STABILIZATION OF LATERITE FOR BASE COURSE CONSTRUCTION

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By

Kedamawit Girmay Berhane

Advisor

ENG. EFREM G/EGZIABHER

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KEDAMAWIT GIRMAY BERHANE

May, 2017

Approved by Board of Examiners

Efrem G/Egziabher	[signature]	12/05/17
Advisor	Signature	Date
Samuel Tadesse (Dr)	[signature]	16/05/17
External Examiner	Signature	Date
Henok Fikre	[signature]	16/05/17
Internal Examiner	Signature	Date
Chairman	Signature	Date

Dr. Agizew Nigussie
Dean, School of Civil &
Environmental Engineering

Director of Postgraduate Program
Addis Ababa University
Addis Ababa Institute of Technology

DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Eng. Efrem Gebre-Egziabher and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

Kedamawit Girmay		May, 2017
Name	Signature	Date

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Acronyms/Abbreviations

AAS	Atomic Absorption Spectroscopy
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
ERA	Ethiopian Roads Authority
HF	Hydrogen Fluoride
$LIBO_2$	Lithium Metaborate
LL	Liquid Limit
MDD	Maximum Dry Density
OBC	Optimum Binder Content
OMC	Optimum Moisture Content
PDM	Pavement Design Manual
PI	Plasticity Index
PMDM	Pavement and Materials Design Manual
SATCC	South African Transport and Communications Commission
SSD	Saturated Surface Dry
STS	Standard Technical Specification
TRL	Transport Research Laboratory
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System

ABSTRACT

The demand for different kinds of naturally occurring construction materials is increasing in areas like the road construction industry. Unfortunately, not all the natural materials along the vicinity of road projects are suitable for the proposed construction because these materials fail to fulfill the standard quality requirements. One of these materials are lateritic materials which often do not fulfill the plasticity index (PI); California Bearing Ratio (CBR) and gradation requirements of many agencies for road base material. Hence, this research was initiated with the motivation of upgrading and utilizing the laterite material, which is one of the abundantly available substandard materials in the Western part of Ethiopia.

In this research, the laterites, found along the Assosa – Kurmuk road, were sampled and stabilized so that they can be used for the construction of the base layer of all standard roads. The stabilization was done using lime and cement as two alternative stabilizers. Moreover, cost comparison were also carried out to assess the cost benefit of using stabilized laterite road base in lieu of the crushed stone road base in such areas where laterites are available in surplus quantity.

Accordingly, it was found that both lime and cement stabilized laterites can be used for road base construction. In both the lime and cement stabilization cases, the optimum binder content to meet the Joint US Army and Air Force (1994) strength and durability requirements is 10% by weight of the host material. However, the optimum binder contents to satisfy the requirements of ERA Standard Technical Specification (2013) are 4% and 6% for both lime and cement stabilized laterites, both percent by weight of the host material. The cost comparison, on the other hand, indicated that based on the current market price during the study period, only the cement stabilized laterite has cost benefit against using the crushed aggregates for the road base construction.

Key words: laterite, cement-stabilization, lime-stabilization, base course, marginal quality materials

1 INTRODUCTION

1.1 Background

Developments all over the world have awakened the sense of economical resource management. People are being inspired to go back and take a closer look at resources which have earlier been neglected, so as to find ways through which they could put such materials into better use. One of the main reasons appears to be increased competition for available materials, as multiple uses of such resources are being discovered, and the cost of acquiring these suitable materials increases simultaneously.

In Ethiopia, similar to the rest of the world, the demand for different kinds of materials is increasing in the construction of pavements in the road construction industry. These materials are either obtained from other cut sections along the road or from a borrow site where the suitable materials are found. If the materials along the road do not meet the required standard specifications or if not available in abundant quantity, hauling the borrowed material from the borrow site to the construction site is a major cost in addition to the cost of producing the materials. These costs, in terms of finance, human and material resources, and time, could however be avoided by upgrading the qualities of the substandard road materials that are available within the short hauling distance.

One of the marginal quality materials that are locally available in the Western part of Ethiopia is laterite. Laterite is a group of highly weathered soil formed by the concentration of hydrated oxides of iron and aluminium (Thagesen, 1996). Lateritic materials are found in abundance quantity along Nekempt - Bure road, Asosa – Kumruk road, Nejo – Mendi road and Mendi – Asosa road stretches (project information). A research conducted by TRL, in 2012, showed that lateritic materials have been widely in use for low volume roads in other countries. The research also indicated that laterites have natural cementing properties and low swelling potential, which are typical of residual soils. However, lateritic materials often do not fulfill the plasticity index (PI); California Bearing Ratio (CBR) and gradation requirements of many agencies for road base (base course) material; they fail as road base (base course) material. Thus, currently lateritic gravels are being used only as capping layer and sub-base layers in Ethiopia (TRL, 1993 and 2012). Nevertheless, the materials could be used for upper pavement layers such as base course and sub-base provided that their qualities are upgraded using cement or lime stabilization (TRL, 1999).

Lime and cement are common stabilizers that have been used for soil stabilization and modification in different parts of the world. (Reids and Brooks, 1999; Basha, et al, 2005; Eze-Uzomaka and Agbo, 2010; Joel and Agbede, 2011; Joel and Agbede, 2010). A research made in Thailand proved that cement stabilized laterite can be used as road base (TRL, 2012). Similarly, a research made in Legon, Ghana showed that cement stabilized laterite material can be used as both base and sub base courses (Achampong et al, 2013).

A study on the investigation of improving the geotechnical properties of lateritic soils by blending with chemical stabilizer was made on lateritic materials sampled from Gidole, South Ethiopia (Kedir, 2011). In this study, Con-Aid was used as a stabilizer. This study concluded that the stabilizer used didn’t bring significant changes in the reduction of plasticity, increment of maximum dry density and California Bearing Ration (CBR) values. This was attributed to the cementateous property of the sampled lateritic materials.

Another study was made investigating the strength characteristics of lateritic soil blended with marble dust (Assefa, 2016). The lateritic samples used for this study were taken from Mekenajo area, Ethiopia. This study showed that the lateritic soil responded well to the marble-dust treatment and resulted in improved strength and resistance to softening of water, reduced plasticity, improved workability and enhanced durability. Furthermore, it was shown that latertitic subgrade stabilization resulted in thinner pavement structures as found from a trial designed pavement.

However, to the author’s knowledge, there is no similar research that has been conducted on stabilization of lateritic materials for base course construction in Ethiopia. Therefore, this study was initiated by the motivation to explore the possibility of using stabilized lateritic materials for road base construction by considering its cost implication.

This research focused on the stabilization of laterite material with cement and lime so that it can be used as a road base (base course) material.

1.2 Problem Statement

Lateritic gravel is readily available in the north-western part of Ethiopia, particularly, in Benishangul Gumuz region. Despite their abundance, the utilization of lateritic gravels in the construction of high standard roads is limited due to their substandard qualities. The 2013 standard specification of Ethiopian Roads Authority specified that lateritic gravels can be used as a road base material for low volume roads. However, for roads with a design traffic volume of more than one million equivalent standard axles, the materials that are commonly used for base course construction are the high quality crushed stones even if materials of marginal qualities exist in abundance quantities and at a cheaper cost. On the other hand, the sources of high quality crushed stones are scarce in some areas where there are ample quantities of laterite. In such areas, the construction cost and time could be reduced significantly if the locally available laterite is used for the construction of the base course of the high standard roads also. This was the motivation that initiated this research.

1.3 Research Questions

The main questions that will be answered through this research are:

- Is it possible to use laterite for road base (base course) construction by stabilization?
- Is it economically feasible to use laterite as a road base (base course) material?

1.4 Research Objective

The general objective of the research is to investigate the possibility of using laterite materials as road base material where they are abundantly available and to assess the economic benefits of doing so.

The specific objectives of the research are:

- To examine the suitability of cement and lime stabilized laterite material as road base material by evaluating it with the standard methods of testing.
- To determine the optimum amount of stabilizing material required to meet the road base requirements.
- To assess the economical feasibility of utilizing the naturally available laterite material in place of those currently in use.

1.5 Limitations of the Research

The study was conducted on samples collected from only three open borrow pits near Asosa along the Asosa – Kurmuk road. Therefore, the results found from the study will not be applicable to all laterites as these soil properties are dependent on topography and location. In addition, the cost comparisons were made on only two alternative pavement structures and will not indicate the cost benefit of other pavement structures. Furthermore, effect of cracking on stabilized materials has not been considered in the study.

2 LITERATURE REVIEW

2.1 Laterite

Laterites and lateritic soils are the products of intensive weathering which is called laterization under sub-tropical and tropical climatic conditions. According to Alexander and Cady (1962), laterite is a highly weathered material which is rich in oxides of aluminium, iron or both. Buchanan (1807) defined laterites based on the ability of a soft red material to harden on exposure to air. Pendleton and Sharasuvana (1946) have defined laterite soils as profiles in which a laterite horizon is found, and lateritic soils as profiles in which immature horizons are found which develop under 'appropriate' conditions.

Fookes (1997) named laterites based on hardening, such as "ferric" for iron-rich cemented crusts, "alcrete" or bauxite for aluminium-rich cemented crusts, "calcrete" for calcium carbonate-rich crusts, and "silcrete" for silica rich cemented crusts. Other definitions have been based on the ratios of silica (SiO_2) to sesquioxides (Fe_2O_3 + Al_2O_3). The ratios of sesquioxides in laterites are less than 1.33, those between 1.33 and 2.0 are indicative of laterite soils, and those greater than 2.0 are indicative of non-lateritic soils (Bell, 1993).

Bridges (1970) states that the term laterite is for "a massive vesicular or concretionary ironstone formation nearly always associated with uplifted peneplains originally associated with areas of low relief and high groundwater".

The term "lateritic soil" refers to materials with lower concentration of oxides (Gidigasu, 1976). The term laterite may be correctly applied to clays, sands, and gravels in various combinations while "lateritic soils" refers to materials with lower concentrations of oxides. Laterites and lateritic soils form a group which comprises a wide variety of red, brown, and yellow, fine-grained residual soils of light texture as well as nodular gravels and cemented soils (Lambe and Whitman, 1979).

Laterites are formed from the leaching of parent sedimentary rocks (sandstones, clays, limestones); metamorphic rocks (schists, gneiss, migmatites); igneous rocks (granites, basalts, gabbros, peridotites); and mineralized proto-ores (Tardy, 1997).

The lateritic soils behave more like fine grained sands, gravels, and soft rocks. It typically has a porous or vesicular appearance which may be self-hardening when exposed to drying; or if they are not self-hardening, they may contain appreciable amounts of hardened laterite rock or laterite gravel (Thagesen, 1996).

According to Gidigasu (1976), the behavior of laterite soils has been found to depend mainly on their particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions.

Site performance and geotechnical characteristics of lateritic soils including their reaction to different stabilizing agents may be interpreted in light of all or some of the following parameters (Gidigasu, 1976):

- Genesis and pedological factors (parent material, climate, topography, vegetation, period of time in which the process have operated)
- Degree of weathering (decomposition, sesquioxides enrichment and clay-size content, degree of leaching)
- Position in the topographic site, and
- Depth of soil in the profile

Laterized soils work well in pavement construction particularly when their special characteristics are carefully recognized. Lateritic soil has also been successfully used in the construction of slopes, embankments, foundations, reinforced retaining walls and dams in both tropical and sub-tropical regions. They are used as sub base and bases for low cost roads and these carry low to medium traffic (TRL, 2012).

2.2 Stabilization

Soil Stabilization is the alteration of soils to enhance their physical properties. Garber and Hoel (2000) describe soil stabilization as the treatment of natural soil to improve its engineering properties. McNally (1998) states that:

> "The improvements in engineering properties caused by stabilization can include increases in strength (shearing resistance), stiffness (resistance to deformation) and durability (wear resistance), reductions in swelling potential or dispersivity (tendency to deflocculate) of wet clay soils and other desirable characteristics, such as dust proofing and water proofing unsealed roads".

Since the inception of the process of stabilization, most materials which have been thought not useful have found application in many areas of engineering. Stabilization is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification (Ola, 1975). A careful consideration of all costs that would be incurred by importing (not readily available) a compliant soil and comparing this to the cost of improving the properties of an unsuitable but readily available soil is important. Interest in stabilization grew with the cyclic loading effects of heavy traffic which creates a need for stronger pavements that often cannot be provided by realistic thickness of unbound granular materials. Moreover, the availability of purpose built - in – situ stabilization equipment that improves homogeneity of mix increased the interest.

According to Molenaar (2007), the principal additives employed for stabilization are:

- gravel, crushed aggregate, grit and loan,
- Portland cement and cement - slag blends,
- Lime (quick - lime, hydrated lime) and gypsum,
- Lime - pozzolan (lime plus fly ash or ground slag) mixtures, and
- Asphalt.

The first group of additives encompasses a category of stabilization referred to as mechanical or granular stabilization while the other additives which are mainly chemical compounds form the second category of stabilization known as chemical stabilization (Molenaar, 2007).

Chemical stabilization involves the blending of natural soils with chemical agents such as cement, lime and fly ash. These agents effectively bind together the soil particles to improve the load - carrying and stress - distributing characteristics, and reduce the shrinkage and swell potential (Molenaar, 2007).

The selection of stabilizing agents depends on the type of the host soil. It is well documented that cement and bitumen are best suited for granular and non -plastic soils, while lime performs better in cohesive ones. Granular stabilization is much more feasible where coarse material is being added to fine one (McNally, 1998).

Currently many natural materials can be stabilized to make them suitable for road pavements provided that the cost of overcoming a deficiency in the locally available material does not exceed the cost of importing another material which is good without stabilization (ERA, 2013). The stabilization techniques are used to increase the ability to distribute the load over a greater area, to reduce the required thickness of the pavement layers, and to eliminate the excavation and exporting of unsuitable material and importing new materials.

2.3 Stabilizer Selection

There are many factors that are considered to select an appropriate type of stabilizer. These factors, per the manual prepared by Joint Departments of the Army and Air Force of USA (1994), are:

- the type of soil to be stabilized,
- purpose of the stabilized layer,
- desired improvement,
- required strength and durability,
- cost of stabilization, and
- environmental conditions.

The U.S Air Force set the guidelines in Figure 2.1 and Table 2.1 to select candidate stabilizers for a particular soil type. The required parameters to use the guideline are particle size distribution, the Atterberg limits, and the soil class (USCS). More than one stabilizer type may be found appropriate while using this guideline. However, other criteria like availability of the stabilizer, cost, and ease of construction, will help to make a distinction between the stabilizer types.

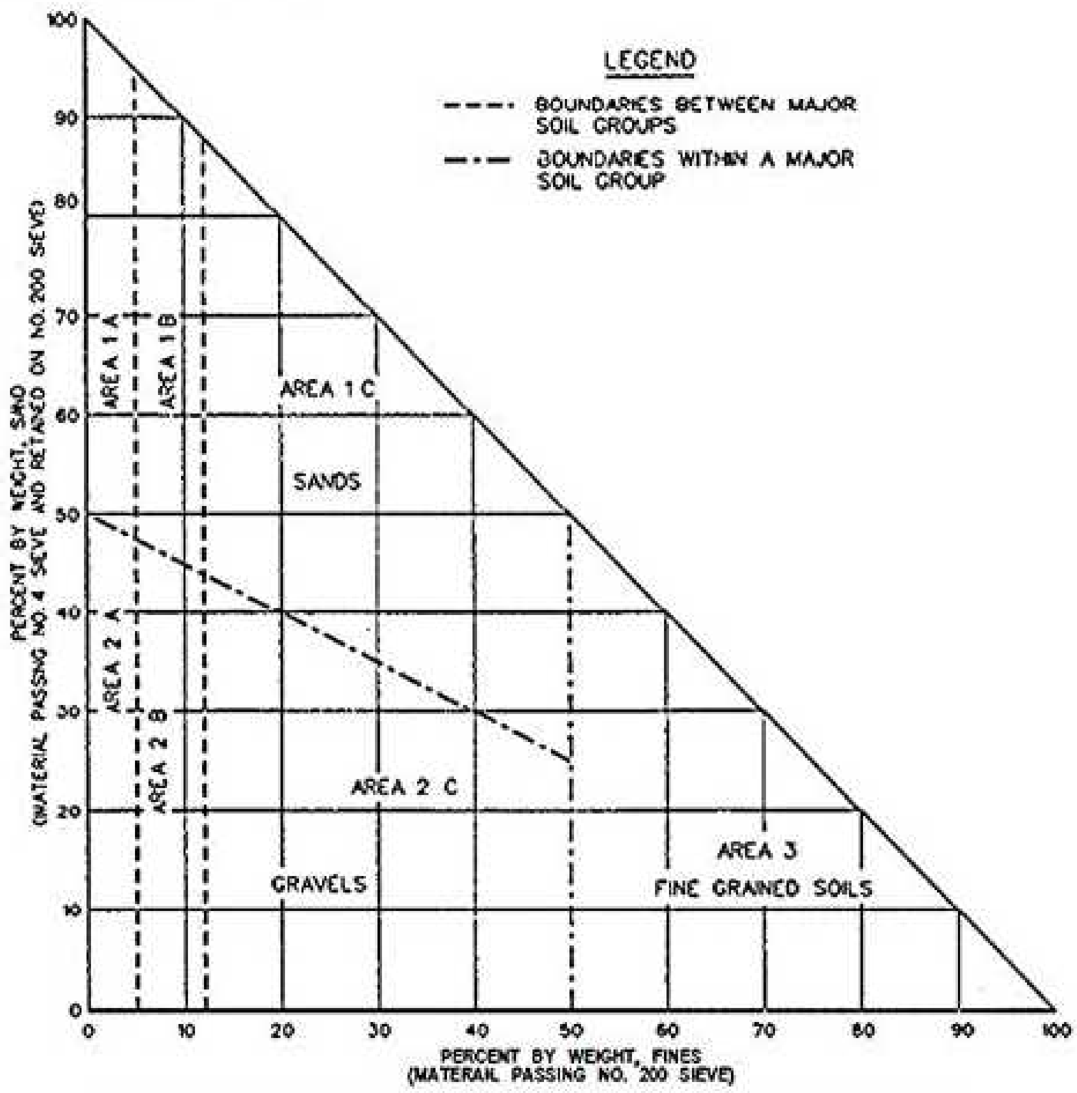


Figure 2-1 Gradation Triangle for Aid in Selecting a Commercial Stabilizing Agent (Joint Departments of the Army and Air Force, 1994)

Table 2.1 Guide for Selecting Stabilizing Additive (Joint Departments of the Army and Air Force, 1994)

Area	Soil Class (a)	Type of stabilizing additive recommended	Restriction on LL and PI of soil	Restriction on percent passing No. 200 sieve (a)	Remarks
1A	SW or SP	1. Bituminous			
		2. Portland cement			
		3. Lime-cement-fly ash	PI not to exceed 25		
1B	SW-SM or SP-SM or SW-SC or SP-SC	1. Bituminous	PI not to exceed 10		
		2. Portland cement	PI not to exceed 30		
		3. Lime	PI not to exceed 12		
		4. Lime-cement-fly ash	PI not to exceed 25		
1C	SM or SC or SM-SC	1. Bituminous	PI not to exceed 10	Not to exceed 30% by weight	
		2. Portland cement	b		
		3. Lime	PI not less than 12		
		4. Lime-cement-fly ash	PI not to exceed 25		
2A	GW or GP	1. Bituminous			Well-graded materials only.
		2. Portland cement			Material should contain at least 45% by weight of material passing No. 4 sieve
		3. Lime-cement-fly ash	PI not to exceed 25		
2B	GW-GM or GP-GM or GW-GC or GP-GC	1. Bituminous	PI not to exceed 10		Well-graded materials only.
		2. Portland cement	PI not to exceed 30		Material should contain at least 45% by weight of material passing No. 4 sieve
		3. Lime	PI not less than 12		
		4. Lime-cement-fly ash	PI not to exceed 25		
2C	GM or GC or GM-GC	1. Bituminous	PI not to exceed 10	Not to exceed 30% by weight	Well-graded materials only
		2. Portland cement	b		Material should contain at least 45% by weight of material passing No. 4 sieve
		3. Lime	PI not less than 12		
		4. Lime-cement-fly ash	PI not to exceed 25		
3	CH or CL or MH or OH or OL or ML-CL	1. Portland cement	LL less than 40 and PI less than 20		Organic and strongly acid soils falling within this area are not susceptible to stabilization by ordinary means.
		2. Lime	PI less than 12		

a. Soil classification corresponds to MIL-STD-619B. Restriction on liquid limit (LL) and plasticity index (PI) is in accordance with Method 103 in MIL-STD-621A

b. PI ≤ 20 + (50 – percent passing No. 200 sieve)/4

From Table 2.1, it can be noted that the various stabilizer selection criteria are mainly based on the index properties of soils particularly plasticity index and liquid limit, and soil class. These properties can easily be identified using simple laboratory tests. The effectiveness of the particular stabilizer that is selected based on the index properties and soil class shall, however, be evaluated using additional strength and/or durability tests.

On the other hand, ERA 2013 PDM set the guideline in Table 2.2 below for selection of stabilizer based on particle size distribution and plasticity of soil.

Table 2.2 ERA Guide to the Type of Stabilization Likely to be Effective (ERA 2013 PDM)

Type of Stabilization	Soil Properties					
	More than 25% passing the 0.075mm sieve			Less than 25% passing the 0.075mm sieve		
	PI≤10	10<PI≤20	PI>20	PI≤6	PI≤10	PI>10
Cement	Yes	Yes	Note 1	Yes	Yes	Yes
Lime	Note 1	Yes	Yes	No	Note 1	Yes
Lime-Pozzolan	Yes	Note 1	No	Yes	Yes	Note 1

Note 1: The agent will have only a marginal effect.

2.4 Lime Stabilization

Soil stabilization significantly changes the characteristics of a soil to produce long-term permanent strength and stability. The term lime stabilization is applied when lime is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction. Lime stabilization can be used for stabilizing both base and sub base materials (Garber and Hoel, 2000).

Lime stabilization is carried out by adding lime to a pulverized soil, and allowing the mixture to harden by carbonation. The physical properties of the soil-lime are affected by the soil type, the lime quantity, degree of mixing and compaction, curing time, degree of pulverization, PH of soil, and dry density of compacted mixture (Moleenar A.A.A, 2007; Yoder E.J. and Witczak M.W., 1975).

The addition of lime to a fine-grained soil in the presence of water initiates several reactions. The soil-lime interactions are influenced by cation exchange, flocculation, pozzolanic reactions and carbonation. The two primary reactions, cation exchange and flocculation-agglomeration, take place rapidly and produce immediate improvements in soil plasticity, workability, uncured strength, and load-deformation properties (Yoder E.J. and Witczak M.W., 1975). Long-term stabilization effects take place during and after curing, and are important from a strength and durability standpoint. These effects are generated to an extent by cation exchange and flocculation–agglomeration, but they are primarily the result of pozzolanic strength gain (Mallela et al, 2004).

2.4.1 Test Methods

The optimum lime content that is required for the proposed modification and stabilization is determined by performing set of laboratory tests. These laboratory tests are conducted on the soil-lime mixtures in order to determine the maximum dry density and optimum moisture content, the optimum lime content and the strength of the compacted mixtures. The standard laboratory tests that are widely used in the design of soil-lime mixtures are shown in Table 2.3 below.

Table 2.3 Laboratory Test Methods for Soil-Lime Mixtures (ASTM and BS Standards)

Test Type	Test Method
Preparation of Soil Lime Mixtures	ASTM D 3551
Atterberg Limit Tests	ASTM D 4318/AASHTO T 89-90
Moisture-Density Relation	ASTM D 1557
Wetting and Drying	ASTM D 559
Freezing and Thawing	ASTM D 560
Compressive Strength	ASTM D 5102/ AASHTO 222
Test Methods for Cement-Stabilized and Lime-Stabilized Materials	BS 1924

2.4.2 Design Lime Content Determination

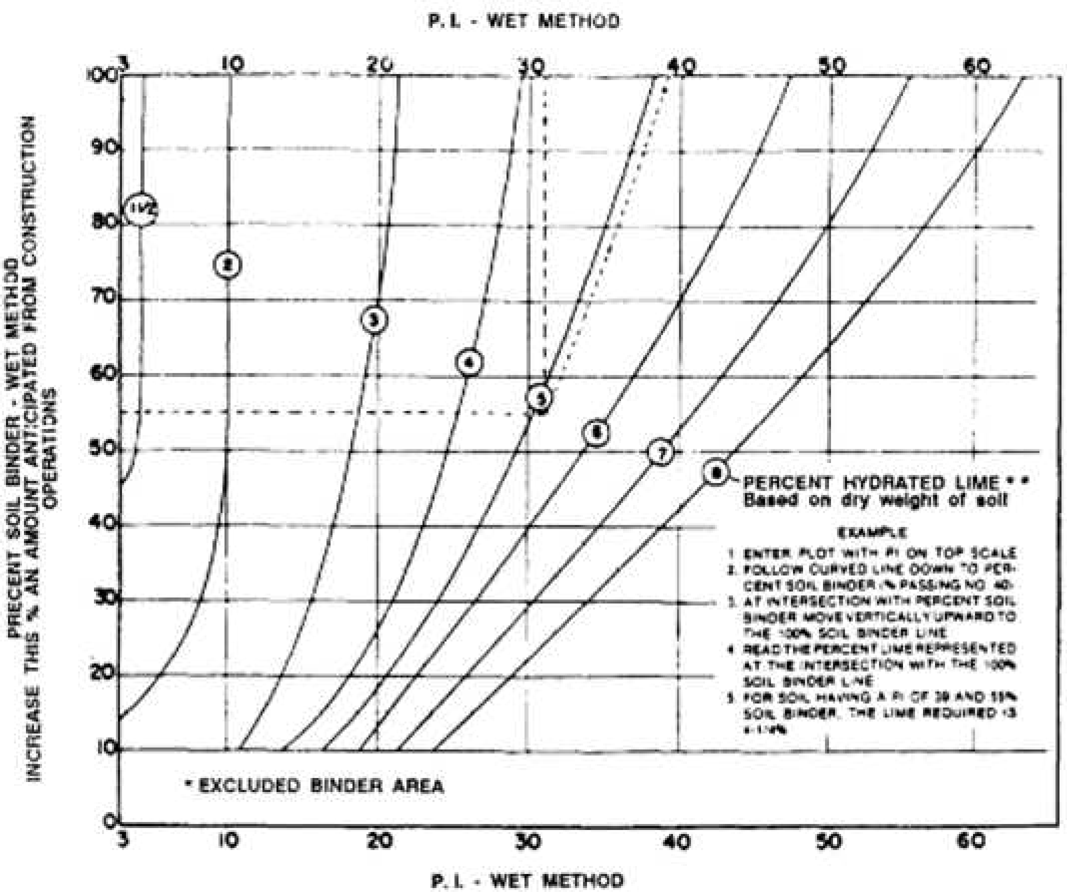
The following steps were recommended for the design of lime – soil mixtures by the manual prepared by Joint Departments of the US Army and Air Force (1994):

i. Determining the gradation of the untreated soil by using the procedure in ASTM D 2487, the gradation requirement is as presented in Table 2.4;

Table 2.4 Gradation Requirement for Lime Stabilized Base Course (Joint Departments of the Army and Air Force, 1994)

Sieve Size	Percent Passing
1 ½ inch	100
¾ inch	70-100
No. 4	45-70
No. 40	10-40
No. 200	0-20

ii. Estimating the initial lime content for moisture-density tests based on Figure 2.2;



* Exclude use of chart for materials with less than 10% - No. 40 and cohesionless materials (P. I. less than 3)

** Percent of relatively pure lime usually 90% or more of Ca and/or Mg hydroxides and 85% or more of which pass the No. 200 sieve. Percentages shown are for stabilizing subgrades and base courses where lasting effects are desired. Satisfactory temporary results are sometimes obtained by the use of as little as 1/2 of above percentages. Reference to cementing strength is implied when such termes as "Lasting Effects" and "Temporary Resulst" are used.

Figure 2-2 U.S Air Force Chart for the Initial Determination of Lime Content (Joint Departments of the Army and Air Force, 1994)

iii. Conducting moisture-density tests to determine the maximum dry density and optimum water content of the soil-lime mixture. The soil lime mixture is prepared using ASTM D 3551 and moisture-density tests are conducted using ASTM D 1557;

iv. Preparing triplicate samples of soil-lime mixture for unconfined compression and durability tests at the initial design lime content and at the lime contents 2% and 4% above design. The samples are prepared at the density and water content that are expected in field construction. The samples should be prepared in accordance with ASTM D 3551 except that when more than 35% of the material is retained on the No. 4 sieve, a 2-inch diameter and 4inch high mould is used to prepare the specimens. The specimens are cured for the desired amount of days in a humid room before testing. Three of the specimens are tested for durability using either wet-dry method (ASTM D 559) or freeze-thaw (ASTM D 560) and the other three specimens are tested appropriately using the unconfined compression test in accordance with ASTM D 5102.

v. Comparing the results of the unconfined compressive strength (UCS) and durability tests with the requirements given in Table 2.5 and 2.6. The design lime content is the lowest lime content which meets the required unconfined compressive strength requirement and satisfies the required durability**.** If the results of the specimens tested do not meet the strength and durability requirements, steps **i** through **iv** shall be repeated with a higher lime content.

Table 2.5 Minimum Unconfined Compressive Strength for Lime Stabilized Soils (Joint Departments of the Army and Air Force, 1994)

Stabilized Soil Layer	Minimum Unconfined Compressive Strength, MPa*	
	Flexible Pavement	Rigid Pavement
Base course	5.17	3.44
Sub base course, select material or subgrade	1.72	1.38

unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime, lime fly ash, or lime-cement-fly ash stabilization.

Table 2.6 Durability Requirements (Joint Departments of the Army and Air Force, 1994)

Type of Soil Stabilized	Maximum Allowable Weight Loss After 12 Wet-Dry or Freeze-Thaw Cycles Percent of Initial Specimen Weight
Granular, PI < 10	11
Granular, PI >10	8
Silt	8
Clays	6

2.4.3 Lime-Treated Road Base Specifications

The requirement for lime-treated road base as specified in many pavement design standards is in terms of the 28-days unconfined compressive strength. Some standards set additional durability requirements based on the wet-dry or freeze-thaw test results. The summary of the cement-treated base materials specifications is given in Table 2.7.

Table 2.7 Specifications for Lime-Treated Base Layer in Flexible Pavement (Different Design Standards)

Standards	Strength Requirement [MPa]	Durability Requirement [% Loss]
ERA 2013 Standard Technical Specification	3.0 – 6.0 for CB1	<8% loss
	1.5 – 3.0 for CB2	
Road Note 31	3.0 – 6.0 for CB1	
	1.5 – 3.0 for CB2	
SATCC	1.5 – 3.0	-
Tanzania PDM	1.0 for C1	-
	2.0 for C2	
US Army and Air Force	5.2	Max. 11 for Granular Soil with PI <10
		Max. 8 for Granular Soil with PI > 10
		Max. 8 for Silt
		Max. 6 for Clay

Most of the strength requirements are based on the 28-days unconfined compressive strength test in cylindrical specimens with diameter-to-height ratio of 1:2. However, the Southern Africa Transport and Communications Commission (SATCC) strength requirement is based on cylindrical specimen with diameter-to-height ratio of 1:1; and ERA 2013 PDM and Road Note 31 strength requirements are set based on the 150mm cube strength. Moreover, the durability requirements refer to the 12-cycle wet-dry or freeze-thaw tests.

2.5 Cement Stabilization

Soil stabilization significantly changes the characteristics of a soil to produce long-term permanent strength and stability. The term cement stabilization is applied when cement is added to a reactive soil to generate long-term strength gain through a hydration reaction. Cement stabilization can be used for stabilizing both base and sub base materials (Garber and Hoel, 2000). In compacted soil-cement, the cement is used to get sufficiently strong and well compacted materials while in cement-modified soils, the cement's effect is reduction in plasticity, volumetric shrinkage and the like (Moleenar 2007).

Cement stabilization to produce hardened mixture is carried out by adding cement to a pulverized soil, and allowing the mixture to harden by hydration of the cement. The physical properties of the soil-cement are affected by a number of factors. It includes the soil type, the cement quantity, degree of mixing and compaction, curing time, degree of pulverization, PH of soil, and dry density of compacted mixture (Moleenar, 2007; Yoder and Witczak, 1975).

The soil-cement interactions are influenced by hydration, cation exchange, carbonation, and pozzolanic reactions, of which the first two are the main factors. Hydration reaction takes place by the reaction of tricalcium silicate (C_3S) and dicalcium silicate (C_2S) with water. Tricalcium silicate and dicalcium silicate constituent 45% and 27% of ordinary Portland cement respectively. Free lime, CH, is formed following the formation of the insoluble silicate gel which crystallizes very slowly into an interlocking matrix. The free lime helps to modify the soil through cation exchange (Yoder and Witczak, 1975).

2.5.1 Test Methods

The soil-cement mixture design is carried out in the laboratory to determine the optimum cement content. The laboratory tests were conducted on the soil-cement mixtures in order to determine the maximum dry density and optimum moisture content, the optimum cement content and the strength of the compacted mixture that fulfills the specified requirements. The laboratory test methods that are widely used in the design of soil-cement mixture are shown in Table 2.8.

Table 2.8 Laboratory Test Methods for Soil-Cement Mixtures (ASTM and BS Standards)

Test Type	Test Method
Moisture-Density Relation	ASTM D 558/AASHTO T 134
Wetting and Drying	ASTM D 559/AASHTO T 135
Freezing and Thawing	ASTM D 560/AASHTO T 136
Compressive Strength	ASTM D 1633
Test Methods for Cement-Stabilized and Lime-Stabilized Materials	BS 1924

2.5.2 Design Cement Content Determination

The optimum cement content of a soil – cement mixture is determined according to the following states as per the manual prepared by Joint Departments of the US Army and Air Force (1994):

i. Determining the gradation and classification of the untreated soil by using the procedures in ASTM D 2487 and ASTM D 422, respectively;

ii. Estimating the initial cement content for moisture-density tests based on the soil classification test result from Table 2.9;

Table 2.9 Cement Requirements for Various Soils (Joint Departments of the US Army and Air Force, 1994)

Soil Classification	Initial Estimated Cement Content (% dry weight)
GW, SW	5
GP, GW-GC, GW-GM, SW-SC,SW-SM	6
GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC, SP	7
CL.ML, MH	9
CH	11

iii. Conducting moisture-density tests to determine the maximum dry density and optimum water content of the soil-cement mixture. The soil cement mixture is prepared in accordance with ASTM D 558 and moisture-density tests are conducted per ASTM D 1557;

iv. Preparing triplicate samples of soil-cement mixture for unconfined compression and durability tests at cement content selected in step 2 and at the cement contents of 2% above and 2% below that of determined in step 2. The samples are prepared at the density and water content that are expected in field construction. The samples should be prepared in accordance with ASTM D 1632 except that when more than 35% of the material is retained on the No. 4 sieve, a 4-inch diameter mould is used to prepare the specimens. The specimens are cured for 7 days in a humid room before testing. Three of the specimens are tested for durability using either wet-dry (ASTM D 559) or freeze-thaw (ASTM D 560) tests and the other three specimens are tested appropriately using the unconfined compression test in accordance with ASTM D 1633.

v. Comparing the results of the unconfined compressive strength and durability tests are with the requirements given in Table 2.10 and 2.11 below. The design cement content is the lowest cement content which meets the required unconfined compressive strength requirement and satisfies the required durability**.** If the results of the specimens tested do not meet the strength and durability requirements, steps **i** through **iv** shall be repeated with a higher cement content.

Table 2.10 Minimum Unconfined Compressive Strength for Cement Stabilized Soils (Joint Departments of the US Army and Air Force, 1994)

Stabilized Soil Layer	Minimum Unconfined Compressive Strength, MPa*	
	Flexible Pavement	Rigid Pavement
Base course	5.17	3.44
Sub base course, select material or subgrade	1.72	1.38

- *unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime, lime fly ash, or lime-cement-fly ash stabilization.*

Table 2.11 Durability Requirements (Joint Departments of the Army and Air Force, 1994)

Type of Soil Stabilized	Maximum Allowable Weight Loss After 12 Wet-Dry or Freeze-Thaw Cycles Percent of Initial Specimen Weight
Granular, PI < 10	11
Granular, PI >10	8
Silt	8
Clays	6

2.5.3 Cement-Treated Base Course Specifications

The requirement for cement-treated base course as specified in many pavement design standards is in terms of 7-days unconfined compressive strength. Some standards set additional durability requirements based on the wet-dry or freeze-thaw test results. The summary of the cement-treated base materials specifications is given in Table 2.12.

Table 2.12 Specifications for Cement-Treated Base Layer in Flexible Pavement (Different Standards)

Standards	Strength Requirement [MPa]	Durability Requirement [% Loss]
ERA 2013 Standard Technical Specification	3.0 – 6.0 for CB1	<8% loss
	1.5 – 3.0 for CB2	
Road Note 31	3.0 – 6.0 for CB1	
	1.5 – 3.0 for CB2	
SATCC	1.5 – 3.0	-
Tanzania PDM	1.0 for C1	-
	2.0 for C2	
US Army and Air Force	5.2	Max. 11 for Granular Soil with PI <10
		Max. 8 for Granular Soil with PI > 10
		Max. 8 for Silt
		Max. 6 for Clay

Most of the strength requirements are based on the 7-days unconfined compressive strength test in cylindrical specimens with the diameter-to-height ratio of 1:2. However, the SATCC strength requirement is based on cylindrical specimen with diameter-to-height ratio of 1:1; and ERA 2013 PDM and Road Note 31 strength requirements are set based on the 150mm cube strength. Moreover, the durability requirements refer to the 12-cycle wet-dry or freeze-thaw tests.

2.5.4 Stabilization Associated Problems and Mitigation Measures

According to ERA PDM (2013), the main problems associated with stabilization are cracks and carbonation.

Shrinkage, particularly in cement-stabilized materials, has been shown to be influenced by (Bofinger et al., 1978),

- Loss of water, particularly during the initial curing period.
- Cement content.
- Density of the compacted material.
- Method of compaction.
- Pre-treatment moisture content of the material to be stabilized.

By taking into account the above mentioned points, there are methods that help to minimize the effect of shrinkage cracking. Some of these methods are proper curing, limiting the amount of cement to a maximum of that required for durability requirement, using pneumatic-tire rollers in lieu of vibratory rollers, and minimizing the initial moisture content of the natural material to be stabilized (ERA, 2013).

Reflective cracking occurs if shrinkage cracks are not controlled, which in turn causes premature failure of the pavement. Inclusion of stress-relief material between the stabilized base course and the pavement surfacing can prevent reflective cracking according to Overseas Road Note 31.

The other problem is carbonation. The risks of carbonation, according to Road Note 31, can be prevented by immediately sealing the compacted stabilized materials, by avoiding the wetting-and-drying of the stabilized material during the curing phase, by applying compaction as early as possible after mixing, and by reducing the possibility of reflection cracks.

3 RESEARCH METHODS, MATERIALS, AND PROCEDURES

3.1 Study Area

The study area is found in western Ethiopia, Benishangul Gumuz Regional State. The largest part of the region has undulating topography with altitude ranging from 580m – 2,731m above mean sea level. According to the geological map of Ethiopia, 1996 ed., the study area is situated over the Western Ethiopia Metamorphic belt, where both intrusive complexes (meta granodiorite, granite) and their associated low-grade metamorphic rocks (schists) dominate. As per the data from the website of the Ethiopian Meteorological Service Agency, the mean annual temperature of the region is above $27^{o}C$ and the mean annual rainfall is less than 450mm.

This study was done on the laterite material that has been collected along **Asosa – Kurmuk** road which has already been constructed. This site was particularly selected because laterite gravel is abundantly available at the abutting land along the road; there are open borrow pits at reasonable intervals along the road; and the borrow pits are accessible to vehicles. Figures 3.1and 3.2 show the location map of the study area.

Figure 3-1 Map of Benishangul – Gumuz and Location of the Study Area – Asosa and Kurmuk (Ethiopian Map, 2017)

(Accessed from http://www.ethiodemographyandhealth.org/BenMap.jpg)

As discussed in the literature review, laterites are formed mainly from the leaching of parent sedimentary and igneous rocks in tropical and subtropical regions. And according to the geological map of Ethiopia (1997), most of the study area is covered with these types of rocks. Hence, the geological formation of the study area is a good indicator that laterite soil is abundant in the area. The geological formation of the area and description of the geology is presented in Figure 3.2 and Table 3.1 below.

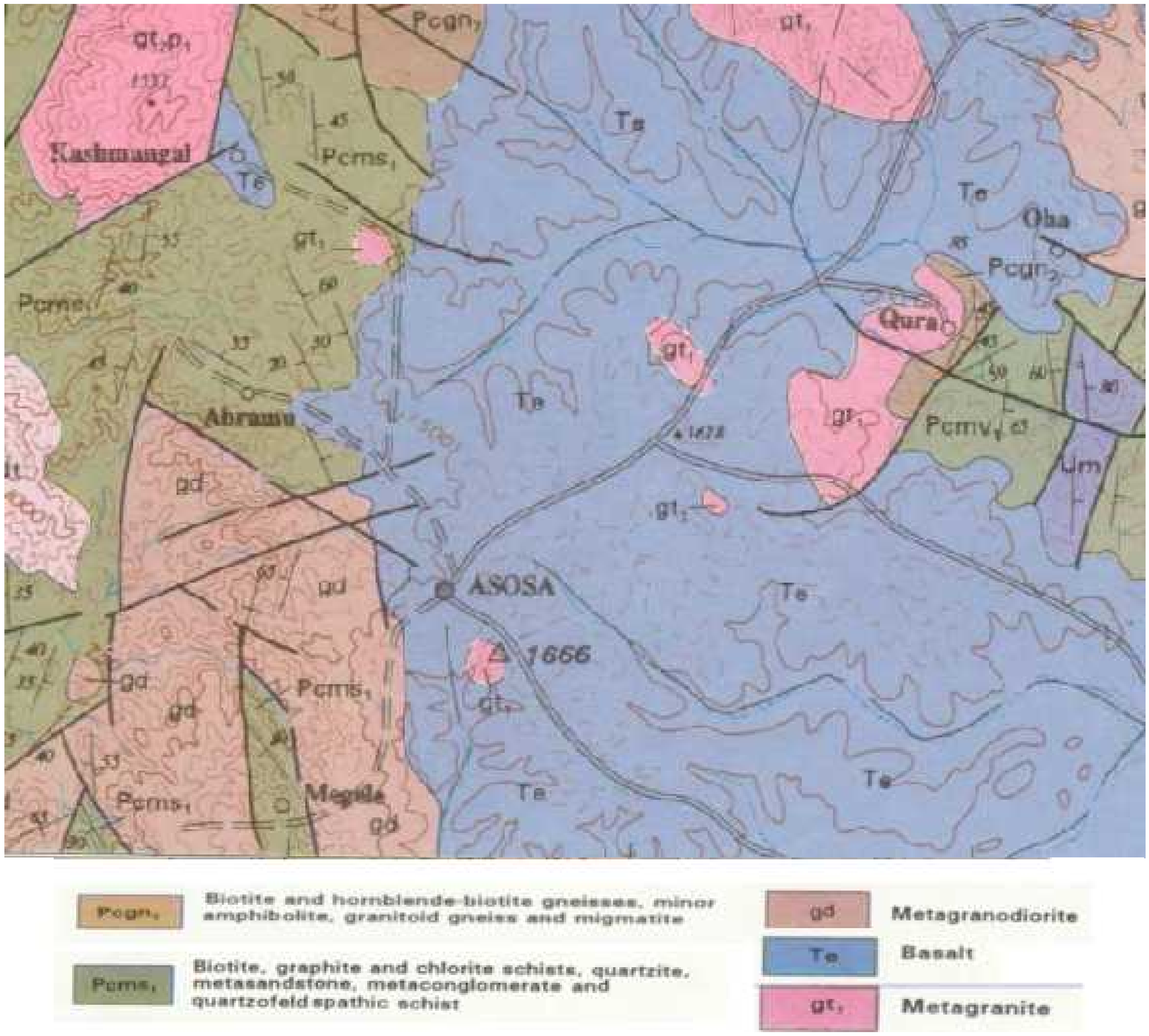


Figure 3-2 Geological Formation of Asosa (Geological Map of Ethiopia, 1997)

Table 3.1 Description of the Geological Formation of Asosa (Geological Map of Ethiopia, 1997)

Geologic Designation	Geologic Description
Biotite and hornblende-biotite gneiss (Pcgn1)	This formation is located around the Sudanese border and around Kurmuk town. It is underlain by high grade gneisses of amphibolite facies. Much of the area is covered by a thin veneer of Quaternary alluvial sediments so that exposures are found along dry stream beds. The major rock type is grey, medium to coarse grained, well banded biotite and hornblende-biotite gneiss.
Metasediments (Pcms1)	The dominant rock types appear to be pelitic schists and rocks of felsic to mafic volcanic origin. Several rock types occur, the most common being phyllite, felsic schist, mafic schist and green schist with beds of graphite schist, quartzite, marble and talc schist.
Metagranodiorite (gd)	This unit also contains rocks of granitic, tonalitic and dioritic composition. They usually bear biotite or hornblende. These rocks are grey and medium to coarse grained with well preserved plutonic texture. These rocks range from massive to well foliated.
Metagranite (gt1)	The rock is light grey or pink and medium to coarse grained. Some bodies are equi-dimensional in plan, but most form north-south or northwest-southeast trending ridges conforming to the regional structural trend of the country rocks.
Alkali olivine basalt (Te)	Most of the area was apparently originally covered by Tertiary volcanic rocks, but now only remnant caps occur. Locally the base of the lavas is seen, palaeo-soil being present between the crystalline basement and the basalt flows, as well as between individual flows

The following pictures show the side borrows in the study area from where the laterite materials were sampled.

Picture 3-1 Laterite Material in the Study Area

3.2 Study Design

This research was designed to answer the research questions and meet its objectives based on experimental findings.

Samples to be used in the research were collected. The materials used in the research were laterite soil. Additionally, commercial ordinary Portland cement and lime produced by Derba Cement Factory were used as stabilizing agents.

The next step was laboratory testing. The laboratory tests were conducted first on the natural materials and then on the modified/stabilized materials. In the first step of the laboratory testing, quality tests were conducted on each of the component materials so that their physical and/or chemical properties were identified. In the second step, laboratory tests were conducted on the modified/stabilized materials to check/assess their suitability as road-base material. Ordinary Portland cement and lime were used to stabilize the laterite material. The laterite - cement and laterite - lime mixtures were designed, tested and their suitability assessed according to the Joint US Army and Air Force methods and specifications (in their publication USA TM 5-882-14/AF MAN 32-8010, 1994). Moreover, comparisons of the qualities of the mixtures were made with ERA 2013 Pavement Design Manual (PDM) and Standard Technical Specification (STS).

Then analysis and interpretation of the laboratory test results/data were performed. In this step, the laboratory test results/data were synthesized:

- to identify the optimum mixture composition,
- to address the effects of the additives (the cement and the lime), and
- to compare the cost of the stabilized materials, based on economic criteria, with crushed stone base course material.

The last step was summarizing the research findings and forwarding recommendations based on the research findings.

3.3 Material Sampling

The laterite materials were collected from three spots along the Asosa – Kurmuk road segment. The laterite samples were collected in January 2015. The samples were collected from open borrow pits that were located at 6.1km, 10.3km and 15.4km from Asosa along the Asosa – Kurmuk road. The borrow pits were located both at the left and right hand sides of the road. Disturbed samples were collected from the depth of 0.5-2.0m below the original ground level after removing the top soil. The laterite sampling locations are indicated in Figure 3.3.

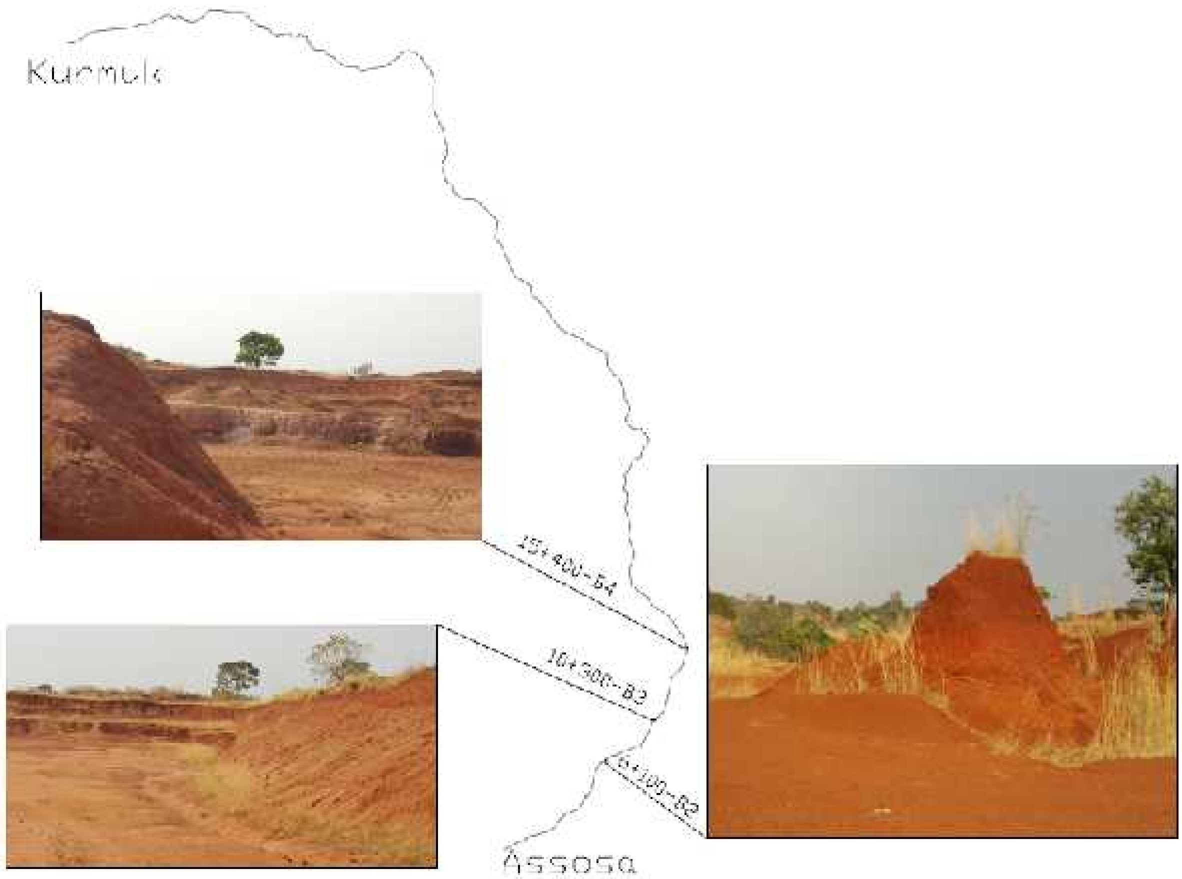


Figure 3-3 Laterite Sample Locations

Both the ordinary Portland cement and lime utilized for the study were manufactured by Derba Cement Factory.

3.4 Data Acquisition

This is a controlled experimental study. The primary data has been obtained from laboratory tests. The test methods that are stated in Tables 3.2, 3.3 and 3.4 were employed in the research process.

Table 3.2 Tests on the Laterite Material

No.	Test	Method
1	*Atterberg Limits*	*AASHTO T 89 and T 90*
2	*Unified Soil Classification*	*ASTM D 2487*
3	*Grain Size analysis*	*ASTM D 422 / AASHTO T 27*
4	*Modified Proctor Density*	*AASHTO T 180*
5	*Modified Three Point CBR*	*AASHTO T 193*
6	*Complete silicate analysis*	*LIBO2 Fusion, HF attack, Gravimetric, and AAS*

Table 3.3 Test on Laterite – Lime Mixtures

No.	Test	Method
1	*Atterberg Limits*	*AASHTO T 89 and T 90*
2	*Moisture Density Relation*	ASTM D 1557 / 558
3	*Standard test method for wetting and drying of compacted soil-lime mixtures*	*ASTM D 559*
4	*Compressive strength of molded soil-lime mixtures*	*ASTM D 5102*
5	*Preparation of Soil Lime Mixtures*	*ASTM D 3551*

Table 3.4 Tests on Laterite – Cement Mixtures

No.	Test	Method
1	*Atterberg Limits*	*AASHTO T 89 and T 90*
2	*Moisture Density Relation*	ASTM D 1557 / 558
3	*Standard test method for wetting and drying of compacted soil-cement mixtures*	*ASTM D 559*
4	*Compressive strength of molded soil-cement cylinders*	*ASTM D 1633*

3.5 Data Quality Assurance

The precision and bias statements of the respective test methods were used to assess the quality of the data obtained from each of the tests.

3.6 Analysis Methods

The data obtained from the laboratory tests of cement/lime treated laterite were analyzed and interpreted using the criteria tabulated in Tables 2.10, 2.11 and 2.12.

4 LABORATORY TEST RESULTS

In this section, summaries of the laboratory test results are presented. The detailed laboratory test results are attached in the Appendix and the analyses and interpretation of the test results are presented in chapter 5.

4.1 Quality Test Results

Quality tests were carried out on the laterite material that was used for this research. The results of the laboratory tests results are presented hereunder.

4.1.1 Laterite

The laterite was subjected to physical and chemical tests to understand its physical properties and composition. The physical tests were conducted in the central laboratory of CORE Consulting Engineers Plc, whereas, the chemical test, which is complete silicate analysis test, was carried out in the Geochemical laboratory of Geological Survey of Ethiopia. These tests were done on each of the three samples, collected from the site. Moreover, the physical tests were conducted on the laterite sample that has been prepared by combining the three samples by **1:1:1** ratio on volume basis.

The samples were combined because samples from nearby borrow locations are usually damped at one location, mixed together and placed during construction. Moreover, the combined samples will also have a better representation of the laterite material around the sampling area.

The chemical tests were conducted primarily to confirm whether the sampled materials have the chemical composition of laterites. As mentioned in the literature review part, the silica (SiO_2) to sesquioxides (Fe_2O_3 and Al_2O_3) ratio of laterites is less than 1.33 (Bell, 2007). In this study, this criterion was used as basis to verify the sampled materials based on the complete silicate test data. Accordingly, it was found out that the materials from each of the sources have the chemical composition of laterite. The test results are presented in Table 4.1. The complete test result is attached as Appendix I-A.

Table 4.1 Laterite Check

Station	SiO_2	Al_2O_3	Fe_2O_3	SiO_2 / (Fe_2O_3 + Al_2O_3)
B2 (6.1 km From Asosa)	40.12	26.15	15.58	0.96
B3 (10.3 km From Asosa)	37.15	31.4	13.9	0.82
B4 (15.4 km From Asosa)	36.15	31.92	14.32	0.78

After the materials were confirmed to be laterites, the remaining samples were subjected to physical tests to assess their index and engineering properties, and compared with the criteria set in ERA 2013 STS under the provision of natural gravels for road-base material. These tests are grain size analysis, Atterberg limits, moisture-density relation, and modified proctor 3-point CBR. The tests were conducted on the combined material samples according to the test methods described in Table 3.2.

Laterites around Asosa, Nedjo – Jarso – Begi, Nejo – Mendi, and Wolayta – Sodo didn't have loosely bound molecular water of hydration (structural water) as shown in previous researches (Abebaw, 2005; G/medhin, 2008; Million, 2009; Tibebu, 2008). Hence, all tests were carried using the normal testing procedures for road base materials by oven drying conventionally. On the other hand, as shown in the above mentioned researches, laterite materials are sensitive to pretreatment conditions and testing procedures. Therefore, similar pretreatment conditions similar to the in-situ conditions were applied and same testing procedures for all prepared specimens were used during the study.

The grain size analysis test was performed to determine the particle size distribution of the material. The particle size distribution is an important factor that governs the degree to which the grains of a particular material are packed against each other for a given compaction energy. In this research, the results of the grain size analysis test were mainly used as an input to determine the soil class.

The Atterberg limit tests were conducted to determine the consistency indices of the laterite. The tests were done in accordance with AASHTO T 89 and AASHTO T 90 test methods. The liquid limit and plasticity index values are among the requirements that were specified in the 2013 ERA STS for natural gravel road base materials. Thus, the test data were used to assess the conformity of the tested laterite with the requirements set by the 2013 ERA STS. Furthermore, the liquid limit and plasticity index values were used as an input in the process of soil classification.

The moisture-density test was carried out to determine the maximum dry density and optimum moisture content of the material. The test was done according to AASTHO T 180. The optimum moisture content was then used to prepare the CBR specimens during the 3-point CBR test. The 3-point CBR test was performed per AASHTO T 193 to determine the strength of the compacted laterite in terms of California Bearing Ratio. In the 3-point CBR test, the CBR strength of the material, at the anticipated field density, is determined from the plot of the density versus CBR values. The anticipated field density value is determined as certain predefined percentage of the maximum dry density of the material. In this study, the expected field density was considered to be 98% of the maximum dry density as specified in the 2013 ERA STS for natural gravel base course materials.

The Atterberg limits, soil classification and CBR test results are summarized and presented in Table 4.3, and the grain size analysis test results are summarized and presented in Figure 4.1. The detailed laboratory test results are attached as Appendix I-B.

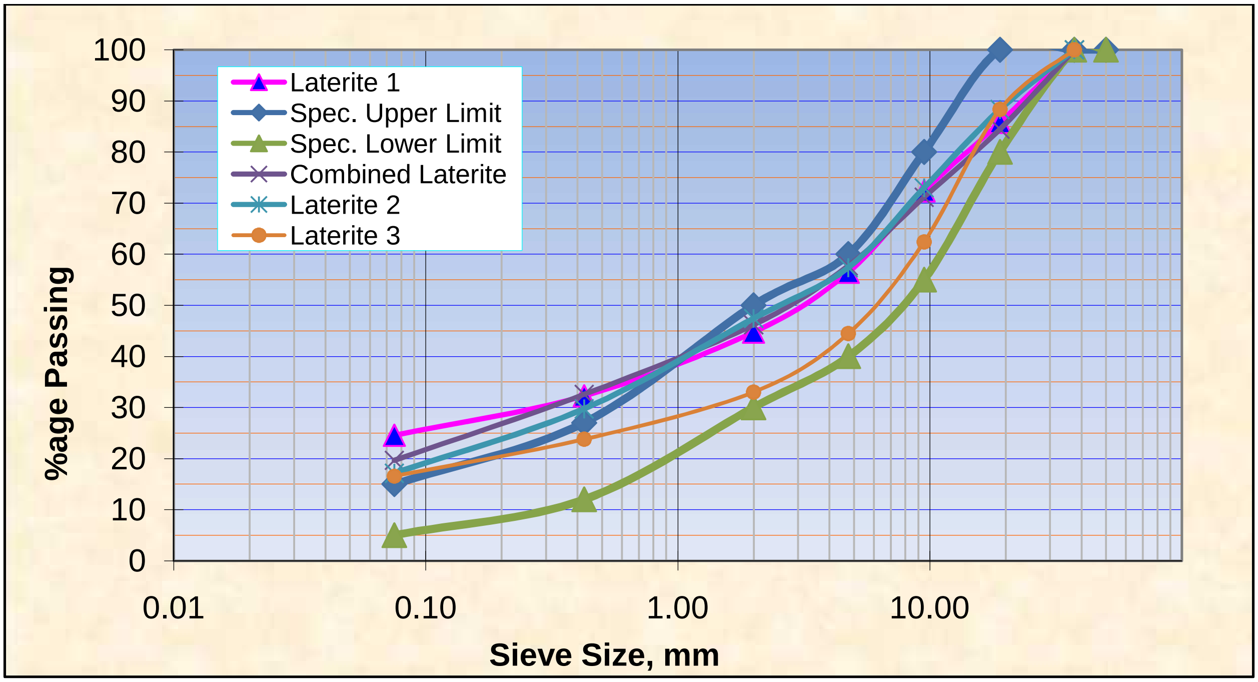


Figure 4-1 Gradation of the Combined Laterite

The recommended particle size distribution for natural gravels for road base material (GB2 and GB3) as given in ERA 2013 STS is summarized below in Table 4.2.

Table 4.2 ERA Recommended Particle Size Distribution for Natural Gravels for Road Base Material (GB2 and GB3)

Sieve Size (mm)	Percentage by Mass Passing
50	100
37.5	80-100
19	60-80
9.5	45-65
4.75	30-40
2.0	20-40
0.425	10-25
0.075	5-15

The results of the particle size analysis indicated that the grading curve of the laterite lies outside (on the finer side) the specification envelop for sizes finer than 1mm. This indicates that the material contains more fine particles than the allowable limit of the specification.

Additionally, according to ERA 2013 STS, the Atterberg limit tests revealed that the combined laterite material has a plasticity index of 20 which is significantly more than the specified value. Moreover, the CBR value of the laterite material at 98% MDD is much lower than the value specified in the specification.

Table 4.3 Summary and Comparison of Test Results of the Combined Laterite

No	Station (Km)	Material Description	Atterberg Limits			Soil Classification	MDD (g/cc)	OMC (%)	CBR at 98% of MDD (%)	Swell (%) at 98% MDD
			LL (%)	PL (%)	PI (%)					
1	Combined	Laterite material	49	29	20	A-2-7 (0) GM (silty gravel)	1.68	18.8	31.5	1.54
ERA Specification-2013			**-**	**-**	**<6**	**-**	**-**	**-**	**>80**	**-**

4.2 Selection of Stabilizer

Based on the Unified Soil Classification System (USCS), the natural laterite material that has been used for this study fell in GM soil group, which is silty gravel containing 19.6% of fractions passing the 0.075 sieve size. Moreover, it has a plasticity index of 20. Hence, according to the guidelines in the Joint Departments of the US Army and Air Force manual and ERA 2013 Flexible Pavement Design Manual, the appropriate stabilizers for this material are lime and cement. Therefore, the stabilization was done using lime and cement and the specific process is discussed and presented in the following sections.

4.3 Lime Stabilized Laterite

The gradation of the untreated laterite material satisfies the grading requirement for lime stabilization. The grading requirements are shown in Table 4.4.

Table 4.4 Joint Departments of the US Army and Air Force Manual (1994) Gradation Requirement for Lime Stabilization

Sieve Size, mm	Percent Passing	
	USA Air Force Army	Laterite
1 ½ inch	100	100
¾ inch	70-100	84.5
No. 4	45-70	57.7
No. 40	10-40	32.6
No. 200	0-20	19.6

The initial lime content, for this type of soil, as indicated in Figure 2.2, is 2.5% of the weight of the dry soil. Hence, in this study, trial mixes were prepared by varying the lime content from 2% to 10%. The tests that have been conducted on the trial mixes and the corresponding results are discussed in the following sections.

4.3.1 Laterite-Lime Mix Preparation

The laterite-lime mixture was prepared in accordance with ASTM D 3551. Accordingly, the laterite was quartered and reduced to 3 to 4 kilograms and the required amount of lime was measured as shown in the first picture of Picture 4.1. Then the laterite-lime mixture was prepared by thoroughly mixing the laterite with the lime in the predetermined proportion until the blend had uniform color as shown in the second and third pictures of Picture 4.1.

Picture 4-1 Preparation of Laterite-Lime Mixture

4.3.2 Atterberg Limit Tests on the Laterite – Lime Mixture

Atterberg limit tests were conducted on the prepared sample to assess the effect of the added lime on the consistency index of the laterite. These tests were also used to determine the minimum lime content that will drop the plasticity index of the treated material to non-plastic or slightly plastic state. According to ERA 2013 STS 2013, the treated materials need to be non-plastic or slightly plastic.

The results of the Atterberg limit tests are presented in Table 4.5.

Table 4.5 Atterberg Limit Tests of the Laterite-Lime Mixtures

Lime Content (% by wt)	Atterberg Limit Values		
	LL	**PL**	**PI**
0	49	29	20
2.0	48	30	18
4.0	47	31	16
6.0	44	32	12
8.0	39	33	6
10.0	36	33	3

As can be seen from the test results, the liquid limit of the laterite material decreased from 49 to 36, while the plastic limit increased from 29 to 33. The plasticity index dropped from the initial value of 20 to 3 as the lime content increased from 0 to 10%.

The trend observed with Atterberg limit test values and lime could be because of the agglomeration of fine clay particles into coarse, friable particles. The agglomeration of the clay particles occurs when the calcium ion in the lime replaces the sodium or potassium ions in the clay. This process is called as cation exchange.

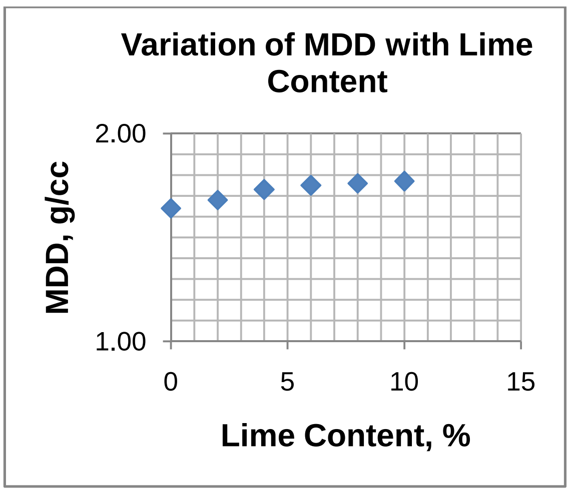
The minimum plasticity index value of a modified soil for effective stabilization is 10% (Garber and Hoel, 2010; Yoder and Witczak, 1975). Effective stabilization with lime begins after the addition of 8% lime, as can be seen from the results in Table 4.5. However, lower binder contents can be applied as far as the strength and durability requirements are fulfilled. Many agencies are reducing the design binder contents to less than 6% due the shrinkage cracking problem.

4.3.3 Moisture Density Test on the Laterite – Lime Mixture

The moisture-density test was used to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil-lime mixture. The test was performed on the soil-lime mixture that was wetted with predetermined amount of water as shoen in the first picture of Picture 4.2. The soil-lime-water mixture was then thoroughly mixed as shown in the second picture of Picture 4.2 and kept covered with moisture tight container for an hour. The mixture was then compacted with modified proctor compaction hammer in a cylindrical mould (third picture of Picture 4.2). The moisture-density relation test was conducted on five trial mixes with 2%, 4%, 6%, 8% and 10% lime contents.

Picture 4-2 Moisture Density Test of the Lime-Laterite Mixture

The test results revealed that the maximum dry density and optimum moisture content of the laterite – lime mixtures increase with the increase in the lime content. The MDD of the laterite – lime mixture increased from 1.68g/cc to 1.77g/cc while the OMC increased from 18.8% to 22%.The increase in the density could be attributed to the increase in the amount of the flocculated particles, which in turn was caused by the increase in the concentration of the lime in the mixture. The increase in OMC, on the other hand could be due to the demand for extra water to compensate the water lost through the cation exchange process. The summaries of the test results are presented in Figure 4.2 and Table 4.6.



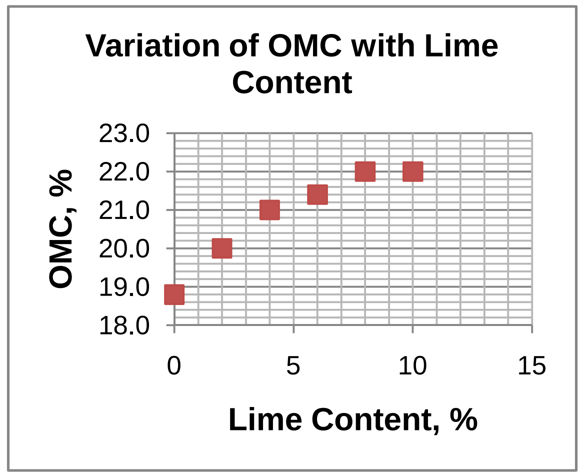


Figure 4-2 Variations of MDD and OMC with Lime Content, % by Weight

Table 4.6 MDD and OMC of the Laterite-Lime Mixtures

Lime Content (% by wt)	MDD (g/cc)	OMC (%)
0	1.68	18.8
2.0	1.68	20.0
4.0	1.73	21.0
6.0	1.75	21.4
8.0	1.76	22.0
10.0	1.77	22.0

4.3.4 Unconfined Compression Test of the Laterite – Lime Specimen

The purpose of the unconfined compression test is to measure the strength of the compacted laterite – lime specimen. In this study, the test was carried out according to ASTM D 5102, in which 4-inch (101.6mm) diameter and 4.584-inch (116.4mm) mold is used for preparing the compacted specimen.

The compacted specimens were prepared per ASTM D 1557. The molded specimens were cured by covering them with plastic sheets for twenty-eight days. At the end of the curing period, the specimens were subjected to unconfined compression tests. The compressive strength of the specimens was then calculated by dividing the maximum compressive load with the cross sectional area of the specimens. The testing procedures are presented in Picture 4.3.

Picture 4-3 Unconfined Compression Test and Test Specimen Preparation

Since 4-inch mold was used, the length-to-diameter ratios (L/D) of the specimens are less than two. Consequently, the compressive strength of these specimens needs to be reduced using certain correction factors. The reduction factors in ASTM C 39 /

AASHTO T 22 were utilized to correct the compressive strength of the specimens in this study. According to ASTM C 39 / AASHTO T 22, the correction factors in Table 4.7 are recommended for various L/D ratios, and interpolated factors are suggested for values not given in the Table.

Table 4.7 ASTM Correction Factors

Length-to-Diameter Ratio [L/D]-X	**Strength Correction Factors-Y**
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87
Interpolating Equation	$Y=0.213X^3-1.04X^2+1.7667X-0.07$

The unconfined compressive strength of the specimens of the five trial mixes are shown in Table 4.8 and the detail test results are attached as Appendix I-C.

The unconfined compressive strength of the laterite increased with the lime content. This increase can be attributed to the cation exchange and pozollanic reaction from the use of lime. The UCS of the laterite increased, after applying correction factors, from 0.50 MPa to 5.43 MPa when treated with lime. The summary of the test results is presented in Table 4.8 below.

Table 4.8 Unconfined Compressive Strength of the Compacted Laterite-Lime Specimen

Lime Content [%]	Compressive Strength (MPa) Specimen ~ with L/D ratio less than 2	Corrected Compressive Strength [MPa] Specimen ~ with L/D ratio = 2
2.0	0.55	0.50
4.0	1.90	1.73
6.0	3.40	3.10
8.0	4.75	4.33
10.0	5.94	5.43

4.3.5 Wetting and Drying Test on the Literite – Lime Specimen

Wetting and drying test is one of the durability tests which are used to determine the resistance of the compacted soil-lime specimen to extreme weathering conditions. The weathering conditions in this test method are simulated by frequent wetting and drying of the specimens. The test was conducted according to ASTM D 559. With this test the soil-lime losses, water content changes and volumetric changes (swell and shrinkage) of the soil-lime specimen can be identified.

In this study, wetting-drying test was preferred to the Freeze-thaw test because the study area is characterized by hot and humid climate and wet season. Hence, the wet-dry test better simulates the conditions in the study area.

The test is carried out in at least two compacted soil-lime specimens after seven days curing period. One of these specimens is control specimen and the remaining is soil-lime loss specimen. The specimens were submerged in poTable water for 5-hours at room temperature and then they were surface dried, weighed and measured, and put in an oven at 71^{o}C for 42 hours. Once dried, the specimens were removed from the oven and weighed and measured after they were allowed to cool. The soil-lime loss specimen is then scratched with two firm strokes of a wire-brush within its full height and width. The specimens were then weighed and measured and the process was repeated 12-times. After the 12-cycle process, the specimens were oven-dried at 110^{o}C to constant weight. The data collected in due course were then used to compute the volume and water change of the control specimen and the soil-lime loss of the remaining specimens.

In the subject case, wet-dry test was carried out in the compacted soil-lime specimens with 8% and 10% lime contents as these specimens have strengths close to the minimum required for base course. Two specimens were molded for the wet-dry test, of which one was control and one was soil-lime loss.

The results of the wet-dry test of the two trial mixtures are summarized in Table 4.9 and detail test results are attached as Appendix I-C.

Table 4.9 Summary of the Wet-Dry Test Results

Lime Content (%)	Design		Actual		Max. Vol. Change [%]	Max. Water Content [%]	Soil-Lime Loss [%]
	MDD [g/cc]	OMC [%]	MDD [g/cc]	OMC [%]			
8	1.76	22.0	1.76	22.1	0.93	20.9	6.4
			1.75	21.9			
10	1.77	22.0	1.77	22.0	1.21	22.0	5.8
			1.77	21.8			

The laboratory test results of the wet-dry test indicated the total weight loss of the laterite specimens with 8% and 10% (by weight) of lime content are lower than the allowable maximum limit of 8% which is specified both in TM 5-822-14/AFMAN 32-8010 (Joint Departments of the US Army and Air Force, 1994) and ERA 2013 STS.

4.4 Cement Stabilized Laterite Material Test Results

As mentioned in section 4.3, the soil class of the untreated laterite material that has been used in this study is GM (silty gravel). For this type of soil, the initial cement content, recommended by the Joint Departments of the Army and Air Force manual (1194) as indicated in Table 2.6, is 7% of the weight of the dry soil. However, in this study, trial mixes were prepared with cement contents varying from 2% to 12%.The cement contents that are lower than 7% were tested because of two reasons. The first reason is the strengths of the laterite-cement specimen with the lower cement contents could be sufficient to meet the requirement of ERA 2013 STS for road base since the strength requirement is lower than the target set in this study. The second reason is to assess if the target strength can be attained with the cement content lower than the one recommended by the guideline. The tests that have been conducted on the trial mixes and the corresponding results are discussed in the following sections.

4.4.1 Laterite-Cement Mix Preparation

The laterite-cement mixture was prepared in accordance with ASTM D 558. Accordingly, the laterite was quartered and reduced to 3 to 4 kilograms. The fractions retained on No.4 (4.75mm) sieve were separated and soaked for 24-hours and those passing No.4 sieve were oven-dried to constant mass (first picture of Picture 4.4). The laterite-cement mixture was then prepared by first blending the oven-dry fraction with the ordinary Portland cement in the predetermined proportion (second picture of Picture 4.4). The blend was thoroughly mixed until uniform color has been observed. At this point, the soaked fraction was then surface-dried using towel and added to the mixture and mixed thoroughly until it is well combined and dispersed within the mixture (third and fourth pictures of Picture 4.4). Then predetermined amount of water was added to the blend and mixed thoroughly (fifth picture of Picture 4.4).

Picture 4-4 Preparation of Laterite-Cement Mixture

4.4.2 Atterberg Limit Tests on the Laterite – Cement Mixture

Atterberg limit tests were conducted on the prepared laterite-cement mixture for the same reasons that were explained in section 4.3.2.

The results of the Atterberg limit tests on the laterite-cement mixture are presented in Table 4.10.

Table 4.10 Atterberg Limit Tests of the Laterite-Cement Mixtures

Cement Content (% by wt)	Atterberg Limit Values		
	LL	PL	PI
0	49	29	20
2.0	48	29	19
4.0	46	29	17
6.0	44	30	13
8.0	38	31	7
10.0	36	31	5
12.0	34	31	4

The test results depicted that the liquid limit of the laterite material decreased from 49 to 34, while the plastic limit increased from 29 to 31, which in turn resulted in the reduction of the plasticity indices from 20 to 4 as the cement content increased from zero to 12%.

The reduction in the plasticity indices of the laterite-cement mixture could be attributed to the free lime ($Ca(OH)_2$) that is created when the tricalcium silicate and dicalcium silicate in the cement undergo hydration reaction. The free lime makes the clay fractions in the laterite to flocculate through the process of cation exchange. The chemical reactions that take place during the hydration of the cement components are shown in equations 4.1a and 4.1b.

$$3Ca.SiO_2 + H_2O \rightarrow 2CaO.SiO_2.H_2O + Ca(OH)_2 \quad (4.1a)$$

$$2Ca.SiO_2 + H_2O \rightarrow CaO.SiO_2.H_2O + Ca(OH)_2 \quad (4.1b)$$

The minimum plasticity index value of a modified soil for effective stabilization is 10% (Garber and Hoel, 2010; Yoder and Witczak, 1975). Effective stabilization with cement begins after the addition of 8% cement, as it can be seen from the results in Table 4.4. However, lower binder contents can be applied as far as the strength and durability requirements are fulfilled. Many agencies are reducing the design binder contents to less than 6% due the shrinkage cracking problem.

4.4.3 Moisture-Density Test on the Laterite – Cement Mixture

The moisture-density test was performed on the laterite-cement mixture in the same manner as the laterite-lime mixture as shown in Picture 4.5. The test was conducted to determine the optimum moisture content and the maximum dry density of the laterite-cement mixtures at each of the cement contents. In this study, six trial mixes were prepared with 2%, 4%, 6%, 8%, 10, and 12% cement contents. The results of the moisture-density tests are presented in Table 4.11.

Picture 4-5 Moisture Density Test of the Laterite-Cement Mixture

The maximum dry density of the laterite material increased with cement content. This increase with cement content can be attributed to the hydration of cement. The MDD of the laterite increased from 1.68g/cc to 1.81g/cc and the OMC of the laterite increased from 18.8% to 21.6% when treated with cement. The increase in OMC can be attributed to the requirement of more moisture that is needed for effective hydration of cement. The summary of the test results are presented in Figure 4.11 above and Table 4.11.

Likewise the laterite-lime mixtures, the maximum dry density and optimum moisture content of the laterite-cement mixtures increased with the increase of the cement content. The MDD of the laterite-cement mixture increased from 1.68g/cc to 1.81g/cc while the OMC increased from 18.8% to 21.6% .The main reason for the increase in the MDD could be the agglomeration of the finer fractions of the laterite due to the hydration reaction and cation exchange processes. The reason for the shift in the optimum moisture content of the laterite-cement mixture could be the same as that of the laterite-lime mixture. Compared to the laterite-lime mixtures, the laterite-cement mixtures have slightly higher MDD and slightly lower OMC. This could be because of the extra agglomeration that is imparted in the cement-laterite mixture due to the quicker rate of hydration reactions. That means, at any given time, the amount of agglomerated particles in the laterite-cement mixtures are higher than those in the laterite-lime mixtures. As a result, there will be more heavier and coarser particles (with lower surface area) in the laterite-cement mixtures than the laterite-lime mixtures. The summaries of the test results are presented in Figure 4.3 and Table 4.11.

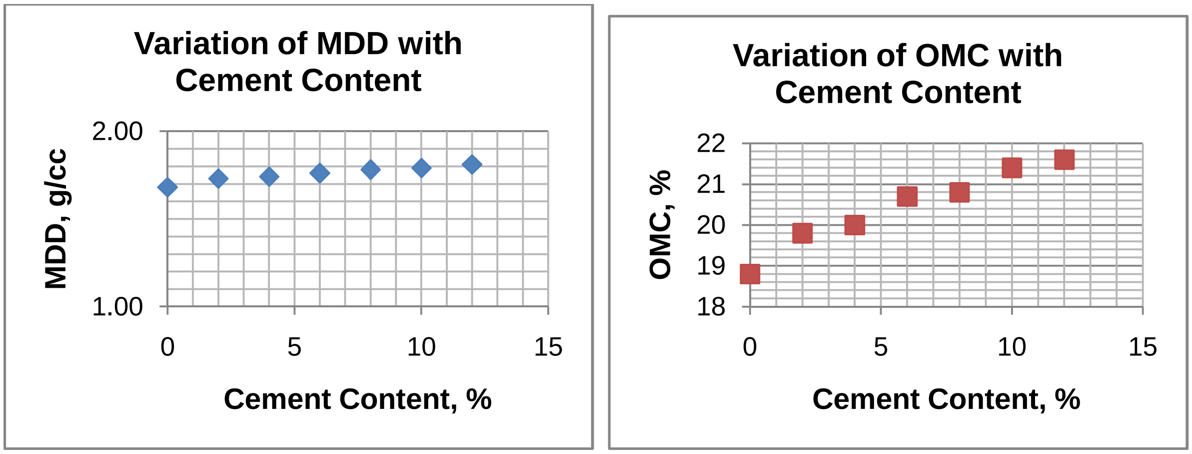


Figure 4-3 Variations of MDD and OMC with Cement Content, % by Weight

Table 4.11 MDD and OMC of the Laterite-Cement Mixtures

Cement Content (% by wt)	MDD (g/cc)	OMC (%)
0	1.68	18.8
2.0	1.73	19.8
4.0	1.74	20.0
6.0	1.76	20.7
8.0	1.78	20.8
10.0	1.79	21.4
12.0	1.81	21.6

4.4.4 Unconfined Compression Test of the Laterite – Cement Specimens

The purpose of the unconfined compression test is to measure the strength of the compacted laterite-cement specimens. In this study, the test was carried out according to ASTM D 1633, in which 4-inch (101.6mm) diameter and 4.584-inch (116.4mm) mold is used for preparing the compacted specimen (first and second picture of Picture 4.6).

The compacted specimens were prepared based on ASTM D 1557. The molded specimens were cured by covering them with plastic sheets for seven days (third picture of Picture 4.6). At the end of the curing period, the specimens were soaked in water for 4 hours and then subjected to unconfined compression tests (fourth picture of Picture 4.6). The compressive strength of the specimens (last picture of Picture 4.6) was then calculated by dividing the maximum compressive load with the cross sectional area of the specimens.

Picture 4-6 Unconfined Compression Test and Test Specimen Preparation

The length-to-diameter ratios (L/D) of the specimens are less than two because 4-inch mold was used. Therefore, the compressive strength of these specimens needs to be reduced using certain correction factors. In this study, the correction factors shown in Table 4.7 are used.

The unconfined compressive strength of the laterite increased with cement content. This increase with cement content can be attributed to the hydration reaction of the cement. The UCS of the laterite increased from 0.46 MPa to 6.22 MPa when treated with cement. The summary of the unconfined compressive strength of the specimens of the six trial mixes are presented in Table 4.12 and the detail test results are attached as Appendix I-D.

Table 4.12 Unconfined Compressive Strength of the Compacted Laterite-Cement Specimens

Cement Content [%]	Compressive Strength (MPa) Specimen ~ Specimen with L/D ratio less than 2	Corrected Compressive Strength (MPa) Specimen with L/D ratio = 2
2.0	0.50	0.46
4.0	1.87	1.70
6.0	3.23	2.95
8.0	4.72	4.31
10.0	5.98	5.47
12.0	6.82	6.22

As can be observed from the test results, the 7-days strength of the laterite-cement specimens are almost equivalent to the 28-days strength of the laterite-lime mixtures. This is because of the higher rate of hydration reaction in the cement-laterite specimens.

4.4.5 Wetting and Drying Test

The effect of wetting and drying on the laterite – cement specimens were investigated following the same testing procedures as indicated in section 4.3.5. Accordingly, the following results were obtained as summarized in Table 4.13 and the detailed test results are attached in Appendix I-D.

Table 4.13 Summary of the Wet-Dry Test Results

Cement Content (%)	Design		Actual		Max. Vol. Change [%]	Max. Water Content [%]	Soil-Cement Loss [%]
	MDD [g/cc]	OMC [%]	MDD [g/cc]	OMC [%]			
8	1.78	20.8	1.77	20.6	1.21	21.0	5.68
			1.77	20.7			
10	1.79	21.4	1.77	21.2	1.13	21.2	5.22
			1.79	21.4			

As can be seen from the laboratory test results, the total weight loss of the laterite specimens with 8% and 10% (by weight) of cement content are lower than the specified allowable maximum limit.

5 ANALYSIS AND COST COMPARISON

5.1 Optimum Binder Content Determination

The primary objective of the stabilization process is to determine the optimum binder content (OBC), so that the stabilized soil fulfills both the strength and durability requirements. Among the various approaches, in this study, the stabilization guidelines and the requirements that had been specified in TM 5-822-14/AFMAN 32-8010 (Joint Departments of the Army and Air Force, USA, 1994) were used for determining the OBC. This method was chosen for two reasons. The first reason is its consideration of both the strength and durability requirements; and the second is the simplicity of the specified tests. The tests, required to determine the OBC in this approach, can be performed in ordinary soil laboratory. Moreover, since the requirements set by this manual are higher than the requirements specified by most of other agencies, the OBC determined by using this manual will also fulfill the requirements of the other agencies. Hence, if the economic analysis of the OBC determined using this approach shows that it is feasible, then the OBC for the other agencies or standards will also be feasible than using crushed base course.

5.2 Optimum Binder Content for the Lime Stabilized Laterite

The unconfined compressive strength test results indicated that the unconfined compressive strength (UCS) of the soil-lime specimen increases linearly with the lime content. As shown in Table 4.7 and Figure 5.1, the UCS values increase from 0.50MPa at 2% cement to 5.43MPa at 10% lime contents. The minimum strength requirement of TM 5-822-14/AFMAN 32-8010 (Joint Departments of the US Army and Air Force, 1994) for stabilized road base is 5.2MPa. This requirement can be fulfilled by the laterite-lime mixtures with lime content of 10% and above.

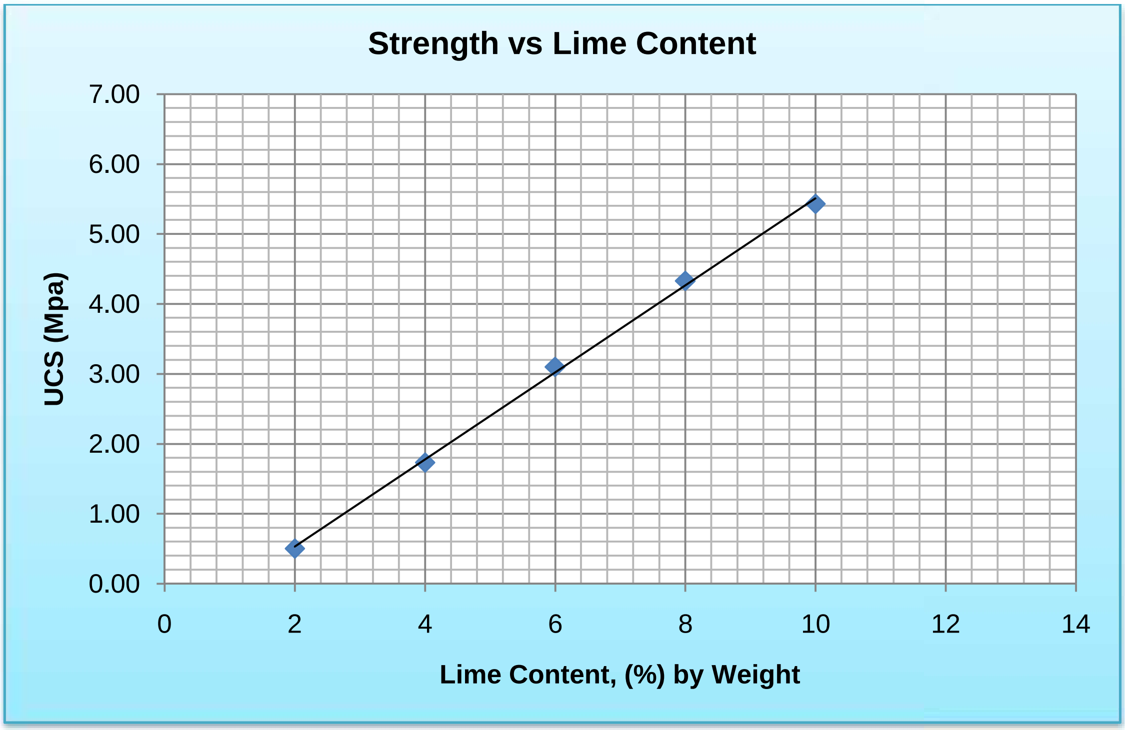


Figure 5-1 Variations of UCS Values of Soil-Lime Mixtures with Lime Content

The strengths of the trial mixes were also compared with the requirements of ERA 2013 STS. The UCS criteria in ERA 2013 STS were set in terms of the strength of the 150mm cube specimens. Hence, the UCS values of the trial specimens were converted to equivalent value of the 150mm cube specimens by using correction factors given by Road Note 31. Accordingly, the correction factors presented in Table 5.1 were used that are based on the height to diameter ratio of the specimens.

Table 5.1 Road Note 31 Correction Factors for Cube and Cylindrical Specimens

Sample Type (Ht.XDia.)	Height/Diameter	Correction Factor
200mmX100mm	2.0	1.25
115.5mmX105mm	1.1	1.04
127mmX152mm	0.8	0.96
116mmX102mm	1.15	1.05[1]

[1] interpolated factor for the actual sample type

The 150mm cube strengths of the trial mixtures are shown in Table 5.2.

Table 5.2 Adjusted Unconfined Compressive Strengths

Lime Content (%)	UCS of 116mm*102mm (MPa)	UCS of 150mm cube (MPa)
2.0	0.55	0.50
4.0	1.90	1.73
6.0	3.40	3.10
8.0	4.75	4.33
10.0	5.94	5.43
ERA STS Requirement	CB1	3.0 – 6.0
	CB2	1.5 – 3.0

As can be seen in Table 5.2, the UCS requirement of ERA 2013 STS for CB1 type of road base is satisfied by a laterite – lime mixture with 6% (by weight) or more lime content. Likewise, the UCS requirement of ERA STS for CB2 type of road base is satisfied by a lime-laterite mixture with 4% (by weight) or more lime content.

As explained in section 4.3.5, specimens of laterite – lime mixtures with 8% and 10% (by weight) of lime contents were subjected to the 12-cycle wet-dry test. The results of the 12-cycle wet-dry test showed that the losses on the weight of the tested specimens with 8% and 10% lime contents are 6.4% and 5.8%, respectively. These are lower than the allowable maximum limit of 8% which was specified both in TM 5-822-14/AFMAN 32-8010 of the US Army and Air Force and ERA STS.

Thus, the optimum lime content that is required to fulfill the requirements of TM 5-822-14/AFMAN 32-8010 of the US Army and Air Force is 10% by weight of the laterite-lime mixture; while the optimum lime content to fulfill the requirements of ERA STS is 4% by weight or more of the laterite-lime mixture, as shown in Table 5.3.

Table 5.3 Optimum Binder Content of Laterite – Lime Mixture

Criteria		Optimum Binder Content (%)	Strength at OBC, MPa
TM 5-822-14/AFMAN 32-8010 of US Army and Air Force	5.17	10.0	5.43
ERA STS	3.0 – 6.0 for CB1 1.5 – 3.0 for CB2	6.0 for CB1 4.0 for CB2	3.10 1.73

5.3 Optimum Binder Content of the Cement Stabilized Laterite

The unconfined compression test results indicated that the unconfined compressive strength (UCS) of the soil-cement specimens increases linearly with the cement content. As shown in Table 4.13 and Figure 5.2, the UCS values increase from 0.46 MPa at 2% cement to 5.74 MPa at 12% cement contents. The minimum strength requirement of TM 5-822-14/AFMAN 32-8010 for stabilized road base is 5.2MPa. This requirement is attained by the laterite-cement mixtures with cement content of 10% or more, by weight of the total mixture.

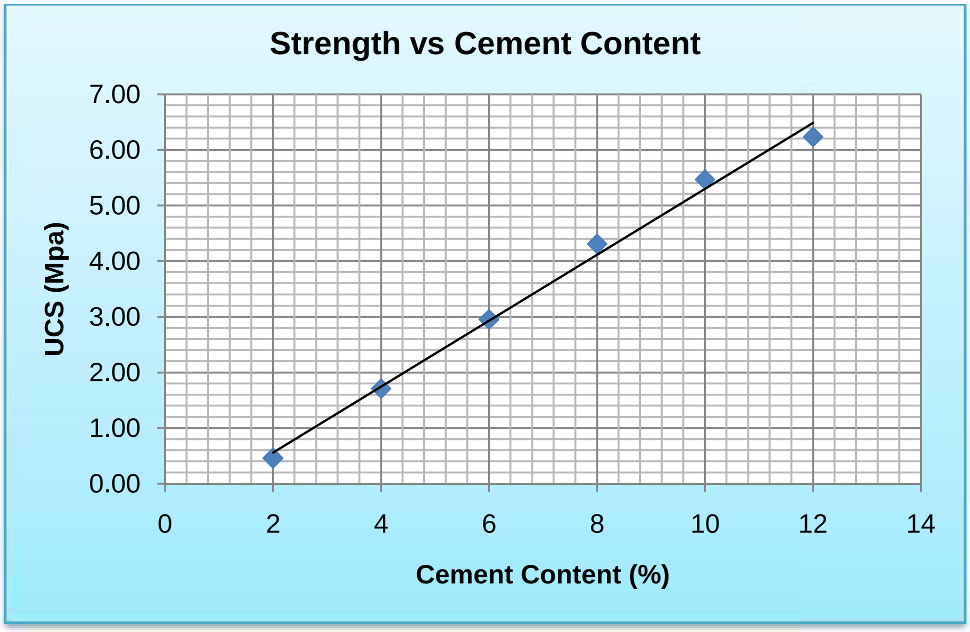


Figure 5-2 Variations of UCS Values of Soil-Cement Mixtures with Cement Content

The strengths of the trial mixes were also compared with the requirements of ERA 2013 STS. This was done by converting the UCS values of the cement stabilized cylindrical specimens to the equivalent UCS values of 150mm cube specimens by using the correction factors, presented in Table 5.1 above. The 150mm-cube strengths that were computed in such a manner for each of the trial mixtures are shown in Table 5.4.

Table 5.4 Adjusted Unconfined Compressive Strength

Cement Content (%)	UCS of 116mm*102mm (MPa)	UCS of 150mm cube (MPa)
2.0	0.50	0.53
4.0	1.87	1.97
6.0	3.23	3.39
8.0	4.72	4.96
10.0	5.98	6.29
12.0	6.82	7.17
ERA STS Requirement	CB1	3.0 – 6.0
	CB2	1.5 – 3.0

It can be observed from Table 5.4 that the UCS requirement of ERA 2013 STS for CB1 type of road base is satisfied by a laterite – cement mixture having 6% or more (by weight) cement contents. For CB2 type road base, the UCS requirement of ERA 2013 STS can be attained by a laterite-cement mixture having 4% (by weight) or more cement content.

As mentioned in section 4.4.5, the wetting and drying tests were performed on the specimens of laterite – cement mixtures having 8% and 10% of cement content. The test results indicated that the total weight losses of the laterite – cement specimens with 8% and 10% cement content are 5.7% and 5.2%, respectively. These are lower than the allowable maximum limit of 8% which is specified both in TM 5-822-14/AFMAN 32-8010 (1994) and ERA 2013 STS. Thus, both mixtures fulfill the durability requirement.

Accordingly, the optimum cement content that is required to attain the requirements of TM 5-822-14/AFMAN 32-8010 (1994) is 10%; while the optimum cement content that is needed to satisfy the ERA 2013 STS requirement is 4% as shown in Table 5.5.

Table 5.5 Optimum Binder Content of the Laterite – Cement Mixture

Criteria		Optimum Binder Content (%)	Strength at OBC, MPa
TM 5-822-14/AFMAN 32-8010 of US Army and Air Force	5.17	10.0	6.29
ERA STS	3.0 – 6.0 for CB1 1.5 – 3.0 for CB2	6.0 for CB1 4.0 for CB2	3.39 for CB1 1.97 for CB2

Generally, higher stabilizing contents are not recommended in the stabilized materials as such mixtures become very stiff when placed, and often exhibit shrinkage cracking. To mitigate the problem of shrinkage cracking, which is inevitable especially in cement stabilized materials, state of the art practices like micro-cracking or pre-cracking are recommended to be applied during the construction work.

In flexible pavement with bituminous surfacing, the shrinkage cracks in the base layer can cause reflective cracks on the surfacing layer. The reflective cracks will in turn accelerate premature failure of the pavement. Thus, strength of the stabilized materials is not required to go beyond certain optimum limit as the materials become brittle otherwise and fail prematurely. Based on this premise, the design requirements of ERA 2013 STS are better than the requirements of the Joint Departments of the US Army and Air Force Manual (1994).

A research made in Thailand proved that cement stabilized laterite can be used as road base (TRL, 2012). Additionally, a research made in Legon, Ghana showed that cement stabilized laterite material can be used as both base and sub base courses (Achampong et al, 2013). Similarly, the findings of this research study highlighted that the abundantly available laterite found in the study area can be upgraded to serve as road base material for road base construction for any kind of road standard.

5.4 Cost Comparison

Cost advantage of the stabilized road base was done in comparison to the utilization of the crushed granular road base. Alternative pavement structures, which accommodate T3 traffic load over S4 subgrade, were selected from structural catalogue of ERA 2013 PDM. The T3 (0.7-1.5m ESA) traffic class and S4 (8% – 15% design CBR) subgrade class were used based on the previous data found from the study conducted in the study area (CORE, 2007). The pavement structures that were used in the present study for the cost comparison are shown in Table 5.6.

Table 5.6 Pavement Structures for Evaluating the Stabilized Road Base against Granular Road Base

Unbound Granular vs Stabilized Road base Pavement Structure			
Chart A1, ERA PDM 2013		**Chart A3, ERA PDM 2013**	
Subgrade Class: S4		Subgrade Class: S4	
Traffic Class: T3		Traffic Class: T3	
Structural Layer	**Thickness (mm)**	**Structural Layer**	**Thickness (mm)**
DBST	30	DBST	30
Granular Road base	225	Cement/Lime-Stabilized Road base, CB2	175
Granular Sub base	275	Cement/Lime-Stabilized Sub base, CS	175

The general principles that are currently being practiced in the country to determine rates were used to fix the rates used in this study. The materials, manpower, and equipment costs that would be involved during material production/purchase, haulage, and placement were used to calculate the unit rates for each of the materials in the pavement structural layers. Additionally, it was assumed that 500m road base is constructed per day for each type of materials (granular or stabilized) to fix the rates. Then the unit rates are attached for each of the structural layers. Finally, the per km cost of the pavement structure with crushed granular road base was compared against the same cost of the pavement structure with the stabilized road base.

5.4.1 Crushed Aggregate Road Base

The unit rate per cubic meter of the crushed aggregate was fixed by making the following assumptions of daily activities:

- 400m^3 of quarry rock is produced;
- 400m^3 of the quarried rock is hauled to the crusher plant, which is to be installed at 2km away from the quarry;
- 400m^3 of rock is crushed;
- 400m^3 of the crushed aggregate is hauled to the site of placement, which is on average 24km away from the crusher plant;
- 800m^3 of compacted base layer is placed over 500m stretch.

The latest material, manpower, and equipment rates found during the preparation of the study were used to estimate the costs of each of these activities. The costs so determined were increased by 35% to account for the overhead, profit, and other contingencies. The summary of the unit rates is presented in Table 5.7 below and the detailed unit rate determination for the crushed aggregate base course is attached as Appendix II-A.

Table 5.7 Summary of Unit Rate Determination for Granular Road base

Activities	Unit Rate (ETB/m^3)
Quarry rock production	79.64
Quarried rock haulage to crusher	41.15
Rock crushing	236.65
Crushed aggregate haulage to the site	74.30
Stockpiling crushed aggregate	26.29
Base course mixing	21.34
Base course hauling	99.07
Base course placing	229.8
Total Cost of Granular Road base Construction	**808.24**

5.4.2 Lime Stabilized Laterite Road Base

In determining the unit rate of the lime treated laterie road base, the in-place mixing of the laterite and lime was considered. It was assumed that 1156 quintal of lime and 680m^3 of laterite are hauled to the site to produce 748m^3/day of loose laterite-lime mixture, which is then placed to be 598m^3/day of compacted literite treated road base. The rate determination for the lime stabilized road base is detailed in Appendix II-B and summarized in Table 5.8.

Table 5.8 Summary of Unit Rate Determination for Lime Stabilized Laterite Road Base

Activities	Unit Rate (ETB/m^3)
Material production (laterite)	25.58
Hauling (laterite and lime)	56.58
Base course placing (laterite and lime)	1,073.87
Total Cost of Lime Treated Laterite Road base Construction	**1,156.03**

5.4.3 Other Structural Layers

The unit rates for the other structural layers of the pavement structure were also carried out to determine the rates. These rates are shown in Table 5.9 and the detailed analyses are shown in Appendix II-A and B.

Table 5.9 Unit Rates of other Structural Layers

Structural Layer	Unit	Unit Rate
Double Surface Treatment	ETB/m^2	155.12
Granular Sub base	ETB/m^3	183.33
Lime-stabilized Sub base	ETB/m^3	765.43

5.4.4 Cost Comparison

The above calculated rates were used to determine the costs of the pavement structures that are shown in Table 5.10.

Table 5.10 Comparison of the Cost of Pavement with Crushed Granular Base against Pavement with Lime-Bound Road Base

Crushed Granular Road Base vs Lime-Bound Road Base											
Pavement with Crushed Granular Road Base						**Pavement with Lime-Bound Road Base**					
Structural Layers	**Thickness (mm)**	**Quantity/ km**	**Unit**	**Rate**	**Cost/km**	**Structural Layers**	**Thickness (mm)**	**Quantity /km**	**Unit**	**Rate**	**Cost/km**
DBST	-	7,000	m^2	155.12	1,023,050.00	DBST	-	7,000	m^2	155.12	1,085,809.99
Granular Road base	225	1,642.5	m^3	808.24	1,844,226.00	Lime Stabilized road base	175	1277.5	m^3	1,156.03	1,476,833.82
Granular Sub base	275	2,062.5	m^3	183.33	721,996.00	Lime Stabilized Sub base	175	1312.5	m^3	765.43	1,004,620.71
				Total Cost/km =	**2,791,457.14**					**Total Cost/km =**	**3,567,264.52**

The cost analyses were conducted assuming that the sound rock quarries are available within a distance of 2km from the road alignment. This is a very favorable scenario which happens very rarely in actual practice. This scenario was considered in the cost analyses to check whether the stabilized laterites could be a feasible option under such an ideal condition. Nevertheless, the utilization of lime-treated laterite material was found not to be feasible under the assumed favorable scenario because of the current high market price of lime during the study period.

The market price of lime was higher than the price of cement during the study period because the demand for lime was lower (Derba company information). Derba Cement Factory produced lime based on need base (demand), hence the production cost of lime was higher since it was not being produced at full scale which didn't give economies of scale to reduce the price.

Additional analysis was made to check the minimum hauling distance, from the quarry source to the crusher, which is required to make the lime-stabilized laterite a feasible option. Accordingly, the lime treated laterite became feasible alternative when the distance between the source of the crushed rock and the road alignment is above 84km, as shown in Table 5.11.

5.11 Comparison of the Cost of Pavement with Crushed Granular Base against Pavement with Lime-Bound Road Base for 84km Hauling Distance

Crushed Granular Road Base vs Lime-Bound Road Base											
Pavement with Crushed Granular Road Base						Pavement with Lime-Bound Road Base					
Structural Layers	**Thickness (mm)**	**Quantity/ km**	**Unit**	**Rate**	**Cost/km**	**Structural Layers**	**Thickness (mm)**	**Quantity/ km**	**Unit**	**Rate**	**Cost/km**
DBST	-	7,000.0	m^2	155.12	1,085,809.99	DBST	-	7,000.0	m^2	155.12	1,085,809.99
Granular Road base	225	1,642.5	m^3	1,271.56	2,088,536.58	Lime Stabilized road base	175	1277.5	m^3	1,156.03	1,476,833.82
Granular Sub base	275	2,062.5	m^3	183.33	378,113.67	Lime Stabilized Sub base	175	1312.5	m^3	765.43	1,004,620.71
Total Cost/km =					**3,552,460.24**	**Total Cost/km =**					**3,567,264.52**

5.4.5 Cement Stabilized Laterite Road Base

In determining the unit rate of the cement treated laterite road base, the same assumptions as considered for the lime treated laterite were considered and the rate determination is detailed in Appendix II-C and summarized in Table 5.12.

Table 5.12 Summary of Unit Rate Determination for Cement Stabilized Laterite Road Base

Activities	Unit Rate (ETB/m^3)
Material production (laterite)	25.58
Material hauling (laterite and cement)	56.58
Base course mixing, placing and curing (laterite and cement)	648.15
Total Cost of Cement Treated Laterite Road Base Construction	**730.31**

5.4.6 Cost Comparison

The above calculated rates were used to determine the costs of the pavement structures that are shown in Table 5.13 below.

Table 5.13 Comparison of the Cost of Pavement with Crushed Granular Base against Pavement with Cement-Bound Road Base

Crushed Granular Road Base vs Cement-Bound Road Base											
Pavement with Crushed Granular Road Base						Pavement with Cement-Bound Road Base					
Structural Layers	Thickness (mm)	Quantity/ km	Unit	Rate	Cost/km	Structural Layers	Thickness (mm)	Quantity /km	Unit	Rate	Cost/km
DBST	-	7,000	m^2	155.12	1,085,809.99	DBST	-	7,000	m^2	155.12	1,085,809.99
Granular Road base	225	1,642.5	m^3	808.24	1,327,533.48	Cement Stabilized road base	175	1,275.5	m^3	730.31	932,973.32
Granular Sub base	275	2,062.5	m^3	183.33	378,113.67	Cement Stabilized Sub base	175	1,312.5	m^3	509.99	669,364.56
Total Cost/km =					**2,791,457.14**	**Total Cost/km =**					**2,688,147.56**

As shown in Table 5.13 above, the pavement structure with cement bound base is cheaper than the pavement structure with crushed granular road base. There is a 3.7% financial saving from the pavement structure that comes from using stabilized laterite.

From the cost comparison, it can be observed that utilization of cement-treated laterite material, when it is readily available, is an economically feasible alternative for the construction of road-base layers. It should be emphasized that the cost analyses were conducted assuming that the sound rock quarries are available within a distance of 2km from the road alignment. This is a very favorable scenario which happened very rarely in actual practice. This scenario was considered in the cost analyses to check whether the stabilized laterites could be a feasible option under such an ideal condition. Therefore, it can be inferred that cost of cement-stabilized laterites could become much cheaper than the granular road base when quarried rocks have to be hauled for more than 2km, which is the case in most instances. Therefore, upgrading and using laterites for base course construction should be considered as one of the economically feasible options during the design and construction of roads in areas where laterites are available in abundant quantity.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

For this study, laterite materials from three sources around Asosa were selected to be stabilized for road base. After the materials were confirmed to be laterites, the remaining samples were subjected to grain size analysis, Atterberg limits, moisture-density relation, and modified proctor 3-point CBR.

Compared to the requirements of ERA STS, the results of the particle size analysis indicated that the grading curve of the laterite lies outside (on the finer side) the specification envelop for sizes finer than 1mm. Furthermore, the Atterberg limit tests revealed that the combined laterite material has a plasticity index of 20 which is significantly greater than the specified value; and the CBR value of the laterite material at 98% MDD is much lower than the value specified in the specification. Hence, the qualities of the material needed to be upgraded by using appropriate stabilization techniques.

According to the guidelines in the Joint Departments of the US Army and Air Force manual (1994) and ERA Flexible Pavement Design Manual (2013), the appropriate stabilizers for the chosen laterite material are lime and cement. Hence, the stabilization of laterite was done using lime and cement using locally available grade 1 lime and ordinary Portland cement produced by Derba Cement Factory.

The Atterberg limit tests showed that the liquid limit of the treated laterite material decreased, while the plastic limit increased which resulted in the decrease of the plasticity index with the increase of the stabilizers (both lime and cement) content. The treated laterite became slightly non-plastic with 8% (by weight) or more of lime content and 10% (by weight) or more of cement content. As can be observed from the test results, the use of lime to treat the laterite was more effective in reducing the plasticity index than cement.

The maximum dry density and optimum moisture content of the treated laterite test results revealed that both the maximum dry density and optimum moisture content of the treated laterite increased with the increase in the lime and cement contents.

Compared to the laterite-lime mixtures, the laterite-cement mixtures have slightly higher MDD and slightly lower OMC.

The unconfined strength of the treated laterite specimens increased linearly with the increase of both lime and cement contents. As can be observed from the test results, the 7-days strength of the laterite-cement specimens are almost equivalent to the 28-days strength of the laterite-lime mixtures.

Among the various available approaches, the stabilization guidelines and the requirements that had been specified in TM 5-822-14/AFMAN 32-8010 (Joint Departments of the Army and Air Force, USA, 1994) were used in the study for determining the OBC for two reasons. The first reason is its consideration of both the strength and durability requirements; and the second is the simplicity of the specified tests. In addition, since the requirements set by this manual are higher than the requirements specified by most of the other agencies, the OBC determined by using this manual is believed to fulfill the requirements of the other agencies. Hence, it can be inferred that the relative cost of the pavement structure with lesser OBC will become much cheaper than the cost used in the analysis for this study.

Accordingly, the optimum binder content for the stabilized laterite using both lime and cement was found to be 10% by weight. The stabilized laterite specimens, with 10% by weight of lime and cement, met both the strength and durability requirements set by Joint Departments of the Army and Air Force (1994). It can also be concluded that the laterite specimens with 10% (by weight) lime and cement contents will meet the requirements set by the other agencies (manuals) including ERA 2013 STS.

The 12-cycle wetting and drying test was preferred to the Freeze-thaw to determine the durability for this study. Accordingly, the test results indicate that the total weight losses of the laterite specimens with 8% and 10% (by weight) of lime and cement contents were lower than the allowable maximum limit of 8% which is specified both in Joint Departments of the US Army and Air Force (1994) and ERA STS (2013). Thus, these specimens fulfill the durability requirement.

Additionally, cost comparisons were made to assess the cost benefit of using stabilized road bases against using crushed granular base. Despite the very favorable assumption of the location of rock quarry for the crushed granular road base, utilization of cement-treated laterite material, when it is readily available, was found to be feasible alternative for the construction of road-base layers. Accordingly, it can be inferred that the cost of cement-stabilized laterites could become significantly cheaper than the granular road base when quarried rocks have to be hauled more than 2km, which is the case in most instances.

Nevertheless, the utilization of lime-treated laterite material was found not to have cost benefit under the assumed favorable scenario because of the current high market price of lime. The lime treated laterites could, however become a feasible alternative when the distance between the source of the crushed rock and the road alignment is above 84km.

Therefore, from this study, it was found out that it is possible to use laterite for road base construction by stabilizing it either with lime or cement. Hence, upgrading and using laterites for base course construction should be considered as one of the feasible options during the design and construction of roads in areas where laterites are available in abundant quantity.

6.2 Recommendations

Based on the results of this study, it is recommended that upgrading and utilization of the locally available laterite material shall be given due consideration for upcoming road construction projects in the study area or in other locations where laterite material is available.

Additional study should be carried out to evaluate the performance of pavement with stabilized laterite base layer with full scale road tests. Besides, further researches are recommended on the following topics, which are related to the use of laterite as a base course material:

- Prediction and quantification of the shrinkage cracking potential in stabilized laterites;
- Characterization of stabilized laterites for mechanistic-empirical pavement design; and
- Comparative evaluation of the performance of pavements with stabilized laterite road base against the performance of pavements with granular road base.

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APPENDICES

Appendix I Laboratory Test Results

Appendix I-A
Complete Silicate Analysis

Geological Survey of Ethiopia; Geoscience Science Laboratory Center Form G0004

Geochemical Laboratory Complete Silicate Analysis Report Format

FILE ID :- 6178/15 pvt Originator Kedamawit Germay

Sample type:- soil Date submmitted 24/03/2015

Preparation: -200 MESH **Element to be determined Major Oxides & Minor Oxides**

NUMBER OF SAMPLES: **3**

Analytical Method: LIBO2 FUSION , HFattack,GRAVIMETERIC and AAS

Analytical Results in PERCENT

FIELD NO	Lab No	SiO2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
B2	6178/15	40.12	26.15	15.58	0.24	<0.01	<0.01	0.98	0.08	0.14	1.91	2.56	11.19
B3	6179	37.15	31.40	13.9	0.14	0.03	<0.01	0.94	0.14	0.12	1.99	3.06	11.53
B4	6180	36.15	31.92	14.32	0.24	<0.01	<0.01	1.32	0.14	0.17	1.71	2.72	12.25

Analysts
Getahun Bikila
Tizta Zemene
Gosa Haile

Checked By

Geological Survey of Ethiopia Central Geological Laboratory

QUALITY CONTROL

WOREDE SAHILU

DATE REPORTED

18-11-15

Appendix I-B

Laterite

Sieve Analysis AASHTO Designation : T 27

Project : Thesis

Date Tested: 28/06/16

Sample of : Laterite

Station : Combined

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **11278**

Wt. of Oven Dry Sample After Washing (gm):- **9063**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
50			
37.5			100.0
25	1511	13.4	86.6
19	241.4	2.1	84.5
12.5	876.5	7.8	76.7
9.5	625.4	5.5	71.1
4.75	1512.6	13.4	57.7
2.36	1102.4	9.8	48.0
2.00	200.2	1.8	46.2
1.18	486.3	4.3	41.9
0.600	586.7	5.2	36.7
0.425	460.5	4.1	32.6
0.300	371.5	3.3	29.3
0.150	672.2	6.0	23.3
0.075	416.1	3.7	19.6
Passing 0.075	2215.0	19.6	

Remark :

Sieve Analysis AASHTO Designation : T 27

Project : Thesis

Date Tested: 28/06/16

Sample of : Laterite

Station : Combined

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **6327**

Wt. of Oven Dry Sample After Washing (gm):- **4775**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
50			
37.5			100.0
25	541	8.6	91.4
19	361.3	5.7	85.7
12.5	428.3	6.8	79.0
9.5	419.7	6.6	72.3
4.75	1004.6	15.9	56.5
2.36	624.4	9.9	46.6
2.00	117.8	1.9	44.7
1.18	282.9	4.5	40.3
0.600	318.7	5.0	35.2
0.425	188.5	3.0	32.2
0.300	127.6	2.0	30.2
0.150	236.6	3.7	26.5
0.075	123.3	1.9	24.5
Passing 0.075	1552.4	24.5	

Remark :

Sieve Analysis AASHTO Designation : T 27

Project : Thesis

Sample of : Laterite

Station : Combined

Date Tested: 28/06/16

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **5559**

Wt. of Oven Dry Sample After Washing (gm):- **4607**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
50			
37.5			100.0
25	506.6	9.1	90.9
19	142.7	2.6	88.3
12.5	452.8	8.1	80.2
9.5	400.1	7.2	73.0
4.75	868.4	15.6	57.4
2.36	476.4	8.6	48.8
2.00	76.2	1.4	47.4
1.18	201.3	3.6	43.8
0.600	383.1	6.9	36.9
0.425	398.6	7.2	29.7
0.300	261.4	4.7	25.0
0.150	301.3	5.4	19.6
0.075	138.4	2.5	17.1
Passing 0.075	951.2	17.1	

Remark :

Sieve Analysis AASHTO Designation : T 27

Project : Thesis

Sample of : Laterite

Station : Combined

Date Tested: 28/06/16

Wet Gradation

Wt. of Oven Dry Sample Before Washing (gm):- **4791**

Wt. of Oven Dry Sample After Washing (gm):- **3996**

Sieve Size (mm)	Wt. of Sample Retained	% Retained	% Passing
50			
37.5			100.0
25	230.4	4.8	95.2
19	329.8	6.9	88.3
12.5	742.4	15.5	72.8
9.5	500.4	10.4	62.4
4.75	859.4	17.9	44.4
2.36	470.3	9.8	34.6
2.00	78.1	1.6	33.0
1.18	148.7	3.1	29.9
0.600	187.2	3.9	26.0
0.425	106.5	2.2	23.8
0.300	99	2.1	21.7
0.150	151.7	3.2	18.5
0.075	92.3	1.9	16.6
Passing 0.075	795.2	16.6	

Remark :

Moisture Density Relation AASHTO Designation : T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO Designation : T 193 & Atterberg Limit AASHTO Designation : T 89-90 Tests

Project : Thesis

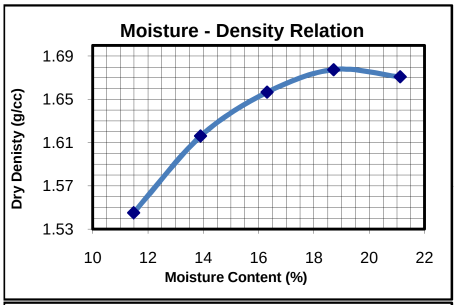
Sample of : Laterite Material

Station : Combined

Date Tested : 28/06/2016

Trial No.	1	2	3	4	5
Weight of Mould + Wet soil (g)	5800	5910	5990	6050	6080
Weight of Mould (g)	4200	4200	4200	4200	4200
Weight of Wet soil (g)	1600	1710	1790	1850	1880
Volume of Mould (cc)	929	929	929	929	929
Wet density (g / cm3)	1.72	1.84	1.93	1.99	2.02
Moisture Content Determination					
Weight of Wet soil + cont. (g)	268.3	246.6	226.1	264.7	212.1
Weight of Dry soil + cont. (g)	244.0	220.5	199.6	228.9	181.2
Weight of Container (g)	32.3	32.8	37.1	37.6	34.9
Weight of water (moisture) (g)	24.3	26.1	26.5	35.8	30.9
Weight of Dry soil (g)	211.7	187.7	162.5	191.3	146.3
Moisture content (%)	11.48	13.91	16.31	18.71	21.12
Dry Density (g / cm3)	1.54	1.62	1.66	1.68	1.67
MDD, g/cc		**1.68**	**OMC, %**		**18.8**

Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould, g	W1	11377	11680	11600	11790	10747	10974
Wt.of mould, g	W2	7700	7700	7400	7400	6320	6320
Wt.of wet sample, g	W3 = W1 - W2	3677	3980	4200	4390	4427	4654
Volume of mould, cc	V	2188	2188	2193	2193	2177	2177
Wet unit weight, g/cc	Dw = W3 / V	1.68	1.82	1.92	2.00	2.03	2.14
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.42	1.42	1.62	1.59	1.71	1.73
Moisture Content Determination							
Wt. of wet sample + cont., g	W3	281.9	234.3	323.6	298.7	217.6	266.3
Wt. of dry sample + cont., g	W4	243.8	190.2	278.5	244.5	186.8	220.2
Wt. of water, g	W5 = W3 - W4	38.1	44.1	45.1	54.2	30.8	46.1
Wt. of container, g	W6	37.3	35.7	35.7	36.7	23.8	23.9
Wt. of dry sample, g	W7 = W4 - W6	206.5	154.5	242.8	207.8	163	196.3
% Moisture Content	W8 = W5/W7*100	18.5	28.5	18.6	26.1	18.9	23.5



SWELL DATA (Surcharge Weight 4.5kg)

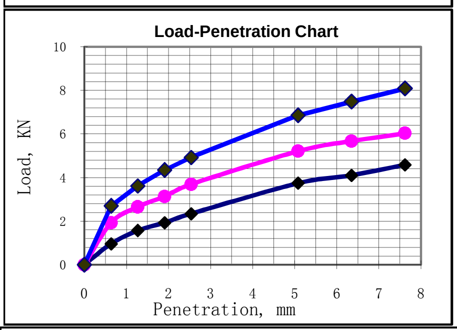
No. of Blows	10				30				65			
Initial Height of Sample: 116mm	Gauge reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	868	1085	2.17	1.87	804	991	1.87	1.61	790	955	1.65	1.42

CBR DATA

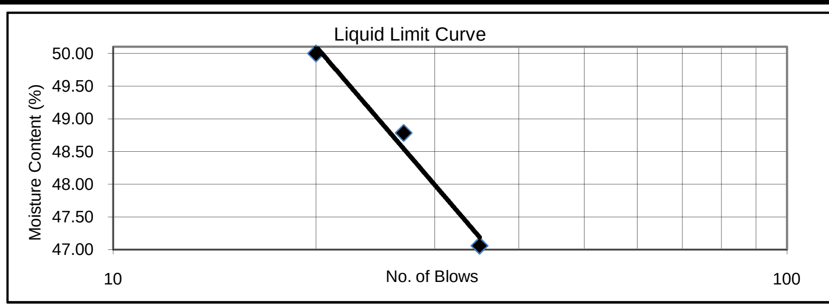
Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		40	0.97			80	1.93			112	2.70		
1.27		65	1.57			110	2.66			150	3.62		
1.91		80	1.93			130	3.14			180	4.35		
2.54	13	97	2.34	2.34	**18.0**	153	3.69	3.69	**28.4**	204	4.93	4.93	**37.9**
5.08	20	155	3.74	3.74	**18.7**	216	5.22	5.22	**26.1**	284	6.86	6.86	**34.3**
6.35		170	4.11			235	5.68			310	7.49		
7.62		190	4.59			250	6.04			335	8.09		

	10	30	65
Soaked CBR, %	18.7	28.4	37.9
Dry Density, g/cc	1.42	1.62	1.71
Swell, %	1.87	1.61	1.42

Density Requirement:	98%	Target Density:	1.65	CBR	31.5



	Liquid Limit			Plastic Limit	
No. of Blows	35	27	20		
Wt. of cont. + wet soil (g) = (w_1)	25.80	26.30	25.00	22.50	20.50
Wt. of cont. + dry soil (g.) = (w_2)	20.20	20.30	19.00	19.30	17.90
Wt. of container (g.) = (w_3)	8.30	8.00	7.00	8.40	9.00
Mass of moisture (g.) (w_1-w_2) = x	5.60	6.00	6.00	3.20	2.60
Wt. of dry soil (g.) (w_2-w_3) = y	11.90	12.30	12.00	10.90	8.90
Moisture Content (%) = (100x/y)	47.06	48.78	50.00	29.36	29.21
		49		**29**	
		Plasticity Index		**20**	



SUMMARY OF ATTERBERG LIMIT, MODIFIED PROCTOR DENSITY & 3-POINT CBR

Project : **Thesis**

Material Type : **Laterite**

Date : **10/7/2016**

Station : **Combined**

S/ No	Station (KM)	Material Description	Depth (cm)	AASHTO T 27 % Passing Sieve (mm)				AASHTO T 89 & 90 Atterberg Limit			Soil Classification	Proctor Density AASHTO T 180		3 - Point CBR AASHTO T 193					
				4.75	2.00	0.425	0.075	LL	PL	PI		MDD (g/cc)	OMC %	No of Blows	Dry Density (g/cc)	CBR %	Swell %	CBR at 98% MDD	Swell at 98% MDD
1	Combiined	Laterite (silty gravel)	50-200	58	46	33	20	49	29	20	A-2-7 (0) or GM	1.68	18.8	10	1.42	19	1.87	32	1.54
														30	1.62	28	1.61		
														65	1.71	38	1.42		

Appendix I-C

Laterite with Lime

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

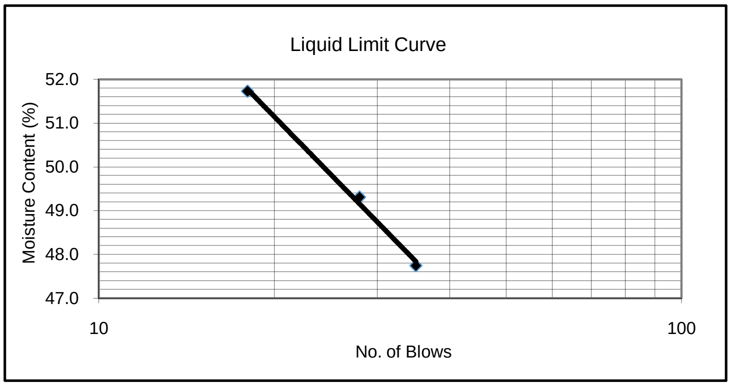
Project : **Thesis**

Sample of : **Laterite + 2% Lime**

Station **Combined**

Date Tested : **20/10/2016**

Number of blows	35	28	18			---
Wt.of Container +Wet soil (gm)	31.1	29.1	30.3		16	12.3
Wt.of Container +Dry soil (gm)	23.7	22	22.8		14.6	11
Wt.of water (gm)	7.4	7.1	7.5		1.4	1.3
Wt.of Container weight (gm)	8.2	7.6	8.3		9.7	6.8
Wt.of Dry soil (gm)	15.5	14.4	14.5		4.9	4.2
Moisture content %	47.7	49.3	51.7		28.6	31.0
				Average %	29.8	



Summary

L.L.: 48

P.L : 30

P.I.: 18

Soil classification : A-2-7 (9)

Remark:

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

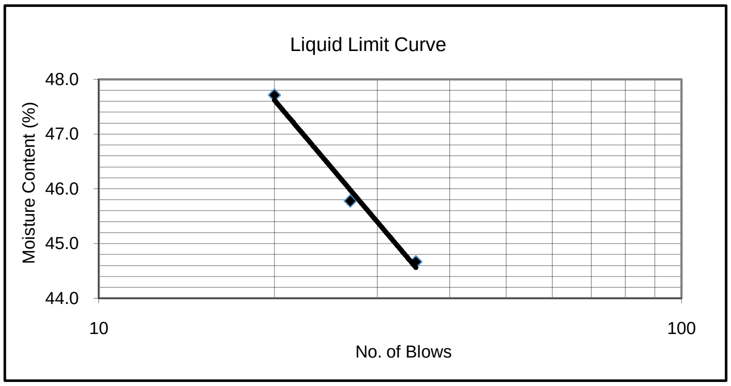
Project : **Thesis**

Sample of : **Laterite + 4% Lime**

Station **Combined**

Date Tested : **20/10/2016**

Number of blows	35	27	20			---
Wt.of Container +Wet soil (gm)	30.6	27.4	29.8		15.7	15.9
Wt.of Container +Dry soil (gm)	23.9	20.9	22.5		14.1	14.4
Wt.of water (gm)	6.7	6.5	7.3		1.6	1.5
Wt.of Container weight (gm)	8.9	6.7	7.2		8.9	9.5
Wt.of Dry soil (gm)	15	14.2	15.3		5.2	4.9
Moisture content %	44.7	45.8	47.7		30.8	30.6
				Average %	30.7	



Summary L.L.: 47

P.L : 31

P.I.: 16

Soil classification : A-2-7 (9)

Remark: ____________________

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

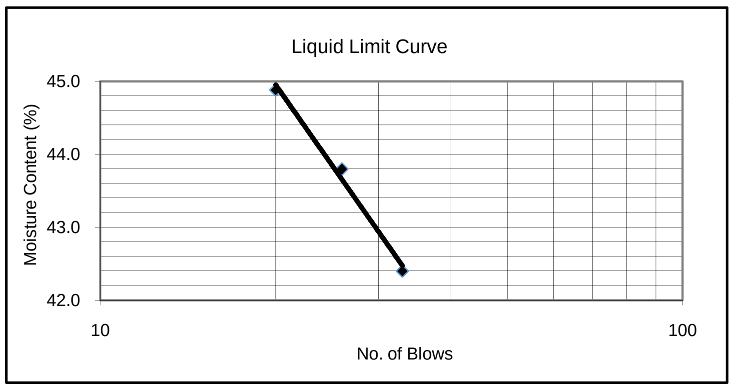
Project : **Thesis**

Sample of : **Laterite + 6% Lime**

Station **Combined**

Date Tested : **20/10/2016**

Number of blows	33	26	20			---
Wt.of Container +Wet soil (gm)	26.6	28	25.6		14.6	13.9
Wt.of Container +Dry soil (gm)	21.3	22	19.9		13.3	12.3
Wt.of water (gm)	5.3	6	5.7		1.3	1.6
Wt.of Container weight (gm)	8.8	8.3	7.2		9.2	7.3
Wt.of Dry soil (gm)	12.5	13.7	12.7		4.1	5
Moisture content %	42.4	43.8	44.9		31.7	32.0
				Average %	31.9	



Summary L.L.: 44

P.L : 32

P.I.: 12

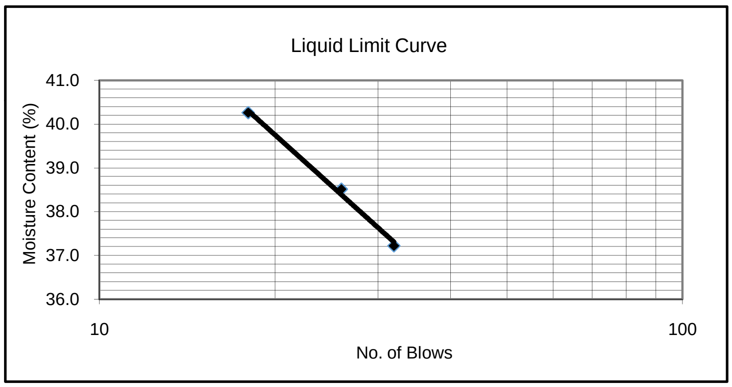
Soil classification : A-2-7 (9)

Remark: ____________________

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis**   Date Tested : **20/10/2016**
Sample of : **Laterite + 8% Lime**
Station **Combined**

Number of blows	32	26	18			---
Wt.of Container +Wet soil (gm)	33.7	29.2	28.6		13.9	16.3
Wt.of Container +Dry soil (gm)	27	23.5	22.4		12.5	14.7
Wt.of water (gm)	6.7	5.7	6.2		1.4	1.6
Wt.of Container weight (gm)	9	8.7	7		8.3	9.8
Wt.of Dry soil (gm)	18	14.8	15.4		4.2	4.9
Moisture content %	37.2	38.5	40.3		33.3	32.7
				Average %	33.0	



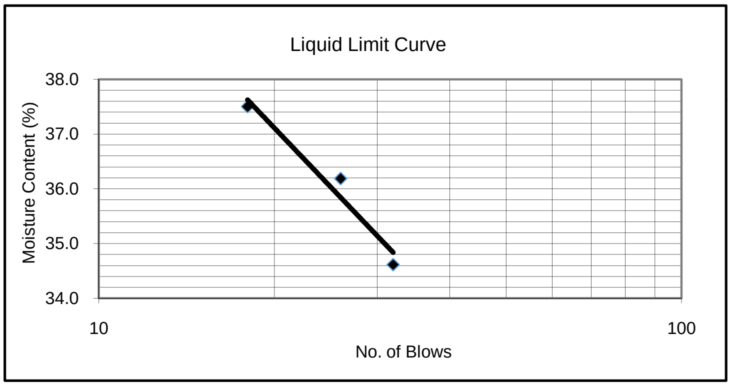
Summary L.L.: 39
P.L : 33
P.I.: 6
Soil classification : A-2-7 (9)

Remark:

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis** Date Tested : **20/10/2016**
Sample of : **Laterite + 10% Lime**
Station **Combined**

Number of blows	32	26	18			---
Wt.of Container +Wet soil (gm)	33.1	28.9	27.9		13.9	16.3
Wt.of Container +Dry soil (gm)	26.8	23.4	22.2		12.5	14.7
Wt.of water (gm)	6.3	5.5	5.7		1.4	1.6
Wt.of Container weight (gm)	8.6	8.2	7		8.3	9.8
Wt.of Dry soil (gm)	18.2	15.2	15.2		4.2	4.9
Moisture content %	34.6	36.2	37.5		33.3	32.7
				Average %	33.0	



Summary L.L.: 36
P.L : 33
P.I.: 3
Soil classification : A-2-7 (9)

Remark:

Moisture - Density Relation

ASTM D 1557 / 558

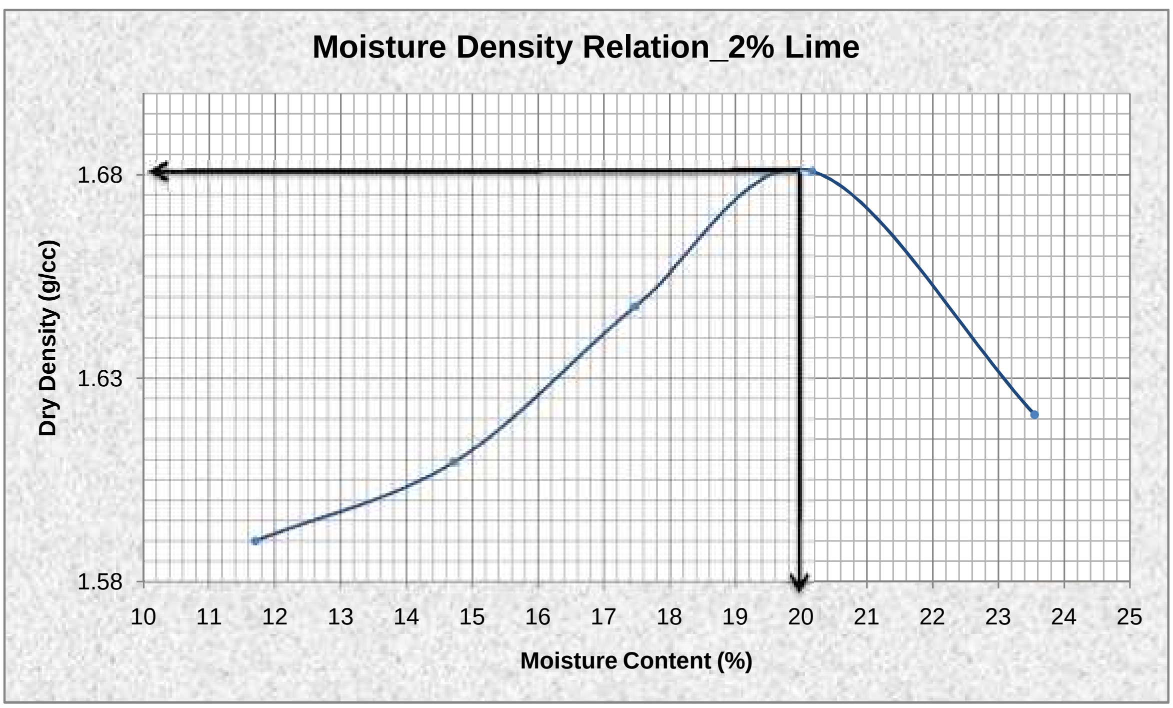
Project: Thesis

Date Tested: 20/10/16

Sample of: Laterite + 2% Lime

Station: Combined

TRIAL NO.	1	2	3	4	5
Weight of Mould + Wet soil (g)	5879	5945	6029	6108	6092
Weight of Mould	4210	4210	4210	4210	4210
Weight of Wet Soil (g)	1669	1735	1819	1898	1882
Volume (cc)	939.7	939.7	939.7	939.7	939.7
Wet density (g/cc)	1.78	1.85	1.94	2.02	2.00
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	290.20	326.04	298.66	295.17	278.60
Weight of Dry Soil + Cont. (g)	263.07	288.71	258.93	251.70	231.54
Weight of Container (g)	31.28	35.10	31.61	36.11	31.73
Weight of Water (moisture) (g)	27.13	37.33	39.73	43.47	47.06
Weight of Dry Soil (g)	231.79	253.61	227.32	215.59	199.81
Moisture Content (%)	11.70	14.72	17.48	20.16	23.55
Dry Density (g/cc)	**1.59**	**1.61**	**1.65**	**1.68**	**1.62**
	MDD (g/cc)		1.68	**OMC (%)**	20



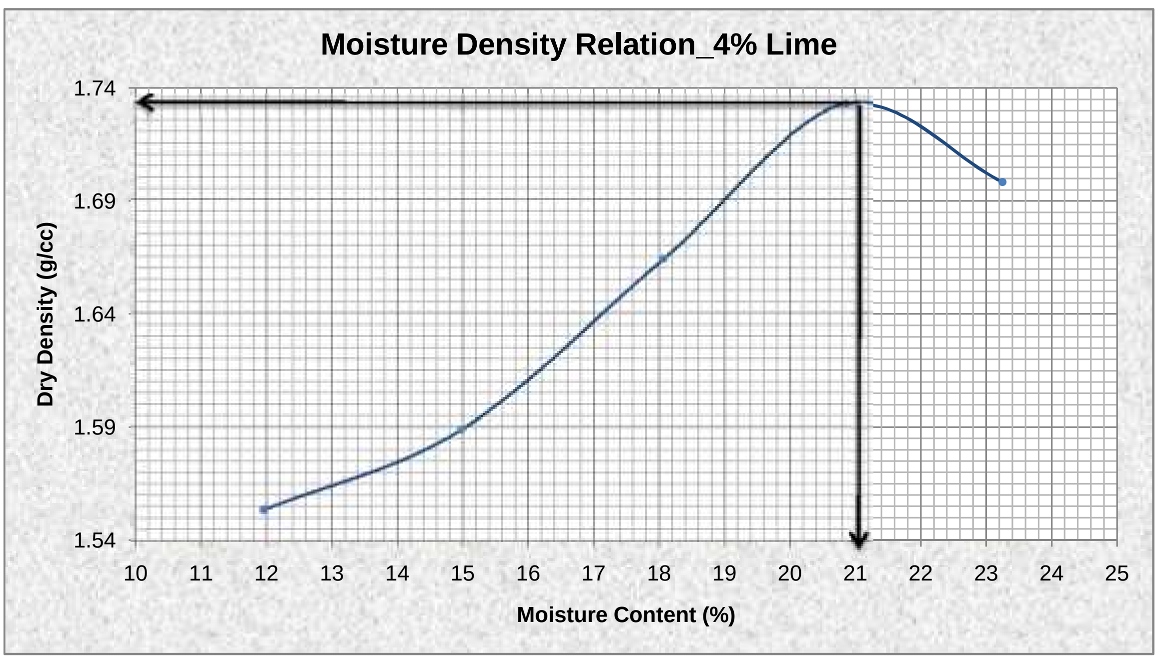
Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Sample of: Laterite + 4% Lime
Station: Combined

Date Tested: 20/10/16

TRIAL NO.	1	2	3	4	5
Weight of Mould + Wet soil (g)	5717	5798	5925	6044	6044
Weight of Mould	4111	4111	4111	4111	4111
Weight of Wet Soil (g)	1606	1687	1814	1933	1933
Volume (cc)	923.4	923.4	923.4	923.4	923.4
Wet density (g/cc)	1.74	1.83	1.96	2.09	2.09
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	336.13	335.76	311.34	286.06	298.71
Weight of Dry Soil + Cont. (g)	304.06	296.09	268.32	242.15	249.09
Weight of Container (g)	35.91	31.32	30.22	31.58	35.66
Weight of Water (moisture) (g)	32.07	39.67	43.02	43.91	49.62
Weight of Dry Soil (g)	268.15	264.77	238.10	210.57	213.43
Moisture Content (%)	11.96	14.98	18.07	20.85	23.25
Dry Density (g/cc)	**1.55**	**1.59**	**1.66**	**1.73**	**1.70**
	MDD (g/cc)		1.73	**OMC (%)**	21



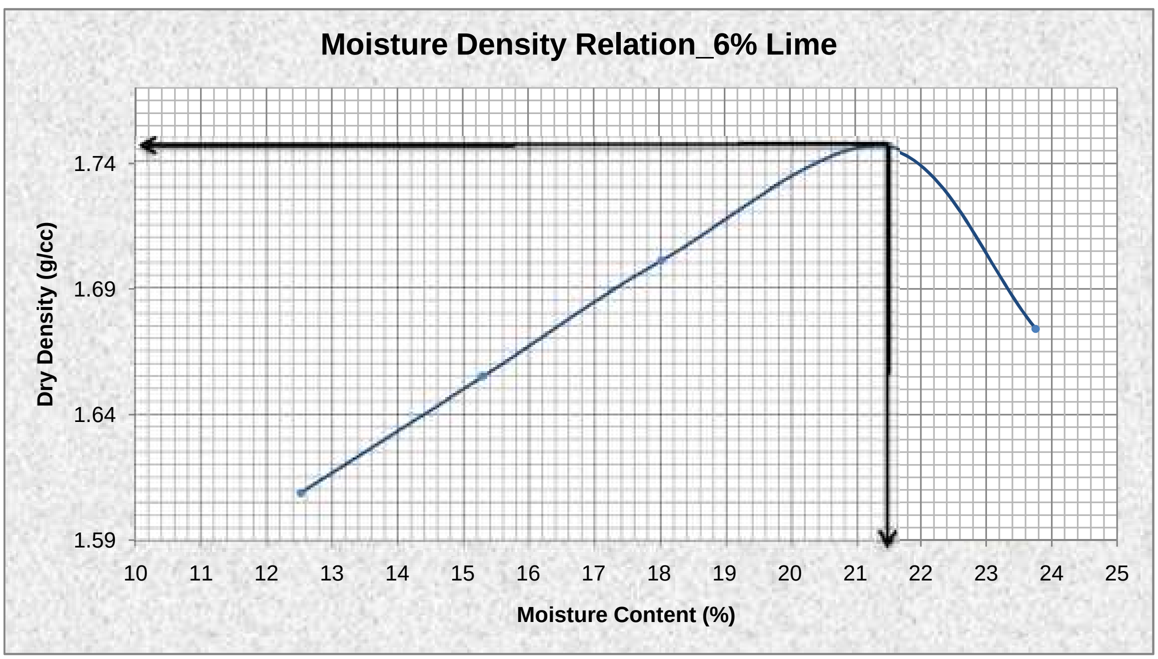
Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Sample of: Laterite + 6% Lime
Station: Combined

Date Tested: 20/10/16

TRIAL NO.	1	2	3	4	5
Weight of Mould + Wet soil (g)	5911	6003	6096	6203	6157
Weight of Mould	4210	4210	4210	4210	4210
Weight of Wet Soil (g)	1701	1793	1886	1993	1947
Volume (cc)	939.7	939.7	939.7	939.7	939.7
Wet density (g/cc)	1.81	1.91	2.01	2.12	2.07
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	316.45	315.43	255.67	264.12	292.40
Weight of Dry Soil + Cont. (g)	284.92	278.48	220.20	223.01	243.16
Weight of Container (g)	33.06	36.91	23.25	31.60	35.93
Weight of Water (moisture) (g)	31.53	36.95	35.47	41.11	49.24
Weight of Dry Soil (g)	251.86	241.57	196.95	191.41	207.23
Moisture Content (%)	12.52	15.30	18.01	21.48	23.76
Dry Density (g/cc)	**1.61**	**1.65**	**1.70**	**1.75**	**1.67**
	MDD (g/cc)		1.75	**OMC (%)**	21.4



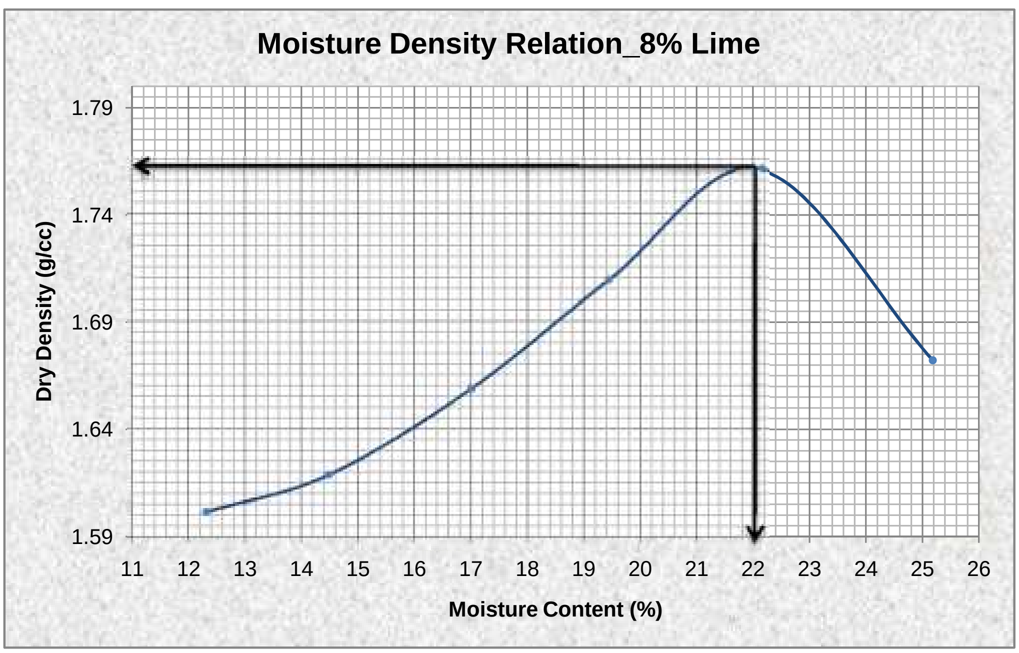
Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Sample of: Laterite + 8% Lime
Station: Combined

Date Tested: 20/10/16

TRIAL NO.	1	2	3	4	5	6
Weight of Mould + Wet soil (g)	5772	5822	5903	5996	6097	6044
Weight of Mould	4111	4111	4111	4111	4111	4111
Weight of Wet Soil (g)	1661	1711	1792	1885	1986	1933
Volume (cc)	923.4	923.4	923.4	923.4	923.4	923.4
Wet density (g/cc)	1.80	1.85	1.94	2.04	2.15	2.09
Moisture Content Determination						
Weight of Wet Soil + Cont. (g)	327.93	337.86	363.36	353.37	313.77	261.71
Weight of Dry Soil + Cont. (g)	295.75	299.79	315.42	302.01	262.81	215.18
Weight of Container (g)	34.45	36.87	33.51	37.84	32.86	30.43
Weight of Water (moisture) (g)	32.18	38.07	47.94	51.36	50.96	46.53
Weight of Dry Soil (g)	261.30	262.92	281.91	264.17	229.95	184.75
Moisture Content (%)	12.32	14.48	17.01	19.44	22.16	25.19
Dry Density (g/cc)	**1.60**	**1.62**	**1.66**	**1.71**	**1.76**	**1.67**
	MDD (g/cc)		1.76	**OMC (%)**	22.0	

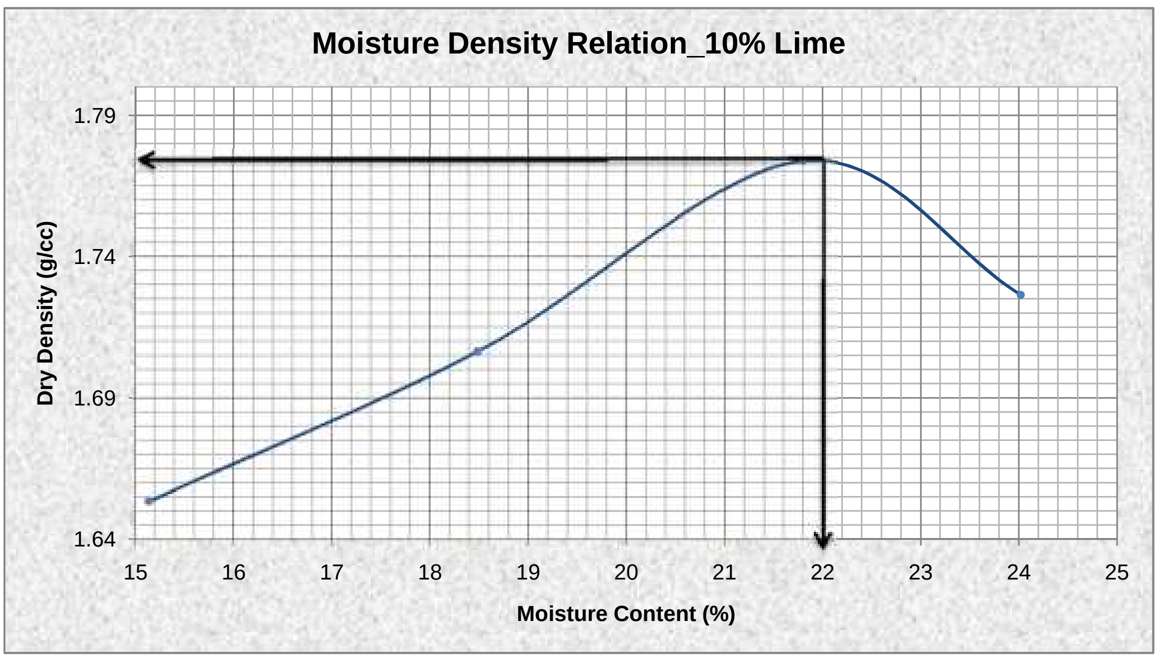


Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Date Tested: 20/10/16
Sample of: Laterite + 10% Lime
Station: Combined

TRIAL NO.	1	2	3	4	5
Water Added	50	150	150	150	
Weight of Mould + Wet soil (g)	5949	6060	6190	6172	
Weight of Mould	4160	4160	4160	4160	
Weight of Wet Soil (g)	1789	1900	2030	2012	
Volume (cc)	939.7	939.7	939.7	939.7	
Wet density (g/cc)	1.90	2.02	2.16	2.14	
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	347.18	320.02	301.75	312.75	
Weight of Dry Soil + Cont. (g)	306.15	274.65	254.80	259.28	
Weight of Container (g)	35.17	29.26	39.34	36.66	
Weight of Water (moisture) (g)	41.03	45.37	46.95	53.47	
Weight of Dry Soil (g)	270.98	245.39	215.46	222.62	
Moisture Content (%)	15.14	18.49	21.79	24.02	
Dry Density (g/cc)	**1.65**	**1.71**	**1.77**	**1.73**	
	MDD (g/cc)		1.77	**OMC (%)**	22.0



Compressive Strength of Molded Laterite - Lime Mixtures
ASTM D 5102

Project : **Thesis**
Sample of : **Laterite + 2% Lime**
Station **Combined**

Date Casted	**7/11/2016**	**10:00am - 11:30am**
Date Tested	**5/12/2016**	**10:30am - 11:30am**
Lime Content (% of Laterite)	**2**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.10	10.12	10.14	
Contact Area (cm2)	80.12	80.44	80.75	
Height (cm)	11.66	11.67	11.69	
Weight (g)	1888	1891	1909	
Weight (g) before applying load	1982	1986	1902	
Comp. Load (kN)	4.33	4.49	4.52	**4.45**
Comp. Strength (MPa)	0.54	0.56	0.56	**0.55**
Wt. Wet Soil (g) + cont	258.5	284.1	260.76	**Average**
Wt. Dry Soil (g) + cont	222.0	242.7	222.47	
Wt. of Cont (g)	39.34	35.7	32.2	
Wt. of Water (g)	36.5	41.4	38.29	
Wt of Dry Soil (g)	182.66	207	190.27	
MC(%)	19.98	20.00	20.12	**20.04**
Vol. comp. sp (cc)	934.18	938.69	944.02	**938.96**
Wet Density (g/cc)	2.02	2.01	2.02	**2.02**
Dry Density (g/cc)	1.68	1.68	1.68	**1.68**

Compressive Strength of Molded Laterite - Lime Mixtures
ASTM D 5102

Project : **Thesis**
Sample of : **Laterite + 4% Lime**
Station **Combined**

Date Casted	**7/11/2016**	**10:00am - 11:30am**
Date Tested	**5/12/2016**	**10:30am - 11:30am**
Lime Content (% of Laterite)	**4**	

Specimen No	**1**	**2**	**3**	
Diameter (cm)	10.11	10.11	10.13	**Average**
Contact Area (cm2)	80.28	80.28	80.60	
Height (cm)	11.65	11.7	11.71	
Weight (g)	1961	1962	1979	
Weight (g) before applying load	1959	1957	1970	
Comp. Load (kN)	15.54	15.08	15.24	**15.29**
Comp. Strength (MPa)	1.94	1.88	1.89	**1.90**
Wt. Wet Soil (g) + cont	259.41	286.06	270.76	**Average**
Wt. Dry Soil (g) + cont	219.6	242.4	229.47	
Wt. of Cont (g)	31.43	31.37	32.2	
Wt. of Water (g)	39.81	43.66	41.29	
Wt of Dry Soil (g)	188.17	211.03	197.27	
MC(%)	21.16	20.69	20.93	**20.93**
Vol. comp. sp (cc)	935.23	939.24	943.77	**939.41**
Wet Density (g/cc)	2.10	2.09	2.10	**2.09**
Dry Density (g/cc)	1.73	1.73	1.73	**1.73**

Compressive Strength of Molded Laterite - Lime Mixtures
ASTM D 5102

Project :	**Thesis**
Sample of :	**Laterite + 6% Lime**
Station	**Combined**

Date Casted	**7/11/2016**	**10:00am - 11:30am**
Date Tested	**5/12/2016**	**10:30am - 11:30am**
Lime Content (% of Laterite)	**6**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.14	10.13	10.14	
Contact Area (cm2)	80.75	80.60	80.75	
Height (cm)	11.72	11.73	11.72	
Weight (g)	2012	2002	2011	
Weight (g) before applying load	2009	1995	2006	
Comp. Load (kN)	27.28	27.98	27.09	**27.45**
Comp. Strength (MPa)	3.38	3.47	3.35	**3.40**
Wt. Wet Soil (g) + cont	252.8	255.6	250.76	**Average**
Wt. Dry Soil (g) + cont	213.5	216.6	211.97	
Wt. of Cont (g)	30.5	33.2	32.2	
Wt. of Water (g)	39.3	39	38.79	
Wt of Dry Soil (g)	183	183.4	179.77	
MC(%)	21.48	21.26	21.58	**21.44**
Vol. comp. sp (cc)	946.44	945.38	946.44	**946.09**
Wet Density (g/cc)	2.13	2.12	2.12	**2.12**
Dry Density (g/cc)	1.75	1.75	1.75	**1.75**

Compressive Strength of Molded Laterite - Lime Mixtures
ASTM D 5102

Project :	**Thesis**
Sample of :	**Laterite + 8% Lime**
Station	**Combined**

Date Casted	**7/11/2016**	**10:00am - 11:30am**
Date Tested	**5/12/2016**	**10:30am - 11:30am**
Lime Content (% of Laterite)	**8**	

Specimen No	**1**	**2**	**3**	
Diameter (cm)	10.13	10.13	10.14	**Average**
Contact Area (cm2)	80.60	80.60	80.75	
Height (cm)	11.64	11.7	11.8	
Weight (g)	2022	2018	2031	
Weight (g) before applying load	2015	2010	2026	
Comp. Load (kN)	38.36	39.16	37.40	**38.31**
Comp. Strength (MPa)	4.76	4.86	4.63	**4.75**
Wt. Wet Soil (g) + cont	261.31	229.76	260.76	**Average**
Wt. Dry Soil (g) + cont	218.9	194.4	219.97	
Wt. of Cont (g)	29.19	32.81	32.2	
Wt. of Water (g)	42.41	35.36	40.79	
Wt of Dry Soil (g)	189.71	161.59	187.77	
MC(%)	22.36	21.88	21.72	**21.99**
Vol. comp. sp (cc)	938.13	942.96	952.90	**944.66**
Wet Density (g/cc)	2.16	2.14	2.13	**2.14**
Dry Density (g/cc)	1.76	1.76	1.75	**1.76**

Compressive Strength of Molded Laterite - Lime Mixtures
ASTM D 5102

Project : **Thesis**
Sample of : **Laterite + 10% Lime**
Station **Combined**

Date Casted	**7/11/2016**	**10:00am - 11:30am**
Date Tested	**5/12/2016**	**10:30am - 11:30am**
Lime Content (% of Laterite)	**10**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.14	10.14	10.14	
Contact Area (cm2)	80.75	80.75	80.75	
Height (cm)	11.8	11.87	11.9	
Weight (g)	2058	2068	2060	
Weight (g) before applying load	2052	2060	2051	
Comp. Load (kN)	47.87	47.64	48.38	**47.96**
Comp. Strength (MPa)	5.93	5.90	5.99	**5.94**
Wt. Wet Soil (g) + cont	274.42	284.24	290.76	**Average**
Wt. Dry Soil (g) + cont	231.1	238.62	243.97	
Wt. of Cont (g)	32.75	32.17	32.2	
Wt. of Water (g)	43.3	45.62	46.79	
Wt of Dry Soil (g)	198.37	206.45	211.77	
MC(%)	21.83	22.10	22.09	**22.01**
Vol. comp. sp (cc)	952.90	958.55	960.98	**957.48**
Wet Density (g/cc)	2.16	2.16	2.14	**2.15**
Dry Density (g/cc)	1.77	1.77	1.76	**1.77**

Standard Test Method for Wetting and Drying of Compacted Soil-Lime Mixtures
ASTM D 559

Project : **Thesis**
Sample of : **Laterite + 10% Lime**
Station **Combined**

Date Casted	8/12/2016	2:00pm - 4:30pm
Date Tested	15/12/2016	1:00pm - 2:30pm
Lime Content (% of Laterite)	10	
Specimen	A	B
Wt. (g) after 7 days	1953.32	1943.55
Diameter (cm) after 7 days	10.08	10.07
Height (cm) after 7 days	11.89	11.86

Cycle	Condition	Date	Time	Parameters after wetting/drying						Vol(cc)		%ΔVol		Moisture Content	
				Weight (g)		Diameter (cm)		Height (cm)							
				A	B	A	B	A	B	A	B	A	B	A	B
	Molding	8/12/2016	2:00pm-4:30pm	1625.69	1628.07	10.08	10.07	11.89	11.86	948.84	944.57				
1	Wetting	15/12/16	9:30am-2:30pm	1982.61	1970.53	10.08	10.07	11.89	11.86	948.84	944.57	0	0	21.955	21.0347
	Drying	(15-17)/12/16	3:00pm-9:00am	1679.98	1659.35	10.07	10.07	11.89	11.86	946.96	944.57	-0.1983	0	3.3395	1.92129
	Brushing	17/12/16	9:00am-9:30am	1670.28		10.07		11.88		946.16	0.00	-0.2823		2.7428	
2	Wetting	17/12/16	9:30am-2:30pm	1956.85	1965.53	10.07	10.07	11.89	11.86	946.96	944.57	-0.1983	0	20.37	20.7276
	Drying	(17-19)/12/16	3:00pm-9:00am	1660.89	1655.66	10.07	10.07	11.88	11.86	946.16	944.57	-0.2823	0	2.1652	1.69464
	Brushing	19/12/16	9:00am-9:30am	1655.05		10.06		11.87		943.49	0.00	-0.564		1.806	
3	Wetting	19/12/16	9:30am-2:30pm	1951.35	1959.53	10.06	10.08	11.88	11.87	944.28	947.24	-0.4802	0.2832	20.032	20.3591
	Drying	(19-21)/12/16	3:00pm-9:00am	1646.25	1647.03	10.06	10.08	11.88	11.86	944.28	946.45	-0.4802	0.1987	1.2647	1.16457
	Brushing	21/12/16	9:00am-9:30am	1641.25		10.05		11.86		940.82	0.00	-0.8452		0.9571	
4	Wetting	21/12/16	9:30am-2:30pm	1941.35	1951.53	10.07	10.08	11.87	11.87	945.37	947.24	-0.3662	0.2832	19.417	19.8677
	Drying	(21-23)/12/16	3:00pm-9:00am	1641.41	1661.35	10.07	10.08	11.86	11.87	944.57	947.24	-0.4501	0.2832	0.967	2.04414
	Brushing	23/12/16	9:00am-9:30am	1633.14		10.06		11.86		942.69	0.00	-0.6477		0.4583	
5	Wetting	23/12/16	9:30am-2:30pm	1936.12	1944.53	10.06	10.08	11.87	11.86	943.49	946.45	-0.564	0.1987	19.095	19.4377
	Drying	(23-25)/12/16	3:00pm-9:00am	1646.21	1664.65	10.06	10.08	11.86	11.85	942.69	945.65	-0.6477	0.1142	1.2622	2.24683
	Brushing	25/12/16	9:00am-9:30am	1639.21		10.06		11.86		942.69	0.00	-0.6477		0.8316	
6	Wetting	25/12/16	9:30am-2:30pm	1940.21	1941.53	10.06	10.07	11.85	11.85	941.90	943.77	-0.7315	-0.0843	19.347	19.2535
	Drying	(25-27)/12/16	3:00pm-9:00am	1645.58	1661.66	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	1.2235	2.06318
	Brushing	27/12/16	9:00am-9:30am	1635.58		10.05		11.86		940.82	0.00	-0.8452		0.6084	
7	Wetting	27/12/16	9:30am-2:30pm	1925.91	1937.53	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	18.467	19.0078
	Drying	(27-29)/12/16	3:00pm-9:00am	1649.17	1662.77	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	1.4443	2.13136
	Brushing	29/12/16	9:00am-9:30am	1636.17		10.04		11.85		938.16	0.00	-1.1258		0.6446	
8	Wetting	29/12/16	9:30am-2:30pm	1895.91	1927.53	10.04	10.07	11.85	11.85	938.16	943.77	-1.1258	-0.0843	16.622	18.3936
	Drying	(29-31)/12/16	3:00pm-9:00am	1620.97	1667.22	10.04	10.07	11.85	11.85	938.16	943.77	-1.1258	-0.0843	-0.29	2.40469
	Brushing	31/12/16	9:00am-9:30am	1613.37		10.06		11.85		941.90	0.00	-0.7315		-0.758	
9	Wetting	31/12/16	9:30am-2:30pm	1880.27	1905.13	10.06	10.07	11.86	11.85	942.69	943.77	-0.6477	-0.0843	15.66	17.0177
	Drying	31/12/16-02/01/17	3:00pm-9:00am	1600.52	1660.02	10.06	10.07	11.86	11.85	942.69	943.77	-0.6477	-0.0843	-1.548	1.96245
	Brushing	2/1/2017	9:00am-9:30am	1590.25		10.06		11.86		942.69	0.00	-0.6477		-2.18	
10	Wetting	2/1/2017	9:30am-2:30pm	1870.71	1889.33	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	15.072	16.0472
	Drying	(2-4)/12/17	3:00pm-9:00am	1590.29	1661.45	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	-2.178	2.05028
	Brushing	4/1/2017	9:00am-9:30am	1581.05		10.05		11.85		940.03	0.00	-0.9288		-2.746	
11	Wetting	4/1/2017	9:30am-2:30pm	1855.26	1876.33	10.05	10.06	11.85	11.85	940.03	941.90	-0.9288	-0.2827	14.121	15.2487
	Drying	(4-6)/01/17	3:00pm-9:00am	1580.69	1666.35	10.05	10.06	11.85	11.85	940.03	941.90	-0.9288	-0.2827	-2.768	2.35125
	Brushing	6/1/2017	9:00am-9:30am	1551.69		10.04		11.85		938.16	0.00	-1.1258		-4.552	
12	Wetting	6/1/2017	9:30am-2:30pm	1844.43	1865.73	10.04	10.06	11.85	11.84	938.16	941.10	-1.1258	-0.3668	13.455	14.5977
	Drying	(6-8)/1/17	3:00pm-9:00am	1564.84	1665.37	10.04	10.06	11.84	11.84	937.37	941.10	-1.2093	-0.3668	-3.743	2.29106
	Brushing	8/1/2017	9:00am-9:30am	1543.43		10.04		11.84		937.37		-1.2093		-5.06	
Oven Dry Specimen=OD		(8-9)/01/17	9:30am-9:30am	1531.36	1664.29	10.04	10.06	11.84	11.84	Water retained in specimen=W (%)				-5.802	2.22472

Corrected oven-dry weight of specimen-B = [ODB/(WA+100)]*100	**1625.69**
Soil-cement Loss, % = [(original wt - final corrected wt)/original wt]*100	**5.80246**

Standard Test Method for Wetting and Drying of Compacted Soil-Lime Mixtures
ASTM D 559

Project : **Thesis**
Sample of : **Laterite + 8% Lime**
Station **Combined**

Date Casted	8/12/2016	2:00pm - 4:30pm
Date Tested	15/12/2016	1:00pm - 2:30pm
Lime Content (% of Laterite)	8	
Specimen	A	B
Wt. (g) after 7 days	1948.23	1933.25
Diameter (cm) after 7 days	10.08	10.07
Height (cm) after 7 days	11.89	11.88

Cycle	Condition	Date	Time	Parameters after wetting/drying						Vol (cc)		%ΔVol		Moisture Content	
				Weight (g)		Diameter (cm)		Height (cm)							
				A	B	A	B	A	B	A	B	A	B	A	B
	Molding	8/12/2016	2:00pm-4:30pm	1629.17	1628.07	10.08	10.07	11.89	11.88	948.84	946.16				
1	Wetting	15/12/16	1:00pm-5:30pm	1969.61	1959.53	10.08	10.07	11.89	11.88	948.84	946.16	0	0	20.8965	20.3591
	Drying	(15-17)/12/16	5:30pm-9am	1666.98	1648.35	10.07	10.07	11.89	11.88	946.96	946.16	-0.1983	0	2.32081	1.24565
	Brushing	17/12/16	9am-9:30am	1657.28		10.07		11.88		946.16	0.00	-0.2823		1.72542	
2	Wetting	17/12/16	9:30am-2:30pm	1943.85	1954.53	10.07	10.07	11.89	11.88	946.96	946.16	-0.1983	0	19.3154	20.052
	Drying	(17-19)/12/16	3:35pm-9:30am	1647.89	1644.66	10.07	10.07	11.88	11.88	946.16	946.16	-0.2823	0	1.14905	1.019
	Brushing	19/12/16	9:30am-10:00am	1642.05		10.06		11.87		943.49	0.00	-0.564		0.79059	
3	Wetting	19/12/16	10:00am-3:00pm	1938.35	1948.53	10.06	10.08	11.88	11.87	944.28	947.24	-0.4802	0.11437	18.9778	19.6834
	Drying	(19-21)/12/16	3:00pm-9:00am	1633.25	1636.03	10.06	10.08	11.88	11.86	944.28	946.45	-0.4802	0.03002	0.25043	0.48892
	Brushing	21/12/16	9:00am - 9:30am	1628.25		10.05		11.86		940.82	0.00	-0.8452		-0.0565	
4	Wetting	21/12/16	9:30am-2:30pm	1928.35	1940.53	10.07	10.08	11.87	11.87	945.37	947.24	-0.3662	0.11437	18.364	19.192
	Drying	(21-23)/12/16	3:00pm - 9:00am	1628.41	1650.35	10.07	10.08	11.86	11.87	944.57	947.24	-0.4501	0.11437	-0.0466	1.36849
	Brushing	23/12/16	9:00am - 9:30am	1620.14		10.06		11.86		942.69	0.00	-0.6477		-0.5543	
5	Wetting	23/12/16	9:30am-2:30pm	1923.12	1933.53	10.06	10.08	11.87	11.87	943.49	947.24	-0.564	0.11437	18.0429	18.7621
	Drying	(23-25)/12/16	3:00pm-9:00am	1633.21	1653.65	10.06	10.08	11.86	11.86	942.69	946.45	-0.6477	0.03002	0.24798	1.57119
	Brushing	25/12/16	9:00am - 9:30am	1626.21		10.06		11.86		942.69	0.00	-0.6477		-0.1817	
6	Wetting	25/12/16	9:30am-2:30pm	1927.21	1930.53	10.06	10.07	11.85	11.86	941.90	944.57	-0.7315	-0.1684	18.294	18.5778
	Drying	(25-27)/12/16	3:00pm-9:00am	1632.58	1650.66	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	0.20931	1.38753
	Brushing	27/12/16	9:00am - 9:30am	1622.58		10.05		11.86		940.82	0.00	-0.8452		-0.4045	
7	Wetting	27/12/16	9:30am-2:30pm	1912.91	1926.53	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	17.4162	18.3321
	Drying	(27-29)/12/16	3:00pm-9:00am	1636.17	1651.77	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	0.42967	1.45571
	Brushing	29/12/16	9:00am - 9:30am	1623.17		10.04		11.85		938.16	0.00	-1.1258		-0.3683	
8	Wetting	29/12/16	9:30am-2:30pm	1882.91	1916.53	10.04	10.07	11.85	11.86	938.16	944.57	-1.1258	-0.1684	15.5748	17.7179
	Drying	(29-31)/12/16	3:00pm-9:00am	1607.97	1656.22	10.04	10.07	11.85	11.86	938.16	944.57	-1.1258	-0.1684	-1.3013	1.72904
	Brushing	31/12/16	9:00pm-9:30pm	1600.37		10.06		11.85		941.90	0.00	-0.7315		-1.7678	
9	Wetting	31/12/16	9:30am-2:30pm	1867.27	1894.13	10.06	10.07	11.86	11.86	942.69	944.57	-0.6477	-0.1684	14.6148	16.342
	Drying	31/12/16-02/01/17	3:00pm-9:00am	1587.52	1649.02	10.06	10.07	11.86	11.86	942.69	944.57	-0.6477	-0.1684	-2.5565	1.2868
	Brushing	2/1/2017	9:00am - 9:30am	1577.25		10.06		11.86		942.69	0.00	-0.6477		-3.1869	
10	Wetting	2/1/2017	9:30am-2:30pm	1857.71	1878.33	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	14.028	15.3716
	Drying	(2-4)/12/17	3:00pm-9:00am	1577.29	1650.45	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	-3.1844	1.37463
	Brushing	4/1/2017	9:00am - 9:30am	1568.05		10.05		11.85		940.03	0.00	-0.9288		-3.7516	
11	Wetting	4/1/2017	9:30am-2:30pm	1842.26	1865.33	10.05	10.06	11.85	11.86	940.03	942.69	-0.9288	-0.3665	13.0797	14.5731
	Drying	(4-6)/01/17	3:00pm-9:00am	1567.69	1655.35	10.05	10.06	11.85	11.86	940.03	942.69	-0.9288	-0.3665	-3.7737	1.6756
	Brushing	6/1/2017	9:00am - 9:30am	1538.69		10.04		11.85		938.16	0.00	-1.1258		-5.5537	
12	Wetting	6/1/2017	9:30am-2:30pm	1831.43	1854.73	10.04	10.06	11.85	11.86	938.16	942.69	-1.1258	-0.3665	12.4149	13.922
	Drying	(6-8)/1/17	3:00pm-9:00am	1551.84	1654.37	10.04	10.06	11.84	11.86	937.37	942.69	-1.2093	-0.3665	-4.7466	1.61541
	Brushing	8/1/2017	9:00am - 9:30am	1530.43		10.04		11.84		937.37		-1.2093		-6.0608	
Oven Dry Specimen=OD		(07-08)/04/14	10:00am-3:00pm	1524.83	1644.29	10.04	10.06	11.84	11.86	Water retained in specimen=W (%)				-6.4045	0.92808

Corrected oven-dry weight of specimen-B = [ODB/(WA+100)]*100	**1629.17**
Soil-cement Loss, % = [(original wt - final corrected wt)/original wt]*100	**6.40449**

Appendix I-D

Laterite with

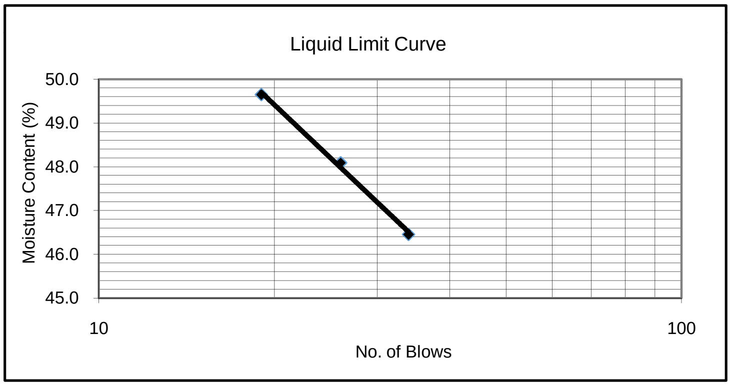
Cement

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis**
Sample of : **Laterite + 2% Cement**
Station **Combined**

Date Tested : **20/10/2016**

Number of blows	34	26	19			---
Wt.of Container +Wet soil (gm)	31.3	27.5	29.4		15	16
Wt.of Container +Dry soil (gm)	24.1	21.2	22.4		13.2	14.2
Wt.of water (gm)	7.2	6.3	7		1.8	1.8
Wt.of Container weight (gm)	8.6	8.1	8.3		7	8
Wt.of Dry soil (gm)	15.5	13.1	14.1		6.2	6.2
Moisture content %	46.5	48.1	49.6		29.0	29.0
				Average %	29.0	



Summary L.L.: 48
P.L : 29
P.I.: 19
Soil classification : A-2-7 (9)

Remark:

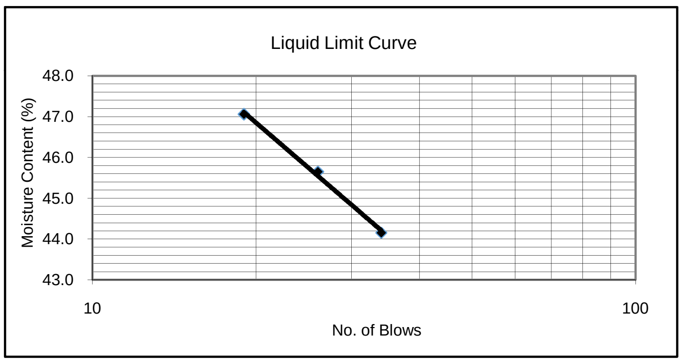
LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis** Date Tested : **20/10/2016**

Sample of : **Laterite + 4% Cement**

Station **Combined**

Number of blows	34	26	19			---
Wt.of Container +Wet soil (gm)	31.4	29.3	28.9		14.2	13.2
Wt.of Container +Dry soil (gm)	24.6	23	22.5		12.7	11.8
Wt.of water (gm)	6.8	6.3	6.4		1.5	1.4
Wt.of Container weight (gm)	9.2	9.2	8.9		7.6	7
Wt.of Dry soil (gm)	15.4	13.8	13.6		5.1	4.8
Moisture content %	44.2	45.7	47.1		29.4	29.2
				Average %	29.3	



Summary L.L.: 46

P.L : 29

P.I.: 17

Soil classification : A-2-7 (9)

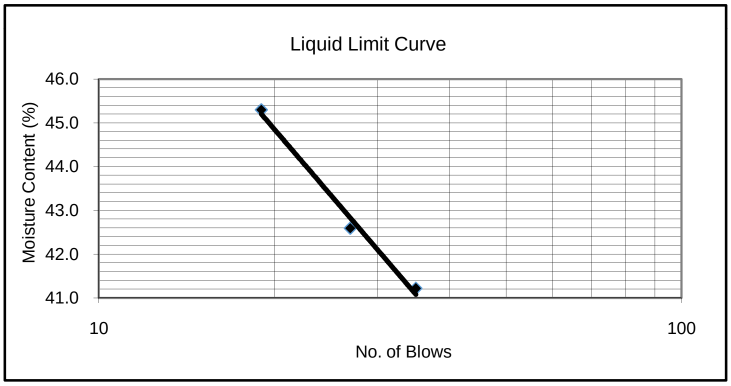
Remark:

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis**
Sample of : **Laterite + 6% Cement**
Station **Combined**

Date Tested : **20/10/2016**

Number of blows	35	27	19			---
Wt.of Container +Wet soil (gm)	29.9	33	25.9		15.8	14.7
Wt.of Container +Dry soil (gm)	23.8	26.1	20.6		14.1	13
Wt.of water (gm)	6.1	6.9	5.3		1.7	1.7
Wt.of Container weight (gm)	9	9.9	8.9		8.6	7.3
Wt.of Dry soil (gm)	14.8	16.2	11.7		5.5	5.7
Moisture content %	41.2	42.6	45.3		30.9	29.8
				Average %	30.4	



Summary L.L.: 44
P.L : 30
P.I.: 13
Soil classification : A-2-7 (9)

Remark:

Reported by: Checked by: Approved by:

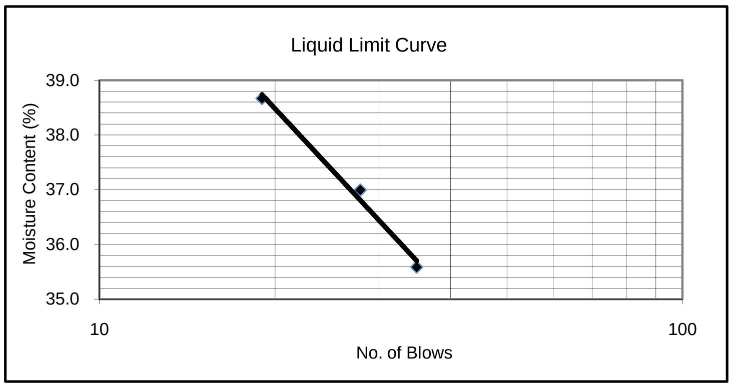
Laboratory Technician Laboratory Team Representative GE Directorate Director

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis**
Sample of : **Laterite + 8% Cement**
Station **Combined**

Date Tested : **20/10/2016**

Number of blows	35	28	19			---
Wt.of Container +Wet soil (gm)	30.4	32.6	27.7		21	18.3
Wt.of Container +Dry soil (gm)	24.6	26.2	21.9		18.4	16.2
Wt.of water (gm)	5.8	6.4	5.8		2.6	2.1
Wt.of Container weight (gm)	8.3	8.9	6.9		9.8	9.4
Wt.of Dry soil (gm)	16.3	17.3	15		8.6	6.8
Moisture content %	35.6	37.0	38.7		30.2	30.9
				Average %	30.6	



Summary L.L.: 38
P.L : 31
P.I.: 7
Soil classification : A-2-4 (9)

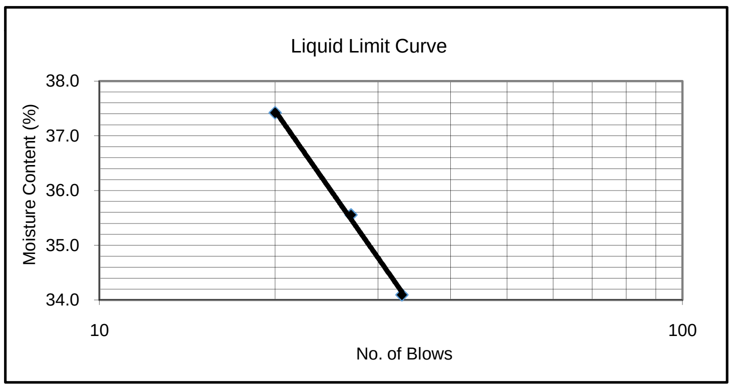
Remark:

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis**
Sample of : **Laterite + 10% Cement**
Station **Combined**

Date Tested : **20/10/2016**

Number of blows	33	27	20			---
Wt.of Container +Wet soil (gm)	30.9	33.4	33.5		19	18.8
Wt.of Container +Dry soil (gm)	24.9	27	27.21		16.6	16.5
Wt.of water (gm)	6	6.4	6.29		2.4	2.3
Wt.of Container weight (gm)	7.3	9	10.4		8.9	9.2
Wt.of Dry soil (gm)	17.6	18	16.81		7.7	7.3
Moisture content %	34.1	35.6	37.4		31.2	31.5
				Average %	31.3	



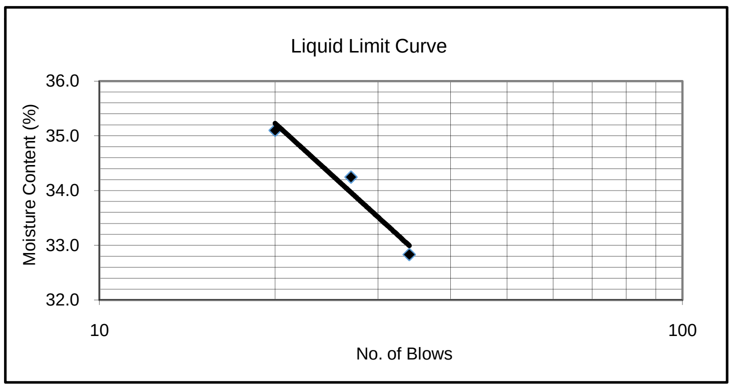
Summary L.L.: 36
P.L : 31
P.I.: 5
Soil classification : A-2-4 (9)

Remark:

LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS
AASHTO T 89-90

Project : **Thesis** Date Tested : **20/10/2016**
Sample of : **Laterite + 12% Cement**
Station **Combined**

Number of blows	34	27	20			---
Wt.of Container +Wet soil (gm)	34.5	28	27.2		21.5	15.4
Wt.of Container +Dry soil (gm)	28	23	21.9		18.6	13.5
Wt.of water (gm)	6.5	5	5.3		2.9	1.9
Wt.of Container weight (gm)	8.2	8.4	6.8		9.3	7.2
Wt.of Dry soil (gm)	19.8	14.6	15.1		9.3	6.3
Moisture content %	32.8	34.2	35.1		31.2	30.2
				Average %	30.7	



Summary L.L.: 34
P.L : 31
P.I.: 4
Soil classification : A-2-4 (9)

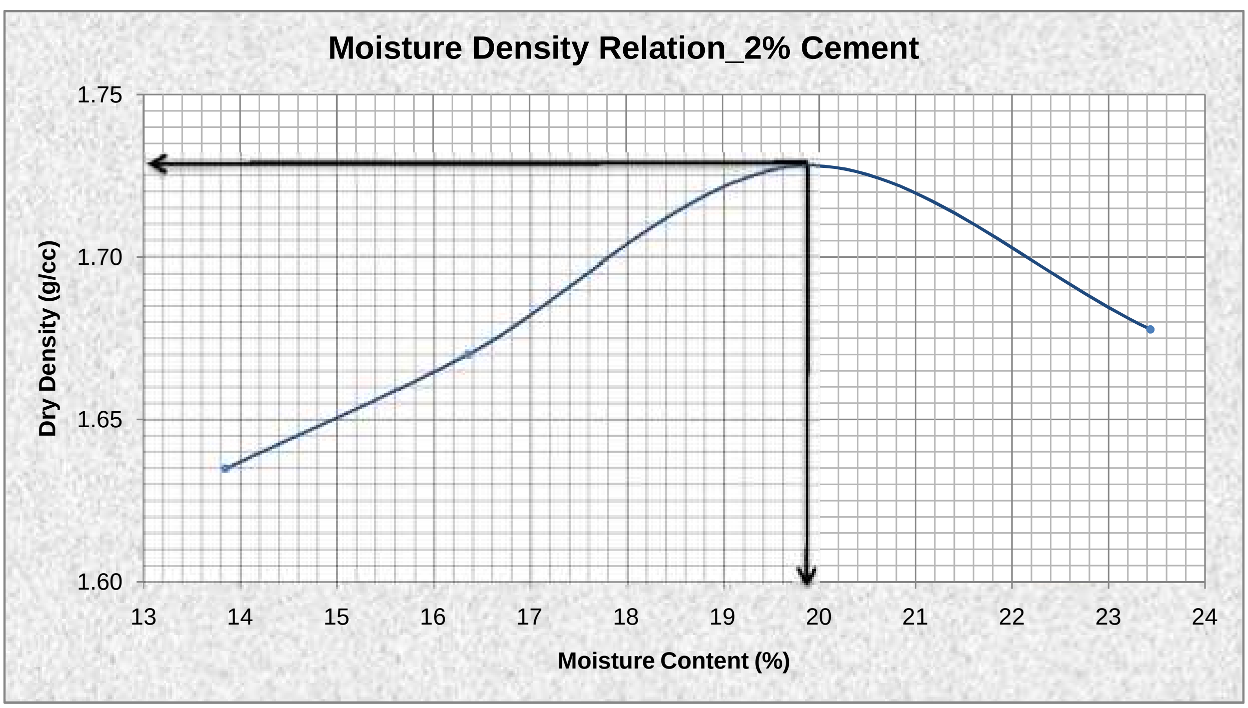
Remark:

Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Date Tested: 24/10/16
Sample of: Laterite + 2% Cement
Station: Combined

TRIAL NO.	1	2	3	4	5
Water Added	50	150	150	150	
Weight of Mould + Wet soil (g)	5959	6036	6156	6156	
Weight of Mould	4210	4210	4210	4210	
Weight of Wet Soil (g)	1749	1826	1946	1946	
Volume (cc)	939.7	939.7	939.7	939.7	
Wet density (g/cc)	1.86	1.94	2.07	2.07	
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	269.60	252.02	234.47	281.84	
Weight of Dry Soil + Cont. (g)	240.64	221.39	200.92	234.32	
Weight of Container (g)	31.46	34.05	31.76	31.55	
Weight of Water (moisture) (g)	28.96	30.63	33.55	47.52	
Weight of Dry Soil (g)	209.18	187.34	169.16	202.77	
Moisture Content (%)	13.84	16.35	19.83	23.44	
Dry Density (g/cc)	**1.63**	**1.67**	**1.73**	**1.68**	
	MDD (g/cc)		1.73	**OMC (%)**	19.8



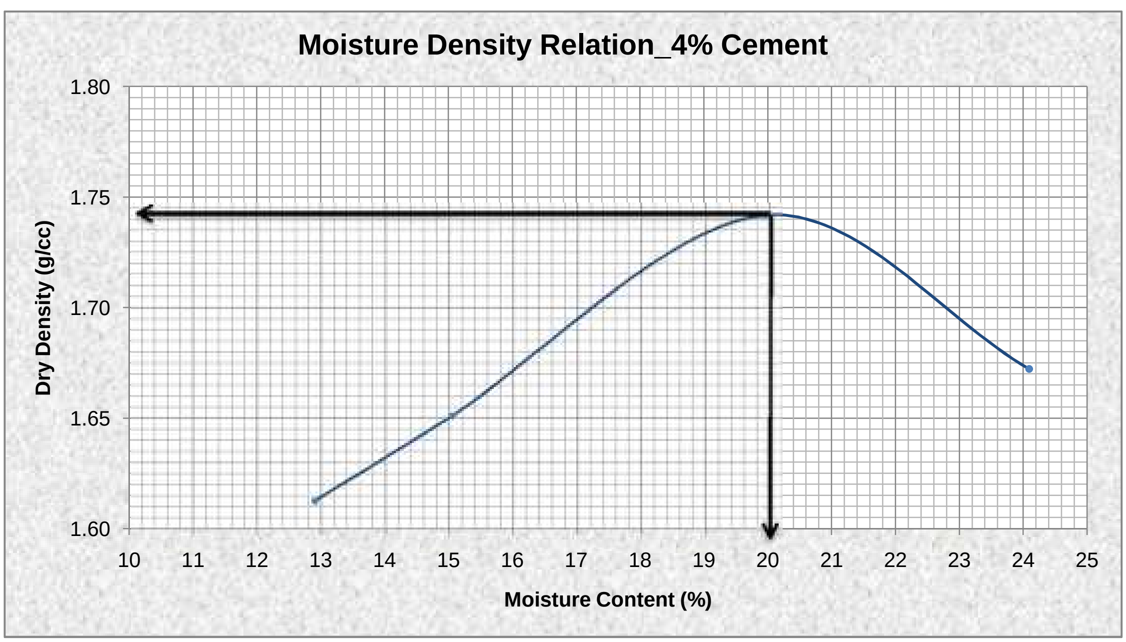
Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Sample of: Laterite + 4% Cement
Station: Combined

Date Tested: 24/10/16

TRIAL NO.	1	2	3	4	5
Water Added		150	150	150	
Weight of Mould + Wet soil (g)	5921	5995	6173	6160	
Weight of Mould	4210	4210	4210	4210	
Weight of Wet Soil (g)	1711	1785	1963	1950	
Volume (cc)	939.7	939.7	939.7	939.7	
Wet density (g/cc)	1.82	1.90	2.09	2.08	
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	290.59	300.24	287.37	297.08	
Weight of Dry Soil + Cont. (g)	261.48	265.82	244.65	246.25	
Weight of Container (g)	35.77	37.00	30.27	35.29	
Weight of Water (moisture) (g)	29.11	34.42	42.72	50.83	
Weight of Dry Soil (g)	225.71	228.82	214.38	210.96	
Moisture Content (%)	12.90	15.04	19.93	24.09	
Dry Density (g/cc)	**1.61**	**1.65**	**1.74**	**1.67**	
	MDD (g/cc)		1.74	**OMC (%)**	20.0



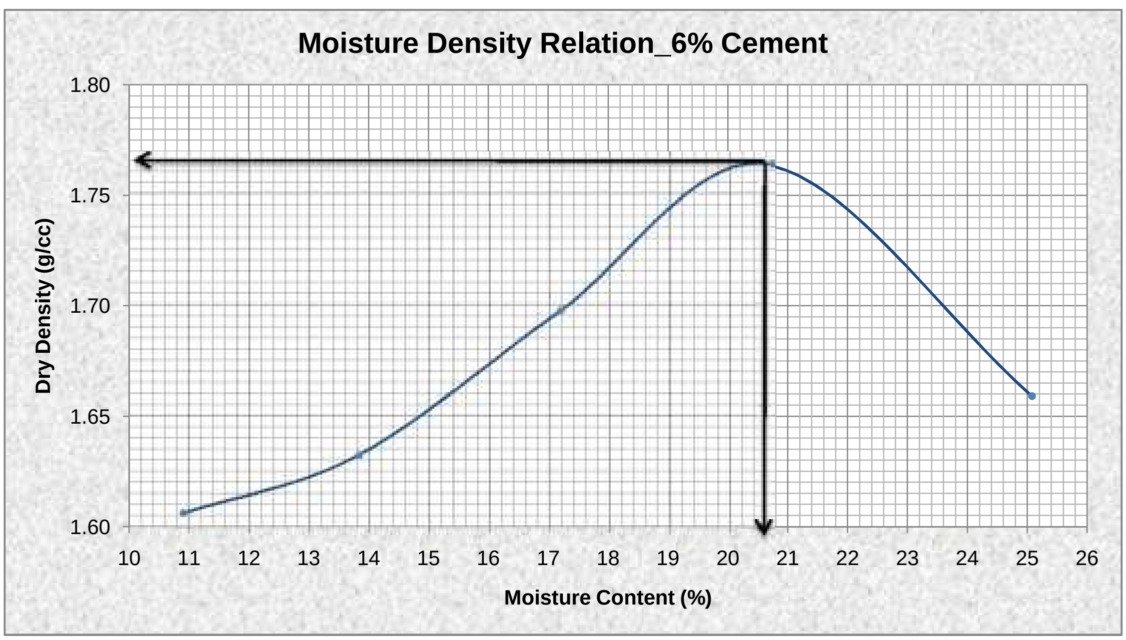
Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Sample of: Laterite + 6% Cement
Station: Combined

Date Tested: 24/10/16

TRIAL NO.	1	2	3	4	5
Water Added		150	150	150	150
Weight of Mould + Wet soil (g)	5884	5956	6079	6210	6160
Weight of Mould	4210	4210	4210	4210	4210
Weight of Wet Soil (g)	1674	1746	1869	2000	1950
Volume (cc)	939.7	939.7	939.7	939.7	939.7
Wet density (g/cc)	1.78	1.86	1.99	2.13	2.08
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	275.57	255.33	300.17	276.46	325.05
Weight of Dry Soil + Cont. (g)	251.87	228.3	260.72	234.36	266.1
Weight of Container (g)	34.60	32.82	31.11	31.09	31.07
Weight of Water (moisture) (g)	23.70	27.03	39.45	42.10	58.95
Weight of Dry Soil (g)	217.27	195.48	229.61	203.27	235.03
Moisture Content (%)	10.91	13.83	17.18	20.71	25.08
Dry Density (g/cc)	**1.61**	**1.63**	**1.70**	**1.76**	**1.66**
	MDD (g/cc)		1.76	**OMC (%)**	20.7



Moisture - Density Relation

ASTM D 1557 / 558

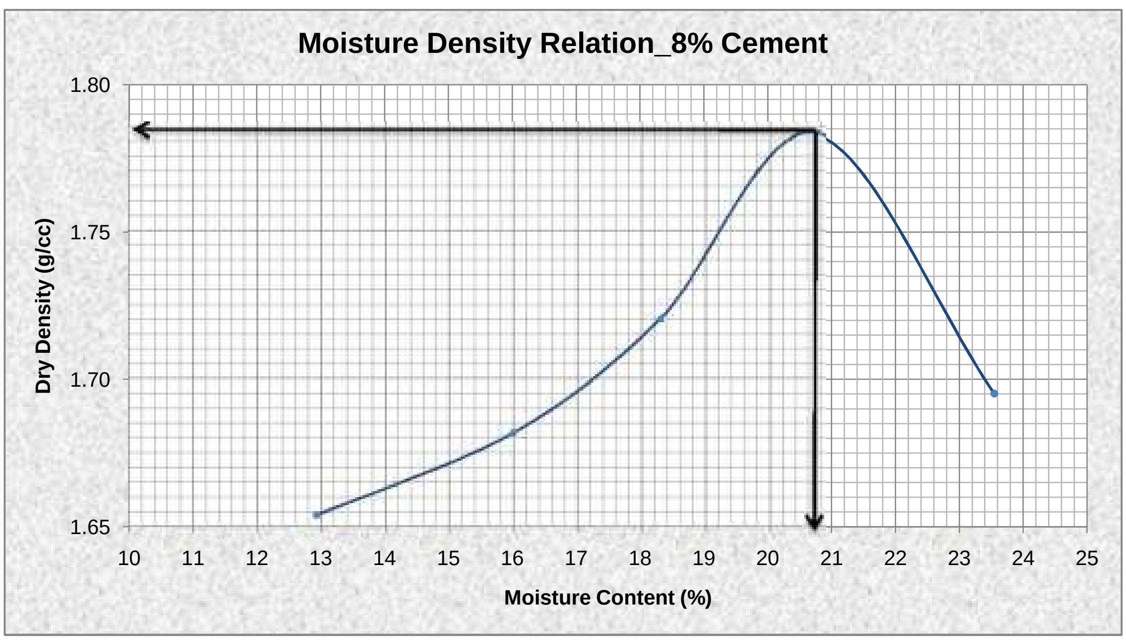
Project: Thesis

Date Tested: 24/10/16

Sample of: Laterite + 8% Cement

Station: Combined

TRIAL NO.	1	2	3	4	5
Water Added	150	150	150	150	150
Weight of Mould + Wet soil (g)	5965	6043	6122	6233	6178
Weight of Mould	4210	4210	4210	4210	4210
Weight of Wet Soil (g)	1755	1833	1912	2023	1968
Volume (cc)	939.7	939.7	939.7	939.7	939.7
Wet density (g/cc)	1.87	1.95	2.03	2.15	2.09
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	306.70	339.05	268.54	271.84	292.30
Weight of Dry Soil + Cont. (g)	275.79	297.25	232.54	231.15	242.83
Weight of Container (g)	36.61	35.86	35.67	34.99	32.75
Weight of Water (moisture) (g)	30.91	41.80	36.00	40.69	49.47
Weight of Dry Soil (g)	239.18	261.39	196.87	196.16	210.08
Moisture Content (%)	12.92	15.99	18.29	20.74	23.55
Dry Density (g/cc)	**1.65**	**1.68**	**1.72**	**1.78**	**1.70**
	MDD (g/cc)		1.78	**OMC (%)**	20.8



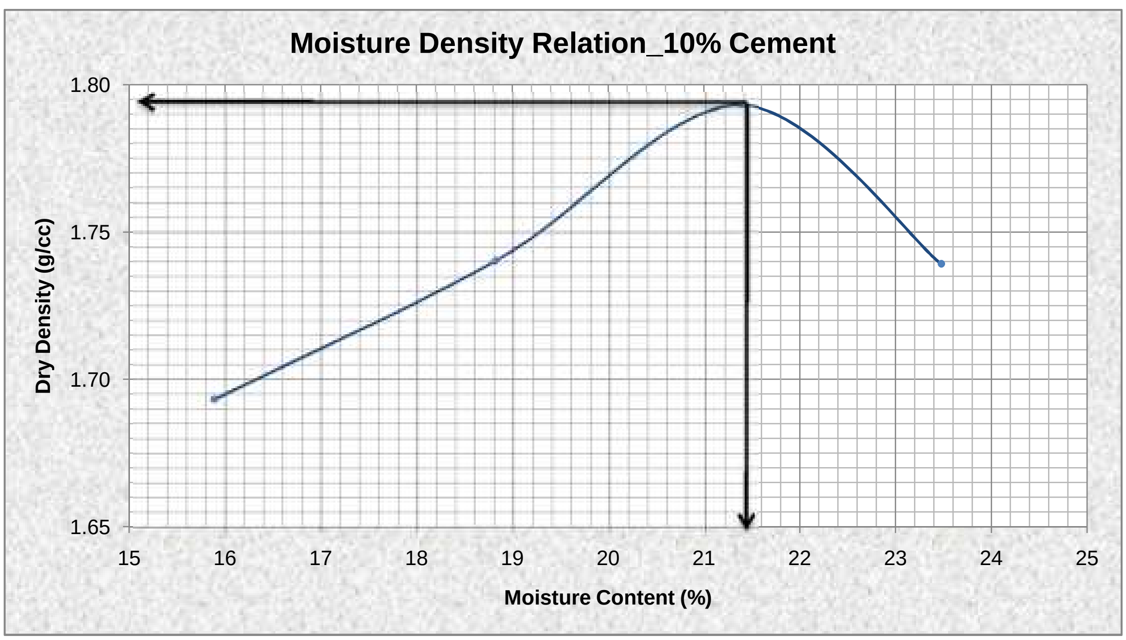
Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Sample of: Laterite + 10% Cement
Station: Combined

Date Tested: 24/10/16
Date Reported: 25/10/16
Submitted By: CORE Cons. Eng. PLC

TRIAL NO.	1	2	3	4	5
Water Added	150	150	150	150	
Weight of Mould + Wet soil (g)	6054	6153	6255	6228	
Weight of Mould	4210	4210	4210	4210	
Weight of Wet Soil (g)	1844	1943	2045	2018	
Volume (cc)	939.7	939.7	939.7	939.7	
Wet density (g/cc)	1.96	2.07	2.18	2.15	
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	363.11	320.31	337.23	287.79	
Weight of Dry Soil + Cont. (g)	317.75	274.51	283.40	239.04	
Weight of Container (g)	32.24	31.03	31.45	31.38	
Weight of Water (moisture) (g)	45.36	45.80	53.83	48.75	
Weight of Dry Soil (g)	285.51	243.48	251.95	207.66	
Moisture Content (%)	15.89	18.81	21.37	23.48	
Dry Density (g/cc)	**1.69**	**1.74**	**1.79**	**1.74**	
	MDD (g/cc)		1.79	**OMC (%)**	21.4

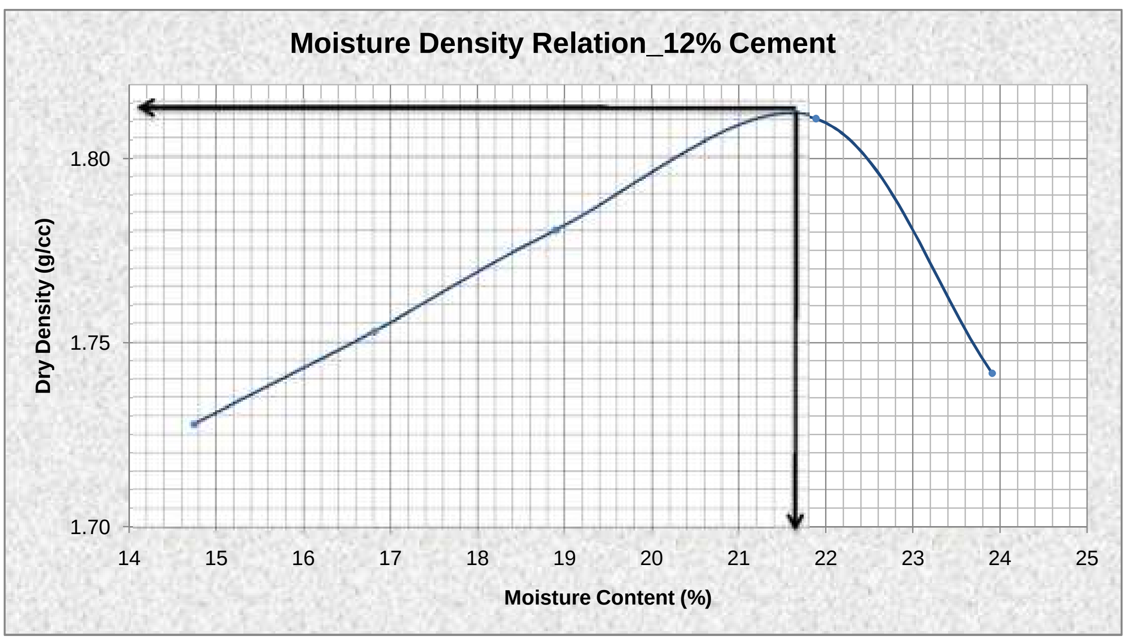


Moisture - Density Relation

ASTM D 1557 / 558

Project: Thesis
Date Tested: 24/10/16
Sample of: Laterite + 12% Cement
Station: Combined

TRIAL NO.	1	2	3	4	5
Water Added	150	150	150	150	150
Weight of Mould + Wet soil (g)	6073	6134	6199	6284	6238
Weight of Mould	4210	4210	4210	4210	4210
Weight of Wet Soil (g)	1863	1924	1989	2074	2028
Volume (cc)	939.7	939.7	939.7	939.7	939.7
Wet density (g/cc)	1.98	2.05	2.12	2.21	2.16
Moisture Content Determination					
Weight of Wet Soil + Cont. (g)	292.28	352.37	336.28	314.53	340.37
Weight of Dry Soil + Cont. (g)	258.83	306.74	288.26	264.34	281.9
Weight of Container (g)	31.94	35.27	34.19	35.00	37.33
Weight of Water (moisture) (g)	33.45	45.63	48.02	50.19	58.47
Weight of Dry Soil (g)	226.89	271.47	254.07	229.34	244.57
Moisture Content (%)	14.74	16.81	18.90	21.88	23.91
Dry Density (g/cc)	**1.73**	**1.75**	**1.78**	**1.81**	**1.74**
	MDD (g/cc)		1.81	**OMC (%)**	21.6



Compressive Strength of Molded Laterite - Cement Mixtures
ASTM D 1633

Project : **Thesis**
Sample of : **Laterite + 2% Cement**
Station **Combined**

Date Casted	**15/11/2016**	**10:00am - 11:30am**
Date Tested	**22/12/2016**	**10:30am - 11:30am**
Cement Content (% of Laterite)	**2**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.09	10.06	10.08	
Contact Area (cm2)	79.96	79.49	79.80	
Height (cm)	11.78	11.73	11.75	
Weight (g)	1958.03	1937.02	1947.53	
Weight (g) before applying load	1987.54	1973.59	1980.53	
Comp. Load (kN)	3.6	4.1	4.30	**4.00**
Comp. Strength (MPa)	0.45	0.52	0.54	**0.50**
Wt. Wet Soil (g) + cont	256.88	195.4	260.76	**Average**
Wt. Dry Soil (g) + cont	219.2	168.23	222.67	
Wt. of Cont (g)	30.4	31.3	32.2	
Wt. of Water (g)	37.69	27.17	38.09	
Wt of Dry Soil (g)	188.79	136.93	190.47	
MC(%)	19.96	19.84	20.00	**19.93**
Vol. comp. sp (cc)	941.93	932.36	937.67	**937.32**
Wet Density (g/cc)	2.08	2.08	2.08	**2.08**
Dry Density (g/cc)	1.73	1.73	1.73	**1.73**

Compressive Strength of Molded Laterite - Cement Mixtures
ASTM D 1633

Project : **Thesis**

Sample of : **Laterite + 4% Cement**

Station **Combined**

Date Casted	**15/11/2016**	**10:00am - 11:30am**
Date Tested	**22/12/2016**	**10:30am - 11:30am**
Cement Content (% of Laterite)	**4**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.08	10.09	10.08	
Contact Area (cm2)	79.80	79.96	79.80	
Height (cm)	11.89	11.88	11.9	
Weight (g)	1976.76	1983.48	1990.62	
Weight (g) before applying load	1993.14	2001.84	1997.49	
Comp. Load (kN)	14.51	15.28	14.96	**14.92**
Comp. Strength (MPa)	1.82	1.91	1.87	**1.87**
Wt. Wet Soil (g) + cont	268	250.5	270.65	**Average**
Wt. Dry Soil (g) + cont	229.2	214.35	230.22	
Wt. of Cont (g)	35.8	36.4	30.6	
Wt. of Water (g)	38.76	36.15	40.43	
Wt of Dry Soil (g)	193.44	177.95	199.62	
MC(%)	20.04	20.31	20.25	**20.20**
Vol. comp. sp (cc)	948.84	949.92	949.64	**949.47**
Wet Density (g/cc)	2.08	2.09	2.10	**2.09**
Dry Density (g/cc)	1.74	1.74	1.74	**1.74**

Compressive Strength of Molded Laterite - Cement Mixtures
ASTM D 1633

Project : **Thesis**
Sample of : **Laterite + 6% Cement**
Station **Combined**

Date Casted	**15/11/2016**	**10:00am - 11:30am**
Date Tested	**22/12/2016**	**10:30am - 11:30am**
Cement Content (% of Laterite)	**6**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.09	10.09	10.08	
Contact Area (cm2)	79.96	79.96	79.80	
Height (cm)	11.79	11.69	11.75	
Weight (g)	1996.39	2002.32	2004.34	
Weight (g) before applying load	2014.22	2024.64	2019.43	
Comp. Load (kN)	25.3	25.71	26.51	**25.84**
Comp. Strength (MPa)	3.16	3.22	3.32	**3.23**
Wt. Wet Soil (g) + cont	228.7	250.47	297.24	**Average**
Wt. Dry Soil (g) + cont	195.0	213.57	252.95	
Wt. of Cont (g)	35.8	37.5	34.48	
Wt. of Water (g)	33.69	36.9	44.29	
Wt of Dry Soil (g)	159.21	176.07	218.47	
MC(%)	21.16	20.96	20.27	**20.80**
Vol. comp. sp (cc)	942.73	934.73	937.67	**938.38**
Wet Density (g/cc)	2.12	2.14	2.14	**2.13**
Dry Density (g/cc)	1.75	1.77	1.78	**1.77**

Reported by:	Checked by:	Approved by:
Laboratory Technician	Laboratory Team Representative	GE Directorate Director

Compressive Strength of Molded Laterite - Cement Mixtures
ASTM D 1633

Project : **Thesis**

Sample of : **Laterite + 8% Cement**

Station **Combined**

Date Casted	**15/11/2016**	**10:00am - 11:30am**
Date Tested	**22/12/2016**	**10:30am - 11:30am**
Cement Content (% of Laterite)	**8**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.07	10.09	10.08	
Contact Area (cm2)	79.64	79.96	79.80	
Height (cm)	11.81	11.69	11.76	
Weight (g)	2026.24	2022.18	2004.71	
Weight (g) before applying load	2036.68	2064.42	2079.43	
Comp. Load (kN)	37.16	38.19	37.76	**37.70**
Comp. Strength (MPa)	4.67	4.78	4.73	**4.72**
Wt. Wet Soil (g) + cont	268.77	188.54	362.91	**Average**
Wt. Dry Soil (g) + cont	228.5	161.44	306.74	
Wt. of Cont (g)	36.7	30.4	36.92	
Wt. of Water (g)	40.31	27.1	56.17	
Wt of Dry Soil (g)	191.76	131.04	269.82	
MC(%)	21.02	20.68	20.82	**20.84**
Vol. comp. sp (cc)	940.59	934.73	938.47	**937.93**
Wet Density (g/cc)	2.15	2.16	2.14	**2.15**
Dry Density (g/cc)	1.78	1.79	1.77	**1.78**

Reported by:	Checked by:	Approved by:
Laboratory Technician	Laboratory Team Representative	GE Directorate Director

Compressive Strength of Molded Laterite - Cement Mixtures
ASTM D 1633

Project : **Thesis**

Sample of : **Laterite + 10% Cement**

Station **Combined**

Date Casted	**15/11/2016**	**10:00am - 11:30am**
Date Tested	**22/12/2016**	**10:30am - 11:30am**
Cement Content (% of Laterite)	**10**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.09	10.09	10.08	
Contact Area (cm2)	79.96	79.96	79.80	
Height (cm)	11.81	11.79	11.82	
Weight (g)	2056.42	2052.08	2044.12	
Weight (g) before applying load	2076.68	2094.42	2109.43	
Comp. Load (kN)	48.23	47.41	47.77	**47.80**
Comp. Strength (MPa)	6.03	5.93	5.99	**5.98**
Wt. Wet Soil (g) + cont	225.42	237.65	259.41	**Average**
Wt. Dry Soil (g) + cont	191.8	201.29	219.92	
Wt. of Cont (g)	34.93	31.32	36	
Wt. of Water (g)	33.62	36.36	39.49	
Wt of Dry Soil (g)	156.87	169.97	183.92	
MC(%)	21.43	21.39	21.47	**21.43**
Vol. comp. sp (cc)	944.33	942.73	943.25	**943.44**
Wet Density (g/cc)	2.18	2.18	2.17	**2.17**
Dry Density (g/cc)	1.79	1.79	1.78	**1.79**

Compressive Strength of Molded Laterite - Cement Mixtures
ASTM D 1633

Project : **Thesis**
Sample of : **Laterite + 12% Cement**
Station **Combined**

Date Casted	**15/11/2016**	**10:00am - 11:30am**
Date Tested	**22/12/2016**	**10:30am - 11:30am**
Cement Content (% of Laterite)	**12**	

Specimen No	**1**	**2**	**3**	**Average**
Diameter (cm)	10.10	10.11	10.08	
Contact Area (cm2)	80.12	80.28	79.80	
Height (cm)	11.81	11.78	11.82	
Weight (g)	2085.32	2076.08	2074.12	
Weight (g) before applying load	2086.86	2104.23	2119.99	
Comp. Load (kN)	54	54.63	55.25	**54.63**
Comp. Strength (MPa)	6.74	6.81	6.92	**6.82**
Wt. Wet Soil (g) + cont	342.93	251.11	359.41	**Average**
Wt. Dry Soil (g) + cont	288.4	213.9	301.92	
Wt. of Cont (g)	35.85	42.18	36	
Wt. of Water (g)	54.53	37.21	57.49	
Wt of Dry Soil (g)	252.55	171.72	265.92	
MC(%)	21.59	21.67	21.62	**21.63**
Vol. comp. sp (cc)	946.20	945.67	943.25	**945.04**
Wet Density (g/cc)	2.20	2.20	2.20	**2.20**
Dry Density (g/cc)	1.81	1.80	1.81	**1.81**

Standard Test Method for Wetting and Drying of Compacted Soil-Cement Mixtures
ASTM D 559

Project : **Thesis**
Sample of : **Laterite + 10% Cement**
Station **Combined**

Date Casted	8/12/2016	2:00pm - 4:30pm
Date Tested	15/12/2016	1:00pm - 2:30pm
Cement Content (% of Laterite)	10	
Specimen	A	B
Wt. (g) after 7 days	1953.32	1943.55
Diameter (cm) after 7 days	10.08	10.07
Height (cm) after 7 days	11.89	11.86

Cycle	Condition	Date	Time	Parameters after wetting/drying						Vol(cc)		%ΔVol		Moisture Content	
				Weight (g)		Diameter (cm)		Height (cm)							
				A	B	A	B	A	B	A	B	A	B	A	B
	Molding	8/12/2016	2:00pm-4:30pm	1635.96	1628.07	10.08	10.07	11.89	11.86	948.84	944.57				
1	Wetting	15/12/16	9:30am-2:30pm	1982.61	1970.53	10.08	10.07	11.89	11.86	948.84	944.57	0	0	21.1894	21.0347
	Drying	(15-17)/12/16	3:00pm-9:00am	1689.98	1619.35	10.07	10.07	11.89	11.86	946.96	944.57	-0.1983	0	3.30204	-0.5356
	Brushing	17/12/16	9:00am-9:30am	1680.80		10.07		11.88		946.16	0.00	-0.2823		2.7409	
2	Wetting	17/12/16	9:30am-2:30pm	1956.85	1965.53	10.07	10.07	11.89	11.86	946.96	944.57	-0.1983	0	19.6148	20.7276
	Drying	(17-19)/12/16	3:00pm-9:00am	1679.89	1615.66	10.07	10.07	11.88	11.86	946.16	944.57	-0.2823	0	2.68527	-0.7623
	Brushing	19/12/16	9:00am-9:30am	1674.05		10.06		11.87		943.49	0.00	-0.564		2.3283	
3	Wetting	19/12/16	9:30am-2:30pm	1951.35	1959.53	10.06	10.08	11.88	11.87	944.28	947.24	-0.4802	0.28319	19.2786	20.3591
	Drying	(19-21)/12/16	3:00pm-9:00am	1673.02	1617.03	10.06	10.08	11.88	11.86	944.28	946.45	-0.4802	0.19871	2.26534	-0.6781
	Brushing	21/12/16	9:00am-9:30am	1668.02		10.05		11.86		940.82	0.00	-0.8452		1.95971	
4	Wetting	21/12/16	9:30am-2:30pm	1941.35	1951.53	10.07	10.08	11.87	11.87	945.37	947.24	-0.3662	0.28319	18.6673	19.8677
	Drying	(21-23)/12/16	3:00pm-9:00am	1667.25	1611.35	10.07	10.08	11.86	11.87	944.57	947.24	-0.4501	0.28319	1.91264	-1.027
	Brushing	23/12/16	9:00am-9:30am	1661.22		10.06		11.86		942.69	0.00	-0.6477		1.54405	
5	Wetting	23/12/16	9:30am-2:30pm	1936.12	1944.53	10.06	10.08	11.87	11.86	943.49	946.45	-0.564	0.19871	18.3476	19.4377
	Drying	(23-25)/12/16	3:00pm-9:00am	1656.11	1614.65	10.06	10.08	11.86	11.85	942.69	945.65	-0.6477	0.11422	1.23169	-0.8243
	Brushing	25/12/16	9:00am-9:30am	1639.49		10.06		11.86		942.69	0.00	-0.6477		0.21578	
6	Wetting	25/12/16	9:30am-2:30pm	1940.21	1941.53	10.06	10.07	11.85	11.85	941.90	943.77	-0.7315	-0.0843	18.5976	19.2535
	Drying	(25-27)/12/16	3:00pm-9:00am	1645.14	1611.66	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	0.56114	-1.0079
	Brushing	27/12/16	9:00am-9:30am	1635.53		10.05		11.86		940.82	0.00	-0.8452		-0.0263	
7	Wetting	27/12/16	9:30am-2:30pm	1925.91	1937.53	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	17.7235	19.0078
	Drying	(27-29)/12/16	3:00pm-9:00am	1630.87	1612.77	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	-0.3111	-0.9398
	Brushing	29/12/16	9:00am-9:30am	1607.44		10.04		11.85		938.16	0.00	-1.1258		-1.7433	
8	Wetting	29/12/16	9:30am-2:30pm	1895.91	1927.53	10.04	10.07	11.85	11.85	938.16	943.77	-1.1258	-0.0843	15.8898	18.3936
	Drying	(29-31)/12/16	3:00pm-9:00am	1610.23	1617.22	10.04	10.07	11.85	11.85	938.16	943.77	-1.1258	-0.0843	-1.5728	-0.6664
	Brushing	31/12/16	9:00am-9:30am	1593.91		10.06		11.85		941.90	0.00	-0.7315		-2.5704	
9	Wetting	31/12/16	9:30am-2:30pm	1880.27	1905.13	10.06	10.07	11.86	11.85	942.69	943.77	-0.6477	-0.0843	14.9337	17.0177
	Drying	31/12/16-02/01/17	3:00pm-9:00am	1600.88	1610.02	10.06	10.07	11.86	11.85	942.69	943.77	-0.6477	-0.0843	-2.1443	-1.1087
	Brushing	2/1/2017	9:00am-9:30am	1580.55		10.06		11.86		942.69	0.00	-0.6477		-3.387	
10	Wetting	2/1/2017	9:30am-2:30pm	1870.71	1889.33	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	14.3494	16.0472
	Drying	(2-4)/12/17	3:00pm-9:00am	1600.12	1611.45	10.05	10.07	11.86	11.85	940.82	943.77	-0.8452	-0.0843	-2.1908	-1.0208
	Brushing	4/1/2017	9:00am-9:30am	1576.17		10.05		11.85		940.03	0.00	-0.9288		-3.6547	
11	Wetting	4/1/2017	9:30am-2:30pm	1755.26	1876.33	10.05	10.06	11.85	11.85	940.03	941.90	-0.9288	-0.2827	7.29235	15.2487
	Drying	(4-6)/01/17	3:00pm-9:00am	1600.26	1606.35	10.05	10.06	11.85	11.85	940.03	941.90	-0.9288	-0.2827	-2.1822	-1.3341
	Brushing	6/1/2017	9:00am-9:30am	1571.00		10.04		11.85		938.16	0.00	-1.1258		-3.9708	
12	Wetting	6/1/2017	9:30am-2:30pm	1734.43	1865.73	10.04	10.06	11.85	11.84	938.16	941.10	-1.1258	-0.3668	6.0191	14.5977
	Drying	(6-8)/1/17	3:00pm-9:00am	1584.22	1605.37	10.04	10.06	11.84	11.84	937.37	941.10	-1.2093	-0.3668	-3.1627	-1.3943
	Brushing	8/1/2017	9:00am-9:30am	1553.22		10.04		11.84		937.37		-1.2093		-5.0576	
Oven Dry Specimen=OD		(8-9)/01/17	9:30am-9:30am	1550.63	1604.29	10.04	10.06	11.84	11.84	Water retained in specimen=W (%)				-5.2159	-1.4606

Corrected oven-dry weight of specimen-B = [ODB/(WA+100)]*100	**1635.96**
Soil-cement Loss, % = [(original wt - final corrected wt)/original wt]*100	**5.2159**

Standard Test Method for Wetting and Drying of Compacted Soil-Cement Mixtures
ASTM D 559

Project : **Thesis**
Sample of : **Laterite + 8% Cement**
Station **Combined**

Date Casted	8/12/2016	2:00pm - 4:30pm
Date Tested	15/12/2016	1:00pm - 2:30pm
Cement Content (% of Laterite)	8	
Specimen	A	B
Wt. (g) after 7 days	1948.23	1933.25
Diameter (cm) after 7 days	10.08	10.07
Height (cm) after 7 days	11.89	11.88

Cycle	Condition	Date	Time	Parameters after wetting/drying						Vol(cc)		%ΔVol		Moisture Content	
				Weight (g)		Diameter (cm)		Height (cm)							
				A	B	A	B	A	B	A	B	A	B	A	B
	Molding	8/12/2016	2:00pm-4:30pm	1629.17	1628.07	10.08	10.07	11.89	11.88	948.84	946.16				
1	Wetting	15/12/16	1:00pm-5:30pm	1971.61	1958.53	10.08	10.07	11.89	11.88	948.84	946.16	0	0	21.0193	20.2977
	Drying	(15-17)/12/16	5:30pm-9am	1678.98	1607.35	10.07	10.07	11.89	11.88	946.96	946.16	-0.1983	0	3.05739	-1.2727
	Brushing	17/12/16	9am-9:30am	1669.80		10.07		11.88		946.16	0.00	-0.2823		2.49391	
2	Wetting	17/12/16	9:30am-2:30pm	1945.85	1953.53	10.07	10.07	11.89	11.88	946.96	946.16	-0.1983	0	19.4381	19.9905
	Drying	(17-19)/12/16	3:35pm-9:30am	1668.89	1603.66	10.07	10.07	11.88	11.88	946.16	946.16	-0.2823	0	2.43805	-1.4993
	Brushing	19/12/16	9:30am-10:00am	1663.05		10.06		11.87		943.49	0.00	-0.564		2.07959	
3	Wetting	19/12/16	10:00am-3:00pm	1940.35	1947.53	10.06	10.08	11.88	11.87	944.28	947.24	-0.4802	0.11437	19.1005	19.622
	Drying	(19-21)/12/16	3:00pm-9:00am	1662.02	1605.03	10.06	10.08	11.88	11.86	944.28	946.45	-0.4802	0.03002	2.01636	-1.4152
	Brushing	21/12/16	9:00am - 9:30am	1657.02		10.05		11.86		940.82	0.00	-0.8452		1.70946	
4	Wetting	21/12/16	9:30am-2:30pm	1930.35	1939.53	10.07	10.08	11.87	11.87	945.37	947.24	-0.3662	0.11437	18.4867	19.1306
	Drying	(21-23)/12/16	3:00pm - 9:00am	1656.25	1599.35	10.07	10.08	11.86	11.87	944.57	947.24	-0.4501	0.11437	1.6622	-1.7641
	Brushing	23/12/16	9:00am - 9:30am	1650.22		10.06		11.86		942.69	0.00	-0.6477		1.29207	
5	Wetting	23/12/16	9:30am-2:30pm	1925.12	1932.53	10.06	10.08	11.87	11.87	943.49	947.24	-0.564	0.11437	18.1657	18.7007
	Drying	(23-25)/12/16	3:00pm-9:00am	1645.11	1602.65	10.06	10.08	11.86	11.86	942.69	946.45	-0.6477	0.03002	0.97841	-1.5614
	Brushing	25/12/16	9:00am - 9:30am	1628.49		10.06		11.86		942.69	0.00	-0.6477		-0.0417	
6	Wetting	25/12/16	9:30am-2:30pm	1929.21	1929.53	10.06	10.07	11.85	11.86	941.90	944.57	-0.7315	-0.1684	18.4167	18.5164
	Drying	(25-27)/12/16	3:00pm-9:00am	1634.14	1599.66	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	0.30506	-1.745
	Brushing	27/12/16	9:00am - 9:30am	1624.53		10.05		11.86		940.82	0.00	-0.8452		-0.2848	
7	Wetting	27/12/16	9:30am-2:30pm	1914.91	1925.53	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	17.539	18.2707
	Drying	(27-29)/12/16	3:00pm-9:00am	1619.87	1600.77	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	-0.5708	-1.6768
	Brushing	29/12/16	9:00am - 9:30am	1596.44		10.04		11.85		938.16	0.00	-1.1258		-2.009	
8	Wetting	29/12/16	9:30am-2:30pm	1884.91	1915.53	10.04	10.07	11.85	11.86	938.16	944.57	-1.1258	-0.1684	15.6976	17.6565
	Drying	(29-31)/12/16	3:00pm-9:00am	1599.23	1605.22	10.04	10.07	11.85	11.86	938.16	944.57	-1.1258	-0.1684	-1.8377	-1.4035
	Brushing	31/12/16	9:00pm-9:30pm	1582.91		10.06		11.85		941.90	0.00	-0.7315		-2.8395	
9	Wetting	31/12/16	9:30am-2:30pm	1869.27	1893.13	10.06	10.07	11.86	11.86	942.69	944.57	-0.6477	-0.1684	14.7376	16.2806
	Drying	31/12/16-02/01/17	3:00pm-9:00am	1589.88	1598.02	10.06	10.07	11.86	11.86	942.69	944.57	-0.6477	-0.1684	-2.4117	-1.8457
	Brushing	2/1/2017	9:00am - 9:30am	1569.55		10.06		11.86		942.69	0.00	-0.6477		-3.6595	
10	Wetting	2/1/2017	9:30am-2:30pm	1859.71	1877.33	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	14.1508	15.3102
	Drying	(2-4)/12/17	3:00pm-9:00am	1589.12	1599.45	10.05	10.07	11.86	11.86	940.82	944.57	-0.8452	-0.1684	-2.4583	-1.7579
	Brushing	4/1/2017	9:00am - 9:30am	1565.17		10.05		11.85		940.03	0.00	-0.9288		-3.9284	
11	Wetting	4/1/2017	9:30am-2:30pm	1744.26	1864.33	10.05	10.06	11.85	11.86	940.03	942.69	-0.9288	-0.3665	7.06433	14.5117
	Drying	(4-6)/01/17	3:00pm-9:00am	1589.26	1594.35	10.05	10.06	11.85	11.86	940.03	942.69	-0.9288	-0.3665	-2.4497	-2.0712
	Brushing	6/1/2017	9:00am - 9:30am	1560.00		10.04		11.85		938.16	0.00	-1.1258		-4.2457	
12	Wetting	6/1/2017	9:30am-2:30pm	1723.43	1853.73	10.04	10.06	11.85	11.86	938.16	942.69	-1.1258	-0.3665	5.78577	13.8606
	Drying	(6-8)/1/17	3:00pm-9:00am	1573.22	1593.37	10.04	10.06	11.84	11.86	937.37	942.69	-1.2093	-0.3665	-3.4343	-2.1314
	Brushing	8/1/2017	9:00am - 9:30am	1542.22		10.04		11.84		937.37		-1.2093		-5.3371	
Oven Dry Specimen=OD		(07-08)/04/14	10:00am-3:00pm	1536.63	1644.29	10.04	10.06	11.84	11.86	Water retained in specimen=W (%)				-5.6802	0.92808

Corrected oven-dry weight of specimen-B = [ODB/(WA+100)]*100	**1629.17**
Soil-cement Loss, % = [(original wt - final corrected wt)/original wt]*100	**5.68019**

Appendix II

Cost Comparison

Appendix II-A
Cost of DBST, Natural Gravel and Crushed Base Course

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Single Seal Surface treatment**
Total quantity of work item : **Performance rate :** **800** **m^2/hr**

Material Cost					Labor cost					Equipment cost				
													Rental rate	
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**hrly**	**Total**
Asphalt 80/100	Ton	0.0018	15810	28.458	Construction Forma I	1	1	84.94541833	84.95	Roller,6t	1	1	277.422	277.422
2Omm Aggregate for surfacing	m3	0.013	308.525	4.01082	Equip. operator III	2	1	92.5687251	185.14	Asphalt Distributor	1	1	1500.65	1500.65
13mm Aggregate for surfacing	m3	0.009	308.525	2.77672	Eq. operator II	2	1	75.1440239	150.29	Chip Spreader	1	1	1267.53	1267.53
					St.Eq. operator I	1	1	59.89741036	59.90	Power Broom	1	1	247.866	247.866
					Helper II	2	1	34.15219124	68.30	Asphalt Kettel,trailer r	1	1	62.5901	62.5901
					Labourer I	10	1	34.15219124	341.52	pnumatic roller	2	1	651.934	1303.87
										hand tools	1	1	25	25
Total				32.4688	Total				890.09	Total				4684.93

A = Material Unit Cost **32.47** Birr/m^2 B = Manpower Unit Cost: **1.11** Birr/m^2 C = Equipment Unit Cost : **5.85616** Birr/m^2

Direct cost of work item =A+B+C= **39.44** Birr/m^2

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **53.24** Birr/m^2

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Double Surface treatment**
Total quantity of work item : **Performance rate :** **800 m^2/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
MC-3000	ton	0.0024	27750.00	66.60	Construction Forma I	1	1	84.95	84.95	Roller,6t	1	1	14.40	14.40
Agregate 10mm	m3	0.0060	308.52	1.85	Equip. operator III	2	1	92.57	185.14	Asphalt Distributor	1	1	135.14	135.14
Agregate 6.5mm	m3	0.0050	308.52	1.54	Eq. operator II	2	1	75.14	150.29	Chip Spreader	1	1	62.59	62.59
					St.Eq. operator I	1	1	59.90	59.90	Power Broom	1	1	1267.53	1267.53
										Asphalt Kettel,trailer mounted	1	1	695.00	695.00
					Labourer I	10	1	34.15	341.52	pneumatic roller	2	1	651.93	1303.87
										hand tools	3.00	1.00	25.00	75.00
Total				69.99	**Total**				821.79	**Total**				3553.53

A = Material Unit Cost 69.99 Birr/m^2 B = Manpower Unit Cost : 1.03 Birr/m^2 C = Equipment Unit Cost : 4.442 Birr/m^2

Direct cost of work item =A+B+C= **75.46** Birr/m^2

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **101.87** Birr/m^2

UF : Utilization Factor **First and Second Seal=** **155.12** Birr/m^2

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

1.35

Project : **Thesis**
Work Item : **Quarry Rock Production**
Total quantity of work item :

Performance rate : 400 M^3/day
50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Explosive	Box	0.006	507.00	3.04	Quarry Foreman	1	1	66.98	66.98	Crawler Dozer, d8r	1	0.25	1650.00	412.50
Blasting Caps	each	0.10	130.00	13.00	Equip. operator III	1	1	92.57	92.57	Compressor cfa 400	1	0.75	803.52	602.64
Drills 4/Month	each	0.040	7.00	0.28	St.Eq. operator I	1	1	59.90	59.90	Wagon Drill	1	0.75	608.46	456.35
					Powder Man II	1	1	31.53	31.53					
					Labourer Foreman	1	1	35.39	35.39					
					Helper I	1	1	34.15	34.15					
					Labourer I	10	1	34.15	341.52					
Total				16.32	**Total**				662.04	**Total**				1471.49

A = Material Unit Cost 16.32 Birr/m^3 B = Manpower Unit Cost 13.24 Birr/m^3 C = Equipment Unit Cost : 29.43 Birr/m^3

Direct cost of work item = A+B+C = 58.99 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 79.64 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis**
Work Item : **Quarry Hauling to Crusher** 1.35

Cap.	16 m^3
Av Dist.	2 km
Av. Spd	30 km/h
for L&UnL	8 min

Total quantity of work item :

Performance rate : 400 M^3/day
50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator II	1	0.50	75.14	37.57	Dump Truck 6x4	2	1.00	520.00	1040.00
					Equip. operator I	2	1.00	66.98	133.95	Loader	1	0.50	625.00	312.50
Total				0.00	**Total**				171.52	**Total**				1352.50

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost 3.43 Birr/m^3 C = Equipment Unit Cost : 27.05 Birr/m^3

Direct cost of work item = A+B+C = 30.48 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 41.15 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Rock Crushing (Base Course Aggregate)**
Total quantity of work item : **Performance rate : 50 M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Quarry Foreman	1	0.25	66.98	16.74	Crusher Plant, 75tph	1	1	7884.53	7884.53
					St.Eq. operator II	1	1.00	64.25	64.25	Loader, Wheel	1	1	625.00	625.00
					Labourer I	3	1.00	34.15	102.46					
					Equip. operator II	1	0.50	75.14	37.57					
					Helper II	1	1.00	34.15	34.15					
Total				0.00	**Total**				255.18	**Total**				8509.53

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost : 5.10 Birr/m^3 C = Equipment Unit Cost : 170 Birr/m^3

Direct cost of work item =A+B+C= **175.29** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **236.65** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Stockpilling (Aggregate) Crushed Material**
Total quantity of work item : **Performance rate : 80 M^3/hr**

Material Cost					Labor cost					Equipment cost				
aterial Ty	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. Operator II	1	0.5	75.14	37.57	loader	1	0.5	625.00	312.50
					Equip. Operator I	2	1	66.98	133.95	Dump truck	2	1	520.00	1040.00
					Helper	1	1	34.15	34.15					
Total				0.00	**Total**				205.68	**Total**				1352.50

A = Material Unit Co 0.00 Birr/m^3 B = Manpower Unit Cost : 2.57 Birr/m^3 C = Equipment Unit Cost : 17 Birr/m^3

Direct cost of work item =A+B+C= **19.48** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **26.29** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35

Work Item : **Base Course Mixing**

Total quantity of work item : **Performance rate : 120 M^3/hr**

Material Cost					Labor cost					Equipment cost				
aterial Ty	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. Operator II	1	1	75.14	75.14	Loader, Wheel	1	1	625.00	625.00
					Equip. Operator I	2	1	66.98	133.95	Water Truck 6x4	2	1	480.00	960.00
					Helper II	3	1	34.15	102.46					
Total				0.00	**Total**				311.55	**Total**				1585.00

A = Material Unit Co 0.00 Birr/m^3 B = Manpower Unit Cost : 2.60 Birr/m^3 C = Equipment Unit Cost : 13 Birr/m^3

Direct cost of work item =A+B+C= **15.80** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **21.34** Birr/m^3

UF : Utilization Factor

* Inclusive of waste

** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed break down of work item unit prices

Project : **Thesis** 1.35
Work Item : **Base Course Hauling**
Total quantity of work item :

Cap.	16 m^3
Av Dist.	24 km
Av. Spd	35 km/h
for L&UnL	8 min

Performance rate : 400 M^3/day
50.00 M^3/hr 400

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1	625.00	625.00
					Equip. operator I	5	1	66.98	334.88	Dump Truck 6x4	5	1	520.00	2600.00
					Helper II	1	1	34.15	34.15					
Total				0.00	**Total**				444.18	**Total**				3225.00

A = Material Unit Cost 0.00 Birr/m ^{3} B = Manpower Unit Cost : 8.88 Birr/m3 C = Equipment Unit Cost : 65 Birr/m^3

Direct cost of work item =A+B+C= **73.38** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **99.07** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Base Course Placing** 800 m3/day
Total quantity of work item : Performance rate : 100 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Crushed Aggergate	m^3	1.50	373.43	560.15	Construction Foreman I	1	0.5	84.95	42.47	Motor Grader	2	1	800.00	1600.00
					Equip. operator III	1	1	92.57	92.57	Roller, 12t	2	1	540.12	1080.24
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	1	0.5	66.98	33.49					
					Helper II	1	1	34.15	34.15					
					Laboure I	10	1	34.15	341.52					
Total				560.15	**Total**				694.49	**Total**				3160.24

A = Material Unit Cost 560.15 Birr/m ^{3} B = Manpower Unit Cost : 6.94 Birr/m^3 C = Equipment Unit Cost : 31.6024 Birr/m^3

Direct cost of work item =A+B+C= **598.70** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **808.24** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

1.35

Project : **Thesis**
Work Item : **Quarry Rock Production**
Total quantity of work item :

Performance rate : 400 M^3/day
50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Explosive	Box	0.006	507.00	3.04	Quarry Foreman	1	1	66.98	66.98	Crawler Dozer, d8r	1	0.25	1650.00	412.50
Blasting Caps	each	0.10	130.00	13.00	Equip. operator III	1	1	92.57	92.57	Compressor cfa 400	1	0.75	803.52	602.64
Drills 4/Month	each	0.040	7.00	0.28	St.Eq. operator I	1	1	59.90	59.90	Wagon Drill	1	0.75	608.46	456.35
					Powder Man II	1	1	31.53	31.53					
					Labourer Foreman	1	1	35.39	35.39					
					Helper I	1	1	34.15	34.15					
					Labourer I	10	1	34.15	341.52					
Total				16.32	**Total**				662.04	**Total**				1471.49

A = Material Unit Cost 16.32 Birr/m^3 B = Manpower Unit Cost 13.24 Birr/m^3 C = Equipment Unit Cost : 29.43 Birr/m^3

Direct cost of work item = A+B+C = 58.99 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 79.64 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis**
Work Item : **Quarry Hauling to Crusher** 1.35

Total quantity of work item :

Cap.	16	m^3
Av Dist.	84	km
Av. Spd	30	km/h
for L&UnL	8	min

Performance rate : 400 M^3/day
50.00 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator II	1	0.50	75.14	37.57	Dump Truck 6x4	24	1.00	520.00	12480.00
					Equip. operator I	2	1.00	66.98	133.95	Loader	1	0.50	625.00	312.50
Total				0.00	**Total**				171.52	**Total**				12792.50

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost 3.43 Birr/m^3 C = Equipment Unit Cost : 255.85 Birr/m^3

Direct cost of work item = A+B+C = 259.28 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 350.03 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Rock Crushing (Base Course Aggregate)**
Total quantity of work item : **Performance rate : 50 M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Quarry Foreman	1	0.25	66.98	16.74	Crusher Plant, 75tph	1	1	7884.53	7884.53
					St.Eq. operator II	1	1.00	64.25	64.25	Loader, Wheel	1	1	625.00	625.00
					Labourer I	3	1.00	34.15	102.46					
					Equip. operator II	1	0.50	75.14	37.57					
					Helper II	1	1.00	34.15	34.15					
Total				0.00	**Total**				255.18	**Total**				8509.53

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost : 5.10 Birr/m^3 C = Equipment Unit Cost : 170 Birr/m^3

Direct cost of work item =A+B+C= **175.29** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **236.65** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Stockpilling (Aggregate) Crushed Material**
Total quantity of work item : **Performance rate : 80 M^3/hr**

Material Cost					Labor cost					Equipment cost				
aterial Ty	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. Operator II	1	0.5	75.14	37.57	loader	1	0.5	625.00	312.50
					Equip. Operator I	2	1	66.98	133.95	Dump truck	2	1	520.00	1040.00
					Helper	1	1	34.15	34.15					
Total				0.00	**Total**				205.68	**Total**				1352.50

A = Material Unit Co 0.00 Birr/m ^{3} B = Manpower Unit Cost : 2.57 Birr/m^3 C = Equipment Unit Cost : 17 Birr/m^3

Direct cost of work item =A+B+C= **19.48** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **26.29** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Base Course Mixing**
Total quantity of work item : **Performance rate : 120 M^3/hr**

Material Cost					Labor cost					Equipment cost				
aterial Ty	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. Operator II	1	1	75.14	75.14	Loader, Wheel	1	1	625.00	625.00
					Equip. Operator I	2	1	66.98	133.95	Water Truck 6x4	2	1	480.00	960.00
					Helper II	3	1	34.15	102.46					
Total				0.00	**Total**				311.55	**Total**				1585.00

A = Material Unit Co 0.00 Birr/m ^{3} B = Manpower Unit Cost : 2.60 Birr/m^3 C = Equipment Unit Cost : 13 Birr/m^3

Direct cost of work item =A+B+C= **15.80** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **21.34** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed break down of work item
unit prices

Project : **Thesis** 1.35
Work Item : **Base Course Hauling**
Total quantity of work item :

Cap.	16 m^3
Av Dist.	24 km
Av. Spd	35 km/h
for L&UnL	8 min

Performance rate : 400 M^3/day
50.00 M^3/hr 400

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1	625.00	625.00
					Equip. operator I	5	1	66.98	334.88	Dump Truck 6x4	5	1	520.00	2600.00
					Helper II	1	1	34.15	34.15					
Total				0.00	**Total**				444.18	**Total**				3225.00

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost : 8.88 Birr/m3 C = Equipment Unit Cost : 65 Birr/m^3

Direct cost of work item =A+B+C= **73.38** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **99.07** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Base Course Placing** 800 m3/day
Total quantity of work item : Performance rate : 100 M^3/hr

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly	Total Hourly	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Crushed Aggergate	m^3	1.50	602.23	903.35	Construction Foreman I	1	0.5	84.95	42.47	Motor Grader	2	1	800.00	1600.00
					Equip. operator III	1	1	92.57	92.57	Roller, 12t	2	1	540.12	1080.24
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	1	0.5	66.98	33.49					
					Helper II	1	1	34.15	34.15					
					Laboure I	10	1	34.15	341.52					
Total				903.35	**Total**				694.49	**Total**				3160.24

A = Material Unit Cost 903.35 Birr/m ^{3} B = Manpower Unit Cost : 6.94 Birr/m^3 C = Equipment Unit Cost : 31.6024 Birr/m^3

Direct cost of work item =A+B+C= **941.90** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **1271.56** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

1.35

Project : **Thesis**
Work Item : **Material Production**
Total quantity of work item :

Performance rate : 750 m^3 /day
93.75 m^3 / hr

Material cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost per unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equipment type**	**Qty**	**UF**	**Rental cost hrly**	**Rental cost Total**
					Equip. operator III	1.00	1.00	92.57	92.57	Crawler Dozer, d8r	1.00	1.00	1650.00	1650.00
					Helper II	1.00	1.00	34.15	34.15					
Total				0.00	**Total**				126.72	**Total**				1650.00

A = Material Unit Cost **0.00 Birr/m^3** B = Manpower Unit Cost: **1.35 Birr/m^3** C = Equipment Unit Cost : Operation **17.60 Birr/m^3**

Direct cost of work item =A+B+C= 18.95 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 25.58 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsides and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

1.35

Project : **Thesis**

Work Item : **Material Hauling**

Total quantity of work item :

Cap.	16	m^3
Av Dist.	10.00	km
Av. Spd	35	km/h
t for L&UnL	8	min

Performance rate : **750** M^3**/day**

93.75 M^3**/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental rate hrly	Total
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1.00	625.00	625.00
					Helper II	1	1	34.15	34.15	Dump Truck 6x4	5	1.00	520.00	2600.00
					Equip. operator I	5	1	66.98	334.88					
Total				0.00	**Total**				444.18	**Total**				3225.00

A = Material Unit Cost 0.00 Birr/m^3

B = Manpower Unit Cost 4.74 Birr/m^3

C = Equipment Unit Cost : 34.40 Birr/m^3

Direct cost of work item = A+B+C = 39.14 Birr/m³

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 52.84 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Subbase Placing** **750.00** m3/day
Total quantity of work item : **Performance rate : 93.75 M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Select Material	m3	1.75	58.09	101.66	Construction Foreman I	1	1	84.95	84.95	Roller, 12t	2	1	540.12	1080.24
					Equip. operator III	1	1	92.57	92.57	Motor Grader	1	1	800.00	800.00
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	2	1	66.98	133.95					
					Labourer I	10	1	34.15	341.52					
					Helper II	4	1	9.32	37.26					
Total				101.66	**Total**				840.54	**Total**				2360.24

A = Material Unit Cost <u>101.66</u> Birr/m^3 B = Manpower Unit Cost : <u>8.97</u> Birr/m^3 C = Equipment Unit Cost : <u>25</u> Birr/m^3

Direct cost of work item =A+B+C= **<u>135.80</u>** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **<u>183.33</u>** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Appendix II-B Cost of Lime Stabilized Base Course and Subbase

Detailed Break Down of Work Item
Unit Prices

1.35

Project : **Thesis**
Work Item : **Material Production** Performance rate : 750 m^3 /day
Total quantity of work item : 93.75 m^3 / hr

Material cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost per unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental cost hrly	Rental cost Total
					Equip. operator III	1.00	1.00	92.57	92.57	Crawler Dozer, d8r	1.00	1.00	1650.00	1650.00
					Helper II	1.00	1.00	34.15	34.15					
Total				0.00	**Total**				126.72	**Total**				1650.00

A = Material Unit Cost **0.00 Birr/m³** B = Manpower Unit Cost: **1.35 Birr/m³** C = Equipment Unit Cost : Operation **17.60 Birr/m³**

Direct cost of work item =A+B+C= 18.95 Birr/m³

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 25.58 Birr/m³

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsides and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices 1.35

Project : **Thesis**

Work Item : **Material Hauling (Lime and Laterite)**

Total quantity of work item :

Cap.	16	m^3
Av Dist.	20.00	km
Av. Spd	35	km/h
t for L&UnL	8	min

Performance rate : **750** M^3**/day**
93.75 M^3**/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental rate hrly	Total
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1.00	625.00	625.00
					Helper II	1	1	34.15	34.15	Dump Truck 6x4	5	1.00	520.00	2600.00
					Equip. operator I	5	1	66.98	334.88	Lime Truck	1	0.5	520.00	260.00
Total				0.00	**Total**				444.18	**Total**				3485.00

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost 4.74 Birr/m^3 C = Equipment Unit Cost : 37.17 Birr/m^3

Direct cost of work item = A+B+C = 41.91 Birr/m³

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 56.58 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Base Course Placing (Lime and Laterite)** **750.00** m3/day
Total quantity of work item : **Performance rate :** **93.75** **M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Select Material	m3	1.58	60.86	96.16	Construction Foreman I	1	1	84.95	84.95	Roller, 12t	2	1	540.12	1080.24
Lime	qtl	1.70	425.50	723.35	Equip. operator III	1	1	92.57	92.57	Motor Grader	1	1	800.00	800.00
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	2	1	66.98	133.95	Lime Spreader	1	0.5	500.00	250.00
		1.58			Labourer I	10	1	34.15	341.52					
		0.32			Helper II	4	1	9.32	37.26					
Total				819.51	**Total**				840.54	**Total**				2610.24

A = Material Unit Cost 819.51 Birr/m^3 B = Manpower Unit Cost : 8.97 Birr/m^3 C = Equipment Unit Cost : 28 Birr/m^3

Direct cost of work item =A+B+C= **856.32** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **1156.03** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

1.35

Project : **Thesis**
Work Item : **Material Production** Performance rate : 750 m^3 /day
Total quantity of work item : 93.75 m^3 / hr

Material cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost per unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental cost	
													hrly	Total
					Equip. operator III	1.00	1.00	92.57	92.57	Crawler Dozer, d8r	1.00	1.00	1650.00	1650.00
					Helper II	1.00	1.00	34.15	34.15					
Total				0.00	**Total**				126.72	**Total**				1650.00

A = Material Unit Cost **0.00** **Birr/m³** B = Manpower Unit Cost: **1.35** **Birr/m³** C = Equipment Unit Cost : Operation **17.60** **Birr/m³**

Direct cost of work item =A+B+C= **18.95** **Birr/m³**

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **25.58** **Birr/m³**

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsides and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

1.35

Project : **Thesis**

Work Item : **Material Hauling (Lime and Laterite)**

Total quantity of work item :

Cap.	16	m^3
Av Dist.	20.00	km
Av. Spd	35	km/h
t for L&UnL	8	min

Performance rate : **750** **M^3/day**
93.75 **M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equipment type**	**Qty**	**UF**	**Rental rate hrly**	**Total**
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1.00	625.00	625.00
					Helper II	1	1	34.15	34.15	Dump Truck 6x4	5	1.00	520.00	2600.00
					Equip. operator I	5	1	66.98	334.88	Cement Truck	1	0.5	520.00	260.00
Total				0.00	**Total**				444.18	**Total**				3485.00

A = Material Unit Cost 0.00 Birr/m^3

B = Manpower Unit Cost 4.74 Birr/m^3

C = Equipment Unit Cost : 37.17 Birr/m^3

Direct cost of work item = A+B+C = 41.91 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 56.58 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Subbase Placing (Lime and Laterite)** **750.00** m3/day
Total quantity of work item : **Performance rate : 93.75 M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Select Material	m3	1.58	60.86	96.16	Construction Foreman I	1	1	84.95	84.95	Roller, 12t	2	1	540.12	1080.24
Cement	qtl	1.02	425.50	434.01	Equip. operator III	1	1	92.57	92.57	Motor Grader	1	1	800.00	800.00
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	2	1	66.98	133.95	Cement Spreader	1	0.5	500.00	250.00
		1.58			Labourer I	10	1	34.15	341.52					
		0.32			Helper II	4	1	9.32	37.26					
Total				530.17	**Total**				840.54	**Total**				2610.24

A = Material Unit Cost 530.17 Birr/m^3 B = Manpower Unit Cost : 8.97 Birr/m^3 C = Equipment Unit Cost : 28 Birr/m^3

Direct cost of work item =A+B+C= **566.98** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **765.43** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Appendix II-C Cost of Cement Stabilized Base Course and Subbase

Detailed Break Down of Work Item
Unit Prices

1.35

Project : **Thesis**

Work Item : **Material Production** Performance rate : 750 m^3 /day

Total quantity of work item : 93.75 m^3 / hr

Material cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost per unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental cost hrly	Rental cost Total
					Equip. operator III	1.00	1.00	92.57	92.57	Crawler Dozer, d8r	1.00	1.00	1650.00	1650.00
					Helper II	1.00	1.00	34.15	34.15					
Total				0.00	**Total**				126.72	**Total**				1650.00

A = Material Unit Cost **0.00** **Birr/m^3** B = Manpower Unit Cost: **1.35** **Birr/m^3** C = Equipment Unit Cost : Operation **17.60** **Birr/m^3**

Direct cost of work item =A+B+C= **18.95** **Birr/m^3**

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **25.58** **Birr/m^3**

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsides and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

1.35

Project : **Thesis**

Work Item : **Material Hauling (Cement and Laterite)**

Total quantity of work item :

Cap.	16 m^3
Av Dist.	20.00 km
Av. Spd	35 km/h
t for L&UnL	8 min

Performance rate : **750** **M^3/day**
93.75 **M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/ unit**	**Title**	**Qty**	**UF**	**Indexed hrly cost**	**Total hrly cost**	**Equipment type**	**Qty**	**UF**	**Rental rate hrly**	**Total**
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1.00	625.00	625.00
					Helper II	1	1	34.15	34.15	Dump Truck 6x4	5	1.00	520.00	2600.00
					Equip. operator I	5	1	66.98	334.88	Cement Truck	1	0.5	520.00	260.00
Total				0.00	**Total**				444.18	**Total**				3485.00

A = Material Unit Cost 0.00 Birr/m^3 B = Manpower Unit Cost 4.74 Birr/m^3 C = Equipment Unit Cost : 37.17 Birr/m^3

Direct cost of work item = A+B+C = 41.91 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 56.58 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Base Course Placing (Cement and Laterite)** **750.00** m3/day
Total quantity of work item : **Performance rate : 93.75 M^3/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed Hourly Cost	Total Hourly Cost	Equipment Type	Qty	UF	Rental rate hrly	Rental rate Total
Select Material	m3	1.58	60.86	96.16	Construction Foreman I	1	1	84.95	84.95	Roller, 12t	2	1	540.12	1080.24
Cement	qtl	1.70	240.00	408.00	Equip. operator III	1	1	92.57	92.57	Motor Grader	1	1	800.00	800.00
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	2	1	66.98	133.95	Cement Spreader	1	0.5	500.00	250.00
		1.58			Labourer I	10	1	34.15	341.52					
		0.32			Helper II	4	1	9.32	37.26					
Total				504.16	**Total**				840.54	**Total**				2610.24

A = Material Unit Cost <u>504.16</u> Birr/m^3 B = Manpower Unit Cost : <u>8.97</u> Birr/m^3 C = Equipment Unit Cost : <u>28</u> Birr/m^3

Direct cost of work item =A+B+C= **<u>540.97</u>** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **<u>730.31</u>** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break Down of Work Item
Unit Prices

1.35

Project : **Thesis**

Work Item : **Material Production (Cement and Laterite)** Performance rate : 750 m^3 /day

Total quantity of work item : 93.75 m^3 / hr

Material cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost per unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental cost hrly	Rental cost Total
					Equip. operator III	1.00	1.00	92.57	92.57	Crawler Dozer, d8r	1.00	1.00	1650.00	1650.00
					Helper II	1.00	1.00	34.15	34.15					
Total				0.00	**Total**				126.72	**Total**				1650.00

A = Material Unit Cost **0.00 Birr/m³**   B = Manpower Unit Cost: **1.35 Birr/m³**   C = Equipment Unit Cost : Operation **17.60 Birr/m³**

Direct cost of work item =A+B+C= 18.95 Birr/m³

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 25.58 Birr/m³

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsides and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

1.35

Project : **Thesis**

Work Item : **Material Hauling (Cement and Laterite)**

Total quantity of work item :

Cap.	16 m^3
Av Dist.	20.00 km
Av. Spd	35 km/h
t for L&UnL	8 min

Performance rate : **750** M^3**/day**
93.75 M^3**/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	Unit	Qty	Rate	Cost/ unit	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rental rate hrly	Total
					Equip. operator II	1	1	75.14	75.14	Loader, Wheel	1	1.00	625.00	625.00
					Helper II	1	1	34.15	34.15	Dump Truck 6x4	5	1.00	520.00	2600.00
					Equip. operator I	5	1	66.98	334.88	Cement Truck	1	0.5	520.00	260.00
Total				0.00	**Total**				444.18	**Total**				3485.00

A = Material Unit Cost 0.00 Birr/m^3

B = Manpower Unit Cost 4.74 Birr/m^3

C = Equipment Unit Cost : 37.17 Birr/m^3

Direct cost of work item = A+B+C = 41.91 Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = 56.58 Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item

Detailed Break down of Work Item
Unit Prices

Project : **Thesis** 1.35
Work Item : **Subbase Placing** **750.00** m3/day
Total quantity of work item : **Performance rate :** **93.75** M^3**/hr**

Material Cost					Labor cost					Equipment cost				
Material Type	**Unit**	**Qty**	**Rate**	**Cost/Unit**	**Title**	**Qty**	**UF**	**Indexed Hourly Cost**	**Total Hourly Cost**	**Equipment Type**	**Qty**	**UF**	**Rental rate hrly**	**Rental rate Total**
Select Material	m3	1.58	60.86	96.16	Construction Foreman I	1	1	84.95	84.95	Roller, 12t	2	1	540.12	1080.24
Cement	qtl	1.02	240.00	244.80	Equip. operator III	1	1	92.57	92.57	Motor Grader	1	1	800.00	800.00
					Equip. operator II	2	1	75.14	150.29	Water Truck 6x4	1	1	480.00	480.00
					Equip. operator I	2	1	66.98	133.95	Cement Spreader	1	0.5	500.00	250.00
		1.58			Labourer I	10	1	34.15	341.52					
		0.32			Helper II	4	1	9.32	37.26					
Total				340.96	**Total**				840.54	**Total**				2610.24

A = Material Unit Cost 340.96 Birr/m^3 B = Manpower Unit Cost : 8.97 Birr/m^3 C = Equipment Unit Cost : 28 Birr/m^3

Direct cost of work item =A+B+C= **377.77** Birr/m^3

Assuming 10 % project overhead, 10 % profit margin and 15% for others, the total surcharge adopted is 35% of direct cost. Thus :

Total cost = **509.99** Birr/m^3

UF : Utilization Factor
* Inclusive of waste
** Inclusive of benefits, travel subsidies and cost of overtime related to the work item