ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TCHNOLOGY

DEPARTEMENT OF CIVIL AND ENVIROMENRAL ENGINEERING

CRITICAL ASSESEMENT ON THE STABILIZATION OF EXPANSIVE SOILS BY DIFFERENT TECHNIQUES

BY:-HABTAMU MARREN

Advisor: Dr.Ing. Samuel Taddesse

A Project Submitted to School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Civil Engineering

(Geotechnical Engineering)

October, 2015

CERTIFICATION

The project titled "**Critical Assessment on the Stabilization of Expansive Soils by Different Techniques**" by Habtamu Mareen meets the regulations governing the award of the degree of Master of Engineering (M.Eng) in Civil Engineering Addis Ababa University and is approved for its contribution to knowledge and literary presentation.

APPROVED BY EXAMINATION BOARED

ADVISOR	DATE AND SIGNATURE
EXTERNAL EXAMINER	DATE AND SIGNATURE
INTERNAL EXAMINER	DATE AND SIGNATURE
CHAIRMAN	DATE AND SIGNATURE

ACKNOWLEDGEMENTS

First of all I would like to thank my advisor Dr.Ing Samuel Tadesse for his invaluable advices, his kind encouragement and his consistent support throughout the study.
My special thanks also go to all who have touch on my study on the graduate program.

Finally, I am greatly indebted to the love and support of my family. Thus, I would like to dedicate this thesis work to my Wife W/r Bereket Bekele and my daughters Soliyan Habtamu and Saron Habtamu and say “Thank You”.

Place: Addis Ababa

Habtamu Marren

ABSTRACT

The evaluation and criticism of the stabilization of expansive soil by different techniques base on the researches done. To list them:-

1. A Research on “Stabilization of expansive clay soil with sugar cane molasses and cement” for the Study Area of Modjo – Ejere – Arerti – Sembo Road Project with different mix ratios and come up with a finding that Soil treated with cement and molasses combination gave a significant improvement in strength than when cement and molasses alone and meaningfully reduced swelling property of the expansive soil. Also it was effective in arresting linear shrinkages and eliminated shrinkage cracks that were observed in soil treated with cement alone.

2. A research on “Stabilization of Expansive clay soil with lime “ for the Study Area Adura-Burbey Road project, Gambella and come up with a finding that expansive Soil treated with the addition of lime alone gave a reduction of the free swell, reduction in plasticity limit; improve the CBR, increase of the unconfined compressive strength.

3. A research on “The chemical treatment of “Block Cotton” soil to make it usable as a foundation material”for the study area of ten samples from Addis Ababa ‘’Black –cotton” soils and come up with a finding that the geotechnical property these expansive soils have been improved from a vary high expansive to a moderate expansive soils by the addition of 6% lime and 12% cement independently by dry weight of the native soil.

4. A researcher on “Evaluation of Sodium Silicate and its Combination with Cement/Lime for soil stabilization” for the study area of in situ soil of Addis Ababa’s Bole Senior Secondary and Preparatory School and borrowed material from Gergi-Bole Road section and has come up with the finding that Sodium Silicat has an inhibiting effect on strength development of clayey sand soil-cement mixture when its quantity is increased to and beyond 2.5% by dry weight of the soil. But Applying lower amount like 1% sodium silicate

by dry weight of the soil in concert with ordinary Portland cement is used it has positive implications on strength development .But using Sodium silicate as chemical stabilization with or without lime is not a suitable additive for montmorillonitic clay (expansive soil) stabilization.

5. A researcher on “Bagasse Ash as a Sub-grade Soil Stabilizing Material” for the Study Area of Addis Ababa, Bole Sub City around Bole Medhanialem church and come up with a finding that While treating expansive soil, with an increase in the bagass ash addition alone, there is a decrease in free swell, free swell index and free swell ratio but it is with a slight decrease in the plasticity and a slight increase in the CBR value. But the addition of bagasse ash in combination with lime improved the CBR value, and plasticity index decreased significantly.

   So, from critically evaluating these, the lime content increase the PI ratio, Free swell ratio and CBR swell ratio all shows increasing, indicating that the PI, the free swell and the CBR swell values are all decreasing in a direct proportion. In addition, in case of the free swell ratio verses the lime content it can be approximated that all the graphs do overlap one over the other meaning the testing procedures and the precision during the testing are approximated to be equal. Yet, a more different scenario is observed during the CBR swell tests verse the lime content this may arise due to the soil sample preparation and testing procedures.

   Another evaluation is as the cement content increase the PI ratio shows increasing indicating that the PI values are decreasing .In addition ,it can be seen that the PI ratio gets flat beyond some 6% to 12% cement addition indicating that further addition do not have an significant impact on the PI value.

Key Words: ***Cement, lime, Sodium silicate, Bagass Ash, Expansive Clay Soil, Sugar Cane Molasses, Soil Modification, Soil Stabilization. Critical Review.***

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAS…..American Association of Highway and Transportation Officials

ASTM ………… American Society for Testing and Materials

BA …………… Bagasse ash

BS ……………British Standard

CAH …………Calcium aluminate hydrate

CEC ……………..Cation Exchange Capacity

CBR…………….. California Bearing Ratio

CSH …………Calcium Silicate Hydrate

ERA ……………………Ethiopian Roads Authority

FSI………………… Free swell index

FSR …………….Free swell ratio

GSA …………….Groundnut shell ash

IS …………Indian Standard

LL ……………Liquid Limit

PL …………Plastic Limit

MDD ………..Maximum Dry Density

OMC …………..Optimum Moisture Content

PI …………Plastic Index

PL …………….Plastic Limit

RHA …………..Rise husk ash

SCBA …………..Sugarcane bagasse ash

SP …………….Swelling pressure

UCS …………Unconfined compressive strength

CBR – California Bearing Ratio

DD – Dry Density

E – Easting

E.C. –Ethiopian Calendar

ERA – Ethiopia Road Authority

GM – Grading Modules

GPS – Global Position System

GSB – Granular Sub-Base

LS – Linear Shrinkage

LAA – Los Angeles Abrasion

MDD – Maximum Dry Density

N – Northing

NNE – North-North East

NP – Non-Plastic

OMC – Optimum Moisture Content

PI – Plastic Index

SA ……..United States of America

UNITS

gm ....Gram

kg ....Kilogram

km ....Kilometer

kN ....Kilo Newton

mm.............. millimeter

g/cm^3 ....Gram per centimeter cube

μ m........... Micrometer

KN/m^2 ....Kilo Newton per meter square

kPa ....Kilo Pascal

mm ....millimeter

meq ....Milliequivalent

oC ....Degree Centigrade

cm^3 ....Centimeter cube

CHAPTER ONE

INTRODUCTION

1.1 Back Ground of the Study

In many areas of Ethiopia and other parts of the world, there are soils that make construction of foundations extremely difficult .These soils identified as expansive or collapsible soils may cause high differential settlement in the structure particularly light buildings and pavements as a result of excessive swell or heave when they are in contacts to moisture and shrinkage when they loss the water. Though, it is impossible to solve all the problems caused by these soils, preventive measures to reduce the possible damage to the structures can be done by taken extreme caution during the design and construction of foundations on these expansive soils.

These foundation design and construction considerations needs the classification of expansive soils as low swelling potential that the damage can be reduced by taking the stranded construction procedures and soils with medium and high swelling potential that the damage can be reduced by either or a combined techniques of the following:-

(a) Replacing the expansive soil under the foundation

(b) Strengthening the structure to withstand the damage

(c) The use of stabilizations.

The methods listed in (a) and (b) above will definitely incur additional huge expense to the project. Thus, changing the nature of the expansive soil by different techniques is more economical.

One method to improve expansive soils is chemical stabilization. Chemical stabilization includes the mixing or injecting of chemical substances into the soil. Portland cement, lime, asphalt, calcium chloride, sodium chloride, and paper mill wastes are common chemical stabilizing agents.

The effectiveness of these additives depends on the soil conditions, stabilizer properties, and type of construction (i.e., houses, roads, etc.).

1.2 Purpose the Study

Lots of books and researches are written and done on improving expansive soils by different techniques. These soils have a potential for shrinkage or swell when subject to moisture fluctuation due various reasons. Mostly are the seasonal climatic weather changes. This phenomenon creates damages especially to pavement and light building structures.

Stabilization of the expansive clay soil by different additives could be one solution to alleviate the problem. Soil stabilization or modification refers to the improvement of the soil physically or chemically by using various techniques including mechanical compaction and the use of various calcium rich chemicals on which the selection of proper stabilization technique depends on the soil type and its condition.

Therefore, the purpose of this project is to critical review the stabilization of expansive soil by different techniques and evaluates the effectiveness of these additives and the testing precisions taken on the soil properties.

CHAPTER TWO

REVIEW ON STABILIZATION BY DIFFERENT TECHNIQUES

Review on the stabilization of expansive soil by different methods done by different researchers is covered .Where, the purpose of the thesis, conceptual review, the study area and material characterization, outcome of the stabilization in the improving the expansiveness or test results obtained; analysis and discussion of results with respect to the theoretical background and with respect to findings of previous studies of each thesis is reviewed. There are lots of researches and investigations which are done on the stabilization of Expansive soils by different techniques both locally and internationally .Due the reasons:

- ❖ Most researches are used as reference to the other research works done. For example Meron Wubshet (Dec.2014) had referred the following Studies
  - i. Bagasse Ash as a Standalone Stabilizer
  - ii. Bagasse Ash as an Admixture with Cement etc
- ❖ considerations of the applicability to our local use
- ❖ similarity of one to the other thought different consideration are taken
- ❖ Last not least is the limitation of time of this work.

That, I have found the following lists of Local Thesis being representative to be critically reviewed for the Stabilization of the expansive clay soil by different techniques. These are:-

2.1 Stabilization of expansive clay soil with sugar cane molasses and cement(Bizualem Taye May. 2015)

2.2 stabilization of expansive clay soil with Lime (Reshide Musema Nov. 2014)

2.3 Cemical treatment of “Black cotton ”soil to make it usable as a Foundation material (Axsum Tesfay Oct. 2001)

2.4 Evaluation of Sodium Silicate and its Combination with Cement/Lime for Soil Stabilization(Ehitabezahu Nigussie Oct. 2011)

2.5 Bagasse ash as a Sub-grade soil Stabilizing Material (Meron Wubshet Dec.2014)

2.1 STABILIZATION OF EXPANSIVE CLAY SOIL WITH SUGAR CANE MOLASSES AND CEMENT

(Bizualem Taye May, 2015)

2.1.1 Description of the Thesis

a) Introduction: Research was done on expansive clay soil sample from Modjo-Ejere Road, with addition of molasses alone, cement alone, and combination of cement and molasses by varying content of stabilizers in steeped concentration of 0, 4, 8 and 12% each by dry weight of the soil, was used to treat the soil. Furthermore, the sample soil was treated with combination of cement and molasses by keeping 4% molasses constant and varying cement content to 4, 8 and 12% by dry weight of the soil .i.e. at 1:1, 2:1 and 3:1 cement to molasses ratio. For the analysis of the effect of the stabilizer on soil, comparison was made on geotechnical properties of the native soil and stabilized soil. The comparison includes by carrying out: pH test, compaction test, Atterberg's limit test, linear shrinkage test, California Bearing Ration (CBR) test, Unconfined Compressive Strength (UCS) test and swelling test on both the native soil and stabilized soil.

b) Study Area: The Modjo – Ejere – Arerti – Sembo Road Project is located in the Central Ethiopia and forms the principal artery for the development of the project areas. The study area of this research covers road segment from Modjo to Ejere (km 0+000 to km 35+000) which falls dominantly in flat terrain condition with some interception of rolling terrain.

c) General Objectives: The objective of this thesis work was to study the suitability of sugar cane molasses and cement (OPC) combination for expansive clay soil stabilization, usable for pavement sub-grade, by increasing their bearing capacity and decreasing their swelling potential. In addition to this, it aims to make comparison on the effect of stabilizers on soils treated with molasses alone, cement alone and cement and molasses combinations.

2.1.2 Quality Assessment

a) Quality Assessment of the Stabilizers

Black strap sugar cane molasses and Ordinary Portland Cement (OPC) which are proposed stabilizers for this study were brought from Wenji/Shoa Sugar

Factory and Derba Cement Factory respectively. Having Quality assessments ascertained.

b) Laboratory Establishing Properties of Native Soil

The engineering property of the native/natural soil was established by conducting tests for the three soil samples from the three test pits: natural moisture content, grain size analysis, Atterberg limits, shrinkage limits, pH test, specific gravity, free swell, modified Proctor, California Bearing Ratio (CBR), CBR Swell, and Unconfined Compressive Strength (UCS). Laboratory tests for the native soil were done.

i. Grain Size Distribution

The sieve and hydrometer analysis test results showed that on average the native soil contained 20% sand, 25% silt and 55% clay by weight.

ii. Atterberg Limits and Shrinkage Limits

Atterberg limits and shrinkage limits tests were conducted and the results are per Table 2.1.

Table 2.1. Atterberg Limits and Shrinkage Limits

Sample no	Depth of the sample (cm)	Visual description of the sample	Atterberg Limits			GI	Shrinkage Limit
			LL	PL	PI		
Test pit # 1	20-60	Block Cotton soil	90	37	53	20	7
Test pit # 2	20-61	Block Cotton soil	90	35	55	20	5.4
Test pit # 3	20-62	Block Cotton soil	87	36	51	20	6.1

The sample materials doesn't fulfill the minimum requirement set by ERA Specification of fill materials which requires materials shall have a liquid limit not exceeding 60% and a plasticity index not exceeding 30 when determined in accordance with the requirements of AASHTO

Based on the grain size analysis tests and Atterberg limit tests, the soils were classified as A-7-5 (20) according to the AASHTO Classification System.

iii. PH Values

The pH values of the native soils were 8.18, 8.2 and 8.21 for test pits one, two and three respectively. These results show that the soils were neutral implying that it was vertic soil (Fitzpatric, 1986 cited in Ndegwa, 2012).

iv. Specific Gravity

The specific gravity values ranged from 2.54 to 2.66 which fell within the range for clay soil.

v. Moisture Density Relations of the subgrade Soils

Modified Proctor tests were conducted on the sub-grade soils to determine the relationship between the moisture content and dry densities. The results showed optimum moisture contents were 26.9%, 28.8% and 27.1% and the maximum dry densities were 1.48 gm/cm3, 1.50 gm/cm3 and 1.51 gm/cm3 for test pits one, two and three respectively.

vi. California Bearing Ration (CBR) Values and CBR Percent Swell Values

The CBR test result values were determined at a density of 95% of the maximum dry density and showed that the sub-grade soils had very low CBR value of 1%, which does not satisfy the minimum requirements stipulated as sub-grade materials and embankment material in ERA specification. Hence, it can be concluded that the sub-grade soil under investigation cannot be used as sub-grade and/or selected fill material for embankment construction unless otherwise its undesirable properties are rectified (ERA, 2013). The CBR percent swell tests were determined the results showed are 9.3%, 11.6% and 10.2%.

vii. Free Swell Test

Free swell tests were conducted according to IS 2720 and values of 110%, 120% and 110% were observed for sample soil.

viii. Unconfined Compressive Strength (UCS)

Unconfined compressive strength tests were conducted for the sample soils and results are given in Table 2.2 and the un-drained shear strengths were calculated as one half of the UCS values as shown in Equation 2.1. The un-drained shear strength (Su) of clays is commonly determined from unconfined compression test. The most critical condition in the soil usually occurs immediately after construction, which represent un-drained conditions, when the un-drained shear strength is basically equal to the cohesion (C). This is expressed as:

$$= \; = \frac{qu}{2} \text{..} \text{Eqa. (2.1)}$$

Table 2.2: UCS, strain at failure and Cohesion Values for the three test pits

Test pits	UCS (KN/m2) =qu	Cohesion (KN/m2) = qu/2	Moisture Content (%)
Test pit # 1	141.03	70.52	27.30%
Test pit # 2	138.76	69.38	27.30%
Test pit # 3	135.83	67.92	27.30%

ix. Indirect Estimation of Potential Swell

a) Potential Swell based on Clay Fraction

The sub-grade soil samples have been plotted on the Van Der Marwe's chart and found to be highly expansive soil (Van Der Marwe, 1964).

b) Potential Swell based on Activity

Activities of the clay soil samples collected for this research were calculated by empirical relations developed by Seed et al, 1962 model and given in Table 2.3 and plotted on clay content against activity chart. All the samples were plotted to have very high swelling potential which is above 25%.

Table 2.3: Activity result calculated according to Seed et al model

Test pits	PI	C	Activity
Test pit # 1	54	49.00	1.38
Test pit # 2	55	49.00	1.41
Test pit # 3	51	50.00	1.28

2.1.3 Establishing Properties of Stabilized Soils

In here test results, discussions and analysis of all experimental work were performed on stabilized soils with molasses only, cement only and cement and molasses combination mixtures. first the effect of each stabilizers on pH value, Atterberg limits, linear shrinkage, moisture-density relation, CBR values and UCS values were established by varying percent of stabilizers from 4% to 12% by 4% increment and compared with native soil/untreated soil engineering property. Then effect of each stabilizer on the property of treated soil were compared and contrasted. However, in this review it is the cement and molasses combination mixture results, discussions and analysis which will be critically reviewed.

a) pH Values

A series of specimens were prepared in soil containing a range of percentages of molasses, cement and cement and molasses content and measurements of pH were made .the pH value of soil-cement and soil-cement and molasses mixtures increase sharply at small cement content and reach values of 13.19 and 12.75 at 4% cement and 4% cement + 4% molasses content respectively.

b) Consistency Limits

Consistency limits were conducted for soils treated with molasses alone, cement alone and cement and molasses combination for different curing periods.

(i) Effect of Cement and molasses on Atterberg Limits

The Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) of soil treated with cement and molasses combination were determined.

Table 2.4: Atterberg Limit values for soils treated with cement and molasses

Average Limits	…Cement + 4% Molasses		
	4%	**8%**	**12%**
LL	48	44	40
PL	29	27	25
PI	19	17	15

PI of the samples decreased significantly with increasing stabilizers percentages. The addition of 12% cement + 4% molasses reduced PI of the natural soil significantly from 53% to 15%. The addition of 8% cement + 4% molasses and 4% cement + 4% molasses reduced the PI of the natural soil sample from 53% to 17% and from 53% to 19% respectively.

(ii). Effect of Stabilizers on Linear Shrinkage

The shrinkage curves for the sample soils from the linear shrinkage tests with the three chemical additives, molasses, cement and cement and molasses were done and the average linear shrinkage for native soils without additives was around 21%. The shrinkage insignificantly decreased with the addition, molasses; however cement and cement and molasses were more effective at arresting shrinkage than the molasses for the same percentage by weight added.

c) Compaction Characteristics of Soils stabilized by Cement and molasses

Sample soils treated with cement and molasses gave the typical bell shaped curve for moisture density relationship characteristics, but theses curves shifted to the left with respect to untreated soil samples. The maximum dry density was in the range of 1.53 gm/cm3 at 22.8% moisture content for soil treated by 12% cement + 4% molasses and lowest maximum dry density was in the range of 1.51 gm/cm3 at 25.1% moisture content for soil treated by 4% cement + 4% molasses. It could be seen that the natural clay soil sample had a MDD of 1.50 gm/cm3 and OMC of 27.4%, the addition of cement and molasses affected on dry density characteristics; however, relatively reduction in moisture contents were observed

a) California Bearing Ratio (CBR) and CBR Swell Values

In This section the CBR values were determined for sample soils used in the experimental work. CBR tests were conducted on the untreated soil samples as well as treated/stabilized soils by molasses, cement and cement and molasses. The tests were conducted by varying stabilizers contents up to 12% and by applying different soaking periods and curing methods.

i. Effect of Molasses stabilization only on CBR

CBR results obtained from all the samples treated by molasses only cure for 14 days and soaked afterwards for four days by 4.5 kg surcharge load show only slight changes than the native soil.

ii. Effect of Cement stabilization only on CBR

As soil stabilization by cement is one of the conventional stabilizer agents and well documented in the literature, one trial CBR tests were conducted on soils treated with cement cure for 7 days and soaked for the same 7 days by 4.5 kg surcharge and results are given below.

Table 2.5: Soaked CBR values for Soils treated with cement and cure for 14 days

Soil Stabilized by Cement	
Stabilizer %	**CBR Value**
4% Cement	27.3
8% Cement	82.3
12% Cement	123

As it may be seen from Table 2.5 CBR results showed significant improvement in strength compared to untreated soil sample. This shows that CBR value of treated soils with cement increases as the quantity of cement increases.

iii. Effect of Cement and molasses on CBR Values

Big difference in CBR values between untreated and treated soils with cement and molasses combination was obtained when compared to the 1.3 % CBR value of untreated soil for all the samples treated by cement and molasses cure for 7 days and soaked for the same days by 4.5 kg surcharge load. Results as given in Table 2.6 and Figure 2.1 show that CBR values increased with higher cement and molasses content.

Table 2.6 Soaked CBR values for Soils treated with cement and molasses

Soil Stabilized by Cement and molasses			
Stabilizer %	Test #1	Test #2	CBR Average Value
4% Cement + 4% Molasses	65	62	63.5
8% Cement + 4% Molasses	99	95	97
12% Cement + 4% Molasses	130	125	127.5

Fig 2.1 Variation of Soaked CBR values of Expansive soil mixed with various proportions of cement and molasses and cure for 14 days.

The significant increase in CBR value may attribute to reactions between cement, molasses, clay soil and water.

iv. CBR Swell of Expansive Clay Soils

Expansive soil treated with molasses showed reduction in CBR swell when compared to 10.4 % of untreated soil. Soil treated with 4.0%, 8.0% and 12% molasses yielded average CBR swell of 2.62%, 2.32% and 2.46% respectively. Soil treated with 8.0 % molasses showed the largest reduction in CBR swell which is 78% smaller than untreated soil. Moreover, it was observed that swelling potential decreases with increasing in molasses content up to 8.0% and then further increases beyond 8% molasses content resulted in increasing of swelling potential. This could be due to variation in clay mineralogy of the expansive soils.

CBR swell also showed significant reduction with the addition of cement and cement and molasses. Soils treated with the two stabilizers, gave CBR Swell of less than 1.0.

b) Unconfined compressive strength(UCS)

i. Effect of Molasses on UCS Values

The increase in UCS values of molasses treated soils may be attributed to cation exchange reaction and flocculation and agglomeration effect and the reduction of UCS values with increasing molasses content beyond a certain limit can also be attributed to coating of individual soil grains with molasses as discussed.

ii. Effect of cement on UCS Values

Peak failure stress of the cement treated specimens for 4%, 8% and 12% cement were 235, 780 and 877 KN/M2 respectively. Average peak failure stress of the untreated specimens was 138.53 KN/M2. Peak failure stress of treated specimens for 12% cement and 4% cement was about 6.3 times and 1.7 times larger than the peak stress failure of untreated specimen respectively. Generally it was observed that UCS values increased with increasing cement content.

iii. Effect of Cement and molasses on UCS Values

The UCS values for on remolded specimens treated with 4% cement + 4% molasses, 8% cement + 4% molasses and 12% cement + 4% molasses and cure for 7 days were found 248, 999 and 859 KN/M2 respectively. Generally, strength of the expansive clay soil increased with higher cement and molasses combination.

2.1 STABILIZATION OF EXPANSIVE CLAY SOIL WITH LIME

(Reshide Musema Nov. 2014)

(A Case Study on the Adura-Burbey DS6 Road Segment)

2.2.1 Research Objective

The general objective was to study the potential benefits obtained by the use of chemical stabilization to render a typical expansive clay soil intended for road sub grade construction in Ethiopia, by increasing its bearing capacity and decreasing its plasticity and Controlling of volume changes.

The main objectives of this thesis are

- ✓ To improve the performance of a material by increasing its strength, stiffness and durability. The performance should be at least equal to, if not better than that of an acceptable to good natural material.
- ✓ To evaluate the engineering properties of untreated and treated specimens.
- ✓ To determine optimum amount of Stabilizing Agent (Lime) needed to attain the required properties of black cotton soils that can be used as a subgrade material

2.2.2. Research Methodology

2.2.2.1. The study area

The study area is located at the south western part of the country named Gambella regional state. The project road begins at adura village around 150km away from the Gambela town and ends at Burbey village,found 45km west of adura village, at the Ethio-Sudan border, Baro River.

2.2.2.2. Description of the research design

Samples were collected by an open excavation from a depth of 0.5 to 1.5m below natural ground level. Tests are conducted for four stations without the addition of lime. The results are shown in table 2.7 below.

Table 2.7 Laboratory test results for the selected stations for further studies

Sample Number	Sample Station	Liquid Limit	Plastic Limit	Plasticity Index	Soil classification
1	3+000.00	57.45	28	29.91	A-7-5(34)
2	23+450.00	56.6	27.28	29.32	A-7-5(32)
3	32+700.00	64.14	31	33.11	A-7-5(38)
4	35+000.00	55.47	27	28.19	A-7-5(32)

From the laboratory results, all the samples exhibit high expansive potential. Following the laboratory results conducted on the samples specified above, samples collected from stations 3+000, 23+450 and 35+000 have relatively similar Index properties and have similar classifications. And the sample collected at station 32+700 has properties relatively higher index properties. **Because of this the emphasis of the research will focus on two categories**. **Category one**, the samples collected at 3+000, 23+450 and 35+000 and **category Two**, sample collected from station 32+700 will be blended and further studies with the addition of lime will be made.

The following laboratory tests will be conducted for this category:Atterberg limits ,Specific gravity ,Free swell, Linear shrinkage ,Shrinkage limits and Unconfined Compressive Stress (not cured strength for category one /7 days curing for category two.

Materials were prepared in accordance with AASHTO T 87-86. These methods involve air drying of samples and breaking up of soil aggregations by rubber covered mallet. The following tests were carried out to determine the soil properties. Atterberg Limits, Shrinkage limit and linear shrinkage, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), California Bearing Ratio (CBR) and CBR Swell, Unconfined Compressive strength (UCS), Specific Gravity and Free swell.

2.2.3 Laboratory Data Analysis and Results

Here the laboratory data‘s for the collected samples are elaborated and analyzed for the natural subgrade soil and the lime with different combination. Laboratory test types and the respective results determined based on AASHTO are discussed below.

a) Atterberg Limits

i. Shrinkage limits and linear shrinkage

The summary of the laboratory results for the samples at station 32+700 and blended samples are tabulated in table 2.8 and 2.9 below respectively. The laboratory results of the shrinkage limit and linear shrinkage tests and results are:-

Table 2.8 Summary of laboratory results for Atterberg limits, Shrinkage Limit and Linear Shrinkage for sample at Sta. 32+700

Serial Number	Soil Type	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)	Linear Srinkage (%)
1	Natural Soil	64.14	31.03	33.11	5.0	22.1
2	Soil+2% lime	60.33	26	34.29	7.6	21.4
3	Soil+4% lime	59.16	26.25	32.91	9.2	20.7
4	Soil+6% lime	56.07	26.27	29.8	9.3	20.1
5	Soil+8% lime	52.48	26.81	25.67	9.4	18.00
6	Soil+10% lime	50.5	28.83	21.67	10.9	17.00
7	Soil+12% lime	45.66	30.56	15.10	11.6	16.00

Table 2.9 Summary of laboratory results for Atterberg limits, Shrinkage Limit and Linear Shrinkage for sample at Sta. Blended material.

Serial Number	Soil Type	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)	Linear Srinkage (%)
1	Natural Soil	56.6	27.28	29.32	5.60	24.90
2	Soil+2% lime	54.52	34	20.34	7.9	23.60
3	Soil+4% lime	53.02	33	19.98	10.10	22.10
4	Soil+6% lime	50.47	32	18.73	10.4	21.40
5	Soil+8% lime	43.83	28	15.54	10.4	21.00
6	Soil+10% lime	41.39	26	15.07	12.10	19.30
7	Soil+12% lime	41	26	15	12.90	17.10

b) Specific Gravity and Free swell

Table 2.10 Summary of laboratory results for Specific Gravity and Free Swell

Serial Number	Soil Type	Specific Gravity(Gs)	Free swell	Specific Gravity(Gs)	Free swell
		Sample at Station 32+700		Sample for Blended	
1	Natural Soil	2.485	70	2.387	70
2	Soil+2% lime	2.50	60	2.416	60
3	Soil+4% lime	2.597	45	2.424	50
4	Soil+6% lime	2.597	40	2.538	40
5	Soil+8% lime	2.614	35	2.548	30
6	Soil+10% lime	2.632	30	2.632	20
7	Soil+12% lime	2.649	25	2.662	10

c) Moisture density relations

Table 2.11 Summary of laboratory results for maximum dry density and optimum water content for sample at station 32+700.

Serial Number	Soil Type	OMC (%)	MDD
1	Natural Soil	25	1.51
2	Soil+2% lime	25.1	1.51
3	Soil+4% lime	26	1.49
4	Soil+6% lime	27.3	1.48
5	Soil+8% lime	28.2	1.48
6	Soil+10% lime	28.5	1.47
7	Soil+12% lime	29.30	1.46

d) California Bearing ratio (CBR) and CBR Swell

Tests were conducted with the addition of lime 0, 2, 6,8,10 and 12 percent hydrated lime. Specimens are molded at respective optimum moisture content as determined in moisture density relationships. Results are tabulated and illustrated in Table 2.12 below.

Table 2.12 Summary of laboratory results for CBR and Percent Swell of the Sample at station 32+700.

Serial Number	Soil Type	CBR Values in %			CBR SWELL (%)		
		10 Blows	30 Blows	65 Blows	10 Blows	30 blows	65 blows
1	Natural Soil	0.7	1.2	2	3.97	3.5	3.11
2	Soil+2% lime	0.9	1.5	1.7	3.9	3.48	3.08
3	Soil+4% lime	0.9	1.9	2.6	3.68	3.23	2.92
4	Soil+6% lime	1.7	2.6	3.3	3.38	2.91	2.62
5	Soil+8% lime	1.7	3.3	4.5	2.91	2.38	2.13
6	Soil+10% lime	2	4.3	5.9	2.64	2.21	1.97
7	Soil+12% lime	3.5	6.5	8.9	2.3	1.97	1.73

e) Unconfined Compressive Stress

Tests were conducted with the addition of lime 0, 2, 6,8,10 and 12 percent hydrated lime. Two samples are tested for the UCS. The first sample was blended sample (sample collected at 3+000, 23+450 and 35+000) and the other sample was from station 32+700. The blended sample was tested for the Immediate UCS and the sample collected at station 32+700 is tested for the 7 days cured stress. Results are shown in table 2.13 below.

Table 2.13 Summaries of laboratory results for Unconfined Compressive Stress for two samples

Serial Number	Soil Type	Immediate(KPA)for Blended material	Cured for 7 days (KPA) for sample at 32+700
1	Natural Soil		
2	Soil+2% lime	113.12	276.21
3	Soil+4% lime	134.56	374.41
4	Soil+6% lime	138.83	484.59
5	Soil+8% lime	167.33	606.47
6	Soil+10% lime	216.94	696.66
7	Soil+12% lime	254.03	791.73

2.2.3. Laboratory Data Analysis and Interpretations

Following laboratory tests performed in accordance with AASHTO laboratory test standards with Lime percentages from 2 to 12 percent‘s by dry weight of the soil sample for each test types. The analysis and interpretations given are as follows:

a) **Plasticity index**: The untreated plasticity index values determined in laboratory were 33.11% and 29.32% for samples at 32+700 and blended samples respectively. Both samples have plasticity index values which fall in the range of 20-55% which is categorized as high swelling potential soils. With 12% lime treatment, the plasticity index values become 15.1% and 15% for samples at station 32+700 and for blended samples respectively. The results fall in the range of 0-15%, which is classified as low swelling potential. Here it can be noted that the addition of 12% lime for both samples has reduced the swelling potential of the problematic soils from high swelling potential soils to low swelling potential which is a satisfactory and required range.

b) **Shrinkage limit**: the shrinkage limit of both samples has improved through stabilization. The untreated shrinkage limit values determined in laboratory were 5% and 5.6% for samples at 32+700 and blended samples respectively.

Both samples have shrinkage limit values which are <10% which is categorized as problematic. With 12% lime treatment, the shrinkage limit values become 11.6% and 12.9% for samples at station 32+700 and for blended samples respectively.

c) **Specific gravity**: The specific gravity of both samples has also increased with the increase of lime percentage. The increase of the specific gravity was in the order of 0.02 and 0.03 for the sample at 32+700 and Blended sample respectively by the addition of 2 percent lime. The maximum increase in specific gravity was 0.16 and 0.28 for sample at 32+700 and Blended samples respectively with the addition of 12% lime.

d) **Free swell:** The free swell has also decreased with the increase of lime percentage for both samples. The decrease of the free swell was in the order of10% by the addition of 2 percent lime for both samples. The maximum decrease in free swell was 45% and 50% for Samples at 32+700 and blended samples respectively with the addition of 12% lime. The untreated free swell values determined in laboratory were 70% for both samples. Both samples have free swell values >50% which is categorized as problematic. With 12% lime treatment, the free swell values become 25% and 10% for samples at station 32+700 and for blended samples respectively. Here it can be seen that the addition of 12% lime for both samples has improved the swelling potential of the problematic soils from a class of problematic soils to non-problematic soils which is a satisfactory and required range.

e) **Moisture density relations:** the dry density and moisture content up on lime treatment has opposite effect with the increase of optimum moisture content and a decrease of MDD. This scenario is generally true for all lime treated expansive soils. because the effects of cation exchange and short-term pozzolanic reactions between lime and the soil results in flocculation and agglomeration of clay particles leading to textural changes. These results are in consistent obtained by Afes and Didier (2000). These results reveal the soils in wetter than original condition to be compacted satisfactorily.

f) **CBR**: The CBR Value increases with the increase of lime with the opposite effect on the CBR Swell. The CBR Value has also increased with the increase in lime Percentage. The effect of lime on CBR and Swell are opposite but with positive outcome after stabilization. The previous CBR Value was 1.46% which is considered as poor subgrade in accordance with ERA Pavement design manual. But through lime treatment the CBR of the soil has improved but, the improvement was not to the required level. The addition of 12% lime has **changed the CBR Value to 8.92% which is still a fair subgrade** to be used on the specific project. **CBR classes of 20-50% for any subgrade are specified as Good CBR values in most literatures.**

g) **UCS:** the unconfined compressive strength has a positive impact up on addition of lime for the immediate and 7 days cured samples. The UCS values have also increased with the increase of lime percentage.

According to (Terzagi etal, 1996) the minimum UCS value for stabilized subgrade Strength gained through lime should be 1725kpa. The values obtained for samples at 32+700 and blended samples are below the requirements and can be said that strength was not achieved for these samples (locations) up to 12% lime. The maximum laboratory results for sample at 32+700 and Blended samples with the addition of 12% lime were 791.73KPaand 254.03 KPa respectively

According to ERA pavement design manual volume 1 (Flexible pavements and gravel roads) chapter three explains details concerning subgrade materials. subgrades with CBR value less than 2 needs special treatment. In our case stabilization is one of the options being used. According to ERA manual subgrades are classified from S1 to S6 based on the California bearing ratio (CBR), and are illustrated in table 2.14 below.

Table 2.14 CBR range subgrade class (ERA 2002 Pavement manual)

Serial No.	Classs	CBR% Range
1	S1	2
2	S2	3-4
3	S3	5-7
4	S4	8-14
5	S5	15-29
6	S6	30+

Before stabilization of the sample at station 32+700, the CBR value was 2.04% and Swell of 3.11 which is an indication of how poor this subgrade material is for subgrade construction. But by stabilizing the sample its CBR and CBR swell are improved slowly depending on the amount of lime used. For example with the addition of 4% lime the CBR Value becomes 2.6%, and swell of 2.92 which falls in S1. The value of CBR with lime stabilization of 12% was 8.92% which is a good improvement for subgrade class lying in S4 (8-14).

From Bowls, 1992 CBR values and the quality of subgrades in pavement design are explained in the table 3.2.11 below.

Table 2.15 CBR range Subgrade quality (Bowls, 1992)

Serial Number	CBR (%) Range	Subgrade Quality
1	0-3	Very poor subgrade
2	3-7	Poor to fair subgrade
3	7-20	Fair subgrade
4	20-50	Good subgrade
5	50+	Excellent subgrde

CBR swell: Before lime treatment the swell was 3.11%.with the addition of 12% lime, the swell of the soil becomes 1.73% which is in the acceptable range and specification for the project. Therefore the design lime content for this section of the route with all the three criteria (Acceptable CBR strength and swell with required plasticity index reductions) is estimated to be 12% lime, which is reasonably good and safe for the roadbed.

Since the thesis is based on the existing road project,the designer has specified to use an improved subgrade with minimum CBR value of 8% and swell of <1%.In order to achieve this criteria (CBR>8% and Swell<1%), the designer has proposed an improved subgrade material from borrows to design the pavement layer thickness.

The use of lime stabilization using 12% lime has improved the CBR value from 1.4% to 8.92%, which was one of the required specifications in the project for improved subgrade. This can imply that the stabilized soil can totally avoids the use of improved subgrade material.

From the previous conditions of the project (Adura-Burbey DS6 road), the problems of the expansive subgrades were mitigated by using Borrow materials of CBR> 3.5% and blanketing material of CBR value of> 8%. These specifications were additional costs for the project. For example they have specified to use a blanketing material of 60cm and an embankment material of 1m to 2.4m which is too costly and can took prolonged construction period.

From this thesis it is evident that stabilization of the problematic soil with 12% lime has

- ✓ Greatly improved the plasticity nature from 33.11% to 15.1%
- ✓ Improved the CBR strength from 1.46% to 8.92%
- ✓ Has improved the workability
- ✓ Has improved the CBR swell from 5.49% to 1.73%

Though mathematical calculations related to costs were not made to clearly identify the effects, one can easily identify the use of lime stabilization can reduce the unnecessary costs related to embankment and blanketing materials to mitigate the problematic soils. Therefore it is advantageous to use lime stabilization rather than utilizing thicker embankments and blanketing material, which are by far costly and time consuming.

2.3 CHEMICAL TREATMENT OF "BLOCK COTTON" SOIL TO MAKE IT USABLE AS A FOUNDATION MATERIAL

(Aksum Tesfaye oct.2001)

2.3.1 Study Area

The abundant occurrence of Expansive soil in Addis Ababa has raised the need for improving the negative geotechnical properties of expansive soils by addition of varying quantities of lime and cement.

Basic properties of these expansive "Black Cotton" soils from different area test pits were determined at the first stage in the laboratory. Then investigation was done in the index properties of ten "Black Cotton" soil samples using 2%, 4%,6%,8%,and 10% of lime by dry weight of soil .Then again The representative soil samples were selected to determine index properties by adding 3%, 6%, 9%, 12%, 15%, 18%, 21% of cement by dry weight of soil ..

2.3.2 Laboratory Test Result and Investigation

Tests were conducted on "Black-cotton" soil treated with different amount of lime and cement. Except for swelling potential tests, all laboratory investigation was made following ASTM soil test procedures. Samples were collected from ten (10) test pits excavated (1.5meters to 3.0 meters depth) for this purpose at different parts of Addis Ababa where this kind of soils predominates.

The collected soil samples are designated as S1, S2, S3. ...S10.

2.3.2.1Native Soils

All the collected soil samples were air-dried, sieved on sieve No.40 (425μm) and tested for atterberg limits, grain size distribution, specific gravity, moisture content, dry unit weight, free swell, and swelling pressure tests.

Table 2.16 laboratory test result of native soil

Description	**Sample designation**								
	S_1	S_2	S_3	S_4	S_5	S_6	S_8	S_9	S_{10}
LL (%)	98	93	99	97	94	97	90	99	92
PL (%)	34	37	32	38	35	37	50	33	34
PI (%)	64	56	67	59	61	60	40	66	58
Specific gravity	2.72	2.72	2.85	2.64	2.56	2.64	2.65	2.75	2.96
Free Swell (%)	85	86	95	110	100	76	90	98	89
Swelling Pressure KN/M2	420	395	440	455	461	400	389	474	401

2.3.2.2 Test results of soil -lime (SL)

properties of ten " Block Cotton" soil samples using 2%,4%,6%,8%,and 10% of lime by dry weight of soil .The representative soil samples were selected.

I. **Plasticity** Effect of lime on the consistency properties of expansive soils samples from 1.5meters to 3.0 meters are done to that end results are given against percentage of lime content and it could be easily seen the improvement achieved by adding lime in to expansive "Block-cotton" soils. Taking the last not least result got fro 10% lime content.

Table 2.17 Laboratory Test results for Soil lime

Consistency	**Sample designation**								
	S_1	S_2	S_3	S_4	S_5	S_6	S_8	S_9	S_{10}
(LL)	43	63	50	72	66	82	65	58	58
(PL)	32	58	43	62	55	45	57	53	54
(PI)	11	5	7	10	11	37	8	4	4

II. Dry Density and optimum Moisture Content (OMC)

Soil lime showed little or no nearly no change in their maximum dry density upon addition of lime in to expansive "Black-cotton" soils and the optimum moisture content increase as the lime content increase.

III. Swell and swelling pressure of soil-Lime Mixture

Soil- lime mixture swelling pressure values are shown blow for one sample:

Table 2.18 Laboratory Test results for Soil lime for sample Designated as S_4

Lime	Specific gravity	Liquid limit LL	Limit Plastic	Plastic Index	Free swell	Swelling Pressure
in %	Gs	in %	in %	in %	in %	KN/m2
0	2.64	97	38	59	110	455
2	2.62	95	40	55	100	410
4	2.62	87	50	37	65.2	350
6	2.62	81	55	26	52	300
8	2.62	76	60	16	33.3	240
10	2.62	72	62	10	26	240

2.3.2.3 Test result of soil-Cement

The representative soil samples were selected to determine index properties by adding 3%,6%,9%,12%,15%,18%,21% of cement by dry weight of soil are used.

a. plasticity

The consistency properties of soil-cement had resulted in the reduction of the plasticity of "Block –cotton"' soil. From the plot of the consistency limit of the representative sample, cement contents greater than 9% had considerable and encouraging results.

Table 2.19 consistency limits of soil-cement

Consistency	Percentage of cement contents							
	0%	3%	6%	9%	12%	15%	18%	21%
(LL)	99	95	92	91	85	82	81	76
(PL)	32	34	35.7	47.5	51.34	52.2	54.01	50.82
(PI)	67	61	56.3	43.5	33.7	29.8	26.99	25.18

b. Dry Density and optimum Moisture Content (OMC)

Compaction test results of Soil cement showed that as the cement content increase from 0% to 6% there is an increasing change in their maximum dry density but from 6% to 12% the maximum dry density decreases from 1.23gm/cc .The optimum moisture content increases from 33.2% for 6% cement content to 36% for 12% cement content.

Table 2.20 Test Result of "Black Cotton" soil MDD/OMC

Cement content	Maximum dry density (gm/cc)	Optimum moisture content (%)
3%	1.28	30.0
3%	1.28	31.0
6%	1.3	33.2
9%	1.25	34.0

12%	1.23	36.0

c. Swell and swelling pressure of Soil-Cement

Swell – Consolidation Method (Free swell method) is used to determine the swelling pressure. Placing the specimen soil sample in a consolidometer and apply a normal load equal to 1psi (7kN/m2) then Inundate the sample and allow it to swell then After the swelling is complete, load the sample in increments until the soil returns to its original volume. The pressure that corresponds to the original volume is the swelling pressure.

Table blow shows the free swell of the representative soils sample (S3) –cement and swelling pressure of soil cement compacted at 95% of the maximum dry density, tested slightly at higher moisture content than optimum moisture content.

Table 2.21 free swell and swelling potential of the soil-cement sample

Cement In %	**Specific gravity**	**Liquid Limit (LL)**	**Plastic Limit (PL)**	**Plastic index PI**	**Free swell**	**Swelling Pressure**
	Gs	%	%	%	%	KN/M2
0	2.85	99	32	67	95	440
3	2.78	95	34	61	90	400
6	2.78	92	35.7	56.3	75	336.8
9	2.78	91	47.5	43.5	67	340
12	2.78	85	51.3	33.7	51	295
15	2.78	82	52.3	29.8	46	280
18	2.78	81	54.01	26.99	40	275
21	2.78	76	20.80	25.2	34	276

2.4 EVALUATION OF SODIUM SILLICAT AND ITS COMBINATION WITH CEMENT/LIME FOR SOIL STABILIZATION

(Ehitabezahu Nigussie)

2.4.1. Objectives

The objective of this thesis work is to study the suitability of sodium silicate for expansive soil stabilization, by increasing their bearing capacity and decreasing the swelling pressure and heave. In addition to this, it aims to investigate suitability of the chemical to decrease pavement thickness by increasing the bearing capacity of substandard subbase materials. Cement and lime are well known subbase and subgrade stabilizers. This study aims to assess the potential improvement in strength and decrease in plasticity of soils by combining these stabilizers with sodium silicate. The study has the specific objective of investigating the response of soils though the application of the chemical additives at various curing durations.

2.4.2 Study Area

For this study two soil samples that represent expansive subgrade and subbase soil that does not fulfill ERA's grading requirement 2002 were obtained from in situ soil of Addis Ababa's Bole Senior Secondary and Preparatory School and borrowed material from Gergi-Bole Road section respectively.

The following particulars were considered with respect to the additives and the mixing ratios used. Expansive clay was treated with lime, sodium silicate and combination of the two additives. Clayey sand was treated with cement, sodium silicate and combination of the two additives. A variation in curing duration was taken as another variable for both.

2.4.3 Mix ratios considerations

The two cases are as follows:

a. **Expansive clay** ;was treated at the following mixing ratios:

- 0%, 2%, 4% and 6% of hydrated lime by dry weight of the soil
- 0%, 1%, 2.5% and 6% of sodium silicate by dry weight of the soil

• Combination of the respective mixing ratios mentioned above (e.g.2% lime and 1% sodium silicate, 2% lime and 2.5 sodium silicate etc.) for the combined application

• Curing durations were varied at 0, 3, 7 and 28 days for Atterberg samples while CBR samples (made using results of standard compaction) were cured for 0, 3 and 7 days. Similarly for

b. Clayey sand with gravel: the following mixing ratios were considered;

• 0%, 3%, 5% and 7% of ordinary Portland cement by dry weight of the soil

• 0%, 1%, 2.5% and 6% of sodium silicate by dry weight of the soil

• The respective mixing ratios mentioned above were applied in concert and

• Treated Atterberg samples cured for 0, 3, 7 and 28 days and CBR samples (made using results of modified compaction) were cured for 0, 3 and 7 days.

2.4.4 Material Characterization

a**). Native Soil:** Standard Testing Procedures of ASTM and AASHTO standards are used for testing soils in the laboratory.

Table 2.22 Soil classification

Index and swelling properties (%)					Soil classification	
Sample	LL	PL	PI	Free Swell	ASTM D 2487 (Unified Soil Classification System)	AASHTO standards
1	130*	38	92	115	Inorganic Fat clay	A-7-6 (41)
2	38	22	16	30	Clayey Sand with gravel	A-2-6

b**). Lime:** Hydrated lime used for the study was obtained from Senkele lime factory.

c**). cement**: Mugher ordinary Portland cement (OPC) was used for the study.

d**. Sodium Silicate**: Liquid sodium silicate used for this study was obtained from Alied Chemicals Plc. Specific gravity and pH values were measured at room temperature at the Chemical Engineering Laboratories of Addis Ababa University.

2.4.5 Mixing Ratios and Sample Designation

Mixing Ratios and Sample Designation

Mixing Procedures: Soil and additives were mixed in such a way that the additive is first added to the prepared sample and dry mixed with the soil. When cement or lime was applied in concert with sodium silicate, soil sample was first dry mixed with the respective cementations stabilizer and sodium silicate was added there after followed by a thorough mixing. Finally, wet mixing was done by sprinkling water uniformly and thorough blending the whole soil matrix. Care was taken not to apply sodium silicate directly on cement as it is observed to form hydration products that made further mixing difficult and non-uniform.

2.4.6 Test Results and Discussion

I. **Atterberg Limits**:

a). **Clayey sand** treated with sodium silicate and/or cement became non-plastic at all curing durations considered. Cured samples are observed to turn in to solid masses as the quantity of cement and sodium silicate increased.

b). Black cotton soil showed

- The highest reduction in PI when it is treated with 6% lime only and cured for 3days which is 78.26% reduction compared to untreated soil. It is from a value of PI 92 to 20.
- The maximum reduction of plasticity index for expansive clay treated with sodium silicate only is 51.09% which was obtained for 1% of sodium silicate cured for 28 days. It is a value from PI 92 to 43.
- The maximum reduction of PI treated by both is 52.17% for soil treated with 4% lime and 1% sodium silicate cured for 28 days compared to untreated soil. These values are comparable to improvements gained by applying sodium silicate alone. It is a value from PI 92 to 42. The result, however, is inconsistent in showing

how the curing duration or quantity of sodium silicate and it combination with lime relates to the reduction in plasticity.

II. Moisture-Density Relations

a) Effect of Additives on Expansive Clay

- Native soil and expansive soil treated with lime yielded the typical bell shaped compaction curves with the highest density being 1.27g/cm3 for 0% additive. These curves sifted to the right with respect to untreated soil sample, which also means addition of lime decreased the maximum dry density and increased the optimum moisture content. This result is in harmony with the findings of Nebro D. (2002).

- The highest dry density achieved at the direst side of the compaction curve for expansive clay treated with sodium silicate shows the surface charge modification effect of liquid sodium silicate.

- However, expansive clay treated with sodium silicate or its respective combination with lime yielded odd curves. A definite optimum moisture content and maximum dry density could not be determined. Standard compaction tests made for trial purposes using larger quantities of sodium silicate also showed agglomerating effect of sodium silicate.

b) Effect of Additives on Clayey Sand

- The dry density of clayey sand treated with the respective quantities of cement does not show significant change in the maximum dry density compared to each other.

- Clayey sand soil treated with sodium silicate showed the typical bell shaped compaction curves for all the quantities of sodium silicate and/or its combination with cement. a decrease in the maximum dry density of the soil was observed with increasing the quantity of sodium silicate except for C5SS2.5

I. **CBR and CBR swell Values**

a) CBR Values of Expansive Clay

- Soil treated with sodium silicate using the third moisture content of the compaction test results does not show any improvement in strength compared to untreated soil sample. Also show that the CBR of treated soil decreases as the quantity of sodium silicate increases. Results also show that curing enhances the strength development of expansive soil treated with sodium silicate

- Soil treated with 2% lime cured for 7 days fulfilled the strength requirements of a subgrade, but since the quantity of lime is low, this result may not necessarily imply long term stabilizing effects. With CBR of 22.85%, soil treated with 4% lime can effectively be used as a subgrade soil. Expansive clay treated with 6% lime yielded CBR of 42.19% which is more than the minimum strength requirement for subbase except it does not fulfill the grading requirement.

- However, the data is inconsistent in showing how mixing lime and sodium silicate relates to strength development. Expansive clay treated with combination with lime and sodium silicate also showed more swelling than expansive clay treated with lime alone.

b) CBR Swell of Expansive Clay

- Expansive soil treated with 6% sodium silicate showed the largest CBR swell which is 59.67% larger than untreated sample. It is from a value of 7.8% to a value of 19.4% CBR swell for 6% sodium silicate.

- CBR swell showed significant reduction with the addtion of lime. CBR swell of expansive clay treated with 6% lime yields almost nil swelling. This finding is also in harmony with results obtained by Nebro D. (2002).

- Results also show swelling potential of expansive clay treated with sodium silicate and/or lime is inversely related to the curing duration.

For instance, L6SS1 which shows 0% swelling for 7 days of curing showed 7.54% increment in swelling values when the curing duration is reduced to 0 days.

c) CBR Values of Clayey Sand

- Clayey sand treated with 3% cement yielded CBR values of more than 215%. The CBR value increases with the percentage of cement added to the soil.

- For seven days of curing, results also show that there is a slight increase in CBR values associated with applying 1% of sodium silicate to the given quantity of cement compared to the respective cement treatments alone. However, CBR values decreased when the quantity of sodium silicate added to soil cement is increased to 2.5% or 6%

- Clayey sand treated with sodium silicate alone, there is at least 19% increase in CBR values for soils treated with 1% of sodium silicate with respect to untreated soil. However, CBR values significantly dropped when the quantity of sodium silicate added to the soil is increased to 2.5%. For soil treated with 6% sodium silicate, however, the CBR values increased at least by 14% compared to untreated soil. These results largely deviate for what is obtained 2.5% of sodium silicate by dry weight of the soil. Therefore, further investigations are recommended.

  - For seven days of curing, results also show that there is a slight increase in CBR values associated with applying 1% of sodium silicate to the given quantity of cement compared to the respective cement treatments alone values of CBR. However, CBR values decreased when the quantity of sodium silicate added to soil cement is increased to 2.5% or 6%. However, the CBR values increased at least by 14% compared to untreated soil. These results largely deviate for what is obtained 2.5% of sodium silicate by dry weight of the soil. Therefore, further investigations are recommended.

2.5 BAGASSE ASH AS A SUB-GRADE SOIL STABILIZING MATERIAL

(Meron Wubshet Dec.2014)

2.5.1 Aim of the study

The growing cost of traditional stabilizing agents and the need for the economical utilization of industrial and agricultural wastes for beneficial engineering purposes has prompted an investigation into the stabilizing potential of bagasse ash in highly expansive clay soil.

Thus, the possible use of agricultural waste, such as bagasse ash, will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such waste. Bagasse ash is an agricultural waste obtained from milling of sugarcane.

The study aimed towards evaluating some of the engineering properties of bagasse ash stabilized expansive soil. The Justifications for are:-

- ✓ Cost savings, because bagasse ash is typically by far cheaper than traditional stabilizers such as cement and lime;
- ✓ The production of traditional stabilizers, such as cement and lime, is environmental unfriendly processes;
- ✓ The extraction of substantial amounts of non-renewable natural resources for road construction creates significant damaging impacts on the local environment and its inhabitants;
- ✓ Waste management can be done economically;
- ✓ The ongoing establishment of huge sugarcane factories in the country.

Therefore, using bagasse ash for improving engineering properties of the Soils is and economical solution for Ethiopia as it is available in large.

2.5.2 Materials and Methods

i. Study Area of the Expansive Soil

The Expansive soil sample used for this research work is collected from Addis Ababa, Bole Sub City around Bole Medhanialem church at 8º 59' 38.42"N and 38º 47' 13.09"E from one test pit. The soil is grayish black in color highly plastic clay.

ii. Bagasse Ash

Waste bagasse ash was obtained from Wonji sugar factory which is located in the Eastern Ethiopia in Oromiya Regional State.

iii. Lime

The lime used in this study was purchased from the open market from authorized dealers in Diredawa.

iv. Methods

Prior to treatment and testing, the sample was prepared in accordance with the method described in AASHTO T87-86. This method involves:

2.5.3 Test Results and Discussions

The relevant engineering property of the soil is evaluated both for natural and stabilized soil samples separately. The tests include Atterberg limits, free swell, free swell index, free swell ratio, moisture density relationship (compaction) and California bearing ratio (CBR).Atterberg limits, moisture density relationship (compaction) and CBR are conducted for uncured and 7 days cured soil samples.

I. Properties of Material Used in the Study

a) Natural Soil

The results of the tests conducted for identification and/or determination of properties of the natural soil before applying bagasse ash are presented in Table 3.3.1 below. Accordingly the soil falls under the A-7-5soil class based on AASHTO soil classification system. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material.

Table 2.23: Geotechnical properties of the natural soil

Property	Quantity
Percentage passing No. 200 sieve, %	98.8
Liquid limit, %	119.5
Plastic limit, %	41.4
Plasticity index, %	78.1
AASHTO soil classification	A-7-5
Specific gravity	2.79
Free swell, %	210
Free swell index, %	163.6
Free swell ratio, %	2.64
Maximum dry density, g/cm^3	1.26
Optimum moisture content, %	32.2
Soaked CBR value, %	0.91
Unsoaked CBR value, %	15.5
CBR-swell,%	11.83
Colour	grayish black

b) Bagasse Ash

The results of chemical tests carried out on bagasse ash in Ethiopia and elsewhere indicate pozzolanicity of the bagasse ash. The combined percent composition of silica, Al2O3 and Fe2O3 is more than 70%. This is adequate to meet the requirement of ASTM C618 standard for pozzolanic materials.

II. Properties of soil-Bagass ash with different contents

a. Effect of Bagasse Ash on Atterberg limits

The plasticity of the soil is decreased by the addition of bagasse ash content. This is clearly shown by the fact that plasticity index of treated soil decreased with increasing additive quantity. These effects are due to the partial replacemen with bagasse ash which is non plastic material and flocculation and agglomeration of clay particles caused by cation exchange may be the other test results are shown in table 3.5.2 (N:B Cure have insignificant change to the uncured value)

Table 2.24 Atterberg limits with varying percentage of Bagasse Ash

Bagasse ash	LL	PL (%)	PI (%)	
(%)	(%)	(%)	0 day	7 day
0	119.55	41.38	78.12	
5	41.52	116	74.48	
	115	44.04		73.23
10	117.2	43.94	73.26	
	115.2	44.04		71.16
15	116	44.47	71.53	
	113.1	46.43		66.67
20	112	47.41	64.59	
	111	48.02		62.98
25	111	49.56	61.44	
	110	50.35		59.65
30	110	50.17	59.83	
	109	49.92		59.08
3% Lime only	94.5	59.91	34.59	
	93.5	60.37		33.13
3% Lime + 15% Bagasse Ash	96.5	64	32.5	
	96	64.43		31.57

b. Effect of Bagasse Ash on Swelling Characteristics

i. **Free Swell**

The reduction in free swell is directly proportional to the quantity of bagasse ash. The highest reduction in free swell is attained when the expansive soil is treated with 30% bagasse ash which is 50% and the untreated value was 212.5% having a reduction of 162.5%.

ii. **Free Swell Index**

From the analysis of test results the free swell index of expansive soil is 176.19% according to swell classification based on free swell index soil has high degree of expansion. As the percentage of bagasse ash increases the free swell index value decreases and decreased up to 17.86 % at 30% bagasse ash and makes the soil low expansive.

iii. **Free Swell Ratio**

From the analysis of test results the free swell ratio decreased from 2.76 to 1.2 with increased bagasse ash from 0% to 30%. According to the free swell classification the native soil is considered as high swelling soil and soil with 30% bagasse ash is soil low expansive.

c. Effect of Bagasse Ash on Specific Gravity

The effect of bagasse ash on the specific gravity of the expansive soil make it decreased from 2.79 to 2.39 with increased bagasse ash content from 0% to 30% in which The reduction in specific gravity is directly proportional to the quantity of bagasse ash.

d. Effect of Bagasse Ash on Compaction Characteristics

The maximum dry density decreases from 1.26g/cm3 to 0.999g/cm3 for uncured and to 0.918g/cm3 for 7 days cured soil samples with increased bagasse ash content from 0% to 30%.The optimum moisture content increases from 32.24% to 51.12% for uncured and 32.24% to 53.78% for 7 days cured soil samples with increased bagasse ash content from 0% to 30%.

e. Effect of Bagasse Ash on CBR and CBR-Swell

1. CBR

When treating the expansive soil at 30% bagasse ash content the uncured soil bagasse sample gives a peak CBR value of 2.91% while that of 7 days cured CBR value is 2.94% from a value of 0.91% for the natural soil. The CBR of the expansive soil increased with all higher bagasse ash contents but the increment is insignificant. The optimum CBR value of soil treated with bagasse ash is almost 220% and 223% higher than the untreated soil sample for uncured and 7 days cured samples respectively

2. CBR-Swell

When treating the expansive soil at 30% bagasse ash content the uncured soil-bagasse sample gives CBR-swell of 3.05% while that of 7 days cured CBR-swell is 2.63% from a value of 11.83% for the natural soil. The CBR-swell of the expansive soil decreased with all higher bagasse ash contents. This shows that the swelling potential of the sample decreased with bagasse ash stabilization.

2.5.4 Effect of Lime on Bagasse Ash Treated Soil, Another perspective

2.5.4.1 Introduction

The reason why the soil-bagasse ash mixture is not a successful soil stabilizer could be explained by chemistry. The pozzolanic reactions are dependent on both access to water, pozzolanic material and the content of calcium ions, and this is simply there is no enough calcium in bagasse ash. This shows that acertain amount of calcium from cement or lime is necessary. The amount of bagasse ash that is going to be mixed with lime was determined according to Texas Department of Transportation manual. The ratio of lime to fly ash that will yield the best engineering property is determined by using lime to fly ash ratios of 1:3, 1:4 and 1:5. According to Texas Department of Transportation manual typical proportions for the fly ash lime blends are 2% to 8% lime blended with 10% to 15% fly ash.(Veisi, M., et al., 2010).

2.5.4.2 Test Results and Discussion

i. Atterberg Limits

When black cotton soil treated with 3% lime the plasticity index decreased from a natural soil value of 78.1% to 34.6% for uncured sample and to 33.1% for 7 days cured sample .While with the addition of 15% bagasse ash only the plasticity index decreased from a natural soil value of 78.1% to 71.5% for uncured samples and to 66.7% for 7 days cured soil samples. For a similar class soil, the plasticity index decreased from a natural soil value of 78.1% to 32.5% without curing and to 31.6%with 7 days cured samples for the addition of 3% lime in combination with/plus 15% bagasse ash.

ii. Compaction Characteristics

a) **Maximum Dry Density:**The effects of bagasse ash on the maximum dry density of the soil-lime, soil-bagasse ash and soil-lime-bagasse ash mixtures are for uncured soil sample maximum dry density decreases for all mixes from a natural soil value of 1.26g/cm3 to 1.23g/cm3,1.15g/cm3 and 0.98g/cm3 with the addition of 3% lime, 15% bagasse ash and 3% lime plus 15% bagasse ash respectively. For 7 days cured soil sample maximum dry density decrease for all mixes from a natural soil value of 1.26g/cm3 to 1.14g/cm3, 1.05g/cm3 and 0.95g/cm3 with the addition of 3% lime, 15% bagasse ash and 3% lime plus 15% bagasse ash respectively The addition of lime and bagasse ash together led to a more decrease of the maximum dry density compared to the addition of lime and bagasse ash separately.

b) **Optimum Moisture Content (OMC**): The addition of lime and bagasse ash together led to a more increase of the optimum moisture content compared to the addition of lime and bagasse ash separately. For 7 days cured soil sample optimum moisture content increase for all mixes from a natural soil value of 32.2% to 46.9%, 50.2% and 53.1% with the addition of 3% lime 15% bagasse ash and 3% lime plus 15% bagasse ash respectively . The addition of lime and bagasse ash together led to a more increase of the optimum moisture content compared to the addition of lime and bagasse ash separately.

iii. CBR and CBR-swell

a) **CBR values**

Results show that generally the CBR of all treated soil increases with addition of lime, lime plus bagasse ash and bagasse ash. Results also show that curing enhances the strength development of expansive soil treated with lime and lime plus bagasse ash but curing has an insignificant change when expansive soil is treated with bagasse ash only. As shown in the figure 3.4.1, the uncured CBR value increases for all mixes from a natural soil value of 0.91% to 9.73%, to 1.55% and to 22.51% with the addition of 3% lime, 15% bagasse ash and 3% lime plus 15% bagasse ash respectively. For 7 days curing period the CBR values increased from the natural soil value of 0.91% to 23.83%, to 1.78% and to 32.9% with the addition of 3% lime, 15% bagasse ash and 3% lime plus 15% bagasse ash respectively. The addition of lime and bagasse ash together led to a more increase of the CBR value compared to the addition of lime and bagasse ash separately. This shows that the load bearing capacity of the sample increased considerably with bagasse ash and lime treatment and curing has a significant effect on the CBR values. The combination of bagasse ash and lime can strongly improve the strength of expansive soils.

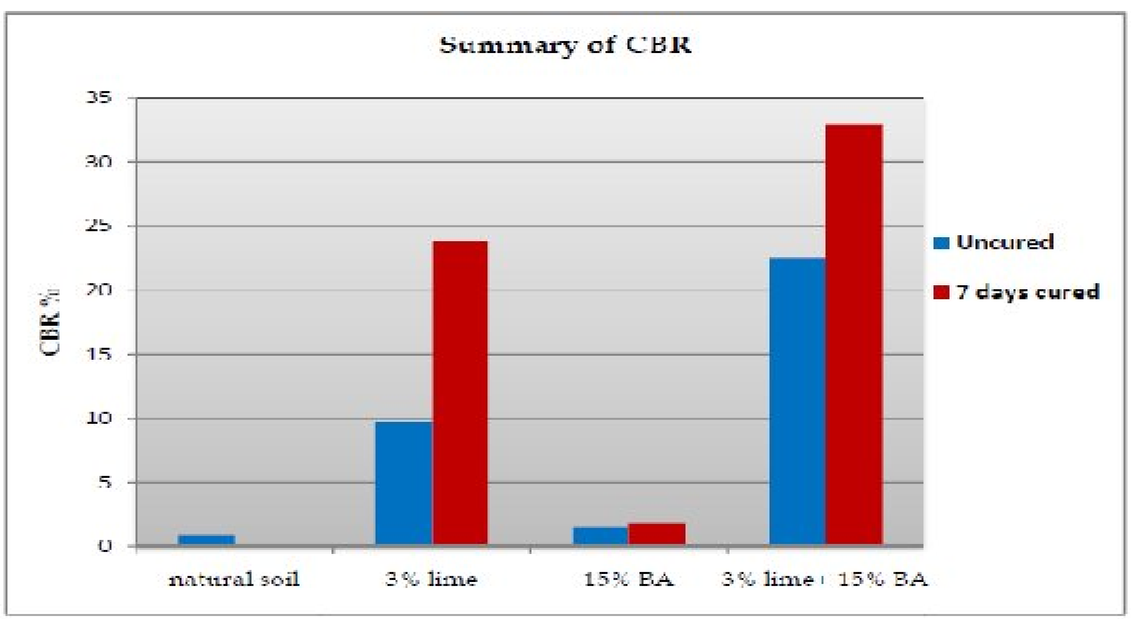

Figure 2.2: Effect of addition of bagasse ash and lime on CBR values

b) **CBR- Swell**

The uncured CBR-swell decreases for all mixes from a natural soil value of 11.83% to 6.07%, to 7.56% and to 2.15% with the addition of 3%,lime, 15% bagasse ash and 3% lime plus 15% bagasse ash respectively. For 7 days curing period the CBR-swell decreased from the natural soil value of 11.83% to 0.95% to 6.78% and to 0.26% with the addition of 3% lime, 15% bagassse ash and 3% lime plus 15% bagasse ash respectively. This shows that the swelling capacity of the expansive soil decreased considerably with bagasse ash and lime treatment and curing has also a significant effect on the CBR-swell values.

2.6 EVALUATION OF THE STABILIZATION TECHNIQUES

2.6.1 Introduction

This section of the study bases on the thesis revised in chapter three but it is the evaluative them on their laboratory results found with respect to native soil on the aim of the stabilization either to be used as a foundation mterial, subgrade materials and sub-bas material.

The following points are considered here in the critical reviewing. These are:-

- ✓ How? And by how much? Is the engineering property of these expansive soils that is their free swell and swelling potential is handled.
- ✓ Was the finding of the research indicative or definitive for filed applications?
- ✓ The importance of the stabilization technique and its practice in the Ethiopian context?
- ✓ Was the stabilization technique generally effective?

2.6.2 Evaluative Reviewing

2.6.2.1 Stabilization of expansive clay soil with sugar cane molasses and cement

(Bizualem Taye May. 2015)

The optimum stabilization amount is combination mixtures of 4% molasses and 4% cement by dry weight with the native soil was used. Laboratory results of the native soil and the stabilized soil are shown in Table 2.25 and

Table 2.26 below. Study Area was (Modjo – Ejere – Arerti – Sembo Road Project).

Table 2.25 Native Soil Properties

Item No	Sample location	Property	Quantity
1	Test Pit # 1,2,3	**AASHTO Soil Classification** Grain Size Distribution (20% sand, 25% silt and 55% clay by weight)	A-7-5
2	Test Pit # 1	Liquid Limit,%	90
		Plastic Limit,%	37
		Plasticity Index,%	53
3	Test Pit # 2	Liquid Limit,%	90
		Plastic Limit,%	35
		Plasticity Index,%	55
4	Test Pit # 3	Liquid Limit,%	87
		Plastic Limit,%	36
		Plasticity Index,%	51
5	Test Pit # 1,2,3	Activity wrt the "A"	Above
6	Test Pit # 1,2,3	PH	8.12,8.2,8.21
6	Test Pit # 1,2,3	specific gravity	Ranged from 2.54 to 2.66
7	Test Pit # 1,2,3	Free swell,%	110,120,110
10	Test Pit # 1	Maximum dry density, g/cm3 & Optimum moisture content,%	1.48 , 26.9
	Test Pit # 2		1.5 ,28.8
	Test Pit # 3		1.51 ,26.9
11	Test Pit # 1,2,3	Soaked CBR value ,%	<1
12	Test Pit # 1,2,3	CBR-Swell,%	9.3,11.6,10.4
13	Test Pit # 1,2,3	UCS value(KN/M2)	140,138.8,135.8

14	Test Pit # 1,2,3	Linear Shrinkage %	20.7,20.7,20.4
15	Test Pit # 1,2,3	colour	Black

Table 2.26 Soil-Cement & molasses Stabilization

Item No	Sample location	Property	Quantity	Remark
1		Cement In %	4	Soil, Cement & Molasses Stabilization is done at 95% MMD of remolded soil sample and cure for 7 days.
		Molasses in %	4	
2	sample soil	Liquid Limit,%	48	
		Plastic Limit,%	29	
		Plasticity Index,%	19	
3	sample soil	PH	12.75	
4	sample soil	Maximum dry density g/cm3	1.51	
5	sample soil	Optimum moisture content,%	25.1	
6	sample soil	Average Soaked CBR value ,%	63.5	
7	sample soil	CBR-Swell,%	0.7	
8	sample soil	UCS value(KN/M2)	248	
9	sample soil	Linear Shrinkage %	10	

Therefore this stabilization Technique 4% molasses plus 4% cement with respect to the native soil was aimed to used as sub-grade material:

- ✓ The expansiveness of the native soil was improved in such a way as: PI reduces from 53% to 19%, CBR swell reduces from 10.4% to 0.7%, Soaked CBR value increased from a value less than 1% to 63.5% and the unconfined compressive strength value increase from a value of 138 KN/M2 to 999KN/M2 we can say that the poor engineering properties of the soil have improved/handled.

- ✓ As the study area of this research covers road segment from Modjo to Ejere (km 0+000 to km 35+000) the research finding can be said definitive.
- ✓ A the growing industry of sugar factors have an increased molasses residue which have a negative impact to the surrounding environment and it have positive result on soil stabilization .The use of the stabilization technique have dual importance and significance in the Ethiopian context .

Generally the stabilization technique of using molasses in combination with cement is effective.

2.6.2.2 STABILIZATION OF EXPANSIVE CLAY SOIL WITH LIME

(Reshide Musema Nov. 2014)

The optimum amount of stabilization is 12% Lime by dry weight with the native soil mixture was used is it is the highest amount of lime in the test conducted used and is the one giving the better results. Laboratory results of the native soil and the stabilized soil are shown in Table 2.27 and Table 2.28 below. The Study Area was Adura-Burbey Road project, Gambella.

Table 2.27: Native Soil Properties

Item No	Sample location	Property	Quantity
1	Test Pit # 1 @Sta. 32+700	AASHTO Soil Classification Grain Size Distribution	A-7-5
	Test Pit # 2@ Blended soil		A-7-6
2	Test Pit # 1 @Sta. 32+700	Liquid Limit,%	64.14
		Plastic Limit,%	31.03
		Plasticity Index,%	33.11
	Test Pit # 2@ Blended soil	Liquid Limit,%	56.6
		Plastic Limit,%	27.28
		Plasticity Index,%	29.32
3	Test Pit # 1 @Sta. 32+700	Linear Shrinkage (%)	22.1

	Test Pit # 2@ Blended soil	Linear Shrinkage (%)	24.9
4	Test Pit # 1 @Sta. 32+700	specific gravity	2.484
	Test Pit # 2@ Blended soil	specific gravity	2.387
5	Test Pit # 1 @Sta. 32+700	Maximum dry density/cm3	1.51
	Test Pit # 1 @Sta. 32+700	Optimum moisture content,%	25
6	Test Pit # 1 @Sta. 32+700	Free Swell %	70
	Test Pit # 2@ Blended soil	Free Swell %	70
7	Test Pit # 1 @Sta. 32+700	Soaked CBR value ,%	2.04
8	Test Pit # 1 @Sta. 32+700	CBR-Swell,%	3.11
9	Test Pit # 1 @Sta. 32+700	UCS value(KN/M2)(immediate)	not Shown
	Test Pit # 2@ Blended soil	UCS value(KN/M2)(7 day cure)	not Shown
11	Test Pit # 1 @Sta. 32+700 & Test Pit # 2@ Blended soil	colour	Black

Table 2.28: Soil -lime stabilized Properties

Item No	Sample location	Property	Quantity
1		Lime in %	12
2	Test Pit # 1 @Sta. 32+700	AASHTO Soil Classification Grain Size Distribution	
	Test Pit # 2@ Blended soil		
3	Test Pit # 1 @Sta. 32+700	Liquid Limit,%	44.66
		Plastic Limit,%	30.56
		Plasticity Index,%	15.1
	Test Pit # 2@ Blended soil	Liquid Limit,%	41
		Plastic Limit,%	26
		Plasticity Index,%	15

4	Test Pit # 1 @Sta. 32+700	Linear Shrinkage (%)	16
	Test Pit # 2@ Blended soil	Linear Shrinkage (%)	17.1
5	Test Pit # 1 @Sta. 32+700	specific gravity	2.647
	Test Pit # 2@ Blended soil	specific gravity	2.662
6	Test Pit # 1 @Sta. 32+700	Maximum dry density/cm3	1.46
	Test Pit # 1 @Sta. 32+700	Optimum moisture content,%	29.3
7	Test Pit # 1 @Sta. 32+700	Free Swell %	25
	Test Pit # 2@ Blended soil	Free Swell %	10
8	Test Pit # 1 @Sta. 32+700	Soaked CBR value ,%(@95%MMD)	8.92
9	Test Pit # 1 @Sta. 32+700	CBR-Swell,%	1.73
10	Test Pit # 1 @Sta. 32+700	UCS value(KN/M2)(immediate)	254.03
11	Test Pit # 2@ Blended soil	UCS value(KN/M2)(7 day cure)	791.73

Therefore this stabilization Technique 12% Lime addition by dry weight respect to the native soil was aimed to used as sub-grade material:

- ✓ The expansiveness of the native soil (Taking Sta@32+700) was improved in such a way as: PI reduces from 33.11% to 15.1%, CBR swell reduces from 3.114% to 1.73%, Soaked CBR value increased from a value 2.04% to 8.925%. The unconfined compressive strength value has increased Hence, the poor engineering properties of the soil have improved yet it can't be said it is fully handled because The CBR is in the range of 7-20(fair) to be used as a sub-grade material. Yet, one of the required specifications in the project desgin for subgrade borrow material with CBR value greater is 8% .So this can imply that the stabilized soil can totally avoids the use of improved subgrade borrow material.

- ✓ As the study area of this research covers road segment from Adura-Burbey (km 0+000 to km 41+000.00) the research finding can be said definitive.
- ✓ Hauling of borrow a material and blanketing thicker materials which incur huge cost to the project (The cost benefit to be determined on bases of the project) and so this use of this stabilization technique has significance importance in the Ethiopian context.

Generally, the stabilization technique of using Lime with the native soil in this case this project is effective.

2.6.2.3 CHEMICAL TREATMENT OF "BLOCK COTTON" SOIL TO MAKE IT USABLE AS A FOUNDATION MATERIAL

(Aksum Tesfaye oct.2001)

In here the chemicals Lime and cement are used independently to stabilize the soil. Hence, the optimum amount of stabilization is 6% for Lime by dry weight with the native soil and 12% for cement by dry weight of the sample are used. They are the optimum amounts to stabilizer the soil to used as a foundation material. Laboratory results of the native soil and the stabilized soil are shown in Table 2.29, Table 2.30 and Table 2.31 below. The Study Areas are ten different areas in Addis Ababa out of which sample four was taken to representative.

Table 2.29 : Native Soil Properties

Item No	Sample location	Property	Quantity
1	Sample S_4	**ASTM Soil Classification** Grain Size Distribution	Inorganic clay of High Plasticity
2	Sample S_4	Liquid Limit,%	97
		Plastic Limit,%	38
		Plasticity Index,%	59
3	Sample S_4	specific gravity Gs	2.64
4	Sample S_4	Maximum dry density,g/cm3	1.3

5	Sample S_4	Optimum moisture content,%	28
6	Sample S_4	Free swell,%	110
7	Sample S_4	Swelling Presure,KN/M2	455
8	Sample S_4	colour	Dark Black

Table 2.30 : Soil-Lime Stabilization

Item No	Sample location	Property	Quantity	Remark
1		Lime Content %	6	Lime content 6% is selected from all the Lime content used is because it is the minimum that gives the required properties. That is the moderate range.
2	Sample S_4	Liquid Limit,%	81	
		Plastic Limit,%	55	
		Plasticity Index,%	26	
3	Sample S_4	specific gravity Gs	2.62	
4		Maximum dry density/cm3	1.22	
5		Optimum moisture content,%	32	
6	Sample S_4	Free swell,%	52	
7	Sample S_4	Swelling Pressure, KN/M2	300	

Table 2.31 : Soil-Cement Stabilization

Item No	Sample location	Property	Quantity	Remark
1		Cement Content %	12	Cement content 12% is selected from all the cement content used is because it is the minimum that gives the required properties. That is the moderate range.
2	Sample S_4	Liquid Limit,%	81	
		Plastic Limit,%	51.3	
		Plasticity Index,%	33.7	
3	Sample S_4	specific gravity Gs	2.62	
4		Maximum dry density/cm3	1.23	
5		Optimum moisture content,%	36	
6	Sample S_4	Free swell,%	51	

7	Sample S_4	Swelling Pressure, KN/M2	295	

Therefore this stabilization Technique 6% Lime addition by dry weight and 12% cement by dry weight of the native soil was aimed to used as a foundation materials is criticized as .:

- ✓ The expansiveness of the native soil (Taking Sample 4) was improved in such a way as: PI reduces from 59% to 26%, free swell decreased from 110% to 51%, swelling pressure of 455 KN/M2 to 300KN/m2 implying from a very high expansive soil to a moderate expansive soil. Hence, the poor engineering properties of the soil have improved.
- ✓ Though the study area of this research covers ten sample from different area of Addis Ababa the finding can't be said definitive rather it is indicative.
- ✓ Replacing the expansive soil by a non expansive to avoid the negative impact of the heaving and contraction due water may incur huge cost to the project (The cost benefit to be determined on bases of the project) and so the use of this stabilization technique has significance importance in the Ethiopian context.

Generally, the stabilization technique of using Lime and cement independently with the native soil for use as a foundation material is effective.

2.6.2.4 EVALUATION OF SODIUM SILICAT AND ITS COMBINATION WITH CEMENT/LIME FOR SOIL STABILIZATION

(Ehitabezahu Nigussie)

In here the Expansive clay was treated with lime, sodium silicate and combination of the two additives for sub-grade materiel use and Clayey sand was treated with cement, sodium silicate and combination of the two additives for sub-base materiel uses are both stabilized with different combination and with variation in curing duration. Table 2.32, Table 2.33 and Table 2.34.

Table 2.32 : Native Soil Properties

Item No	Sample location	Property	Quantity
1	Sample S1	ASTM Soil Classification	Inorganic Fat Clay
		AASHTO soil classification	A-7-6(41)
2	Sample S2	ASTM Soil Classification	Clayey Sand with gravel(SC)
		AASHTO soil classification	A-2-6
3	Sample S1	Liquid Limit,%	130
		Plastic Limit,%	38
		Plasticity Index,%	92
4	Sample S2	Liquid Limit,%	38
		Plastic Limit,%	22
		Plasticity Index,%	16
5	Sample S1,S2	Maximum dry density/cm3	1.27,1.88
6	SampleS1, S2	Optimum moisture content,%	37.2,12.5
7	Sample S1	Free swell,%	115
9	Sample S1	colour	Black

Table 2.33 :Expansive Clay Soil with Lime/Sodium Silicate Properties

Item No	Sample location	Property	Quantity
1		Lime %	Variable
		Sodium Silicate %	Variable
2	Sample S1	ASTM Soil Classification	The minimum PI=30 was found for Lime 4% and Sodium silicate 1% and 28 days of curing
3	Sample S1	Liquid Limit,%	
		Plastic Limit,%	
		Plasticity Index,%	

4	Sample S1	Maximum dry density/cm3 ,Optimum moisture content,%	The curves found are odd due this a definite MDD and OMC could not be determined.
5	Sample S1		
	Sample S2	CBR %	a value of 47.5 is at L6SS1and 7 day curing
6		CBR swell,%	0% at L6SS1 and seven day of curing

Table 2.34 : Clayey sand -Cement/Sodium Silicate properties

Item No	Sample location	Property	Quantity
1	Sample S2	Cement %	Variable
2	Sample S2	Sodium Silicate %	Variable
3	Sample S2	ASTM Soil Classification	
		Liquid Limit,%	non-plastic
		Plastic Limit,%	non-plastic
		Plasticity Index,%	non-plastic
4	Sample S2	Maximum dry density/cm3 ,Optimum moisture content,%	the min.dry density is observed at C5SS2.5 ,MDD=1.76 at OMC=16
5	Sample S2	CBR %	CBR value showed increased value with the addition of cement and sodium silicate with proportions yet the values are inconsistent to curing periods of 3 and 7 days.

Table 2.35 : Clayey sand -Cement/ 1% Sodium Silicate properties

Item No	Sample location	Property	Quantity
1	Sample S2	Cement %	Variable
2	Sample S2	Sodium Silicate %	1
3	Sample S2	ASTM Soil Classification	
		Liquid Limit,%	non-plastic
		Plastic Limit,%	non-plastic
		Plasticity Index,%	non-plastic
4	Sample S2	Maximum dry density/cm3 ,Optimum moisture content,%	MDD ranges between 1.84 to 1.86 and OMC ranges 13.1 to 14.5 for cement contents 3%,5%,7%
5	Sample S2	CBR % for 7 day of curing(for 3 day no CBR values change than cement alone)	CBR value showed increased value more than 216.5 this value is 3% cement alone. The maximum increment in the value is 4.95% than that of cement alone

Three cases to consider: they are as follows:

1. **The Expansive soil treated with lime and sodium silicate (**Table 2.33): Since sodium silicate alone has an agglomeration effect on expansive soils and when with combination of lime there is no definite curve to show MDD verses OMC. Also there is inconsistent continuity of data over the curing durations. Sodium silicate is not suitable additive for stabilizing expansive soil with or along with lime for use of subgrade stabilization material.

Hence it is ineffective.

2. **Clayey Sand treated with cement and sodium silicate** (Table 2.34): this stabilization Technique with different cement percent and different

sodium silicates addition by dry weight and different curing period. It was aimed was aimed to used as a sub-base materials.

As can be seen in the Tables above , the addition of Sodium silicate with cement has brought improvements to the clayey sand soil but due the reasons that a definite relationship couldn't be determined for this and also the Researcher have pointed out that further investigations are recommended.

3. **Consideration of Table 2.33 for a specific case of applying 1% sodium silicate**: by dry weight of the soil in concert with ordinary Portland cement has positive and encouraging implications on strength development of soil-cement.

   - ✓ CBR value showed increased value more than 216.5 (this value is for 3% cement alone). The maximum increment in the value CBR by the addition of sodium silicate is 4.95% than that of cement alone.
   - ✓ Findings can't be said definitive rather it is indicative.

Generally, the stabilization technique of using Sodium silicate with cement has positive and encouraging results with the native soil for use as a sub base material is ineffective.

2.6.2.5 BAGASSE ASH AS A SUB-GRADE SOIL STABILIZING MATERIAL

(Meron Wubshet DEC.2014)

In here the Expansive clay was treated with Bagass ash only and then Bagass ash combination with lime. The optimum amount of stabilization used is 30% for bagass ash only and 3% Lime plus 15% bagass ash are used by dry weight of the native soil. They are the optimum amounts to stabilizer the soil for use as a sub-grade material. Laboratory results of the native soil and the stabilized soil are shown in Table 2.36, Table 2.37 and Table 2.38 below. Study Area is Addis Ababa, Bole Sub City around Bole Medhanialem church.

Table 2.36 Native Soil Properties

Item No	Property	Quantity
1	Percentage Passing No.200 Sieve ,%	98.8
2	Liquid Limit,%	119.5
3	Plastic Limit,%	41.4
4	Plasticity Index,%	78.1
5	AASHTO Soil Classification	A-7-5
6	specific gravity	2.79
7	Free swell,%	210
8	Free swell index,%	163.6
9	Free swell Ratio,%	2.64
10	Maximum dry density/cm3	1.26
11	Optimum moisture content,%	32.2
12	Soaked CBR value ,%	0.91
13	Unsoaked CBR value,%	15.5
14	CBR-Swell,%	11.83
15	colour	Grayish black

Table 2.37 Soil-Bagass ash only stabilization

Item No	Property	Quantity	Remark
1	Bagass ash amount in %	30	30% bagass Ash is considered due the treason that the general property of the soil get improved as the Bagass ash addition increases.
2	Liquid Limit,%	109	
3	Plastic Limit,%	49.92	
4	Plasticity Index,%	59.08	
5	specific gravity	2.39	
6	Free swell,%	50	

7	Free swell index,%	17.86	
8	Free swell Ratio,%	1.2	
9	Maximum dry density/cm3	0.918	
10	Optimum moisture content,%	53.78	
11	Soaked CBR value ,%	2.91	
12	Unsoaked CBR value,%	2.94	
13	CBR-Swell,% for uncured	3.05	
14	CBR-Swell,% for 7 days curing	2.63	

Table 2.38 Soil-Bagass - ash & Lime stabilization

Item No	Property	Quantity	Remark
1	Bagass ash amount in %	15	Researches done around Bole area indicate that the optimum lime content required is 3% with 15% Bagass ash.
2	Lime amount in %	3	
3	Liquid Limit,%	96.5	
4	Plastic Limit,%	64	
5	Plasticity Index,% uncured	32.5	
6	Plasticity Index,% 7 days cured	31.6	
7	Maximum dry density g/cm3	0.95	
8	Optimum moisture content,%	53.1	
9	Soaked CBR value ,%	32.9	
10	Unsoaked CBR value,%	22.51	
11	CBR-Swell,% for uncured	3	
12	CBR-Swell,% for 7 days curing	0.26	

Two cases to consider: are as follows:

1. The Expansive soil was stabilized with bagass ash only: the highest amount of use of Bagass ash, 30% addition by dry weight of the native soil was aimed to use as a sub-grade material.
    - ✓ The expansiveness of the native soil was improved in such a way as: PI reduces from 78.1% to 59.08%, free swell decreased from 210% to 50%, free swell index from 163.6% to 17.86%, free swell ration 2.64% to 1.2%, CBR swell 11.83% to 3.05% and soaked CBR increases from 0.915% to 2.91%. Here, the poor engineering properties of the soil have improved is because due to the pozzolanic reactions of bagasse ash with soil. But the quality of the CBR has not changed from being very poor.
    - ✓ The decrease in CBR swell of expansive soil by the Bagasse ash is due to cation exchange and flocculation and agglomeration of the soil particles.
    - ✓ The study area of this research covers one sample from Addis Ababa the finding can't be said definitive rather it is indicative.

Generally, the stabilization technique of using bagass ash only with the native soil for use as a sub-grade material is ineffective.

2 The Expansive soil was stabilized with 15% bagass ash plus 3% lime: soil was stabilized with this combination bagass ash and lime addition by dry weight of the native soil was aimed to use as a sub-grade material.

- ✓ The expansiveness of the native soil was improved in such a way as: PI reduces from 78.1% to 32.08%, CBR swell reduced 11.83% to 3.0% for uncured and 0.7% for 7 days cures, and soaked CBR increases from 0.915% to 32.91%. Here, the poor engineering properties of the soil have improved. Plus the quality of the CBR has changed from being very poor to good sub –grade material.
- ✓ The study area of this research covers one sample from Addis Ababa the finding is indicative.

Generally, the stabilization technique of using 15% bagass ash plus 3% lime the native soil for use as a sub-grade material is effective.

CHAPER THREE

CRITICAL EVALUATION OF THE DIFFERENT STABILIZATIONS

The critical evaluation of the different stabilizations will be done in a consideration of the common naming, the expansive soils having different soil properties and the common stabilizing agents for the different techniques covered. For which the stabilizing agents are lime and cement.

So, to avoid the effect of the different soil parameters or properties a property ratio of the old and new is presented by equation (3.1).

$$\textbf{Property Ratio} = \frac{\textbf{Old property - New property}}{\textbf{Old property}} \qquad \text{.............. Equation (3.1)}$$

Where Old property is the native soil property and

New property is the stabilized soil property

3.1 Lime Stabilization

The following expansive soils samples have been taking from different study area with different lime proportions by dry weight of the native soil. These are:

i. Sample 1

Representative expansive soil from Addis Ababa city/Aksum T. /

Table 3.1 Native and Soil-Lime stabilized soil laboratory test results, sample1

Lime in %	Plastic Index in %	Free swell in %	Swelling Pressure KN/M2
0	59	110	455
2	55	100	410
4	37	65.2	350
6	26	52	300
8	16	33.3	240
10	10	26	240

ii. Sample 2

Representative expansive soil from Addis Ababa city/Ehiabezahu N. /

Table 3.2 Native and Soil-Lime stabilized soil laboratory test results, Sample 2.

Lime	Plastic index PI	Free swell	MDD	CBR VALUE	CBR Swell
In %	In %	In %	gm/cm³	In %	In %
0	92	115	1.27	2.0	7.8
2	52	105	1.23	6.0	7.4
4	40	74	1.225	22.85	0.5
6	26	58	1.22	42.19	0

iii. Sample 3

Expansive soil from Adura-Burbey Road project, Gambella/ Reshid M. /

Table 3.3 Native and Soil-Lime stabilized soil laboratory test results, Sample 3.

Lime In %	Plastic index PI In %	Linear shrinkage In %	Free swell In %	MDD gm/cm³	CBR VALUE In %	CBR Swell In %	UCS Values KN/M3
0	33.11	221	70	1.51	2.04	3.11	NOT SHOWN
2	32.9	21.4	60	1.51	1.7	3.08	296.21
4	32.19	20.7	45	1.49	2.6	2.92	374.41
6	29.8	20.1	40	1.48	3.3	2.62	484.59
8	25.67	18	35	1.48	4.5	2.13	606.47
10	21.67	17	30	1.47	5.9	1.97	696.66
12	15.1	16	25	1.46	8.92	1.73	791.73

From the Tables 3.1,Table 3.2,Table 3.3 the plasticity index and the free swell are the common soil properties .so their property ration are presented by the graphs as follows.

Fig. 3.1: PI Ratio verses the Lime content of the samples1, 2 and 3

Fig. 3.2: Free Swell Ratio verses the Lime content of the samples1, 2 and 3

Fig 3.3: CBR Swell Ratio verses the Lime content of the samples 2 and 3

From the above the three figers, fig.3.1,3.2,and 3.3 as the lime content increase the PI ratio, Free swell ratio and CBR swell ratio all shows increasing ,indicating that the PI, the free swell and the CBR swell values are all decreasing in a direct proportion. In addition, in case of the free swell ratio verses the lime content it can be approximated that all the graphs do overlap one over the other meaning the testing procedures and the precision during the testing are approximated to be equal. Yet, a more different scenario is observed during the CBR swell tests of sample 1 and 2 this may arise due to the soil sample preparation and testing procedures.

3.2 Cement Stabilization

The following expansive soils samples have been taking from different study area with different cement proportions by dry weight of the native soil. These are:

i. Sample 1

Representative expansive soil from Addis Ababa city/Aksum T. /

Table 3.4 Native and Soil-cement stabilized soil laboratory test results, sample1

Cement In %	**Plastic index PI** In %	**Free swell** In %	**Swelling Pressure** KN/M2
0	67	95	440
3	61	90	400
6	56.3	75	336.8
9	43.5	67	340
12	33.7	51	295
15	29.8	46	280
18	26.99	40	275
21	25.2	34	276

ii. Sample 2

Representative expansive soil from Mojo-Ejera Road project/Bizualem T. /

Table 3.5 Native and Soil-cement stabilized soil laboratory test results, sample 2

Cement In %	**Plastic index PI** In %	**Linear shrinkage** In %	**MMD** gm/cm^3	**CBR** VALUE In %	**CBR** Swell In %	**UCS** Values KN/M3
0	53	20.1	1.5	1.3	10.4	141
4	24	7.1	1.47	27.3	0.39	235
8	20	5.7	1.49	82.3	0.36	780
12	21	4	1.5	123	0.05	877

Fig 3.6: PI Ratio verses the cement content of the samples 1 and 2

From the above fig.3.4 as the cement content increase the PI ratio shows increasing indicating that the PI values are decreasing .In addition ,it can be seen that the PI ratio gets flat beyond some 6% to 12% cement addition indicating that further addition do not have an significant impact on the PI value.

CHAPTER FOUR

CONCLUSIONS AND RECOMNDATIOS

Based on the review done on this study the following conclusions and recommendations may be drawn.

4.1 CONCLUSION

Within the scope of the study the following conclusions can be drawn out:

1. The increase in the lime addition to the expansive soils and the decrease in the PI, the free swell and the CBR swell is directly proportional.
2. The PI ratio gets flat beyond some 6% to 12% cement addition indicating that further addition does not have a significant impact on the PI values.
3. Expansive Soil treated with cement and molasses combination gave a significant improvement in strength than when cement and molasses alone and meaningfully reduced swelling property of the expansive soil. And also they were effective in arresting linear shrinkages and eliminated shrinkage cracks that were observed in soil treated with cement alone. Hence the geotechnical property of the expansive soil is improved.
4. Expansive Soil treated with the addition of lime alone gave a reduction of the free swell, reduction in plasticity limit; improve the CBR value, increase of the unconfined compressive strength. Having the optimum lime content being the highs amount (the cost of lime consideration) the geotechnical property of the expansive soil is improved.
5. While treating expansive soil, the addition of bagasse ash in combination with lime improved the CBR value, and plasticity index decreased significantly than when Bagass ash alon. Hence the geotechnical property of the expansive soil is improved.
6. Treating expansive soil using Sodium silicate as chemical stabilization, it has an inhibiting effect on strength development of clayey sand soil-cement mixture when its quantity is increased to and beyond 2.5% by dry weight of the soil. But Applying lower amount like 1% sodium silicate by dry weight of the soil in concert with ordinary Portland cement is used it has positive implications on strength development .

In addition, using Sodium silicate as chemical stabilization with or without lime is not a suitable additive for montmorillonitic clay (expansive soil) stabilization.

4.2 RECOMENDTION

1. As the researches are done in the laboratory their actual performance on the field shall be studied.

2. Awareness needs be raised about construction practices of chemical stabilization in Ethiopia and testing procedures need to be standardized

3. Investigation on, before the use sugar cane molasses composition of sugar factories in different part of the country shall be done.

4. As stabilization of expansive soil with cement and molasses mixture is a relatively new concept and are scanty in the literature, chemical interactions and mechanisms involved in cement, sugar cane molasses, water and expansive clay soil shall be studied

5. Combination of bagasse ash and lime can strongly improve the strength of the expansive soil can be used as a good subgrade material. So, combining two local materials (bagasse ash and lime) can effectively improve the poor geotechnical properties of this soil and help in increasing land resources availability for construction projects and reduce the amount of lime needed for the stabilization purpose.

6. Sugarcane bagasse ash as was reviewed can be used as a soil stabilizing material in combination with lime with economical and environmental benefits. Therefore concerned bodies like sugar industries and government entities should be made aware about this potential soil stabilizing material and promote its standardized production and usage.

7. Further study the use of bagasse ash as a soil stabilizing material on different types of soils.

Last but not least is this review shall have a continues scenario so that students, researches and anyone interested on could easily get accessible.

REFERENCE

1. *Bizualem T.(May. 2015) Stabilization of expansive clay soil with sugar cane molasses and cement*
2. *Reshide M. (Nov. 2014) stabilization of expansive clay soil with Lime*
3. *Axsum T.(Oct. 2001) Chemical treatment of "Black cotton "soil to make it usable as a foundation material*
4. *Ehitabezahu N.(Oct. 2011) Evaluation of Sodium Silicate and its Combination with Cement/Lime for Soil Stabilization*
5. *Meron W.(Dec.2014) Bagasse ash as a Sub-grade soil Stabilizing Material*
6. *AASHTO (2001). American Association of State Highways and Transport Officials. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. Part 1-Specification.Tewenty First Edition. Washington, D.C.*
7. *AASHTO (2001). American Association of State Highways and Transport Officials. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. Part 2-Tests.Tewenty First Edition. Washington, D.C.*
8. *AASHTO (2008). American Association of State Highways and Transport Officials. Standard Recommended Practice for Stabilization of Sub-grade Soils and Base Materials. Washington, D.C.20001*
9. *ASTM (2003). American Society for Testing and Materials. Annual of Book of ASTM Standards. Volume 04.08. Soil and Rock (I): D 420-D-5611.100 Barr Harbor Drive. West Conshohocken, PA 19428-2959.*
10. *Chen, F.H. (1988) Foundations on Expansive Soils. Chen and Associates: 96 South Zuni, Denver, CO80223, U.S.A.*
11. *Dalls, N. and Nair, S. (2009) Recommended Practice for Stabilization of Subgrade Soils and Base Materials. NCHP, Texas Transportation Institute and Texas A&M University, Texas.*
12. *ERA (2013).Ethiopian Roads Authority. Pavement Design Manual. Volume I-Flexible Pavements. Addis Ababa, Ethiopia.*

13. *ERA (2002). Ethiopian Roads Authority. Site Investigation Manual. Addis Ababa, Ethiopia.*

14. *ERA (2011).Ethiopian Roads Authority, (January, 2011). Road Sector Development Program (RSDP) 13 years Performance and Phase IV. Addis Ababa, Ethiopia.*

15. *ERA (2013).Ethiopian Roads Authority. Site Investigation Manual. Addis Ababa, Ethiopia.*

16. *Nelson, J.D. and Miller, D.J. (1992). Expansive Soils: Problems and Practice in Foundation and Pavement Engineering. John Wile & Sons, INC. New York.*

17. *Amer Ali Al-Rawas and Mattheus, F.A. (2006). Expansive Soils recent advances in characterization and treatment. Taylor & Francis Group, London, UK.*

18. *Fransiscus S. Hardianto and Wayne A. Ericson (1994). Stabilization of phosphatic clay using Lime Column. Bromwell & Carrier, Inc.#02-088-102*

19. *Muni Budhu (2007).Soil Mechanics and Foundations. John Wiley &Sons.Inc*

20. *NG. Pulling, (2005). Determination of optimum concentration of lime solution for soil stabilization, Master s Thesis: University Technology: Malaysia*

21. *Terzaghi, K. and Peak R.B., Soil Mechanics in Engineering Practice, 2nd Edition, Wiley Inc., New York, 1967.*

22. *Terzaghi, K., Peak R.B. and Mesri, G., Soil Mechanics in Engineering Practice, 3rd Edition, John Wiley and Sons Inc., New York, 1996.*

23. *US Army Corps of Engineering (1984). Soil stabilization for Pavements, Washington DC, EM 1110-3-137*

24. *Department of the Army, the Navy and the air Force, (October, 1994). Soil Stabilization for Pavements.TM 5-822-14/AF Jman 32-1019, Washington DC*

25. *Bowles, J., "Engineering properties of soil and their measurements," McGraw-Hill Boston, 4th edition, 1992*