02
0.2574	345.78
0.2647	340.75
0.2721	335.76
0.2794	330.79
0.2868	325.86

Unit Weight	
Diameter (m)	0.068
Hieght (m)	0.136
Mass (Kg)	0.896
Area (m^2)	0.00363
Volume,m3	0.0005
Bulk density (kg/m3)	1813.7
Bulk Unit Weight(kN/m3)	17.79
NMC %	31.66
Dry Density (kg/m3)	1377.58
Dry Unit Weight(kN/m3)	13.51



q (Kpa)	365.20
C(Kpa)	182.60

Wt of Wet Soil(gr.)=	895.80
Wt of Dry Soil(gr.)=	680.4
NMC(%)=	31.66

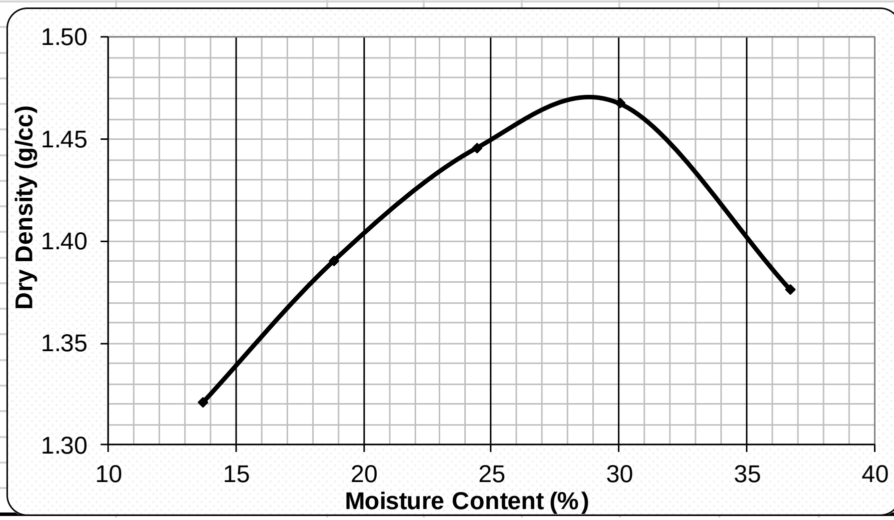
Annex E: Blended Soil in Lab at (8% of ANSS +Native Soil)

Table 27Moisture Density Relationship of treated Soil (with 8% dosage of stabilizer):

Moisture Content and Density Relationship

AASHTO T-180, Method A

Trial No	1	2	3	4	5
Mold weight + sample (gm)	5770	5912	6050	6154	6130
Mold weight (gm)	4352	4352	4352	4352	4352
Sample weight (gm)	1418	1560	1698	1802	1778
Mold volume (Cm3)	944	944	944	944	945
Bulk density(g/cm3)	1.50	1.65	1.80	1.91	1.88
Wet weight +can	175.00	228.40	210.60	227.10	240.80
Dry weight + can	156.12	195.74	173.70	179.76	182.40
Weight of can	18.60	22.50	22.60	22.40	23.40
Weight of moisture	18.88	32.66	36.90	47.34	58.40
Weight of dry soil	137.52	173.24	151.10	157.36	159.00
Moisture content (%)	13.73	18.85	24.42	30.08	36.73
Dry density (g/cm3)	1.32	1.39	1.45	1.47	1.38



MDD (g/cc)	1.47
OMC (%)	29.0

Annex F: Pictures of Laboratory Test

F.1 Mixing of Soil and Stabilizer in the Laboratory

Figure 19: Mixing of Soil and Stabilizer in the Laboratory

Figure 20: Mixing of Soil and Stabilizer in the Laboratory

F.2 Atterbeg Limits

Figure 21: Atterberg Limits

F.3 Unconfined Compressive strength UCS

Figure 22: UCS tests in the Laboratory

Annex G: Application of the Stabilizer on the project Site, at Kality industrial Access Road Construction Project.

Figure 23: Placing and spreading on site

Figure 24: Spreading

Figure 25: Mixing on site

Figure 26: Compacting