Stabilization of A'a Lava Gravel as Base Course Material Using Pozzolana/ Volcanic Ash

By

Eden Sitotaw Kebede

A thesis summited to

Civil Engineering Program

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Award of Degree of Masters in Civil Engineering (Geotechnical Engineering)

Office of Graduate Studies

Adama Science and Technology University

December, 2018

Adama, Ethiopia

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Approval Page

We, the undersigned, members of the Board of Examiners of the final open defense by Eden Sitotaw have read and evaluated her thesis entitled "Stabilization of A'a Lava Gravel as Base Course Material Using Pozzolana/Volcanic Ash" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Geotechnical Engineering.

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Declaration

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Eden Sitotaw

Signature: _______________

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SYMBOLS AND ABBREVIATION

AASHTO	American Association of Highway and Transportation Officials
AC	Asphalt Concrete
ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California Bearing Ratio
CSRB	Crushed Stone Road Base
DD	Dry Density
E	Easting
ERA	Ethiopia Road Authority
GB	Granular Base
GPS	Global Position System
G_s	Specific Gravity
LAA	Los Angeles Abrasion
MDD	Maximum Dry Density
N	Northing
NP	Non-Plastic
OMC	Optimum Moisture Content
PDM	Pavement Design Manual
PI	Plastic Index
RSDP	Road Sector Development Program
SRB	Stabilized Road Base
SSD	Saturated Surface Dry
TCDSC	Transport Construction and Design Sharing Company
UCS	Unconfined Compressive Strength

ABSTRACT

Stability of a road base layer is depends on the quality of material and particle size distribution. And in order to construct stable pavement with in proposed construction period and cost, using locally available materials plays a significant role. However, these materials are not always suitable and cannot be found in areas close to the construction site, stabilizing locally available material would be a good alternative to achieve the desired pavement construction work. A'a lava gravels occur extensively in Boset and Fentale woredas of Oromia regional state. But in the past it never have been used in road construction due to its absence of fine material, light weight, rough surfaces and high porosity even though it would substantially reduce road construction costs in many instances. Therefore in this study Natural Pozzolana material were collected from Adama Area in order to stabilize the gravel by blend the two materials. Pozzolanicity test was conducted using unconfined compression test conducted on two specimens of the volcanic ash /Pumicite, the average UCS value for 3days to 7days of curing which increases from 86.5 to 151Kpa. And also the characteristics of A'a lava gravel using Gradation, Los Angeles Abrasion, Aggregate Crushing Value, Absorption and Specific gravity tests were conducted in the laboratory. Then finaly to check the performance of mechanically stabilized A'a lava gravels to be used as road base material in order to achieve the Ethiopia Road Authority manual specification, it was blended with some trail proportion of 5, 10, 15, 20, and 25 % of pozzolana material/pumicite by mass and different tests including compaction, CBR, grain size distribution and atterberg limit are conducted in the laboratory. Based on the laboratory test results it is shown that, from both Modified proctor and CBR test for different percent of pumicite, it has been observed that the optimum amount of pumice in order to improve A'a lava gravel properties is 20 % by mass proportion. CBR laboratory test results compared with similar researches and it shows that stabilized A'a lava gravel performed well when it comes to load carrying capacity. The cost comparison, on the other hand, indicated that based on the current market price during the study period, stabilized A'a lava gravel with pumice has cost benefit against using the crushed aggregates for the road base construction.

Key Words: A'a lava gravel, Natural Pozzolana, CBR, Compaction, UCS

CHAPTER ONE

INTRODUCTION

1.1 Background

In previous times mankind has used the natural earth surface for transportation. But through time the road surface were widened and covered with rock and gravel thus made suitable to track and for the increasing number of traffic which causes challenges from environmental condition has led to establishing pavement design guidelines involving two major pavement types which are based on assumption that aggregate are important ingredients of pavement structure. As geotechnical engineer, determining and designing the proper type of earthwork and road construction material grades required for the intended traffic load and structures to be constructed.

In our country specified materials have been outlined to be used as base course materials which mainly include crashed stone and natural river gravels. However availability of good quality aggregate may be a problem in some locations and there is future risk of getting this scares materials support fast growing road infrastructure construction (Berhanu Girma, 2009). Therefore improvement of poor road network density which retains economic development especially in rural areas of Ethiopia is needed.

This gives rise to the need for use of locally available marginal materials by modifying physical and engineering properties which is recommend practice by conducting local experimental analysis (ERA, 2013). To achieve this, mechanical or chemical stabilization which has proved to be good solution in our country have been using.

A’a lava Gravels are marginal materials that are found extensively (abundantly) located in rift valley areas specifically in Boset and Fentale woredas in eastern part of Ethiopia where connective roads are not properly constructed yet. Problems associated with this gravels are lack of finer materials in comparison to standard specification and broke easily which make them unsuitable for base course construction. This thesis study is all about stabilization of A’a lava rock gravel with pozzolanic material (volcanic ash) to be used as a base course material aims at improving undesired properties of the gravels to make them an alternative of standard materials. Experimental investigation will be carried on A’a lava gravel samples were collected from Boset area and pozzolana from Adama in order to find optimum amount of stabilizers needed to produce material that can serve as alternative base course construction material.

1.2. Problem Statement

In Ethiopia, the road sector plays a great role for the economic development of the country; has set out a successive Road Sector Development Program (RSDP) to speed up the improvement and expansion of the road network to maintain sustainable development in the country. The most common type of pavement structure used for highway construction is flexible pavement which is made up of natural or treated subgrade, unbound sub–base and base–course materials and bituminous bound surfacing materials. The quality of these pavement structures largely depend on aggregate materials which are the main constituents of pavement structural layers (ERA, 2013). The standard materials for base course construction are mainly crushed stones and natural aggregates found from rivers. But sometimes it might not be available to get these materials at nearby locations from road projects or fail to provide expected quality. Finding and transporting quality materials from far distances usually beyond 10km off-set from center line of proposed alignment induce additional costs to the government as well as contractors in addition to delays to construction (ERA, 2011).

The use of locally available marginal materials by improving their properties is a best alternative to overcome this problem (Berhanu Girma, 2009). A’a lava gravel which extensively found around Boset and Fentale woredas has not been used as a source of road construction materials. A’a lava rock gravels can be easily dug out from the surface using simple hand tools after opening up work space using bulldozers. Problems associated with this gravels are lack of enough fine particles to meet the grading specifications and the pores on it that makes it weak. Researchers have indicated the use of cinder gravels for road base construction by stabilizing them mechanically and chemically (Berhanu Girma, 2009). A’a lava rock gravels have the similar composition but less pores and better strength. Therefore this experimental study will focus on investigating the possible use of mechanical stabilized A’a gravels as road base materials for heavy trafficked pavement by conducting laboratory test on samples which will be collected from Boset. Pozzolana material that found near to that area and material will be used as additives to improve the physical and engineering properties of the gravel.

1.3. Objective of the Research

1.3.1. General objectives

The general objective of the research is to stabilize A’a lava gravel with pozzolana to be used as a road construction material in base course construction for heavy traffic load pavement.

1.3.2. Specific objectives

- Characterizing A’a lava gravel and natural pozzolana material by conducting laboratory tests.
- To examine the response of A’a lava gravel in terms of change in strength by adding different amount of pozzolana material.
- To identify the optimum mixture composition, in order to meet the ERA specification for road base material.
- To assess the economic feasibility of utilizing the stabilized naturally available A’a lava gravel material in place of those currently in use.

1.4 Organization of the Thesis

This thesis has six chapters. The first chapter discussed the general introduction of the study, objective the problem statement and methodology of the study. In the second chapter, a comprehensive literature review on the origin and formation of A’a lava gravel and Pozzolanic material is discussed in addition to stabilization techniques, function of base course and also related works on weak gravel in road construction and economical aspects of blending material. The third chapter is about the general description of the study area and the proposed material sources are described. Chapter four contains the laboratory test and results. In chapter five, the laboratory test results are discussed. In the last chapter, conclusion and recommendations are presented. And then reference materials used in this research work are sited and listed appropriately. Finally the thesis ends with appendices which contain detail experimental results of laboratory investigation.

CHAPTER TWO

LITERATURE REVIEW

2.1The Location and Engineering Properties of A’a lava Gravels in Ethiopia

2.1.1 Introduction

A’a lava rock gravels are incredibly rough and jagged black rock surrounding this thick dense core is a sharp spiny surface of cooling rock. A’a lava rocks generally have a rough surface and high porous nature (https://www.universetoday.com/29655/aa-lava/Fraser Cain, 2009).

Pozzolanic material deposits are found wherever there are active or recently active volcanoes. It also obtained from various sources and can be naturally occurring minerals or industrial byproducts. It defined as (ASTM C125) "a siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties”. They do not necessarily interact with Portland cement in the same way, and the mechanisms involved in hydration of coal fly ash (FA) and silica fume to form hydration products are different.

Pozzolans were the first cementitious materials used by early civilisations and some of the most important historical buildings rely on pozzolanic cement systems. Different pilot study has been conducted in different countries of worldwide to investigate the possibility of using naturally occurring pozzolan materials as a stabilizer agent for road base and sub base construction. And it is found to be an alternate natural binders which can be effectively useful as a material and also save money since those materials are found abundantly in extensive areas of the countries where recent volcanic activities were occur.

2.1.2 Definition of A’a lava gravel

Lavas, particularly basaltic ones, come in two primary types: *pahoehoe* (pronounced 'paw-hoey-hoey") and *a’a* (pronounced "ah-ah"). The pahoehoe flow has a comparatively smooth or "ropy" surface. The surface of the A’a flow consists of free chunks of very angular pieces of lava. The difference in color is in the case of A’a lava is a reflection of age. The older A’a has weathered and the iron in it has oxides somewhat, giving it a reddish appearance (even young A’a flows are occasionally slightly brown or reddish, due to the oxidation that occurs during flow). (https://www.universetoday.com/29655/aa-lava/Fraser Cain, 2009). Therefore we can say that the A’a lava found in the study area is created by recent volcanic activity since it does not finish its oxidation reaction so that its color is still black.

Figure 2-1 Image of A’a lava (https://www.universetoday.com/29655/aa-lava/Fraser Cain, 2009)

It’s incredibly rough and jagged black rock, surrounding this thick dense core is a sharp spiny surface of cooling rock. A’a lava rocks generally has a rough surface and high porous nature (https://www.universetoday.com/29655/aa-lava/Fraser Cain, 2009), with its pores chiefly in the form of vesicles, interconnected pores of the pumice.

A’a lava gravels have weak particles which can be broken down and they are well graded but lacking of fine materials. Compaction can improve their gradation by producing finer particles although this may lead to reducing the required amount of coarser particles. This property makes them difficult to be compacted to a stable layer (Newil, D. and Kassaye Aklilu., 1980).

The material have moderate durability, high porosity and CBR value is less than that is required to be used as base course material for heavily trafficked roads. Besides their availability have the advantages of being easily dug out using simple hand tools like or mechanical shovel and small crusher can be used to meet the proposed grading after opening up a working surface using dozer.

2.2 Pozzolanic Materials

2.2.1 Definition of Pozzolana

Pozzolanas are materials’ containing reactive silica which in themselves possess little or no cementitious value but which combines with lime in finely divided form in the presence of water to produce cementing compounds.

The name pozzolana was given to such material in honor of the place Puzzolini, a village near Naples, Italy, following the 79 AD eruption of Mount Vesuvius, where it was found that Roman had built hydraulic structures by mixing lime and the volcanic ash, thus producing `hydraulic lime which can set under water. (http://www.civilgraduate.com/pozzolanas-materials-and-their-uses.html/civilgraduate.com, 2016).

According to American Concrete Institute (ACI) pozzolana is defined as “either raw or calcined natural material that has pozzolanic properties (for example, volcanic ash pumicite, Opaline, Chert and shales and some diatomaceous earths).” ACI also defines pozzolan as “a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of water, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. (Paul J. Tikalsky and Morris V.Huffman, 2011).

The natural pozzolans in the raw or calcined state are designated as Class-N pozzolans and are described in ASTM C 618 specifications as “ Raw or calcined natural pozzolans that comply with the applicable requirements for the class given herein, such as some diatomaceous earth; opaline chert and shales; tuffs and volcanic ashes or Pumicites, any of which may or may not be processed by calcination; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales” (Paul J. Tikalsky and Morris V.Huffman, 2011).

Pumicite is a finely divided volcanic ash composed of angular and porous particles of siliceous glass and varying proportions of crystal fragments differing from pumice only in grain size. Pumicites are mainly rhyolite or dacites in composition. They occur as stratified or massive deposits, commonly as lake beds (Paul J. Tikalsky and Morris V.Huffman, 2011).

2.2.2 Types of Pozzolana

Pozzolanic Materials are classified into two groups: Natural Pozzolanas such as volcanic ash and Artificial Pozzolanas such as fly ash. Natural Pozzolanas represent all those naturally occurring materials such as volcanic ash or Pumicite, Diatomaceous earth, Shales, opaline, Chert, and tuffs. Artificial Pozzolans represents all those Pozzolans formed from processing of materials originally without Pozzolanic properties such as fly ash, blast furnace slag, bumed clay or shale, micro silica or silica fumes. Furthermore, Lea classified natural Pozzolans into three groups based on their origin, namely volcanic origin, sedimentary origin and those of mixed origin (Arip-Kituyan E. Olekambainei., 2004.)

Pozzolanic material deposits are found wherever there are active or recently active volcanoes, such as in the Mediterranean, the Pacific region, and central and eastern Africa including Ethiopia. The physical condition of volcanic ashes may range from loose fine material to coarse deposits containing quite large particles. Deposits may be loose, with an appearance and texture similar to a compacted coal or wood ash. Other deposits are cemented, sometimes with appearance and properties similar to stone, and in this form they are normally referred to as tuffs. The color of deposits can vary from off-white to dark grey (Melav Kennedy Saroni, March,2014.)

Volcanic ashes are requires only minor processing before use as a pozzolana. Most of the time it founds as loosely cemented and can easily be excavated by hand, although others may need mechanical or pneumatic equipment. Some lithic tuffs may require blasting with explosives. But sometimes the ash may require drying, and in dry sunny climates this can simply be achieved by spreading the ash in a thin layer on a specially prepared drying floor, similar to those commonly used to dry crops. Alternatively, in wet climates, and for large quantities, inclined rotary driers are normally used (Thomas Teshome, 2015).

If the ash is cemented it will need to be crushed before entering the dryer. Some volcanic ashes will already be in a very fine, loose powdered form and may not require crushing or grinding. Other ashes may be of sufficient fineness but be cemented together. These will require milling or crushing. Coarse ashes and lithic tuffs will need to be ground in a ball mill or similar (Melav Kennedy Saroni, March,2014.)

2.2.3 Uses of Pozzolana

Natural pozzolans have been used for centuries. The use of volcanic ash and alcined clay dates back to 2000 BC and earlier in other cultures. Many of the Roman, Greek, Indian, and Egyptian pozzolan concrete structures can still be seen today, attesting to the durability of these materials.

The North American experience with natural pozzolans dates back to early 20th century public works projects, such as dams, where they were used to control temperature rise in mass concrete and provide cementitious material. In addition to controlling heat rise, natural pozzolans were used to improve resistance to sulfate attack and were among the first materials to be found to mitigate alkali-silica reaction. The most common natural pozzolans used today are processed materials, which are heat treated in a kiln and then ground to a fine powder they include calcined clay, calcined shale, and metakaolin.

And also Pozzolans are in worldwide use as a cement replacement material due to the fact that they improve the durability of cement, reduce the cement production costs and also reduce the environmental degradation associated with cement production as well as disposal of various industrial wastes effectively. Common Pozzolanic materials that have been utilized are fly ash, sludge and in some countries, natural Pozzolans. Fly ash is in wide use whereas the addition of natural Pozzolans of volcanic origin is used to a lesser extent (Arip-Kituyan E. Olekambainei., 2004.).

2.2.4 Pozzolana as Road Construction Material

It is common in different countries of worldwide to use a high quality aggregates or even hydraulic binders such as Pozzolan Portland Cement in order to strengthening road, even if this method may cause undesirable environmental impact and consume a lot of money. But there are other alternate natural binders; such as natural Pozzolanic materials (e.g. Volcanic Ash) can be effectively useful as a material and also save money since those materials are found abundantly in extensive areas of the countries where recent volcanic activities were occur.

Pozzolans are in worldwide use as cement replacement material. Pozzolans are also used in the road construction industry as a stabilizer in construction of aggregate-lime-pozzolan mix (ALP) pavements. This mix has successfully been used for road bases and shoulders in various parts of America especially in Pennsylvania (Cumberledge G., Hoffman G.L.,*et al*, 1976.). ALP mixes, in comparison with crushed stone aggregate, provide stiff bases that considerably reduce rutting. Furthermore, the PSI-value decreased much slower in the ALP pavement, and cracks developed much earlier and propagated much faster in the crushed-stone pavement (Wang. MC. and Kilareski. WP., 1979,)

A pilot study has been conducted in Tanzania to investigate the possibility of using naturally occurring pozzolan materials as a sand stabilizing agent for road base and sub base construction. The pozzolan material investigated was to be used in the coastal area of Tanzania, which lacks good road construction materials that meet material specification requirements. The coastal area produces mainly sand and some poor-quality limestone that is not particularly suitable for road construction. Pozzolan samples collected from different parts of Tanzania were investigated. The collected pozzolan samples were mixed with lime to stabilize sand that could be used in a base or sub base course. Laboratory tests were done to determine properties of individual pozzolans and lime–pozzolan–sand mixtures. The compressive strength and split tensile tests were performed to determine the pozzolan mixtures' strength development and their suitability for road construction. From the results of the pilot study it can be concluded that several natural pozzolan occurrences in Tanzania have the higher strength development that meets the Tanzania Pavement and Materials Design Manual provisions for cement-stabilized base courses. Therefore, there is a possibility of using natural pozzolans for road construction (Mbaki Onyango, Innocent Macha *et al*, 1989,).

On another pilot study on the effectiveness of pozzolanic material in the use of stabilizing base course showed that the major part demonstrates good strength properties, utilization of the resources is considered highly viable, economically and environmentally friendly, Pozzolan resources can be utilized in several sectors-road, housing and cement industry as a substitute for high energy consuming, ordinary binder materials as well as for other purposes in the building sector, several natural pozzolans investigated in the pilot study show higher strength results for similar binder dosages than in blast furnace slag-sand mixtures. Further recommendations from this pozzolan pilot study include developing new strategies for road works to promote innovative and appropriate road construction technology, to develop design guidelines and technical specifications and to develop maintenance for repair of pozzolan bases in the case of possible failures or repair after excavations for example pipes (K. Eriksen, W. Zhang *et al*, 2001.).

2.3 The Function of Base Course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials. The base course is the layers of material that have a primary functions to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure.

In general base course and sub base in a pavement have to provide sufficient cover over the sub grade, to limit the stresses and strains induced by wheel loading such that sub grade shear failures do not occur and the sub grade does not densify significantly, thus contributing to a loss of shape of the pavement surface (Thomas Teshome, 2015).

Therefore in order to achieve those criterions, a base course must have a number of attributes such as stability, resistance to wear, impermeability, and workability.

2.4 Stabilization

Stabilization refers to improving the physical and engineering properties of certain material so as to make it suitable for our desired purpose to be an alternative to standard material. Stabilization should be thought of not only in terms of corrective treatment but also as a preventive measure against adverse conditions (ERA, 2013). These adverse conditions may develop either in the course of construction or any time during the life of the structure (Berhanu Girma, 2009). Soils that do not possess the desired characteristics for a particular construction reduce Pavement life and can be improved by adding stabilizers. There are two most common categories of stabilization techniques. These are mechanical and chemical stabilization (J.B.Oza, and Dr. P.J. Gundaliya, 2013).

2.4.1 Mechanical Stabilization

Mechanical stabilization produces by compaction an interlocking of soil-aggregate particles. The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted. Mechanical stabilization can be accomplished by uniformly mixing the material and then compact the mixture. As an alternative, additional fines or aggregates maybe blended before compaction to form a uniform, well graded, dense soil-aggregate mixture after compaction. In some cases, natural gravels can be improved by blending with sand, crusher dust or other inert material, a process referred to as mechanical stabilization. The choice of methods should be based on the gradation of the material.

2.4.2 Cement Stabilization

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. Cement can be used to modify base course materials to improve performance. The addition of cement reduces plasticity and provides cementious bonds that contribute to improved performance by increasing shear and bearing strength, especially in wet conditions (Kedamawit Girmay, 2017).

2.4.3 Lime Stabilization

Soils may be improved through the addition of chemical or cementitious additives. Such additives range from Natural Pozzolana, waste products to manufactured materials. These additives can be used with a variety of soils to help improve their native engineering properties. Stabilizer can fulfill one (or at the most two) of the following functions:

- Increase the compressive strength and impact resistance of the soil construction, and also reduce its tendency to swell and shrink, by binding the particles of soil together.
- Reduce or completely exclude water absorption (causing swelling, shrinking and abrasion) by sealing all voids and pores, and covering the clay particles with a water proofing film.
- Reduce cracking by imparting flexibility which allows the soil to expand and contract to some extent.
- Reduce excessive expansion and contraction by reinforcing the soil with fibrous material
- The choice of the most suitable stabilizer will mainly depend on local availability and costs, but also to some extent on social acceptance.

2.4.4 Lime – Pozzolan Stabilization

Lime by itself can react with soils containing as little as 7 percent clay and Plasticity Indices as low as 10. If the soil is not sufficiently reactive, lime can be combined with an additional source of silica and alumina. Such “pozzolans” include fly ash, readily available natural pozzolans (pumice) and ground blast furnace slag. The additional silica and alumina from the pozzolan react with the lime to form the strong cementitious matrix that characterizes a lime-stabilized layer. Properly proportioned mixtures of lime and pozzolans can modify or stabilize nearly any soil, but are typically used for soils with low to medium plasticity (National lime association, 2006).

Many researchers have indicated that the combination of natural pozzolans and lime can serve as an alternative cementations material to be used as a cement. Volcanic ash (like fly ash), volcanic Pumice and Scoria are pozzolanic materials because of their reaction with lime liberated during the hydration of cement. Amorphous silica present in the pozzolanic materials combines with lime and forms cementitious materials (Dinku Abebe, 2005). These materials can also improve the durability of concrete and the rate of gain in strength and can reduce the rate of liberation of heat that is beneficial for mass concrete. Lightweight concrete made with Pumice and pozzolanic cement with volcanic ash/lime have survived more than 2000 years and provides an example of low strength concrete with a very long term performance. Pumice is a natural pozzolan abundantly found in Ethiopia (Newil, D. *et al*, 1980).

2.4.5 Bitumen Stabilization

Bitumen stabilization can be used to introduce some cohesion into non plastic materials or to make cohesive materials less moisture sensitive. Limestone is commonly mixed with bitumen emulsion (usually 2% residual bitumen) to produce a high quality base course (Thomas Teshome, 2015).

2.4.6 Chemical Stabilization

Proprietary chemicals are occasionally proposed to improve materials for base course use, but there is limited well documented experience of their successful use. Some of these are: Wetting agents (to improve compaction), hygroscopic salts (e.g. calcium, magnesium or sodium chlorides), natural polymers (e.g. ligno sulphonates), synthetic polymer emulsions (e.g. acrylates), modified waxes, sulphonated oils, and biological enzymes (Thomas Teshome, 2015).

2.5 Selection of Stabilizing Agent

According to the manual prepared by Joint Departments of the Army and Air Force of USA There are many factors that are considered to select an appropriate type of stabilizer.

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

Selecting and determining the best suited stabilizing agent will be a great extent that affects the effectiveness of stabilization process. Selection of stabilizers can be performed based on plasticity, particle size distribution and also considering the constructability aspect. Lime stabilization has the advantage of slow hydration reaction over cement which makes it suitable for construction in high temperature areas. For materials containing low plasticity fines cement is best suited stabilizing agent. Addition of reactive silica in the form of natural pozzolana to a material having low plasticity fines makes the material suitable for lime stabilization.

ERA 2013 PDM set the guideline in Table 2-1 below for selection of stabilizer based on particle size distribution and plasticity of soil.

Table 2-1 ERA Guide to the Type of Stabilization Likely to be Effective

Type of Stabilization	Soil Properties					
	More than 25% passing the 0.075mm			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-Pozzolana	Yes	Note 1	No	Yes	Yes	Note 1

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

2.6 General Location of A’a lava rock in Ethiopia

These volcanic gravels occur extensively in Boset and Fentale woredas in Oromia regional state of Ethiopia. But in the past it never have been used in road construction, only the locals used it to mark boundary, even though their use would substantially reduce road construction costs in many instances. One of the reasons is lack of fine material and also failure to conform to the grading specification for conventional crushed rock bases. Since these gravels have similar characteristics with cinder gravel, stabilizing it with pozzolona would meet the requirement criterion of ERA for base course Material.

2.7 Summary of Literature Review

It is common in different countries of worldwide to use a high quality aggregates or even hydraulic binders such as Pozzolan Portland Cement in order to strengthening road, even if this method may cause undesirable environmental impact and consume a lot of many. But as summarized from the above literature review alternate natural binders; such as natural Pozzolanic materials (e.g. Volcanic Ash) can be effectively useful as a material and also save money since those materials are found abundantly in extensive areas recent volcanic activities were occur.

In different study on the effectiveness of pozzolanic material in the use of stabilizing base course showed that the major part demonstrates good strength properties, utilization of the resources is considered highly viable, economically and environmentally friendly, Pozzolan resources can be utilized in several sectors-road, housing and cement industry. Several natural pozzolans investigated in the pilot studies show higher strength results for similar binder dosages than in blast furnace slag-sand mixtures. From the results of the pilot studies it can be concluded that several natural pozzolan have the higher strength development that meets the standard provisions for cement-stabilized base courses. Therefore, there is a possibility of using natural pozzolans for road construction.

A’a lava gravel which is incredibly rough and high porous nature with lack of fine materials occurs extensively and abundantly in Boset and Fentale woredas in Oromia regional state of Ethiopia. And also pozzolanic materials are available in rift valley areas of Ethiopia. Therefore from different literatures and studies on pozzolan, stabilizing this locally available gravel with pozzolana material would fill the pores and its binding property will increase the compressive strength.

CHAPTER THREE

RESEARCH METHODS AND MATERIALS

3.1 General Description of the Study Area

3.1.1 The Area of Boset Woreda

Boset is one of the woredas in the Oromia Region of Ethiopia. Part of the Misraq Shewa Zone located in the Great Rift Valley; Boset is bordered on the south by the Arsi Zone, on the west by the Awash River which separates it from Adama, on the north by the Amhara Region, and on the east by Fentale. The administrative center of the woreda is Welenchiti which served by a railway station ad highway on the Addis Ababa–Djibouti line, other towns in Boset include Bofe, Bole and Doni. This woreda is predominantly level land with undulating features; almost 90% is less than 1500 meters above sea level; Boset Guddo is the highest point. The geographic coordinates are 8°39'59.99" N 39°29'59.99" E at the start and end, respectively. Rivers include the Tebo. A survey of the land in this woreda shows that 26.2% is arable or cultivable, 30% pasture, 15.8% forest, and the remaining 28% is considered barren, degraded or otherwise unusable. The Nura Era and Tibila State Farms are major agricultural centers. Fruits and vegetables are important cash crops.

Industry in the woreda includes 19 small scale industries that employed 28 people, as well as 576 legally registered business enterprises which include 69 wholesalers, 318 retailers and 189 service providers of differing types. Boset has 97 kilometers of dry-weather and 103 of all-weather road, for an average of road density of 136.8 kilometers per 1000 square kilometers.

The topography is identified as 40 % flat, 35% undulated and the rest 25% is steeply. The soil type is also characterized by 25% sandy, 18% black soil, 25% red-brown, 25% pumis, and 7% volcano (ICRA., 1999.).

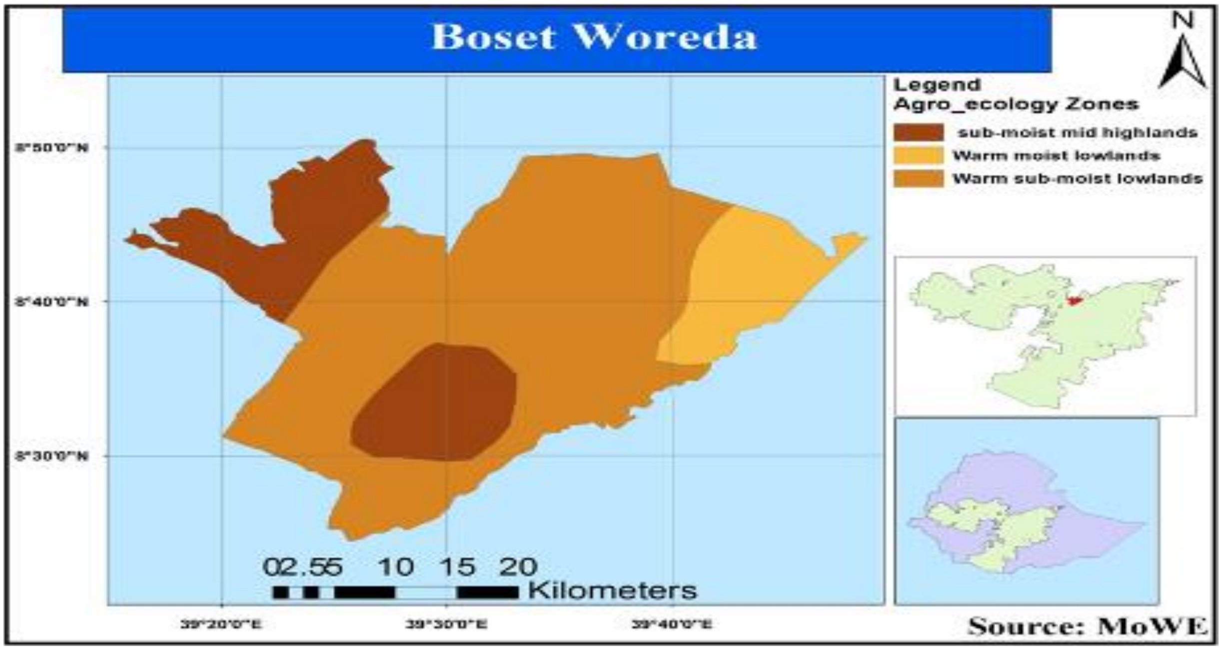

Figure 3-1 Location of the study area, Boset woreda

3.1.2 Climate

Boset is identified as predominantly lowland (kola) woreda. Only 1% of the woreda is high land while midland 20% and low land covers 79% of the total area. The temperature is variable ranges from the highest of 35°C to the lowest of 10°C. The maximum temperature was observed from 32.4°C to 35°C in the months of February and May while the daily mean minimum temperature was ranging from 10.1°C to 15.6°C in the months of October and July with the mean annual temperature is 22.55°C. The average annual rainfall ranges from 600mm to 900mm (ICRA., 1999.). Two rainy seasons are experienced annually, the main rainy season lasts from the end of June to the end of September and the other rainy season is from the end of February to the end of April which have lower rain volume and the rest of the months in the year being generally dry. The evapotranspiration of the area was estimated as high as 1872 mm per year or 5.10 mm/day.

3.1.3 Proposed Material Source

It is very important to select the appropriate road construction material in order to ensuring long term service of the road and optimize the construction cost. The first measurement to be taken for the selection of the best of the locally available materials for road construction is knowledge of their properties and behavior and how these vary in time and space. The general term of selection criteria is based on the general classification could be adequate to exclude almost all unsatisfactory materials but it have a disadvantage of excluding some materials which have a capable of giving satisfactory performance when using appropriate stabilizing method.

The samples in this research were collected from Adama and Boset woreda. The A’a lava gravel was collected from Boset woreda, Borchity kebele from an area which is located right at the entrance of Wolenchity to Metehara highway. The location from GPS indicates Latitude: 8° 39' 59.99" N, Longitude: 39° 25' 59.99" E. The volcanic ash was collected from Adama, around the west entrance of express way. The volcanic ash, in this research, is used as a stabilizer for the gravel so that the appropriate blending proportion that meets road base requirement is determined.

Figure 3-2 Material sites for A’a lava gravel

Figure 3-3 Material Site for the Volcanic Ash/Pumicite (Material Source for Muger Cement Factory)

3.2 Methodology

This research was designed to achieve the desired general and specific objectives of this thesis based on experimental findings.

Disturbed samples were collected from the two different sites for the A’a lava gravel and the natural pozzolana (volcanic ash). The gravel was collected from Boset woreda (locally called Borchity) whereas the natural pozzolanas were collected in Adama where Mugger Cement Factory material source location for its cement production.

The next step was laboratory testing. The laboratory tests were conducted first on the natural materials and then on the stabilizer natural pozzolana finally on the stabilized material. In the first step of the laboratory testing, quality tests were conducted on each of the component materials so that their physical and strength properties were identified. In the second step, laboratory tests were conducted on the blended materials of different trial proportion starting from 5% of pumic addition by mass of the lava gravel until the optimum proportion was identified to assess its suitability as road-base material. Natural pozzolanaic material was used to stabilize the A’a lava gravel material. The blended A’a lava gravel and pozzolana were designed, tested and their suitability assessed according to ERA specification.

The appropriate natural pozzolana (volcanic ash) for this test was selected based on UCS test conducted in the laboratory for three and seven days of curing. So then the gravel was blended with the natural pozzolana (volcanic ash) and modified proctor test and CBR test was conducted in different trial proportion until the optimum proportion was identified. For the optimum blending proportion, strength tests were conducted to check if the blended material achieves requirement of the pacifications of Ethiopian Road Authority (ERA).

The series of tests conducted include:

- Gradation
- Los Angeles Abrasion
- Atterberg Limit
- Aggregate Crushing Value
- Aggregate Impact Value
- Specific Gravity and Absorption

- Unconfined Compression Test
- Compaction
- California Bearing Ratio

CHAPTER FOUR

LABORATORY TESTS AND RESULTS

In this chapter of the thesis, the discussion of testing procedures followed while conducting this research. Standard procedures of AASHTO, ASTM and BS have been used whenever appropriate.

4.1 Materials Used

Base course is structural layer of a pavement which designed to carry and distribute the traffic loads to the sub-grade evenly so as the load won’t exceed the bearing capacity of sub-grade. Therefore the selection of appropriate material is the most important task in road construction since the material affects the service life of a project and cost. Using locally available construction materials goes a long way into more savings in the construction industry. In this research locally available with A’a lava gravel and Pozzolanic material was blended to fill in the deficiency of the gravels to the objective of using it as a base course material. The test results are shown below for the Pozzolanic material and A’a lava gravel used in this research.

4.2 Characterization of the A’a lava Gravel

4.2.1 Particle Size Distribution and Gradation

Particle size distribution of fine and coarse grained aggregates is determined by sieving method. This method is used primarily to determine the grading of materials proposed for use as aggregates. The results are used to determine compliance of particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates.

A grain size analysis is used to determine the relative distribution of various particle sizes in the gravels. To do this analysis, a weight preparation method is performed which is given in AASHTO T-146 and weighed sample of dried aggregate is shaken over a nest of sieves having selected sizes of square openings. The sample is shaken with a mechanical sieve shaker, and the weight of material retained on each sieve is determined and expressed as a percentage of the original sample. Detailed procedures for performing a grain size analysis of coarse and fine aggregates are given in AASHTO Method T-27 (American Association of State Highway and Transportation Officials., 1993.).

According to the ERA grading limit for naturally occurring granular materials of particle size distribution for suitable materials corresponding to maximum nominal size of 37.5 mm and 20 mm, GB2 and GB3 respectively as shown below in Table 4.1.

Table 4-1 ERA grading limits for mechanically stable natural gravels and weathered rocks for use as base course material (GB2, GB3)

Test Sieve (mm)	**Percentage by mass of total aggregate passing test sieve**	
	Nominal maximum particle size	
	37.5 mm	**20 mm**
50	100	
37.5	80-100	100
20	60-80	80-100
10	45-65	55-80
5	30-50	40-60
2.36	20-40	12-27
0.425	10-25	10-15
0.075	5-15	5-15

The sample gravel’s nominal maximum size is 37.5 mm. Since it is coarser and falls short of fine material GB2 Particle size distribution is used throughout this thesis work.

The ERA specification gradation for GB2 and gradation before and after compaction data is plotted on an aggregate grading chart below on Figure 4.1, 4.2 and 4.3. Detail laboratory test results of Particle size distribution of A’a lava gravel shown in Table A-2 on Appendix-A.

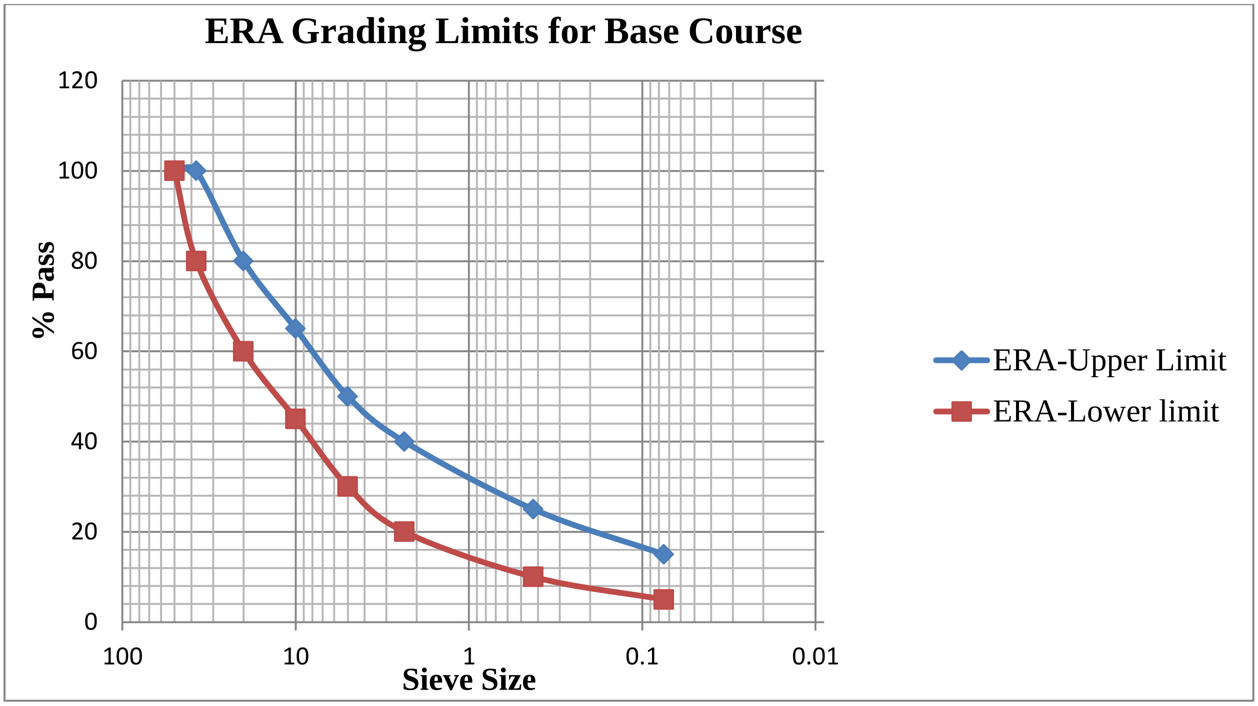

Figure 4-1 ERA grading limits of base course for GB2

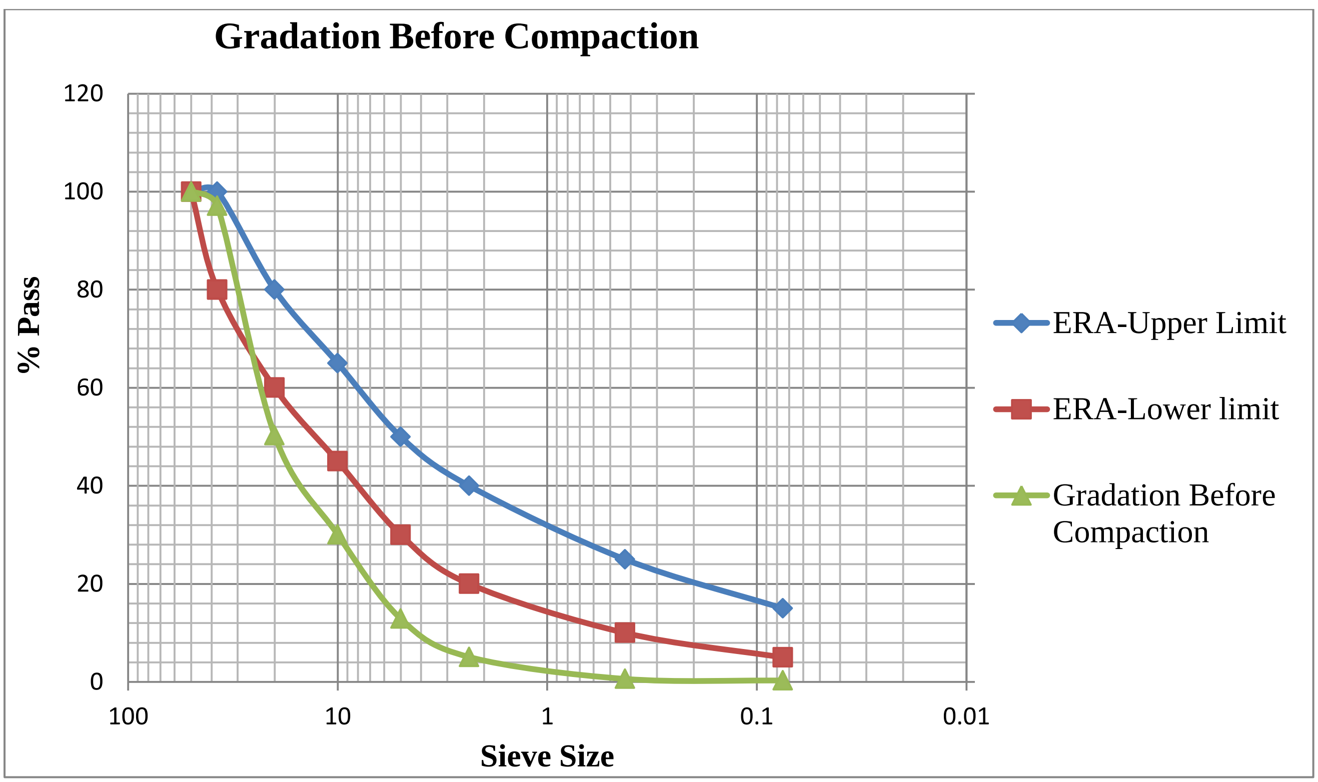

Figure 4-2 Gradation before compaction of A’a lava gravel

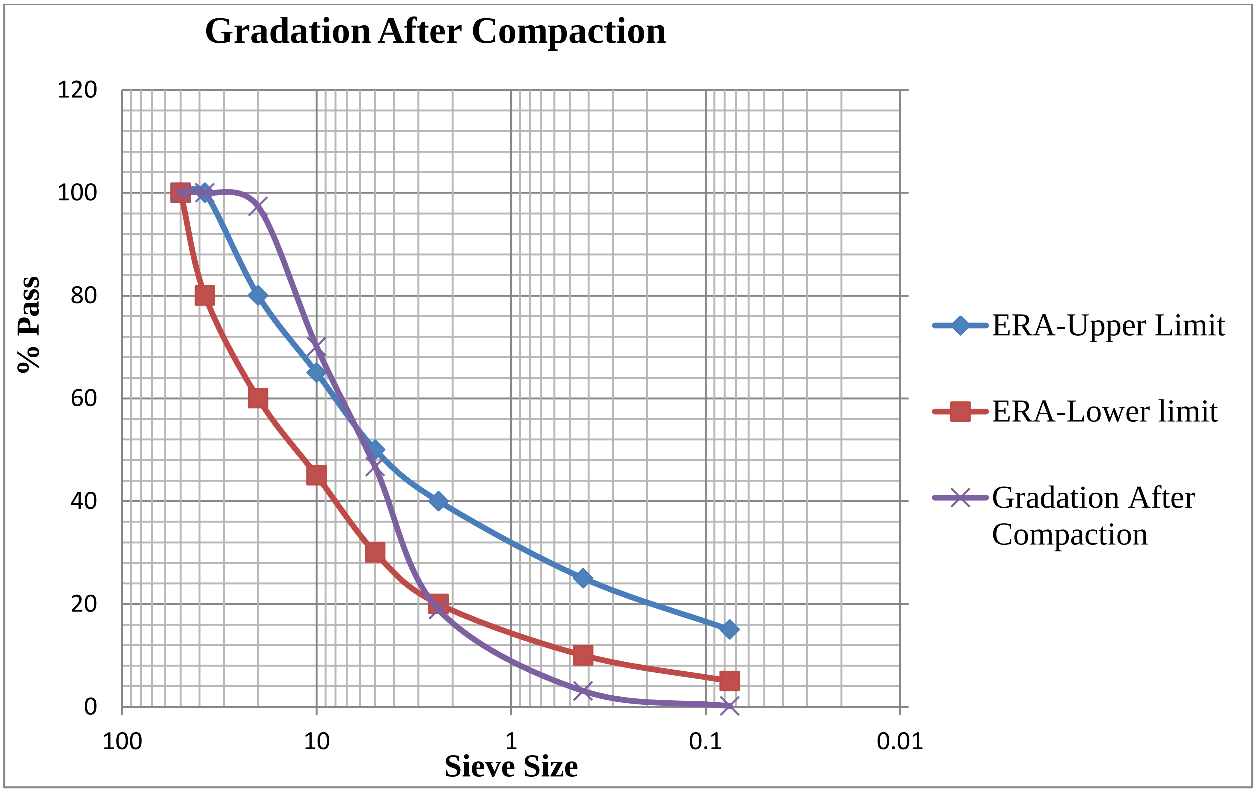

Figure 4-3 Gradation after compaction of A’a lava gravel

4.2.2 Specific Gravity and Absorption

In order to determination some special characteristics of A’a lava gravel, specific gravity and absorption tests have been taken.

AASHTO T-85 defines absorption as the increase in the weight of aggregate because of water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by AASHTO T-255 (AASHTO, 1993.).

AASHTO T-85 defines the Bulk specific gravity (SSD) as the ratio of mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15hours at stated temperature, compared to the weight in air of an equal volume of gas free distilled water at a stated temperature. Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including Portland cement concrete, bituminous concrete and other mixtures that are proportioned or analyzed on an absolute volume basis. The bulk specific gravity is used if the aggregate is wet, that is, if its absorption has been satisfied.

For this specific lava gravel 15 hours immersion in water has been satisfactory since it is lightweight, pores aggregate. Therefore, this method for both absorption and specific gravity is intended for coarser gravels that are retained on 10 mm sieve size.

The laboratory test results showed that the specific gravity is 2.87 and water absorption is 2.61% as shown in Table 4-2.

Table 4-2 Specific gravity and water absorption of A’a lava gravel

Description	**Trial 1**	**Trial 2**
Weight of air dried sample, g	1000	1000
Weight vessel + sample + Water (A), g	4555	4555
Weight of vessel + water (B), g	3894	3894
Weight of saturated surface dry sample (C), g	1004	1002
Weight of oven dried sample (D), g	978	977
Specific gravity = [D/(C-(A-B))]	2.85	2.89
Average Specific Gravity	**2.87**	
Water absorption (%) = [(C-D)/D]*100	2.66	2.56
Average Water Absorption (%)	**2.61**	

4.2.3 Aggregate Impact value

Aggregate Impact value test measures a relative resistance of an aggregate to sudden shock or impact (toughness). Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breakdown into smaller pieces. The aggregates should therefore have sufficient toughness to resist the disintegration due to impact. This testing method is applicable by blowing 15 times with a frequency less than a second to an aggregates passing 14.0 mm test sieve and retained on a 10.0 mm test sieve.

For the proposed sample gravel, the aggregate impact value is found to be 19.78%. The results are presented in Table A-4, Appendix-A.

4.2.4. Aggregate Crushing Value (ACV)

BS 812 described ACV as a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. It is applicable to aggregate passing a 14.0 mm test sieve and retained on 10.0 mm test sieve. But this method is not suitable for aggregates with an aggregate crushing value higher than 30, and in such cases the method for ten per cent fines value described in BS 812-111 is applicable.

For the A’a lava gravel, the aggregate crushing value is found to be 28.86%. The results are presented in Table A-5, Appendix-A.

4.2.5. Los Angeles Abrasion (LAA)

The aggregate used in surface course of the highway pavements are subjected to wearing due to movement of traffic. When vehicles move on the road, the soil particles present between the pneumatic tires and road surface cause abrasion of road aggregates. The steel rimmed wheels of animal driven vehicles also cause considerable abrasion of the road surface. Therefore, the road aggregates should be hard enough to resist abrasion. Resistance to abrasion of aggregate is determined in laboratory by Los Angeles test machine. The principle of Los Angeles abrasion test is to produce abrasive action by use of standard steel balls which when mixed with aggregates and rotated in a drum for specific number of revolutions also causes impact on aggregates (http://wwww.theconstructorcivilengineeringhome/theconstructor.com, 2017).

Therefore in general the Los Angeles Abrasion (LAA) test is widely used as an indicator of the relative quality of aggregates under impact (toughness) breaking down into smaller pieces from abrasive action (hardness) and durability of mineral aggregates subjected to impact and abrasion. This testing offers insight into how asphalt and concrete aggregates will stand up to wear and tear over time. It's also a good indicator of changing properties in an aggregate source as part of a quality control or quality assurance program.

The acceptable limits are set by the Los Angeles Abrasion Test AASHTO T-96. The limits vary from 30.0 to 50.0 percent, depending on the classification of the aggregate. The percentage is a measure of the degradation or loss of material as a result of impact and abrasive actions. The Los Angeles Abrasion test is an empirical test; it is not directly related to field performance of aggregates. Field observations do not generally show a good relationship between Los Angeles abrasion values and field performance. Specifically, the test may not be satisfactory for some types of aggregates. Some aggregates such as slag and some lime stones, tend to have high Los Angeles Abrasion loss but perform adequately in the field (World Road Association , 2002).

Table 4-3 below shows the average calculated values LAA for tested sample by use of the Los Angeles Abrasion machine is 26.2 %. This value satisfies the ERA manual specification and shows that the gravel is a strong material.

Table 4-3 Resistance of Abrasion of A'a lava gravel by use of the Los Angeles Abrasion machine

Designation	**Trial 1**	**Trial 2**
No. of revolution	500	500
Total weight of sample, g	5000	5000
Weight of tested sample retained on 2.36mm sieve, g	3694.4	3686
% Loss	26.11	26.28
Average Loss %	**26.2**	

4.2.6. Modified Proctor Test

Modified proctor test is taken to determine the relation between the moisture content and density of soils compacted in a mold of a given size with a 4.8 Kg rammer dropped from a height of 305mm.

This test is normally preferred in testing materials for higher shearing strength. And since in this research heavily trafficked asphalt road was considered, modified proctor test is used. The Ethiopia Road Authority recommends using AASHTO T-180 method D. In this test, a specimen is prepared by compacting soil in 152.4 mm mold in three approximately equal layers to give a total compacted depth of about 127 mm, each layer being compacted by 56 uniformly distributed blows from the rammer.

Table 4-4 Determination of moisture content and dry density of A’a lava gravel only

For A'a lava gravel				
Determination No.	1	2	3	4
Volume of Mold, cm3	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	9842	9957	9965	9984
Mass of Compacted soil, g	3357	3472	3480	3499
Bulk density, g/cm3	1.58	1.64	1.64	1.65
Water Content, %	9.09	11.54	14.12	20.00
Dry density, g/cm3	1.45	1.47	1.44	1.37
Water Content Determination				
Mass of container, g	93.5	95.5	96	60.5
Mass of container + wet soil, g	134.5	139	144.5	126.5
Mass of container + dry soil, g	131	134.5	138.5	115.5
Mass of water, g	3.5	4.5	6	11
Mass of dry soil, g	38.5	39	42.5	55
Water content, %	9.09	11.54	14.12	20.00

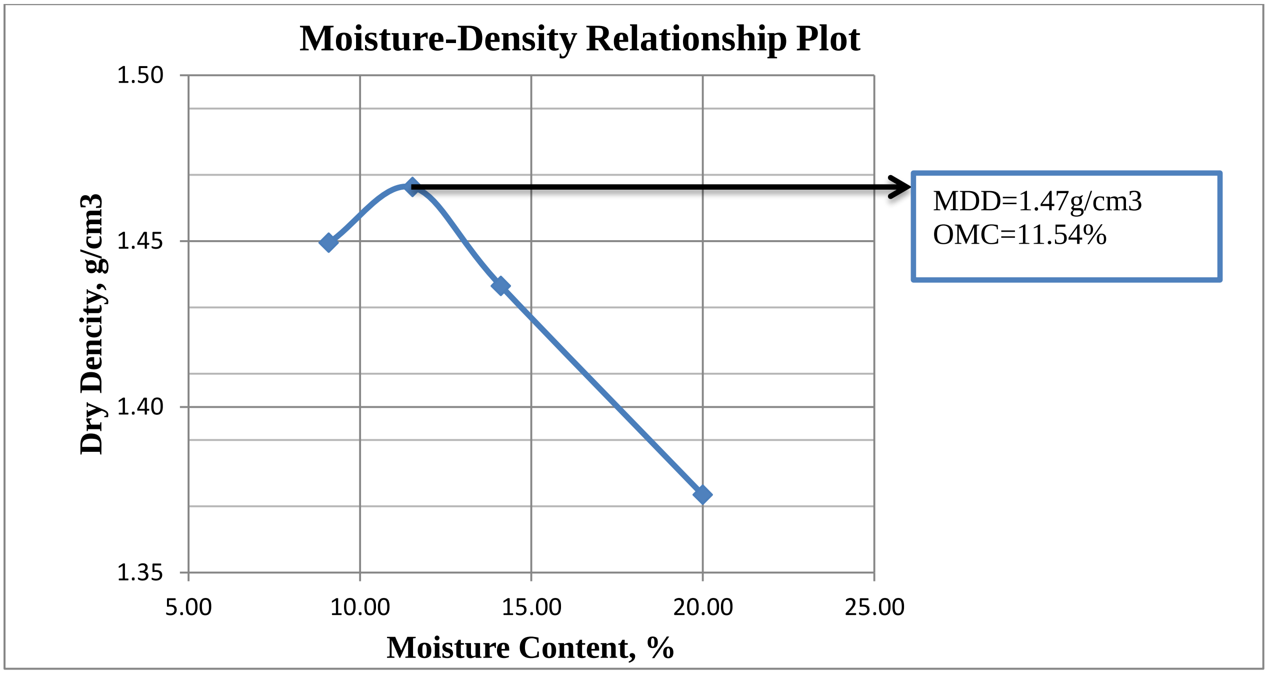

Figure 4-4 Moisture-Density relations curve of the A'a lava gravel

4.2.7. California Bearing Ratio (CBR) Test

The California bearing ratio test is one of the most commonly used methods to evaluate the strength of a sub grade soil, sub base, and base course material for design of thickness for highways and airfield pavement**.**

The CBR test is penetration test meant for the evaluation of subgrade, sub base and base course strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for pavement design.

This method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted or undisturbed sample of soil. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR).

According to ERA manual, for road-base material, when compacted to its maximum dry density in the laboratory, the material should have a minimum CBR of 80% after four days immersion in water. The Californian Bearing Ratio (CBR) shall be determined at a density of 98% of the maximum dry density when determined in accordance with the requirements of ASTM test method D 1557 and AASHTO T193. The three point CBR of the natural A'a lava gravel according to this method was maximum dry density.

Table 4-5 Dry density determination before and after soaking for lava gravel only

Blows	Before Soaking		After Soaking	
	DD(g/cc)	Moisture (%)	DD(g/cc)	Moisture (%)
10	1.44	11.94	1.46	34.18
30	1.47	12	1.49	28.57
65	1.54	14.93	1.56	26.15

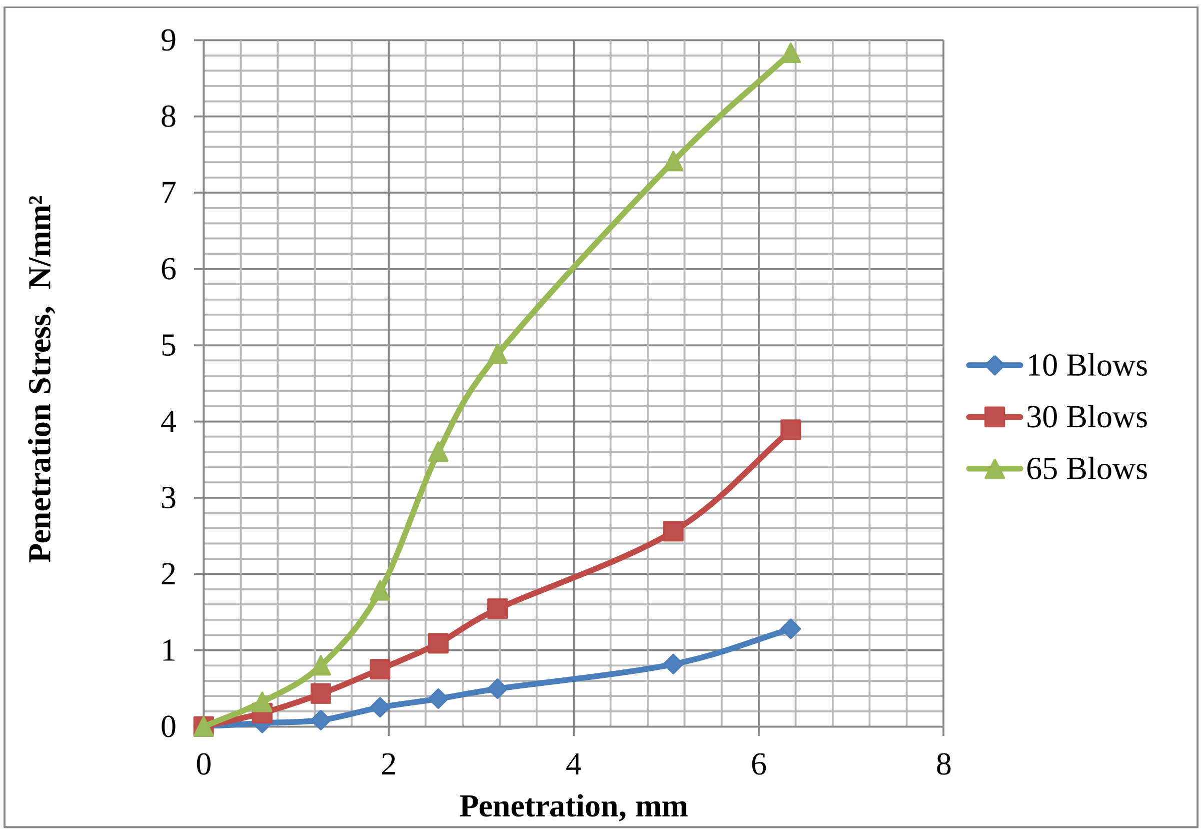

Figure 4-5 Stress- Penetration curve of A'a lava gravel only

4.3. Characterization of the pozzolana material

4.3.1. Modified proctor test

Modified proctor test is taken to determine the relation between the moisture content and density of soils compacted in a mold of a given size with a 4.8 Kg rammer dropped from a height of 305mm. A soil at a selected water content is placed in three layers in to a mold of given dimensions, with each layer compacted by 56 blows of a 24.4 N rammer dropped from a distance of 305-mm, subjecting the soil to a total compaction effort of about 600 KN-m/m3.The resulting dry unit weight is determined. The procedure is repeated for a different amount of water contents to establish a relationship between the dry unit weight and the water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

The laboratory report for the optimum moisture content of volcanic ash/pumicite is 30.65% and a maximum dry density 1.24 g/cm^3. The optimum moisture content obtained from this test was used while conducting UCS test for the same material. Figure 4-5 shows the moisture density relation of the volcanic ash /pumicite by the standard compaction method.

Table 4-6 Determination of moisture content and dry density of pozzolana material

Determination No.	1	2	3	5	6
Volume of Mold, cm3	2123	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	8803	9259	9532	9915	9891
Mass of Compacted soil, g	2318	2774	3047	3430	3406
Bulk density, g/cm3	1.09	1.31	1.44	1.62	1.60
Water Content, %	15.58	20.69	24.07	30.65	39.22
Dry density, g/cm3	0.94	1.08	1.16	1.24	1.15
Water Content Determination					
Mass of container, g	93.5	85	60.5	7.5	51.5
Mass of container + wet soil, g	138	120	94	48	87
Mass of container + dry soil, g	132	114	87.5	38.5	77
Mass of water, g	6	6	6.5	9.5	10
Mass of dry soil, g	38.5	29	27	31	25.5
Water content, %	15.58	20.69	24.07	30.65	39.22

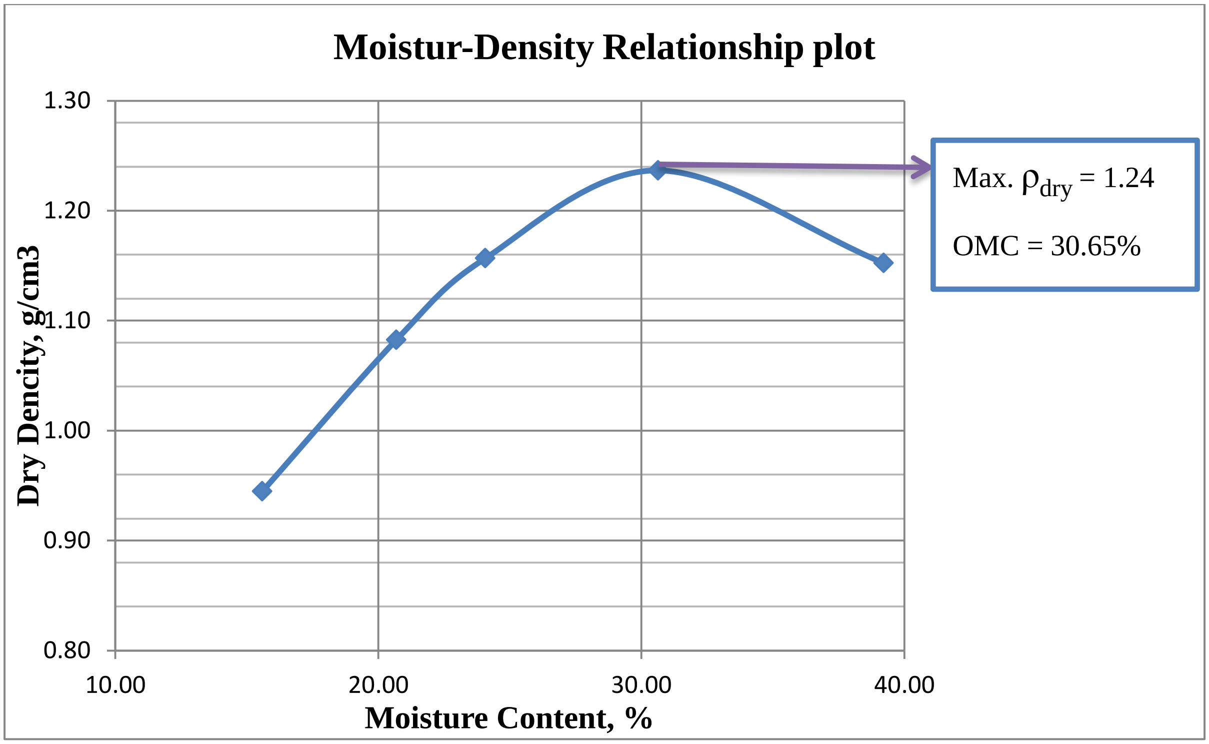

Figure 4-5 Moisture-Density relations of the volcanic ash /Pumicite

4.3.2 Unconfined Compressive Strength Test

It is not always possible to conduct the bearing capacity test in the field. Sometimes it is cheaper to take the undisturbed soil sample and test its strength in the laboratory. Also to choose the best material for the embankment, one has to conduct strength tests on the samples selected. Under these conditions it is easy to perform the unconfined compression test on undisturbed and remolded soil sample.

The unconfined compression test is used to measure the shearing resistance of cohesive soils by the application of an axial load using either strain-control or stress-control condition. The unconfined compressive strength is defined as the maximum unit stress obtained within the first 20% strain. The method is used primarily for saturated, cohesive soils recovered from thin-walled sampling tubes. The unconfined compression test is inappropriate for dry sands or crumbly clays because the materials would fall apart without some land of lateral confinement.

This was the key test on checking the suitability and strength of pumice material on pavement construction. For use of compressive strength, the strength obtained on 7days can be identify the strength expected to be obtained on 28days, where by strength on 7days are approximately to be 2/3 of the strength on 28days.

In this research the sample is remolded using optimum moisture content and density obtained from standard compaction. After the samples were extracted from the mold as shown in Figure 4-4 they were covered with plastic bag in order to get its strength by losing its moisture gradually. This air curing technique was used in which the samples were kept in normal air temperature covered with a polyethylene sheet and out of reach of water intrusion during the curing period. Air curing technique was used to strengthen the stabilized material by gradual moisture content reduction, instead of the usual water curing technique or water submergence technique which has been a common practice in past experiments. By using this technique, the material gradually loses its moisture content through the curing period and become drier and harder (Huat, Behzad Kalantari *et al*, 2008). Then the samples were penetrated on the third and seventh day. The average UCS values for day three and seven of Volcanic Ash/Pumicite are presented in Table 4-7.

Table 4-7 Average UCS values for one and seven days curing of Pumicite

Curing Day	UCS, Kpa		Average UCS, Kpa
	Spacimen-1	Spacimen-2	
3	85	88	86.5
7	153	149	151

4.3.3 Specific Gravity

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values. The objective of this test is to:

1. To measure the strength or quality of the material
2. To determine the water absorption of aggregates

Specific gravity 'G_s' is defined as the ratio of the weight of an equal volume of distilled water at that temperature both weights taken in air. This method is shown the relationship of air, water, and solids in a given volume of material. The knowledge of specific gravity is needed in calculation of soil properties like void ratio, degree of saturation, etc. Table 4-3 shows the laboratory result of the specific gravity of pumicite is 2.5.

Table 4-8 Specific gravity of volcanic ash/ Pumicite

Pycnometer No.	**P1**	**P2**
Mass of dry soil (Ms),g	25	25
Mass of Pycnometer + Water + Soil (Ma),g	167	162
Mass of pycnometer + water (Mb),g	152	147
Specific gravity at 25°c (Gs)	2.5	2.5
Correction Factor	0.99996	0.99996
Specific gravity (Gs)	2.50	2.50
Average Specific Gravity	2.50	

4.3.4 Atterberg Limit

The presence of clay mineral in fine-grained soils makes the soil to be remolded without crumbling if some moisture exists. This cohesive nature is caused by the adsorbed water surrounding the particles. At very low moisture, the soil behaves more like solid but when the moisture gets very high, the soil and water may flow like a liquid. Atterberg developed Liquid Limit, Plastic Limit and Shrinkage Limit to describe the consistency (Braja M.Das, 2008).

The liquid limit may be defined as the minimum moisture content at which the soil will flow under the application of a very small shear force. At this moisture content the soil is assumed to behave practically as a liquid. The plasticity limit may be defined in general terms, as the minimum moisture content at which the soil remains in plastic condition. The plastic limit is further described as the lowest moisture content at which the soils can be rolled in to thread of 3.2mm diameter without crumbling.

Material with plasticity that is too low tends to loosen quickly as a result of diminished bonding and the rate of gravel loses is generally very high. Loose material is pushed off into the drains or washed away by run-off or blown away by wind when dry. High gravel lose reduces re-gravelling cycle periods causing high maintenance cost and general whole life costs. High plasticity on the other hand causes the wearing course to be slippery when wet and the material may soften to an extent where the gravel layer may actually deform and fail instantly under traffic.

According to AASHTO T 089-96, no trial requiring more than 35 blows or less than 15 blows shall be recorded for the determination of liquid limit. But in this case in different trials not more than 6 blows required and in the plastic limit test, the volcanic Ash/Pumicite crumbles before it rolls into a thread of 3.2mm. Therefore, the volcanic Ash/Pumicite is classified as a non-plastic material according to AASHTO T090-96 recommend.

Since both material are non-plastic materials the plasticity index and the plastic product of the blended material is zero as shown in Table 4-9.

Table 4-9 Determination of plastic index and plastic product for the blended material

Percentage of Volcanic Ash/ Pumicite	**Plasticity Index**	**Plasticity Product**
0	NP	Zero
5	NP	Zero
10	NP	Zero
15	NP	Zero
20	NP	Zero
25	NP	Zero

4.4 Tests Results for A’a lava Gravels Blended with Pozzolana Material

4.4.1 Modified Proctor Test

In construction of highway embankments, earth dams and many other engineering structures, loose soils must be compacted to improve their strength by increasing their unit weight. Compaction is one kind of densification that is realized by rearrangement of soil particles without outflow of water. It is realized by application of mechanic energy. It does not involve fluid flow, but with moisture changing altering. Therefor the soil obtains satisfactory engineering properties such as, shear strength, compressibility, or permeability and the degree of compaction is measured in terms of its dry unit weight.

The determination of the relationship between water content and density of soils is used in determining the compaction of the material. The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density for the layer with minimum voids. By achieving high densities, not only is the shear strength and elastic modules improved but also the ingress of water is reduced or eliminated.

Therefor laboratory compaction tests are taken in order to determine the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved. One of laboratory compaction is Modified Procter Test which was developed to simulate larger compaction effort for more serious loads and bigger equipment.

In this research, a heavily trafficked asphalt road was considered hence the modified proctor test is used. The Ethiopia Road Authority recommends using AASHTO T-180 method D. In this test, a specimen is prepared by compacting soil in 152.4 mm mold in three approximately equal layers to give a total compacted depth of about 127 mm, each layer being compacted by 56 uniformly distributed blows from the rammer.

Maximum Dry Density and corresponding Optimum Moisture Content for five, ten, fifteen, twenty and twenty five percent of volcanic ash are presented in Appendix Table C-1, to C-5 respectively. Summary of maximum dry density and corresponding optimum moisture content for different volcanic ash/pumicite percentage are presented in Figure 4-8 from the compaction test.

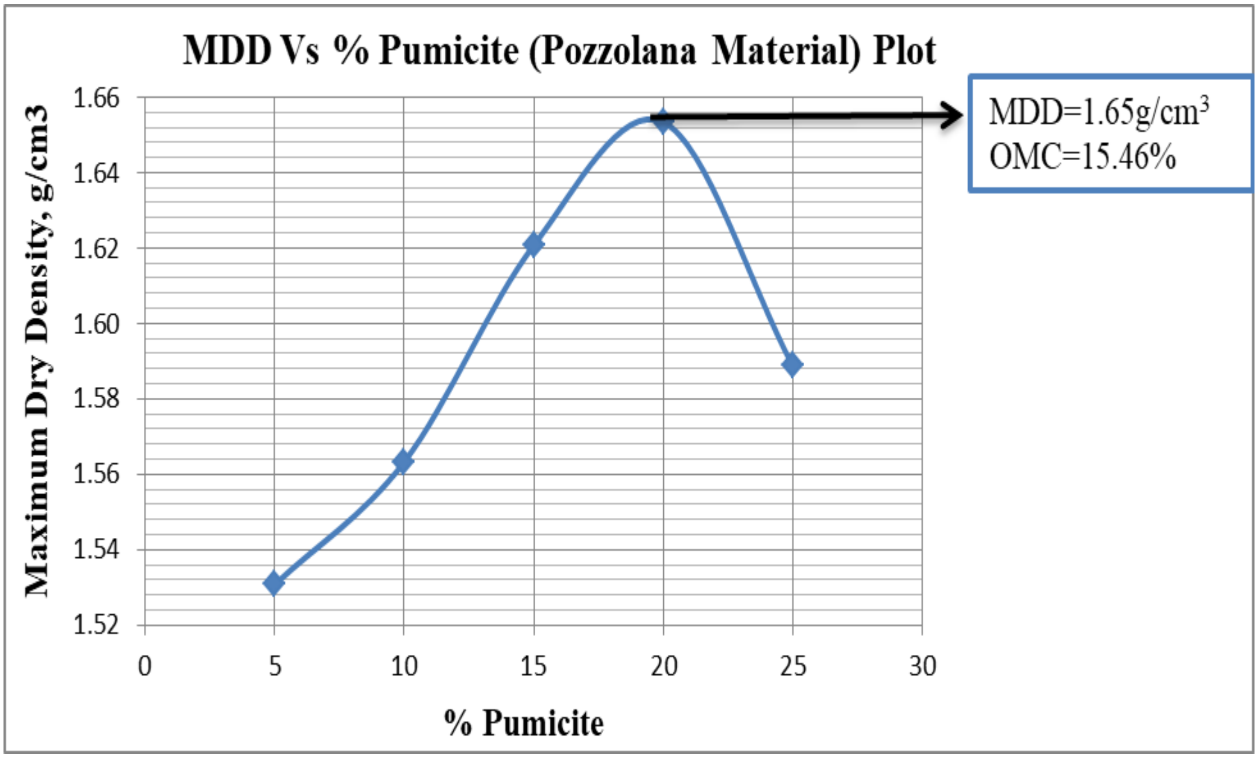

Figure 4-8 Maximum dry density variation for different percentage of pumicite presence

4.4.2. California Bearing Ratio (CBR) Test

In order to investigate the Un-soaked and soaked CBR of the stabilized sample material i.e. at the optimum moisture content from compaction test, blending proportion of 5, 10, 15, 20 and 25% volcanic ash/pumicite by mass proportion, the samples were penetrated and also the sample was soaked in water for a period of 96 hours and penetrated. The CBR values for soaked and un-soaked are given in Table 4-11 and Figure 4-9.

Table 4-11 Soaked and un-soaked CBR values of different proportion of pumicite

% of Pumicite	CBR%	
	Un-soaked	Soaked
0	72	49
5	95	53
10	171	73
15	239	104
20	328	159
25	243	114

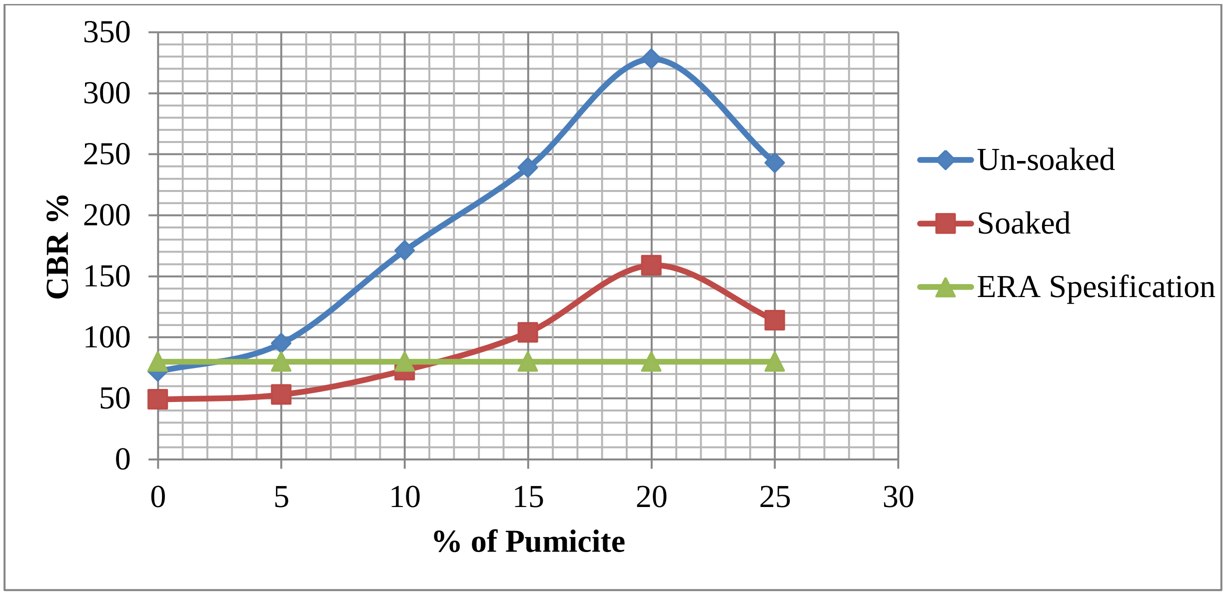

Figure 4-9 Soaked and un-soaked CBR values curve of different proportion of pumicite

4.4.3. Gradation of the Blended Material

A wide range of materials can be used as unbound base course including crushed quarried rock, crushed and screened, mechanically stabilized, modified or naturally occurring "as dug" or "pit run" gravels. Their suitability for use depends primarily on the design traffic level of the pavement and climate. However, all base course materials must have a particle size distribution and particle shape which provide high mechanical stability and should contain sufficient fines (amount of material passing the 0.425 mm sieve) to produce a dense material when compacted. In circumstances where several suitable types of base course materials are available, the final choice should take into account the expected level of future maintenance and the total costs over the expected life of the pavement (ERA, 2002).

Therefore in order to achieve the particle size distribution of road base this gradation process is used to check whether it falls in ERA upper and lower limit boundary. The gradation curves before and after compaction of the blended material is shown in Figure 4-10 and Figure 4-11 respectively.

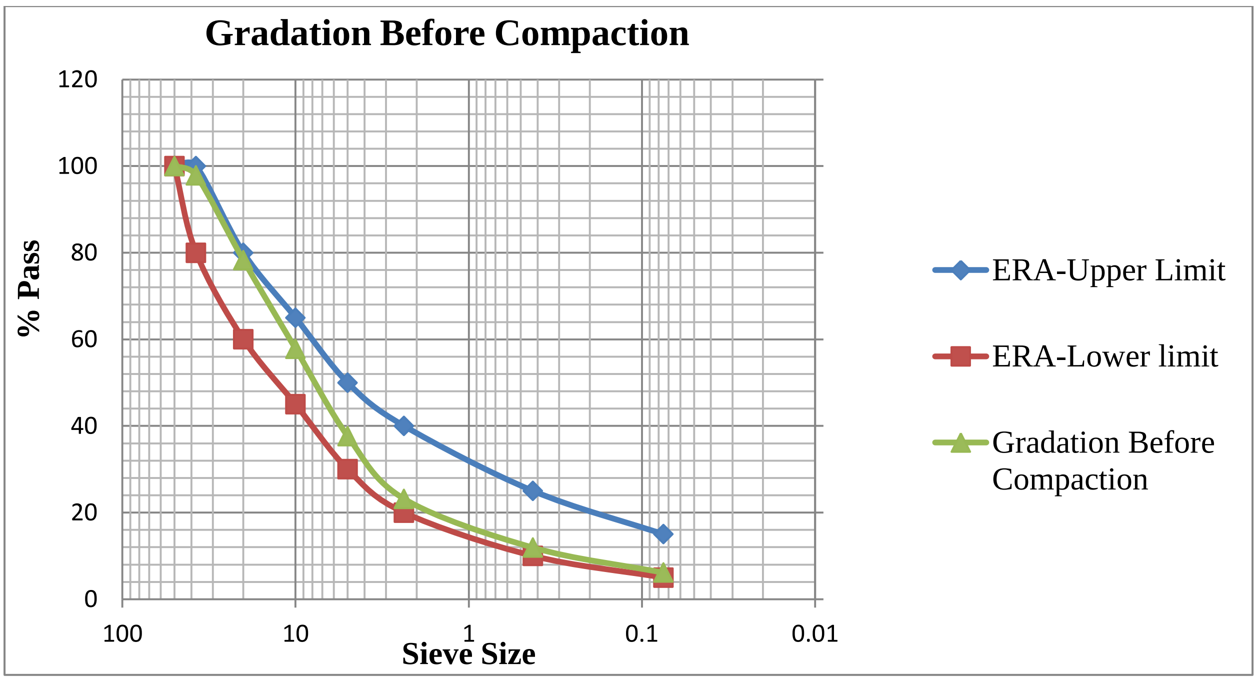

Figure 4-10 Particle size distribution curve of A’a lava gravel with 20% of pumicite by its weight before compaction

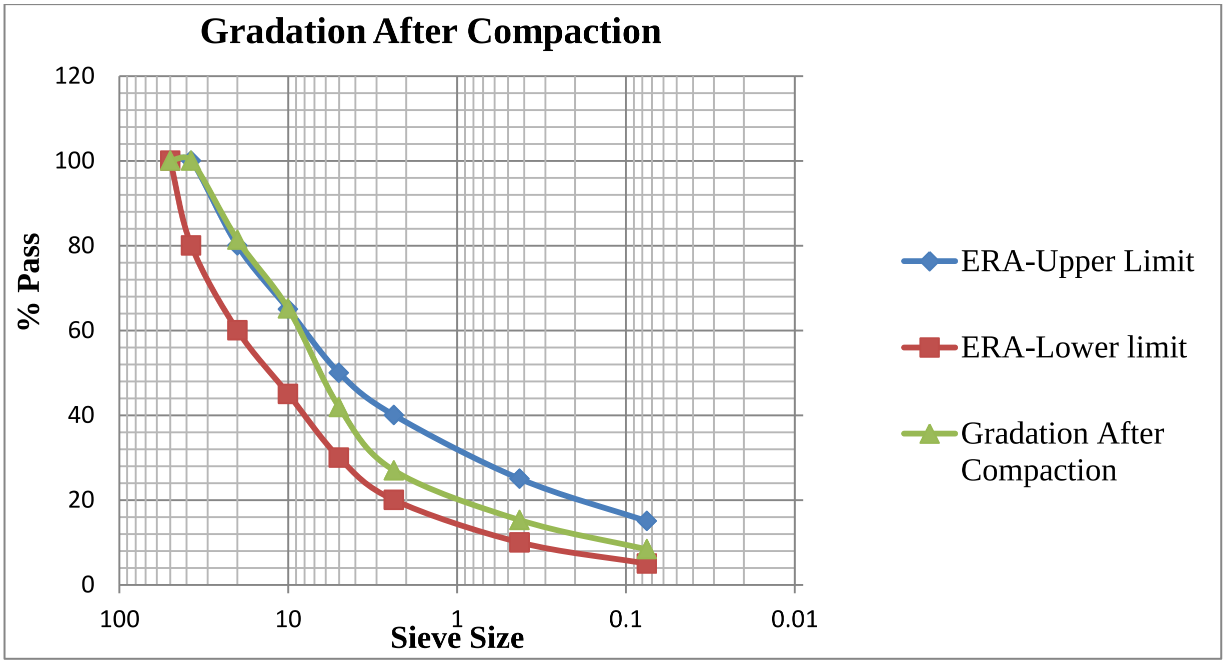

Figure 4-11 Particle size distribution curve of A,a lava gravel with 20% of pumicite by its weight after compaction

CHAPTER FIVE

DISCUSION OF THE TEST RESULTS

5.1 Specific Gravity and Absorption

From the laboratory test conducted on the natural A’a lava gravel the water absorption value was 2.61% but according to ERA the water absorption shall be not exceeding 2% when determined in accordance with the standard. This high water absorption capacity of the gravel is due to the fact that it is light weight aggregate and the porosity at its natural state. The specific gravity of the A’a lava gravel is 2.87 and the specific gravity of the volcanic ash/pumicite is 2.50. The specific gravity of the volcanic ash is lower than that of the gravel is because of the fineness of the pozzolan mineral and is light weight.

5.2 Aggregate Impact Value Test

Another method used in the determination of the A’a lava gravel against impact load is by aggregate impact value test. According to the test method stated in British Standard the aggregate impact value should be less than 35% in order to say that an aggregate has a good resistance to impact. And the laboratory result obtained was 19.78% as shown in Table A-4 which indicated that the A’a lava gravel has a great toughness to resist disintegration due to impact.

5.3 Aggregate Crushing Value Test

The aggregate crushing value of the A’a lava gravel is 28.86% as shown in Table A-5 and according to ERA specification for the ACV should preferably be less than 25 and in any case less than 29, therefore the result obtained shows that A’a lava gravel have a satisfactory performance against the resistance of gradually applied crushing load.

5.4 Los Angeles Abrasion Test

According to the laboratory result as shown in Table 4-3 the average calculated values LAA for A’a lava by use of the Los Angeles Abrasion machine is 26.2%. The Ethiopia Road Authority Manual Specification recommends that the Los Angeles Abrasion value shall not exceed 45% at 500 revolutions unless otherwise specified in the project specification. The Los Angeles Abrasion result of the A’a lava gravel shows that it is strong in resistance to abrasion. Therefore this shows that the gravel have a resistance of wearing due to movement of traffic if used in surface course of the highway pavements.

5.5 Unconfined Compression Test

In order to check the strength and whether the pozzolana has cementation property, the unconfined compression strength test was conducted on two samples cured for three and seven days which were compacted at a density obtained from modified compaction test that has taken on the pumicite. The test results showed an increment in the UCS value with in curing time. For the three days of curing an average UCS value was 86.5 kPa and for seven days of curing the average UCS value was 151 kPa as presented in Table 4-7.

Therefore the unconfined compressive strength test results presented that the pozzolana material/pumicite increases in strength with the increment of curing time was given. This proves that the pumicite has a cementation property and gain its strength along with the curing period. Since this material is non- plastic and has cementation property, it indicates that the material is pozzolanic material.

5.6 Atterberg Limit Test

The natural pozzolana and A’a lava gravel has no plasticity characteristics and the plastic product is also zero for 0, 5, 10, 15, 20 and 25 % of the blending proportion of pozzolana material by mass with. This is due to the non-plastic nature of the gravel and the volcanic ash /pumicite. Pozzolana material crumbles before it rolls into a 3.2mm rod in addition to that of the liquid limit test, the volcanic ash/pumicite closes not more than 6 blows for repeated trials.

Since the liquid limit and the plastic limit cannot be determined the material is reported to be a non-plastic material.

According to ERA specification, all road-base materials shall have a maximum plasticity index of 6. A maximum plasticity product of 60 is recommended or plasticity modulus of 90 is recommended alternatively. This shows that for a material to perform very well as a road base, its plasticity should be between zero and six. For this blended material, it has no plasticity at all and as a result the plastic product and the plasticity modulus is zero. Therefore; all the blending proportions satisfy the ERA manual specification.

5.7 Modified Proctor Test

In the first trial a 5% increment of the volcanic ash/pumicite was made until the density dropped at 25% of volcanic ash/pumicite. Table C-1 to Table C-5 in Appendix C shows the moisture-dry density relationship for 5% up to 25% of volcanic ash/pumicite blended with the gravel, respectively. From the final summarization of Table C-6 maximum dry density and corresponding optimum moisture content for different volcanic ash/pumicite percentage presented. As the laboratory results indicated that the maximum dry density and the corresponding optimum moisture content increases along with the increment of pozzolana material/pumicite. From 5% to 15% of volcanic ash/pumicite the maximum dry density and the corresponding optimum moisture content increases linearly due to the addition of fine material. But at the 20% volcanic ash/pumicite the optimum moisture content decreases relative to 5% to 15% while the density still increases. The continues addition of pozzolana to 25% pumicite the optimum moisture content increases highly when compared with the 20% pumicite but the dry density decreases significantly. The objective of compaction is to achieve a maximum density at optimum moisture content.

The curve of the maximum dry density vs. percentage of volcanic Ash/Pumicite relationship shows that the maximum dry density increases from 5% up to 20% of volcanic ash/Pumicite by mass and a further increase in the percentage of Pumicite bring a decrement in the maximum dry density. Therefore the laboratory result shows that adding 20% of pumicite gave the maximum dry density of the natural A’a lava gravel has improved from 1.47g/cm^2 to 1.65 g/cm^3 at optimum moisture content of 15.46%.

Stability of a road base layer is depends on the interlocking of its grains. But since A’a lava gravel is lack of fine material it has a relatively low density while the content of fine in the grain is lower. Adding Pumicite, fills up the voids in the gravel and increases the interlocking of grains and makes it dense up to an optimum point. At the optimum pumicite which is at 20% the density is high as all the voids are filled up at this point. But additional increment in the Pumicite brings a decrement in the maximum density.

Therefore in order to gain its stability from grain-to-grain contact adding fine-grained soil to the A’a lava gravel gives its strength and leads to the increment of density up to an optimum point. In this study addition of 20% of pozzolana material/pumicite gives the A’a lava gravel to gain its optimum amount of fine grained soil fills all the voids and it became denser so then the blended material meet the requirement strength to carry the proposed traffic load.

5.8 CBR Test

From the CBR test on the A’a lave gravel the three point CBR value was 49%. From the summarized CBR values, for 5% and 10% the pumicite by mass for soaked sample does not satisfies the ERA manual requirements. But for 15, 20 & 25 % of pumicite by mass the CBR value increases from104 to 114% for in a case of soaked and for un-soaked the value increases from 95% to 243% for 5,10,15,20 and 25% of pumicite by mass of the lava gravel. The CBR values increases up to 20% of pumicite by mass and decreases afterwards which the decrement shows that more than 20% of pumicite presence indicates that the pumicite also started carrying the load. This trend agrees with the compaction test results.

Therefore the overall CBR test results confirms that the blended material for 20% pumicite by mass of A’a lava gravel is best material when used as a road base material because of its high value of CBR for un-soaked which is 328% and even for soaked condition 114%, the material shows that it satisfies the ERA specification for base course which is the minimum soaked CBR shall be 80% when determined in accordance with the requirements of ASTM D-1883.

5.9 Particle Size Distribution

Grading of the lava gravel and the blended material was made against GB2 grading limit. From the grading curve of the A’a lava gravel absence of fine material is observed which is out of ERA’s upper and lower grading limit specification. But after compaction a certain improvement in the gradation has observed due to breakdown of A’a lava gravel. Even if there is an improvement in gradation due to compaction it still needs additional fine material in order to achieve ERA’s specification.

From the gradation curves for the optimum blending proportion based on optimum moisture content and dry density relation determined by modified proctor test has shown that the gradation before compaction falls within ERA specification Limit. For the coarser sieves which are above sieve No.10 the percentage of retained is smaller and gets close to ERA’s specification upper limit for GB2. Similarly for sieves less than No.10 the additional 20% volcanic ash has filled the absence of fine material in the natural A’a lava gravel. Similarly the gradation after compaction also meets the ERA specification limit.

Therefore in general, from the laboratory sieve analysis, modified proctor test and CBR teste it has been observed that blending A’a lava gravel with 20% of pozzolana material by it mass would satisfy the ERA specifications for base course material for heavy trafficked pavement.

5.10 Comparison of CBR Test Result with Related Works

The laboratory test results of CBR in this thesis work can be compared with the other similar research data as shown in the Table 5.1.

Table 5-1 CBR test values of stabilized road material in different research work

Research Work	Previous Research (Yetayu Eshete, 2011)		Previous Research (Tomas Teshome, 2015)		Current Research	
Stabilization type	Cinder Gravel with Fine Grained Soil		Cinder Gravel with Natural Pozzolana		A'a lava Gravel with Natural Pozzolan	
Location	Butajira-Gobe road		Mojo-Ziway Route		Boset and Fentale	
	% of stabilizer	CBR value	Time of curing	CBR value	% of stabilizer	CBR value
	0	76	0	98	0	72
	5	88	3	128	5	95
	10	95	7	178	10	171
	15	110	14	181	15	239
	20	120	28	245	20	328
	25	55			25	243

From the above table stabilized A’a lava gravel with pumice has high CBR value than the other two stabilized road base materials. It is because the lava gravel has high specific gravity and from the characteristics tests it have a better strength to carry a load as shown in this study. From the Tomas Teshome’s research, even if the CBR value is determined for different curing time after the optimum blending proportion determined it shows that the presence of natural pozzolana in the gravel increases the strength of blended material with curing time because of the pozzolanicity property.

5.11 Cost Comparison

Adama City Asphalt Concrete Project is selected for cost comparison since it is currently under construction and the quarry site for base course material is near to stabilized material. In order to do the cost comparison the thickness of the pavement layers should be determined. Therefore the CBR values of subgrade and base course and traffic data is collected as a secondary data from TCDSC.

All samples collected from test pits were tested for the following tests in CORE Consulting Engineering PLC according to AASHTO standards.

Summary of laboratory Test Results of Subgrade Soils are shown in Table 5-11

Table 5-2 Summaries of CBR Laboratory Test Results

Station (Km)	LL, %	PI, %	CBR, %	MDD, %	OMC, %	2mm	0.425mm	0.075mm	Swell, %	Soil Classification
0+0.50	38	14	18	1.72	13	96	87	54	1.6	A-6(5)
0+500	46	16	8	1.47	17	99	95	88	2.05	A-7-5(17)
1+000	48	18	15	1.47	20	100	97	91	1.76	A-7-5(17)
1+500	42	15	14	1.57	18	95	88	74	1.96	A-7-6(11)
2+000	38	14	16	1.49	23	99	96	88	1.71	A-6(13)

As it can be seen in the above table , the CBR values shows that the subgrade material can be used as a road bed which have a CBR value of greater than 5%. Moreover, the CBR swell values show that the subgrade materials have no a potential of heave. Therefor using the above CBR data the minimum CBR values of the subgrade soils, the design CBR will be 8% in order to be safe. This brings a subgrade class of S4 according to ERA’s pavement Design Manual Vol I, 2013.

Table 5-3 Project Traffic Classes with Different Design Period

Design Period	One Direction, CESAL
10 Years Design Period	10.1 million
ERA Traffic Class	T6
15 Years Design Period	25.7 million
ERA Traffic Class	T8
20 Years Design Period	41.5 million
ERA Traffic Class	T8

From traffic count data and analysis, the forecasted cumulative standard axle loads of the project for design period of 10, 15 and 20 years equals to 10.1, 25.7 and 41.5 million and referring to the available traffic classes, their ESA’s values, falls under T6 and T8 traffic class respectively as per ERA pavement Design Manual 2013.

Also the summarized CBR value of base course, sub base and subgrade including the 80%A’a lava gravel blended with pumice is stated below in Table 5-3.

Table 5-4 summarized CBR value of subgrade, sub base, base course and stabilized A’a lava gravel

Material	**CBR, %**
Sub grade	8
Sub base	66.7
Base course	241.84
A’a lava gravel blended with pumice	328

In this study the general principles that are currently being practiced in Ethiopia is used to determine the cost rates. 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 400m road base is constructed per day for each type of materials. 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 with the same cost of the pavement structure of stabilized road base.

Table 5-5 Pavement Structures for Evaluating the Stabilized Road Base against Granular Road Base

Unbound CSBC vs Stabilised basecourse pavement structure										
Station (KM)		Estimated Strength			Chart C1, ERA PDM for Unbound CSBC			Chart C2, ERA PDM for stabilized Base course		
From	To	CBR, %	ERA SG Class	Traffic Class	AC	CSBC	GSB	AC	SRB	GSB
0.0	2.0	8	S4	T8	150	200	225	150	150	225

5.11.1 Crushed Aggregate Road Base

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

- 500m^3 of quarry rock is produced;
- 500m^3 of the quarried rock is hauled to the crusher plant, which is to be installed at 500m away from the quarry;
- 500m^3 of rock is crushed;
- 500m^3 of the crushed aggregate is hauled to the site of placement, which is on average 27km away from the crusher plant;
- 960m^3 of compacted base layer is placed over 400m stretch. Since the width of the road is 12m.

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 25% to account for the overhead, profit, and other contingencies. The summary of the unit rates is presented in Table 5-6 below and the detailed unit rate determination for the crushed aggregate base course is attached in Appendix D from Table D-1 to Table D-3.

Table 5-6 Summary of Unit Rate Determination for Granular Road base

Activities	Unit Rate (Birr/m³)
Quarry rock production	103.15
Base course aggregate production (crushing)	74.23
Base course hauling and placing	113.95
Total cost of crushed rock base course construction	**291.33**

5.11.2 Stabilized A’a lava Gravel with Pumice Road Base

In order to determining the unit rate of the stabilized A’a lava grave with pumice road base, the in-place mixing of the gravel with pumice was considered. It was assumed that to produce 800m^3/day blended road base 160m^3 of pumice and 740m^3 of A’a lava gravel are hauled on the site. The rate determination for the punice stabilized road base is detailed in Appendix D from Table D-4 and D-6 and summarized in Table 5-7

Table 5-7 Summary of Unit Rate Determination for A’a lava gravel-pumice Road Base

Activity	Unit Rate (Birr/m³)
Material production (A'a lava gravel and pumice)	38.1
Hauling and placing (A'a lava gravel and pumice)	99.91
Total cost of stabilized A'a lava gravel with pumice	**138.92**

5.11.3 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 5-8 and the detailed analyses are shown in Appendix D from Table D-6 to Table D-9.

Table 5-8 Unit Rates of other Structural Layers

Structural Layer	Unit	Unit Rate
Wearing Surface(15cm Asphalt Concrete)	Birr/m²	131.26
Granular Sub Base	Birr/m³	141.683

5.11.4 Cost Comparison

The above calculated rates were used to determine the costs of the pavement structures that are shown in Table 5-9. While the cost analyses were conducted the sound rock quarries are available within a distance of 27km from the road alignment. This is 3km away from A’a lava gravel sample have been collected since the sample collected 24.5km away from Adama city and the stabilizer pumice is found 2km from the road alignment. This scenario was considered in the cost analyses to check whether the stabilized material could be a feasible option under such an ideal condition. The stabilized lava gravel road base material was found to be feasible under this scenario because of the source of both materials are in approximately equal distance. So then the advantage of the A’a lava grave is that it is abundantly found and the production cost is less than from crushed aggregate which is currently used.

Table 5-9 Comparison of the Cost of Pavement with Crushed Granular Base against Pavement with stabilized A’a lava with pumice Road Base

Crushed Granular Road Base Vs. Stabilized Lava Gravel with Pumice											
Pavement with Crushed Granular Road Base						**Pavement with A'a lava gravel with pumice**					
Pavement	Thickness, mm	Quantity, Km	Unit	Rate	Cost/Km	Pavement	Thickness, mm	Quantity, Km	Unit	Rate	Cost/Km
AC	150	1200	M²	1025.7	1230840	AC	150	1200	M²	1025.7	1230840
CSBC	200	1501.01	M³	291.33	437289	SRB	150	1125.75	M³	138.92	156389
GSB	225	1350	M³	141.68	191268	GSB	225	1350	M³	141.68	191268
Total Cost/Km					**1859397**	**Total Cost/Km**					**1578497**

Therefor the overall estimated cost of stabilized A’a lava gravel with pumice is less by 280,900birr/km from crushed granular road base material.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Natural A’a lava gravel is abundantly available in eastern part of Ethiopia specifically in Boset and Fentale woredas were still need road construction. And since A’a lava grave have a property of high water absorption due to its high porosity and also it needs improvement to meet the ERA grading specification due to its luck of fine material. Therefore this thesis attempted to introduce new alternate road base construction material from locally available materials by stabilizing A’a lava gravel with pumicite. From this thesis the following conclusions are made:

1- The gradation of A’a lava gravel after compaction shows significant breakdown of courser gravel that shows an improvement to meet the ERA grading specification but still need stabilization by additional fine material.

2- The LAA, ACV and AIV test results shows that the A’a lava gravel’s toughness and have a strong property against abrasion due to wearing movement and gradual loading. So it passes the ERA specifications for natural gravels.

3- The Volcanic Ash/Pumicite under Unconfined Compression Strength tests shows the increment of strength with curing time which proves that it has Pozzolanic property.

4- From MDD- percent and CBR-percent of blende material curve shows the optimum amount of pumicite is 20 % by mass. And also the gradation before and after compaction of this optimum blending proportion falls within ERA specification limit. Therefor the overall laboratory results prove that blending 80% of A’a lava gravel with 20% of pumicite will satisfy the ERA specifications for heavy trafficked road base course material.

5- Additionally, costs were made to assess the cost benefit of using stabilized road bases against using crushed granular base. The stabilized lava gravel road base material was found to be feasible because of the advantage of the A’a lava grave is that it is abundantly found and the production cost is less than from crushed aggregate which is currently used since both road base materials are found in the same distance from the road alignment.

Therefore, from this study, it was found out that it is possible to use A’a lava gravel for road base construction by stabilizing it 20% of pumice by its weight. Hence, upgrading and using this lava for base course construction should be considered as one of the feasible options during the design and construction of roads in areas where A’a lava gravel are available in abundant quantity.

6.2 Recommendations for future work

This thesis attempted to stabilize A’a lava gravel found around Fentale woreda by blending with optimum proportion of Natural Pozzolana. Due to financial, laboratory chemicals and equipment availability and time limitation this thesis work did not cover the whole tests that should be conducts. Therefore the following recommendations should be considered for a better way of using A’a lava gravel.

1- Ethiopia had volcanic activity along the rift valley but not much study has been done on availability, distribution and geographical morphology of A’a lava materials in Ethiopia. Therefore proper study on this material should be conducted.

2- Chemical analysis of Natural pozzolana should be taken in order to define its composition.

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APPENDIXES

APPENDIX-A

Test Result of A’a lava Gravels

Table A-1 ERA gradation limits of particle size distributions for base course material (GB2)

Test Sieve (mm)	Percentage by mass of total aggregate passing test sieve	
	Nominal maximum particle size	
	37.5 mm	**20 mm**
50	100	
37.5	80-100	100
20	60-80	80-100
10	45-65	55-80
5	30-50	40-60
2.36	20-40	12-27
0.425	10-25	10-15
0.075	5-15	5-15

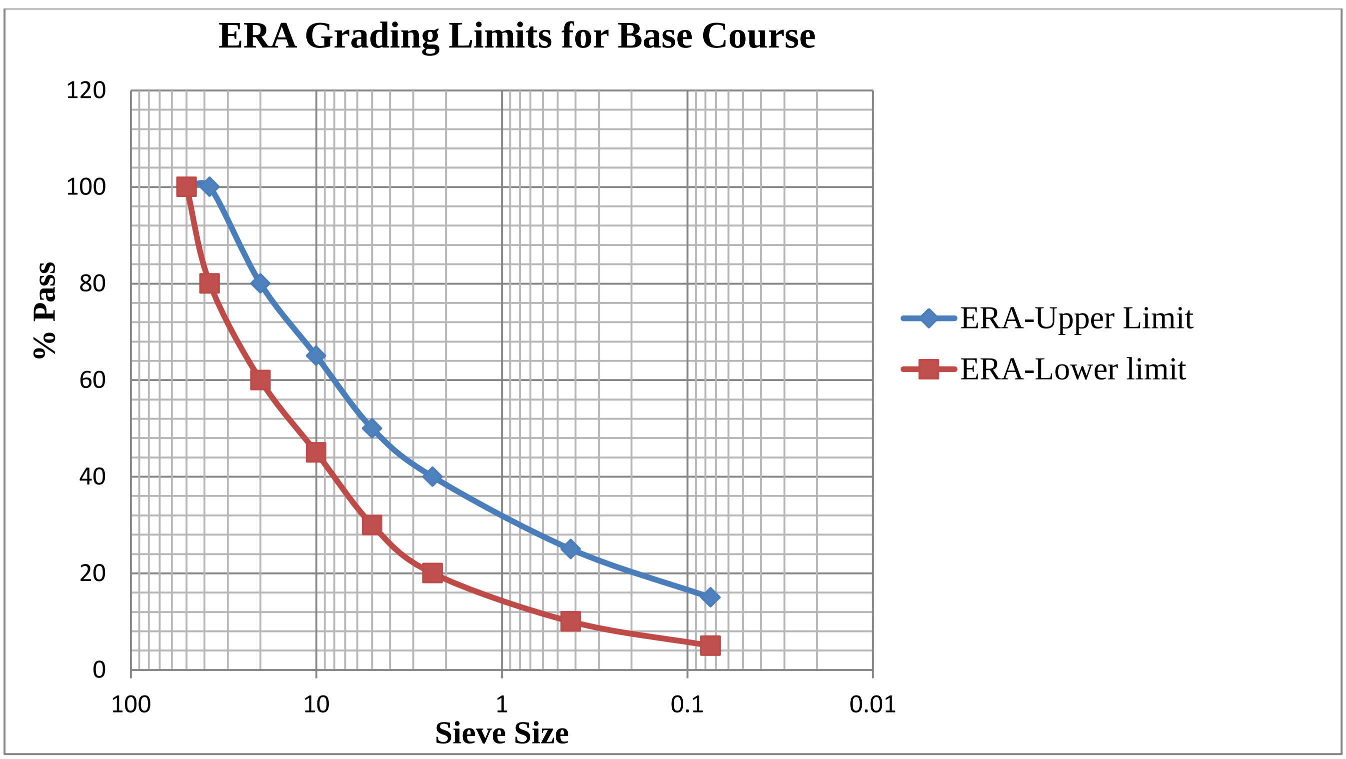

Figure A-1 ERA gradation limits for base course material (GB2)

Table A-2 Particle size distributions of A'a lava gravels before compaction

Washed Gradation Before Compaction					
Sieve	Weight Retained	% Retained	% Pass	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50	0	0	100	100	100
37.5	88	2.93	97.07	80	100
20	1404	46.74	50.33	60	80
10	608.91	20.27	30.06	45	65
5	516.09	17.18	12.88	30	50
2.36	234.01	7.79	5.09	20	40
0.425	134.25	4.47	0.62	10	25
0.075	9.91	0.33	0.29	5	15

Total Weight of sample before Washed	3004 g

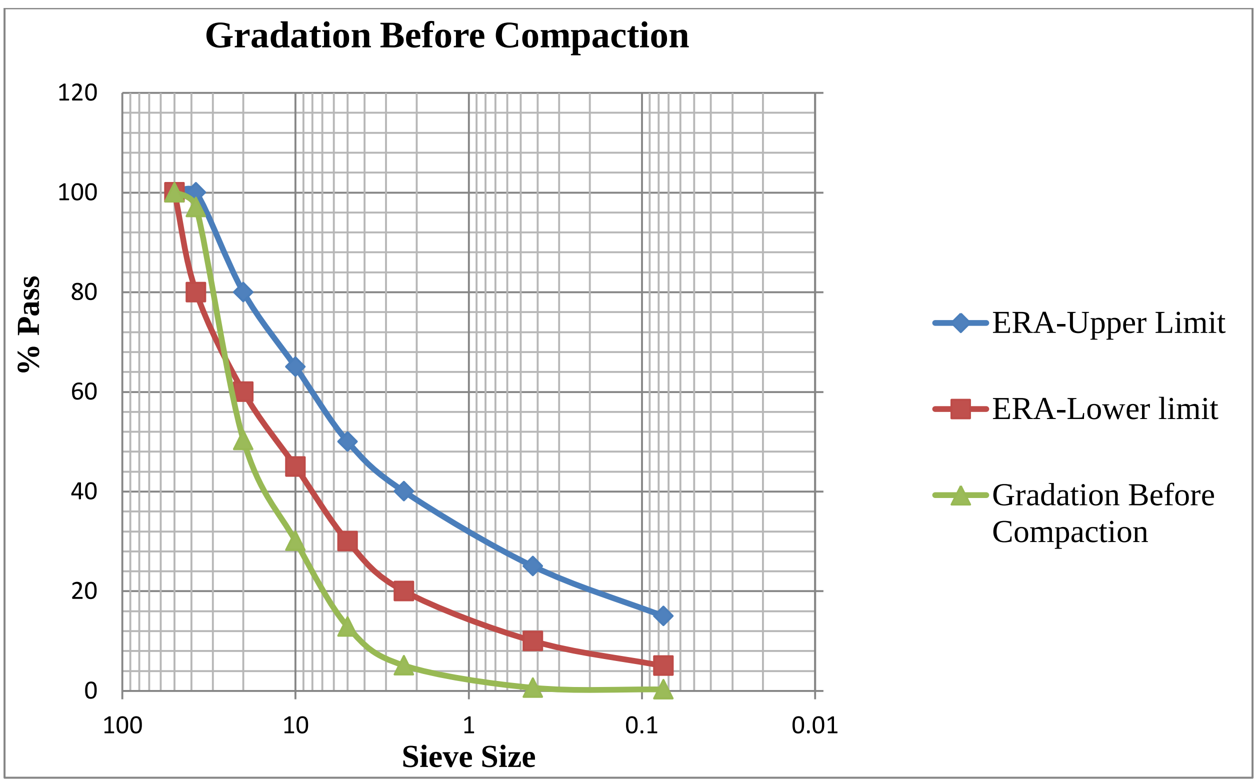

Figure A-2 Particle size distributions curve of A'a lava gravels before compaction

Table A-3 Particle size distributions of A'a lava gravels before compaction

Washed Gradation After Compaction					
Sieve	Weight Retained	% Retained	% Pass	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50	0	0	100	100	100
37.5	0	0.00	100.00	80	100
20	80	2.67	97.33	60	80
10	817.01	27.27	70.06	45	65
5	700.75	23.39	46.67	30	50
2.36	832	27.77	18.90	20	40
0.425	473.67	15.81	3.09	10	25
0.075	88	2.94	0.15	5	15

Total Weight of Sample Before Washed	2996 g

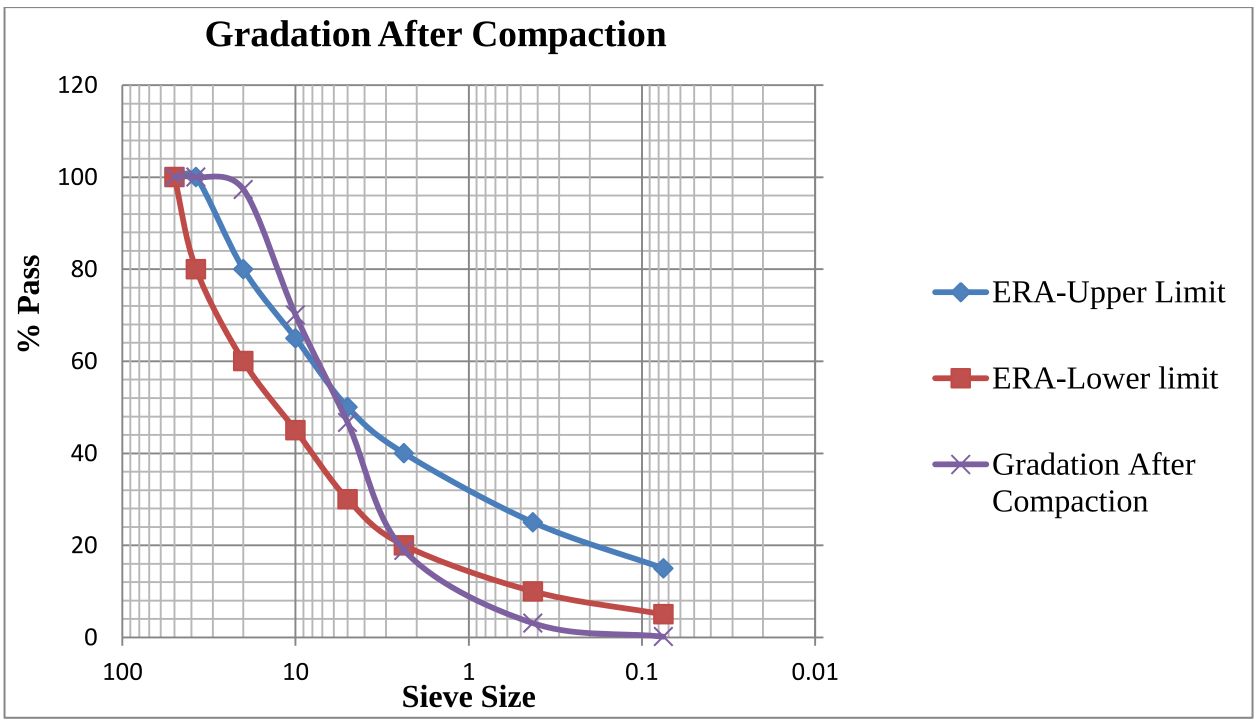

Figure A-3 Particle size distributions curve of A'a lava gravels after compaction

Table A-4 Aggregate impact value (AIV) test

Designation	Trial 1	Trial 2
Weight of total sample Pass 14mm and Retain 10mm sieves M1, g	405	400
Weight of tested sample retained on 2.36mm sieve M2, g	80	79.2
AIV(%)=(M2/M1)*100	19.75	19.8
Average	19.78	

Table A-5 Aggregate crushing value (ACV) test

AGGREGATE CRUSHING VALUE (ACV) Test Method: BS 812-112 : 1990		
Location: Borchota Material type: A’a Lava Gravel Date sample: Sample from: ________________ Date test:		
Test No.	1	2
Weght of total sample Pass 14mm and Retain 10mm sieves (M1), g	1500	1500
Weght of tested sample retained on 2.36mm sieve (M2), g	431.23	434.56
AIV(%)=(M2/M1)*100	28.75	28.97
Average	28.86	

Table A-6 California bearing ratio test on A’a lava gravel only

CALIFORNIA BEARING RATIO TEST
TEST METHOE-AASHO T193

Sample Station	Adama	Cast Date	27/7/2018
Material Description	20% Pumicite	Penetration Date	1/7/2018
Test Description	Unsoked		

Moisture Determination

	10 Blows		30 Blows		65 Blows	
	Before Soaking	After Soaking	Before Soaking	After Soaking	Before Soaking	After Soaking
Mass of Container, gm	60	61	95	95	96	95
Mass of Container + wet soil, gm	135	167	179	176	173	177
Mass of Container +Dry soil, gm	127	140	170	158	163	160
Mass of Water, gm	8	27	9	18	10	17
Mass of Dry Soil, gm	67	79	75	63	67	65
Moisture Content, %	11.94	34.18	12.00	28.57	14.93	26.15

Density Determination

	10 Blows		30 Blows		65 Blows	
	Before Soaking	After Soaking	Before Soaking	After Soaking	Before Soaking	After Soaking
Weight of Mould, gm	3064	3064	3064	3064	3064	3064
Weight of Soil + Mold	5200	5659	5241	5601	5398	5672
Volume of Soil, cm	1321	1321	1321	1321	1321	1321
Weight of Soil, gm	2136	2595	2177	2537	2334	2608
Wet Density, gm/cm³	1.62	1.96	1.65	1.92	1.77	1.97
Moisture Content, %	11.94	34.18	12.00	28.57	14.93	26.15
Dry Density, gm/cm³	1.44	1.46	1.47	1.49	1.54	1.56

Loading-Penetration

		10 Blows			30 Blows			65 Blows		
Penetration, mm	Area, mm²	Load, N	Penetration stress, Mpa	CBR,%	Load, N	Penetration stress, Mpa	CBR,%	Load, N	Penetration stress, Mpa	CBR,%
0.000	1935	0	0.0000		0	0.0000		0	0.0000	
0.635	1935	89	0.0460		344	0.1778		629	0.3251	
1.270	1935	165	0.0853		833	0.4305		1555	0.8036	
1.910	1935	486	0.2512		1457	0.7530		3457	1.7866	
2.540	1935	705	0.3643	5.280	2114	1.0925	15.83343	6979	3.6067	52
3.180	1935	959	0.4956		2987	1.5437		9454	4.8858	
5.080	1935	1583	0.8181	7.943	4953	2.5597	24.85136	14347	7.4145	72
6.350	1935	2477	1.2801		7530	3.8915		17097	8.8357	

Swelling data

Hright of spacimen, mm	125	No. of Blows	Before Soaking	After Soaking	Swell, %	Average
		10	0.00	0.00	0.00	0.00
		30	0.00	0.00	0.00	
		65	0.00	0.00	0.00	

Remark: For the sample lava gravel only penetration the CBR value is 72% at 5.08 penetration.

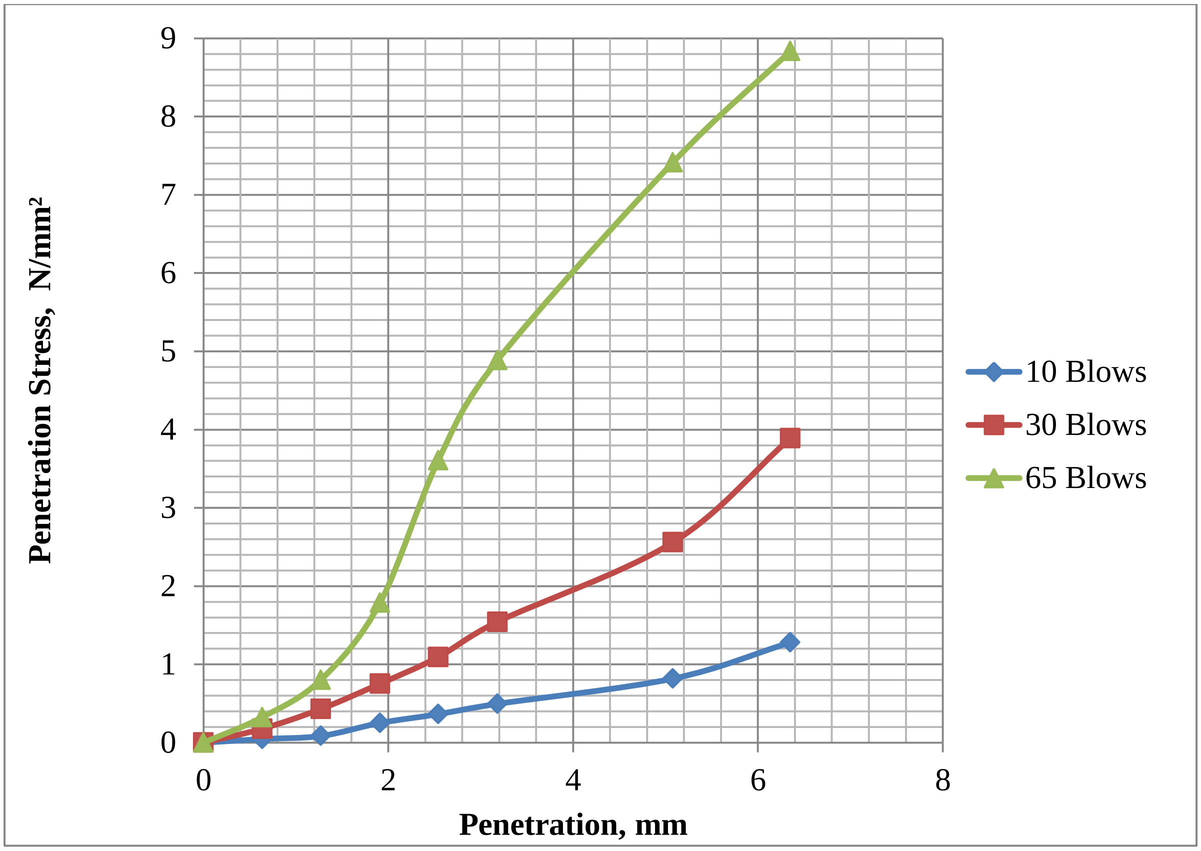

Figure A-4 Stress-penetration curve of A'a lava gravel only

APPENDIX-B

Test Results of Natural Pozzolana Material (Volcanic Ash)

Table B-1 Determination of moisture content and dry density of Pumicite

Determination No.	1	2	3	5	6
Volume of Mold, cm3	2123	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	8803	9259	9532	9915	9891
Mass of Compacted soil, g	2318	2774	3047	3430	3406
Bulk density, g/cm3	1.09	1.31	1.44	1.62	1.60
Water Content, %	15.58	20.69	24.07	30.65	39.22
Dry density, g/cm3	0.94	1.08	1.16	1.24	1.15
Water Content Determination					
Mass of container, g	93.5	85	60.5	7.5	51.5
Mass of container + wet soil, g	138	120	94	48	87
Mass of container + dry soil, g	132	114	87.5	38.5	77
Mass of water, g	6	6	6.5	9.5	10
Mass of dry soil, g	38.5	29	27	31	25.5
Water content, %	15.58	20.69	24.07	30.65	39.22

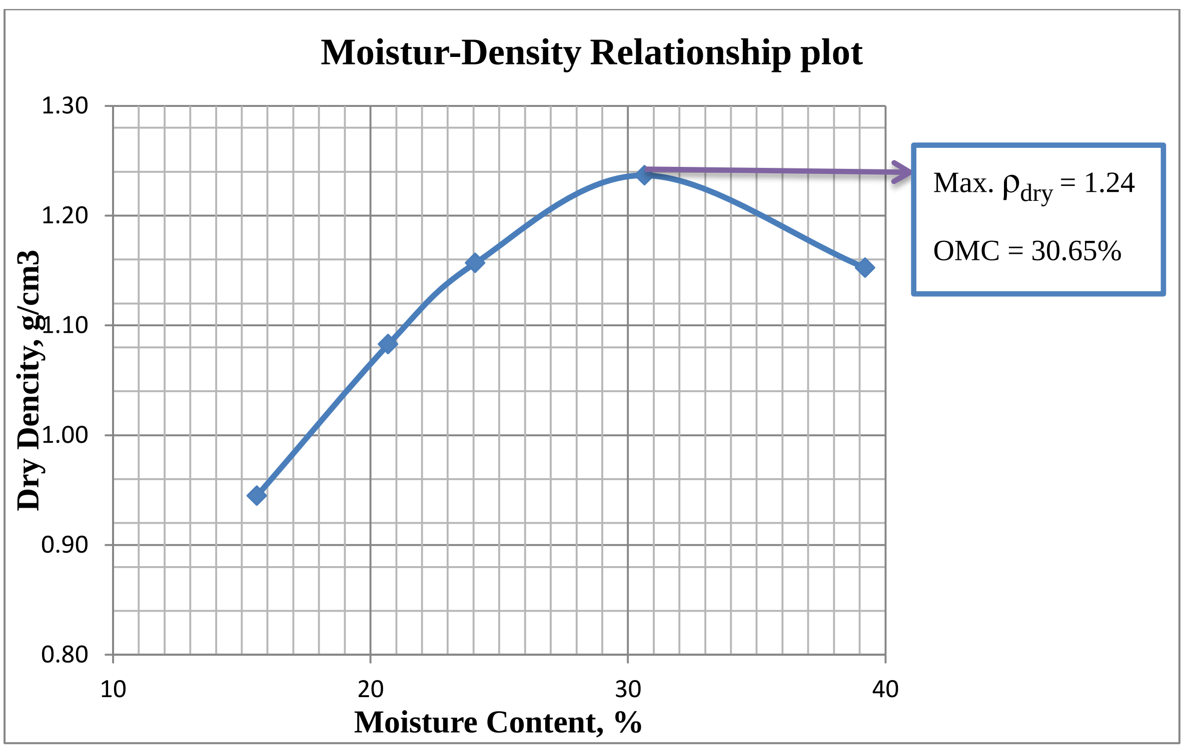

Figure B-1 Moisture-Density relations of the volcanic ash /Pumicite

Figure B-2 Extraction of sample from the mold (left) and covering with plastic bag (right)

Table B-2 Unconfined Compression Test of Pumicite 3 days Cured/Specimen-1

UNCONFINED COMPRESSION TEST TEST METHOD-ASTM D2166			
Sample Station	Adama	Cast Date	12/6/2018
Material Description	Pumicite	Penetration Date	12/6/2018
Diameter of Sample, mm	38	Ring Calibration Factor, KN/div	
Moisture Determination		**Density Determination**	
Container No.		Initial Area of Specimen, mm²	1017.88
Mass of Container, gm	60	Initial Height of Specimen, mm	76
Mass of Container + wet soil, gm	89	Volume of Spacimen, mm³	77358.88
Mass of Container +Dry soil, gm	82	Weight of Specimen, gm	123
Mass of Water, gm	7	Wet Density, gm/mm³	0.0016
Mass of Dry Soil, gm	22	Moisture Content, %	31.82
Moisture Content, %	31.82	Dry Density, gm/cm³	1.206
Axial Deformation, mm	Axial Strain, %	Area, m²	Axial Stress, Kpa
0	0.000000	0.001018	0
0.151	0.198684	0.001136	10

0.175	0.230263	0.001137	12
0.298	0.392105	0.001139	22
0.356	0.468421	0.001139	29
0.464	0.610526	0.001141	39
0.537	0.706579	0.001142	49
0.6	0.789474	0.001143	58
0.67	0.881579	0.001144	68
0.74	0.973684	0.001145	78
0.809	1.064474	0.001146	85
0.873	1.148684	0.001147	83
0.979	1.288158	0.001149	71

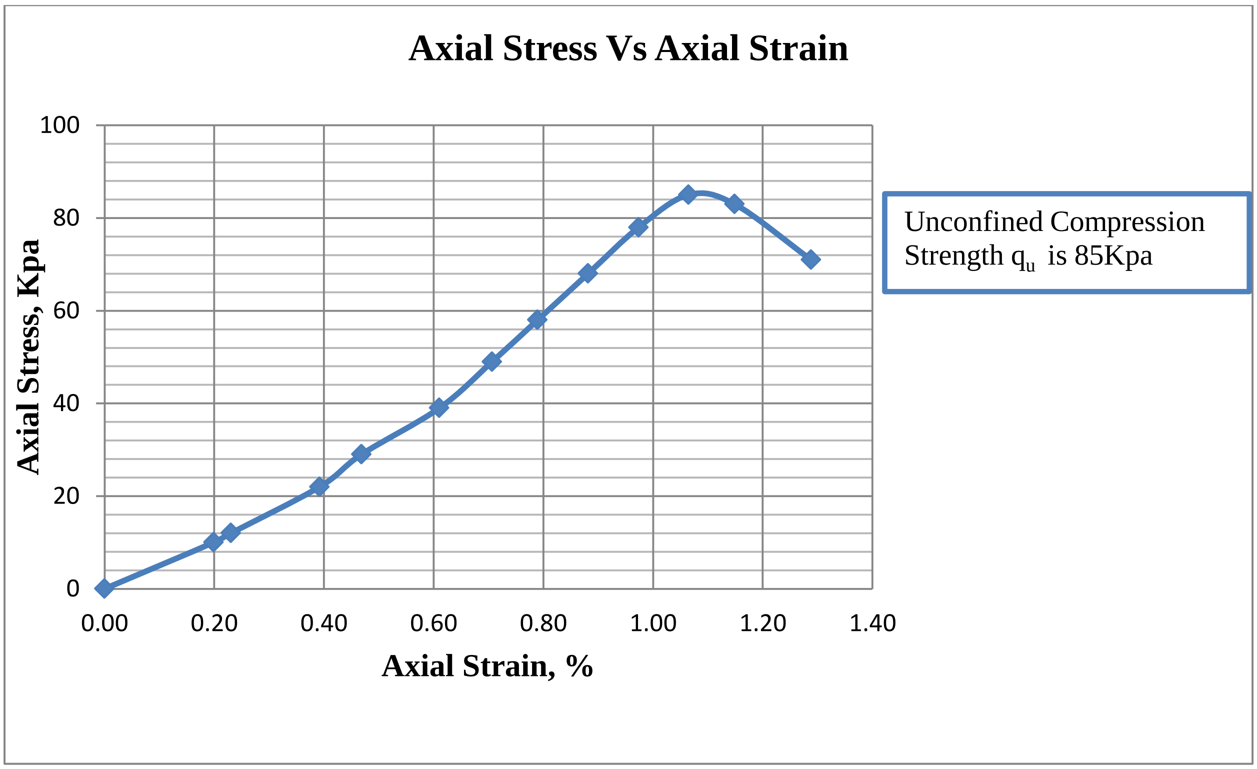

Figure B-2 Axial Stress-Strain relations of the Pumicite 3 days Cured/Specimen-1

Table B-3 Unconfined Compression Test of Pumicite 3 days Cured/Specimen-2

UNCONFINED COMPRENCIVE TEST TEST METHOE-ASTM D2166			
Sample Station	Adama	Cast Date	12/6/2018
Material Description	Pumicite	Penetration Date	12/6/2018
Diameter of Sample, mm	38	Ring Calibration Factor, KN/div	
Moisture Determination		**Density Determination**	
Container No.		Initial Area of Specimen, mm²	1017.88
Mass of Container, gm	92	Initial Height of Specimen, mm	76
Mass of Container + wet soil, gm	125	Volume of Spacimen, mm³	77358.88
Mass of Container +Dry soil, gm	117	Weight of Specimen, gm	124
Mass of Water, gm	8	Wet Density, gm/mm³	0.0016
Mass of Dry Soil, gm	25	Moisture Content, %	32.00
Moisture Content, %	32.00	Dry Density, gm/cm³	1.212

Axial Deformation, mm	Axial Strain, %	Area, m²	Axial Stress, Kpa
0.000	0.000000	0.001018	0
0.178	0.234553	0.001137	12
0.261	0.343117	0.001138	20
0.351	0.462404	0.001139	28
0.444	0.584372	0.001141	37
0.533	0.700978	0.001142	48
0.542	0.713041	0.001142	50
0.614	0.808202	0.001143	61
0.695	0.914086	0.001145	73
0.799	1.050797	0.001146	85
0.832	1.095027	0.001147	88
0.906	1.191529	0.001148	82

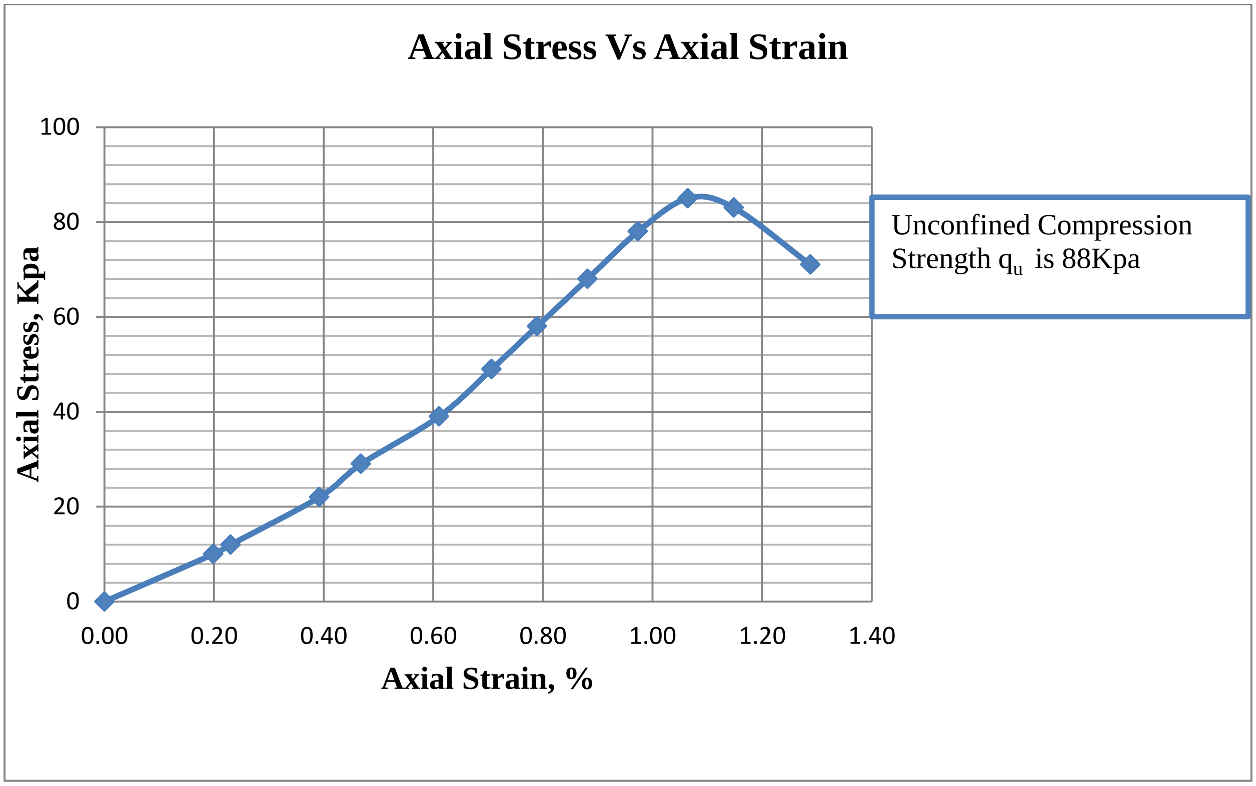

Figure B-3 Axial Stress-Strain relations of the Pumicite 3 days Cured/Specimen-2

Table B-4 Unconfined Compression Test of Pumicite 7 days Cured/Specimen-1

UNCONFINED COMPRENCIVE TEST TEST METHOE-ASTM D2166			
Sample Station	Adama	Cast Date	12/6/2018
Material Description	Pumicite	Penetration Date	20/6/2018
Diameter of Sample, mm	38	Ring Calibration Factor, KN/div	
Moisture Determination		**Density Determination**	
Container No.		Initial Area of Specimen, mm²	1017.88
Mass of Container, gm	61	Initial Height of Specimen, mm	76
Mass of Container + wet soil, gm	93	Volume of Spacimen, mm³	77358.88
Mass of Container +Dry soil, gm	84	Weight of Specimen, gm	112
Mass of Water, gm	9	Wet Density, gm/mm³	0.00145
Mass of Dry Soil, gm	23	Moisture Content, %	39.13
Moisture Content, %	39.13	Dry Density, gm/cm³	1.04
Axial Deformation, mm	Axial Strain, %	Area, m²	Axial Stress, Kpa
0.000	0.000000	0.001017	0
0.242	0.318816	0.001138	51
0.295	0.388553	0.001139	73
0.332	0.437237	0.001139	94
0.360	0.474079	0.001140	116
0.389	0.512237	0.001140	137
0.411	0.541184	0.001140	159
0.438	0.576711	0.001141	178
0.468	0.616184	0.001141	199
0.498	0.655658	0.001142	216
0.521	0.685921	0.001142	237
0.545	0.717500	0.001142	249
0.560	0.737237	0.001143	253
0.564	0.742500	0.001143	250
0.579	0.762237	0.001143	241

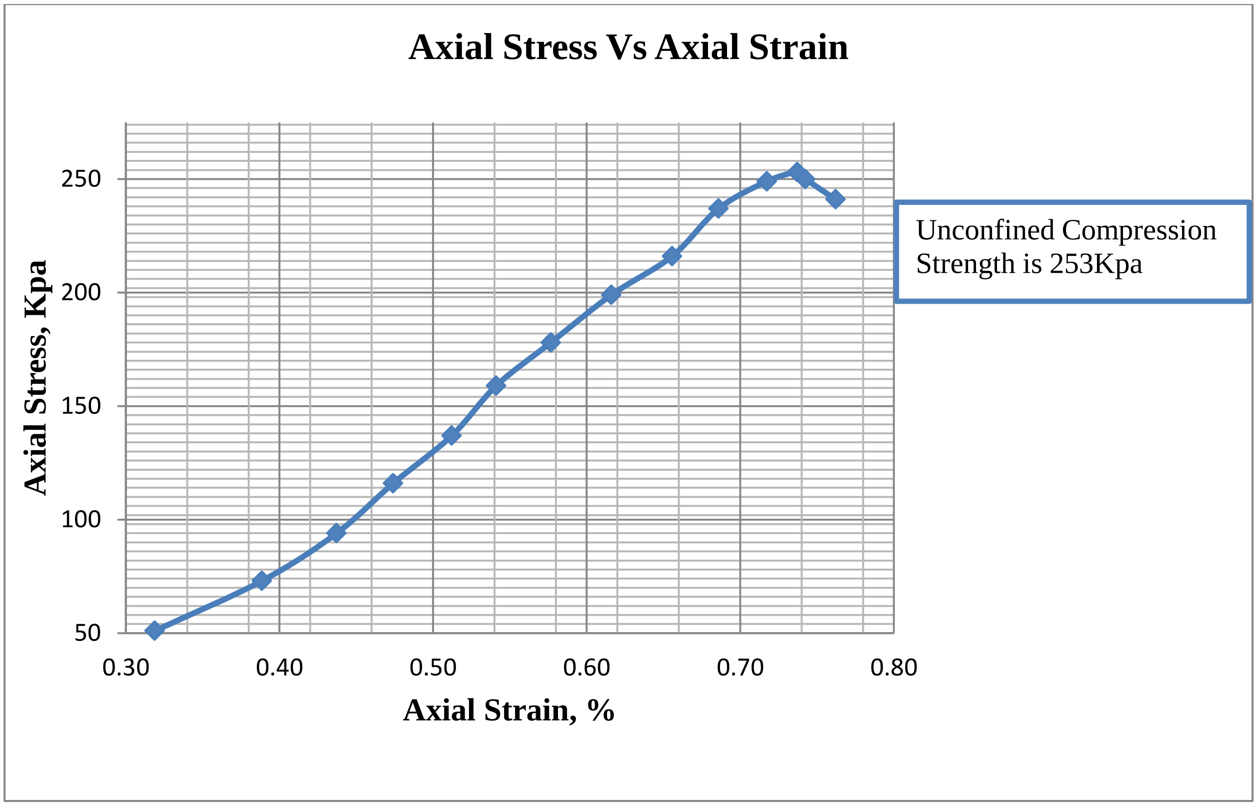

Figure B-4 Axial Stress-Strain relations of the Pumicite 7 days Cured/Specimen-1

Table B-5 Unconfined Compression Test of Pumicite 7 days Cured/Specimen-2

UNCONFINED COMPRENCIVE TEST TEST METHOE-ASTM D2166			
Sample Station	Adama	Cast Date	12/6/2018
Material Description	Pumicite	Penetration Date	20/6/2018
Diameter of Sample, mm	38	Ring Calibration Factor, KN/div	
Moisture Determination		**Density Determination**	
Container No.		Initial Area of Specimen, mm²	1017.88
Mass of Container, gm	60	Initial Height of Specimen, mm	76
Mass of Container + wet soil, gm	98	Volume of Spacimen, mm³	77358.88
Mass of Container +Dry soil, gm	87	Weight of Specimen, gm	112
Mass of Water, gm	11	Wet Density, gm/mm³	0.00145
Mass of Dry Soil, gm	27	Moisture Content, %	40.74
Moisture Content, %	40.74	Dry Density, gm/cm³	1.03
Axial Deformation, mm	Axial Strain, %	Area, m²	Axial Stress, Kpa
0.000	0.000000	0.001018	0
0.224	0.295099	0.001137	49
0.281	0.370069	0.001138	70
0.326	0.429528	0.001139	93
0.364	0.478647	0.001140	125
0.396	0.521302	0.001140	147
0.423	0.556202	0.001140	169
0.441	0.580762	0.001141	182
0.470	0.618247	0.001141	203
0.502	0.660902	0.001142	223
0.522	0.686754	0.001142	241
0.550	0.724239	0.001142	249
0.562	0.739750	0.001143	245

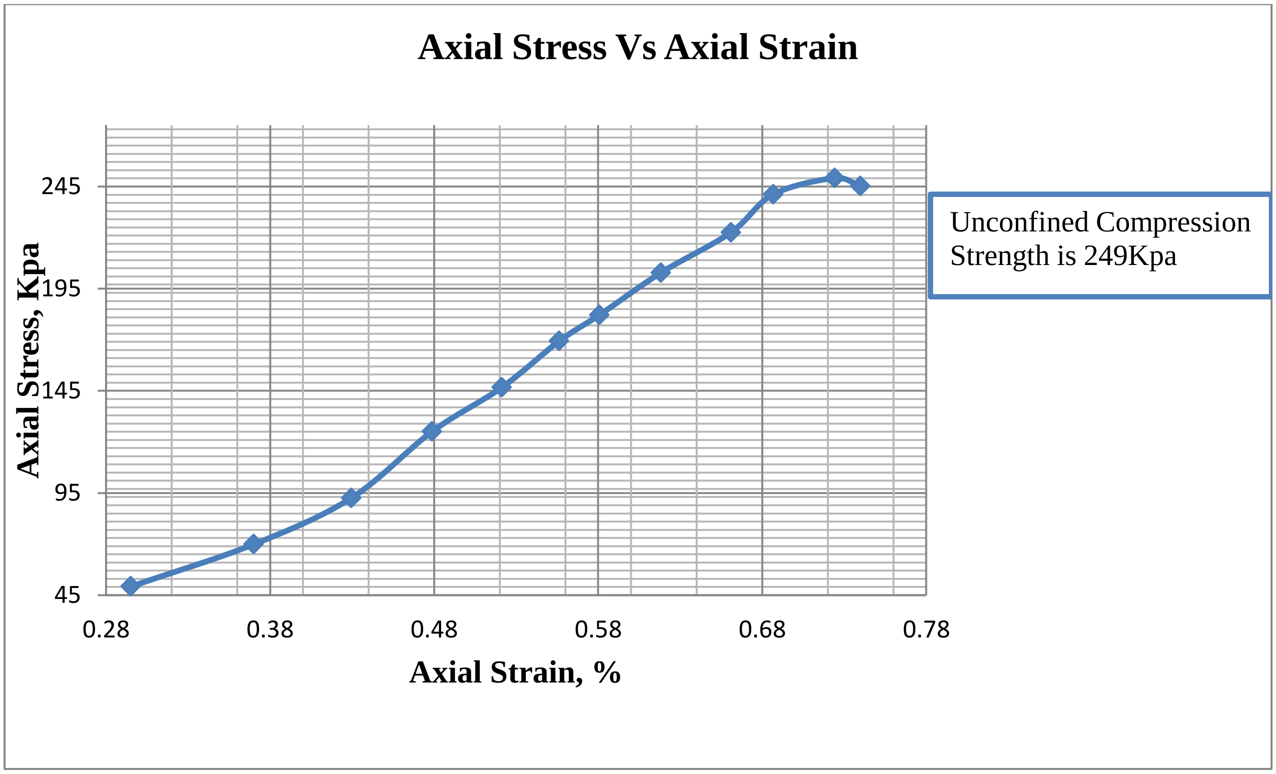

Figure B-5 Axial Stress-Strain relations of the Pumicite 7 days Cured/Specimen-2

APPENDIX-C

Test Results of A’a Lava Gravel Blended with Natural Pozzolana (Volcanic Ash)

Figure C-1 During extraction of blended gravel for modified proctor test

Table C-1 Moisture-Dry density relationship of A'a lava gravel blended with 5% pumicite

Determination No.	1	2	3	4
Volume of Mold, cm3	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	9901	10050	10269	10524
Mass of Compacted soil, g	3416	3565	3784	4039
Bulk density, g/cm3	1.61	1.68	1.78	1.90
Water Content, %	10.00	12.05	16.44	25.44
Dry density, g/cm3	1.46	1.50	1.53	1.52
Water Content Determination				
Mass of container, g	96	95.5	96	60.5
Mass of container + wet soil, g	129	142	138.5	132
Mass of container + dry soil, g	126	137	132.5	117.5
Mass of water, g	3	5	6	14.5
Mass of dry soil, g	30	41.5	36.5	57
Water content, %	10.00	12.05	16.44	25.44

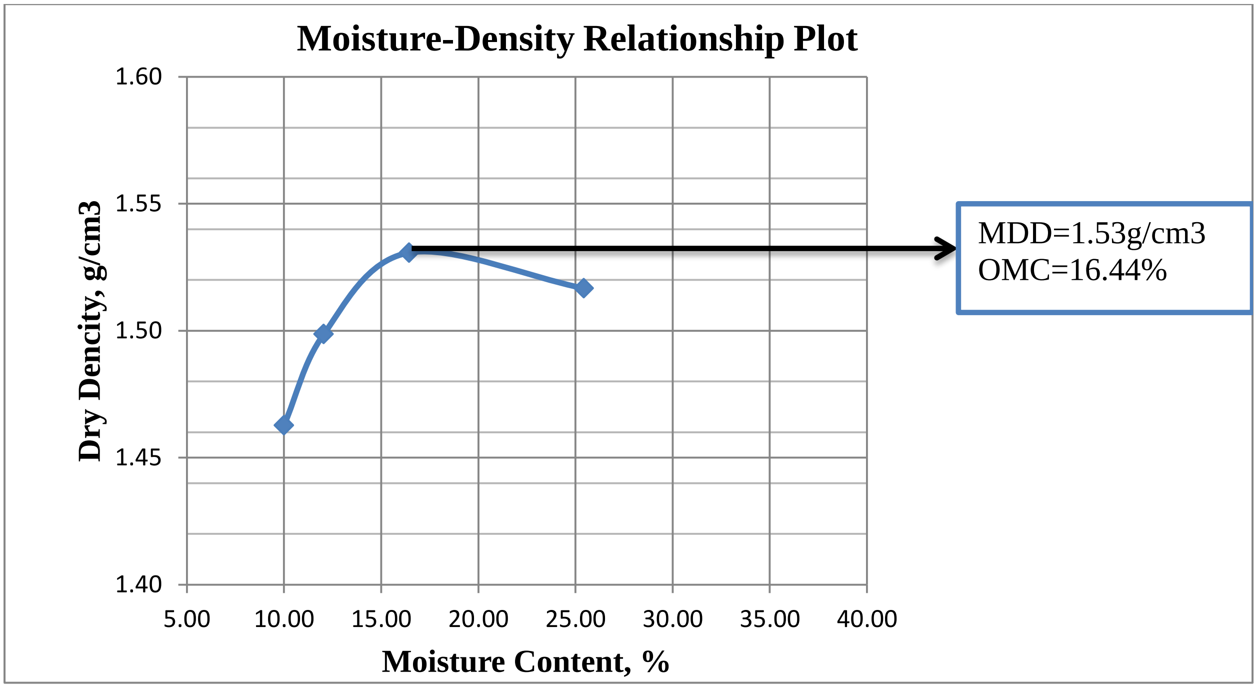

Figure C-1 Moisture-Dry density curve of A'a lava gravel blended with 5% pumicite

Table C-2 Moisture-Dry density relationship of A'a lava gravel blended with 10% pumicite

Determination No.	1	2	3	4
Volume of Mold, cm3	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	10087	10387	10407	10400
Mass of Compacted soil, g	3602	3902	3922	3915
Bulk density, g/cm3	1.70	1.84	1.85	1.84
Water Content, %	12.82	17.57	21.13	30.88
Dry density, g/cm3	1.50	1.56	1.53	1.41
Water Content Determination				
Mass of container, g	96	77	96	77
Mass of container + wet soil, g	140	120.5	139	121.5
Mass of container + dry soil, g	135	114	131.5	111
Mass of water, g	5	6.5	7.5	10.5
Mass of dry soil, g	39	37	35.5	34
Water content, %	12.82	17.57	21.13	30.88

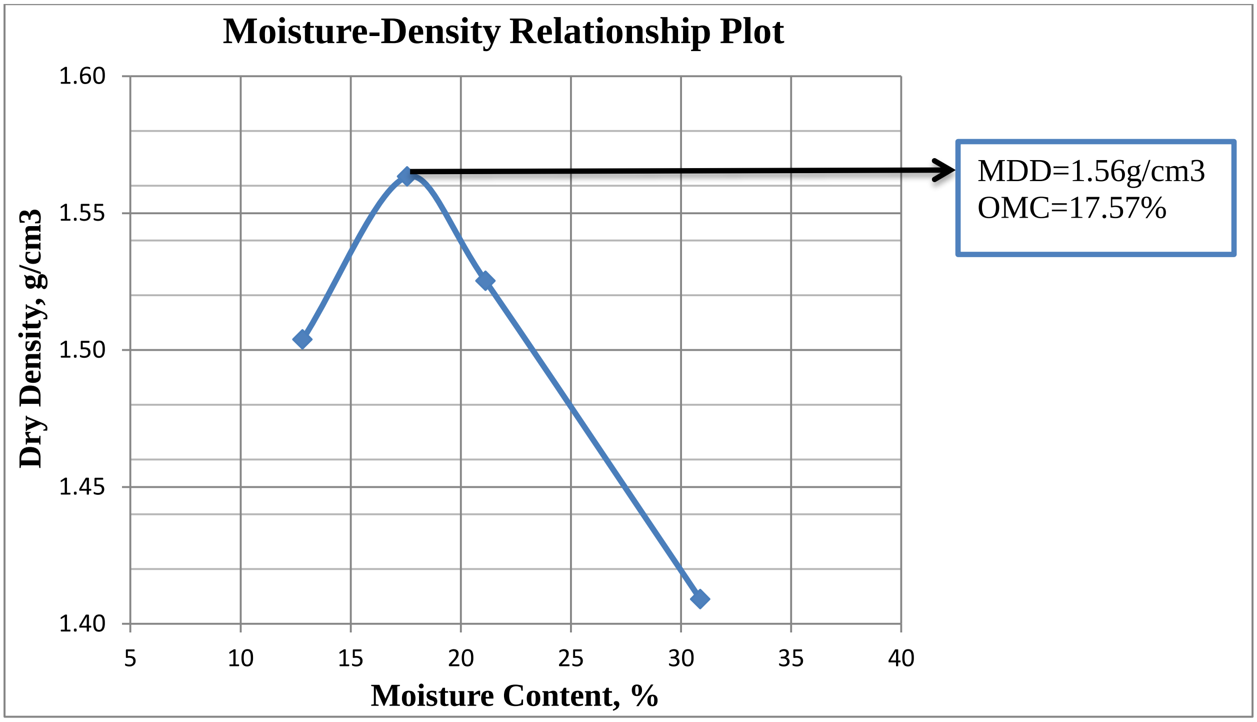

Figure C-2 Moisture-Dry density curve of A'a lava gravel blended with 10% pumicite

Table C-3 Moisture-Dry density relationship of A'a lava gravel blended with 15% pumicite

for 15% pumice				
Determination No.	1	2	3	4
Volume of Mold, cm3	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	10034	10280	10555	10442
Mass of Compacted soil, g	3549	3795	4070	3957
Bulk density, g/cm3	1.67	1.79	1.92	1.86
Water Content, %	10.53	13.64	18.68	28.70
Dry density, g/cm3	1.51	1.57	1.62	1.45
Water Content Determination				
Mass of container, g	78	78.5	61	60.5
Mass of container + wet soil, g	120	128.5	115	130
Mass of container + dry soil, g	116	122.5	106.5	114.5
Mass of water, g	4	6	8.5	15.5
Mass of dry soil, g	38	44	45.5	54
Water content, %	10.53	13.64	18.68	28.70

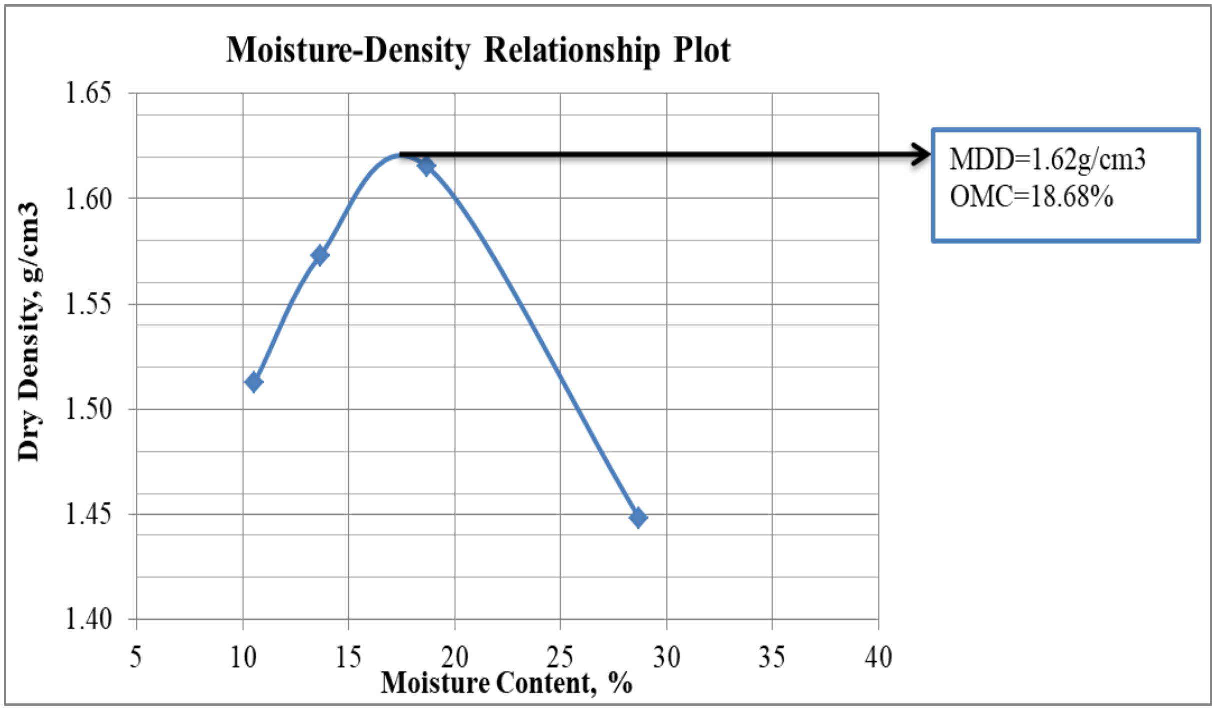

Figure C-3 Moisture-Dry density curve of A'a lava gravel blended with 15% pumicite

Table C-4 Moisture-Dry density relationship of A'a lava gravel blended with 20% pumicite

Determination No.	1	2	3	4
Volume of Mold, cm3	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	10240	10398	10537	10529
Mass of Compacted soil, g	3755	3913	4052	4044
Bulk density, g/cm3	1.77	1.84	1.91	1.90
Water Content, %	10.68	13.08	15.46	23.30
Dry density, g/cm3	1.60	1.63	1.65	1.54
Water Content Determination				
Mass of container, g	60.5	60	60.5	60.5
Mass of container + wet soil, g	117.5	120.5	116.5	124
Mass of container + dry soil, g	112	113.5	109	112
Mass of water, g	5.5	7	7.5	12
Mass of dry soil, g	51.5	53.5	48.5	51.5
Water content, %	10.68	13.08	15.46	23.30

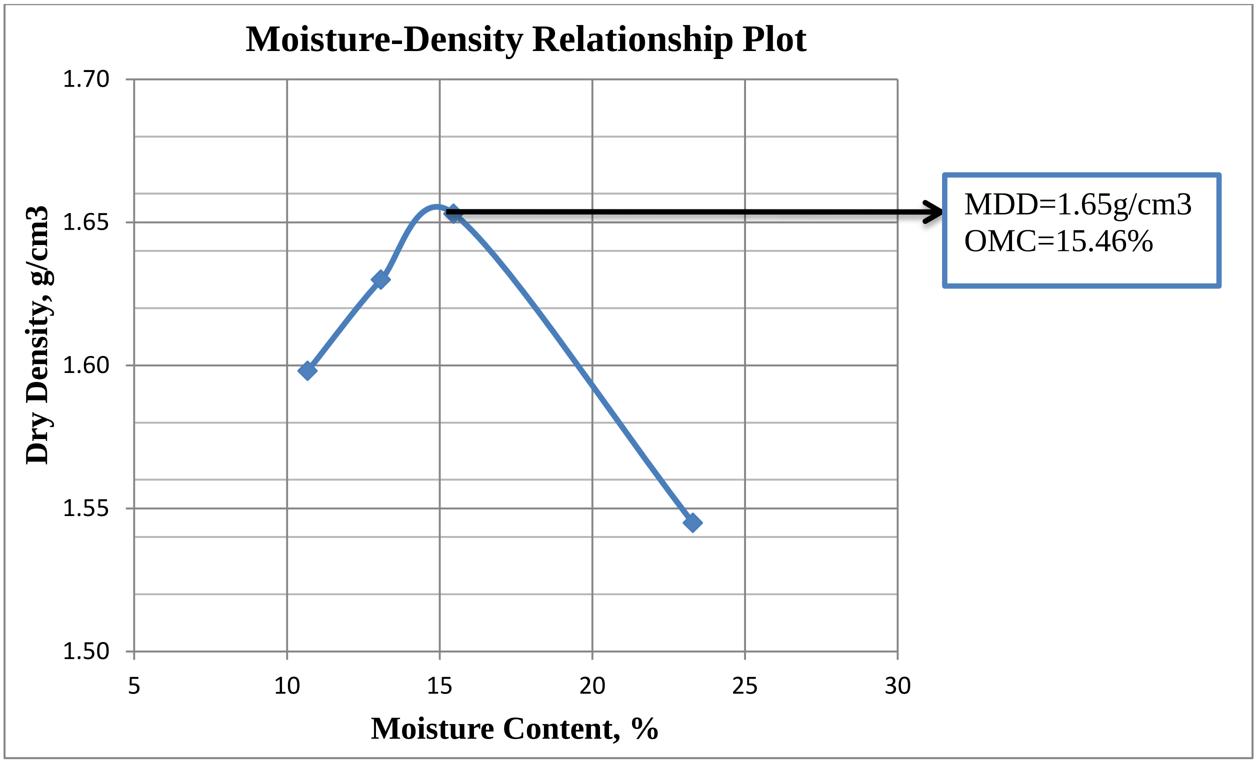

Figure C-4 Moisture-Dry density curve of A’a lava gravel blended with 20% pumicite

Table C-5 Moisture-Dry density relationship of A’a lava gravel blended with 25% pumicite

Determination No.	1	2	3	4
Volume of Mold, cm3	2123	2123	2123	2123
Mass of Mold, g	6485	6485	6485	6485
Mass of mold + Compacted Soil, g	10294	10611	10678	10749
Mass of Compacted soil, g	3809	4126	4193	4264
Bulk density, g/cm3	1.79	1.94	1.98	2.01
Water Content, %	14.73	22.32	26.85	36.75
Dry density, g/cm3	1.56	1.59	1.56	1.47
Water Content Determination				
Mass of container, g	60	60.5	61	60
Mass of container + wet soil, g	134	129	129.5	140
Mass of container + dry soil, g	124.5	116.5	115	118.5
Mass of water, g	9.5	12.5	14.5	21.5
Mass of dry soil, g	64.5	56	54	58.5
Water content, %	14.73	22.32	26.85	36.75

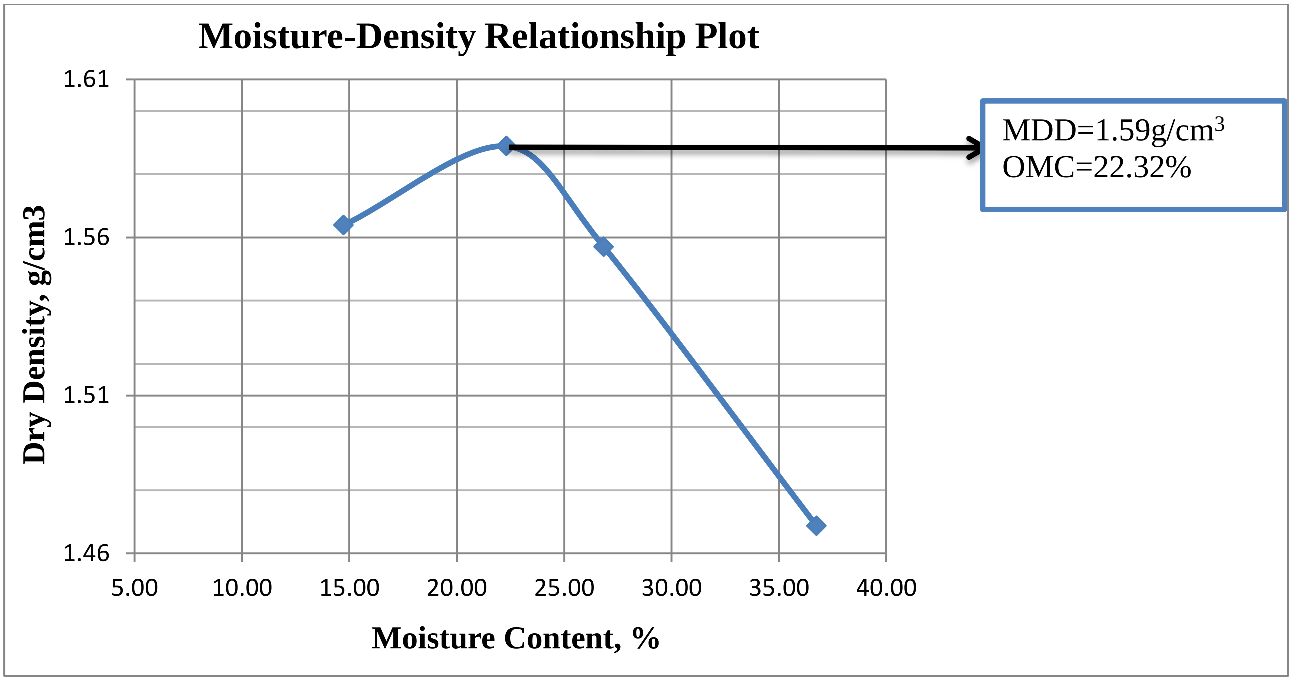

Figure C-5 Moisture-Dry density curve of A'a lava gravel blended with 25% pumicite

Table C-6 Maximum dry density vs. % volcanic ash/pumicite for different blending proportions

% Volcanic Ash	MDD, g/cm3	OMC, %
0	1.47	11.54
5	1.53	16.44
10	1.56	17.57
15	1.62	18.68
20	1.65	15.46
25	1.59	22.32

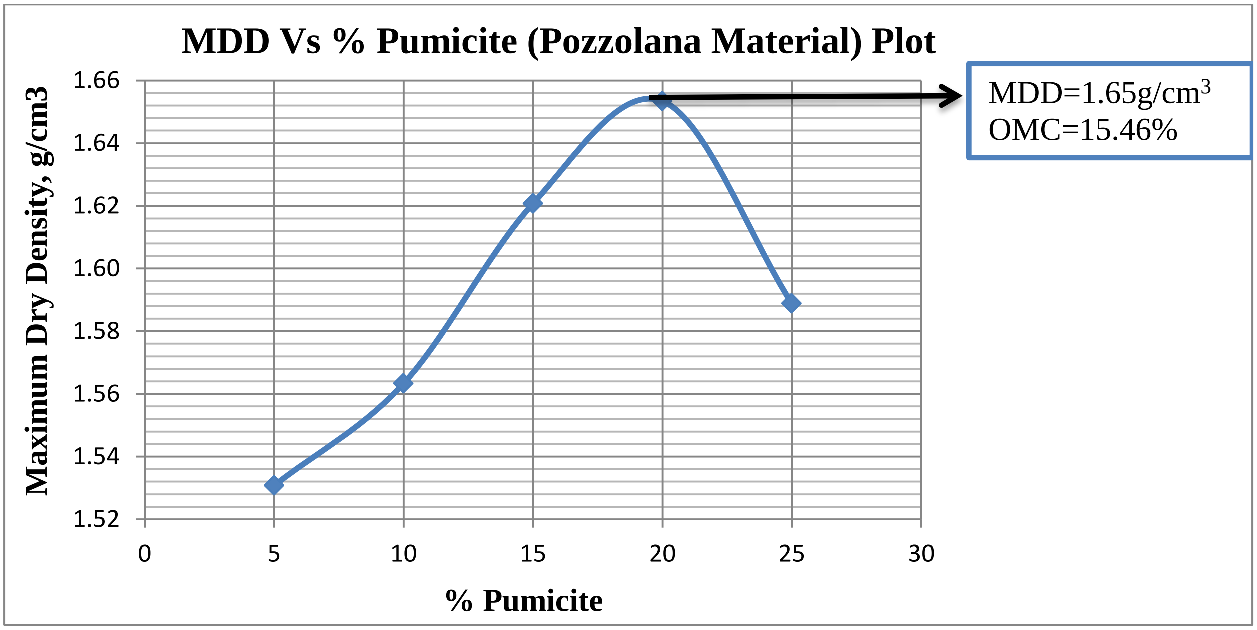

Figure C-6 Maximum dry density vs. % volcanic ash/pumicite curve for different blending proportions

Table C-7 Un-soaked CBR for 5% pumicite by mass of A'a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	2/7/2018
Material Description	10% Pumicite	Penetration Date	2/7/2018
Test Description	Un-soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5503
Mass of Container + wet soil, gm	129.5	Volume of Soil, cm³	1321
Mass of Container +Dry soil, gm	119.5	Weight of Soil, gm	2439
Mass of Water, gm	10	Wet Density, gm/cm³	1.84633
Mass of Dry Soil, gm	59.5	Moisture Content, %	16.81
Moisture Content, %	16.81	Dry Density, gm/cm³	1.58
Loading-Penetration			

Penetration, mm	Standard Load, KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.000	
0.635		1578	1935	0.816	
1.270		3409	1935	1.762	
1.910		5939	1935	3.069	
2.540	6.9	10193	1935	5.268	76
3.180		12732	1935	6.580	
5.080	10.3	18925	1935	9.780	95
6.350		20320	1935	10.501	

Swelling data	
Height of specimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For un-soaked sample of 5% pumicite and 95% of lava gravel penetration the CBR value is 95 at 5.08 penetrations.

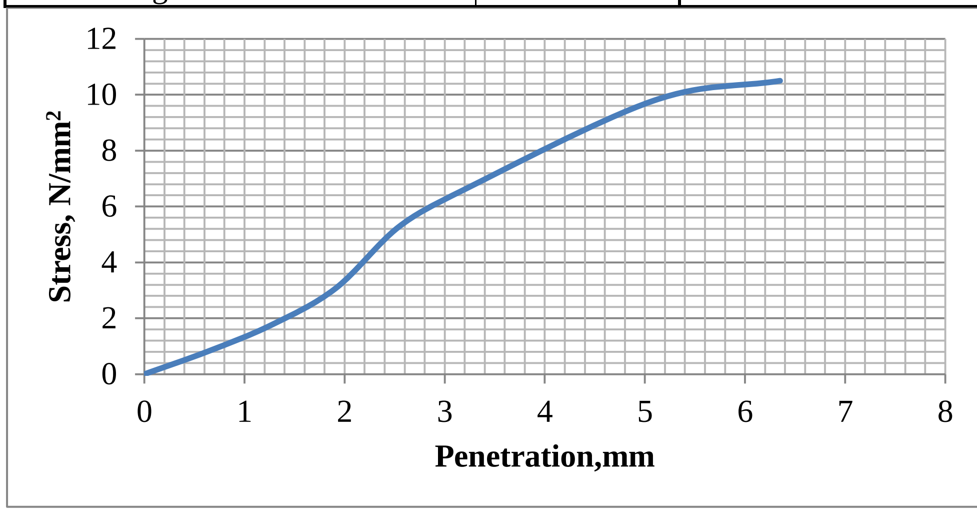

Figure C-7 Un-soaked stress vs. penetration curve of for 5% pumicite by mass of A'a lava gravel

Table C-8 Soaked CBR for 5% pumicite by mass of A'a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	2/7/2018
Material Description	10% Pumicite	Penetration Date	6/7/2018
Test Description	Soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5748
Mass of Container + wet soil, gm	134	Volume of Soil, cm³	1321
Mass of Container +Dry soil, gm	116.5	Weight of Soil, gm	2684
Mass of Water, gm	17.5	Wet Density, gm/cm³	2.03179
Mass of Dry Soil, gm	56.5	Moisture Content, %	30.97
Moisture Content, %	30.97	Dry Density, gm/cm³	1.55
Loading-Penetration			

Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.000	
0.635		465	1935	0.240	
1.270		1208	1935	0.624	
1.910		2997	1935	1.549	
2.540	6.9	6120	1935	3.163	46
3.180		9031	1935	4.667	
5.080	10.3	10489	1935	5.421	53
6.350		12942	1935	6.688	

Swelling data	
Height of specimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For soaked sample 5% pumicite and 95% of lava gravel penetration the CBR value is 53 at 5.08 penetrations.

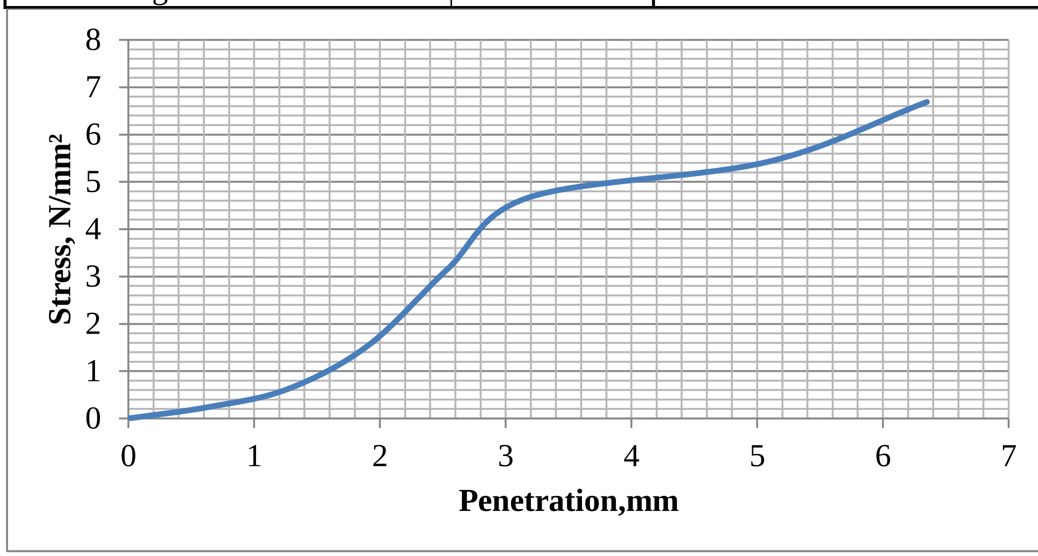

Figure C-8 Stress vs. penetration curve of soaked for 5% pumicite by mass of A'a lava gravel

Table C-9 Un-soaked CBR for 10% pumicite by mass of A'a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHTO T-193			
Sample Station	Adama	Cast Date	2/7/2018
Material Description	10% Pumicite	Penetration Date	2/7/2018
Test Description	Un-soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60.5	Weight of Soil + Mold	5569
Mass of Container + wet soil, gm	137	Volume of Soil, cm³	1321
Mass of Container +Dry soil, gm	125.5	Weight of Soil, gm	2505
Mass of Water, gm	11.5	Wet Density, gm/cm³	1.89629
Mass of Dry Soil, gm	65	Moisture Content, %	17.69
Moisture Content, %	17.69	Dry Density, gm/cm³	1.61

Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.000	
0.635		2355	1935	1.217	
1.270		6937	1935	3.585	
1.910		10855	1935	5.610	
2.540	6.9	16344	1935	8.447	122
3.180		21332	1935	11.024	
5.080	10.3	34097	1935	17.621	171
6.350		42636	1935	22.034	

Swelling data	
Height of specimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For un-soaked sample 10% pumicite and 90% of lava gravel penetration the CBR value is 171% at 5.08 penetrations.

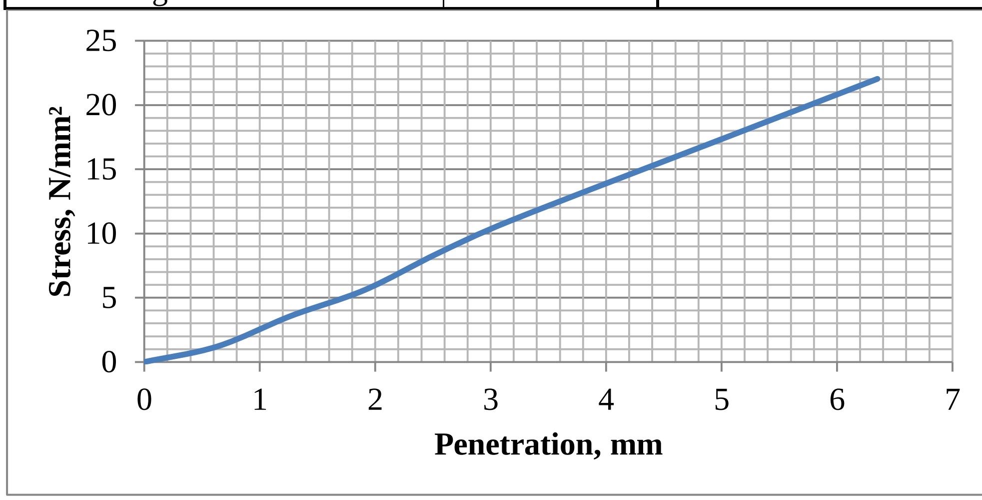

Figure C-9 Un-soaked stress vs. penetration curve of for 10% pumicite by mass of A'a lava gravel

Table C-10 Soaked CBR for 10% pumicite by mass of A'a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	2/7/2018
Material Description	20% Pumicite	Penetration Date	6/7/2018
Test Description	Soaked		

Moisture Determination		Density Determination	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60.5	Weight of Soil + Mold	5865
Mass of Container + wet soil, gm	172.5	Volume of Soil, cm	1321
Mass of Container +Dry soil, gm	144.5	Weight of Soil, gm	2801
Mass of Water, gm	28	Wet Density, gm/cm³	2.12036
Mass of Dry Soil, gm	84	Moisture Content, %	33.33
Moisture Content, %	33.33	Dry Density, gm/cm³	1.59

Loading-Penetration					
Penetration, mm	Standard Load, KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		577	1935	0.30	
1.270		1780	1935	0.92	
1.910		3602	1935	1.86	
2.540	6.9	8588	1935	4.44	64
3.180		10000	1935	5.17	
5.080	10.3	14521	1935	7.50	73
6.350		17212	1935	8.90	

Swelling data	
Height of specimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For soaked sample of 10% pumicite and 90% of lava gravel penetration the CBR value is 73% at 5.08 penetrations.

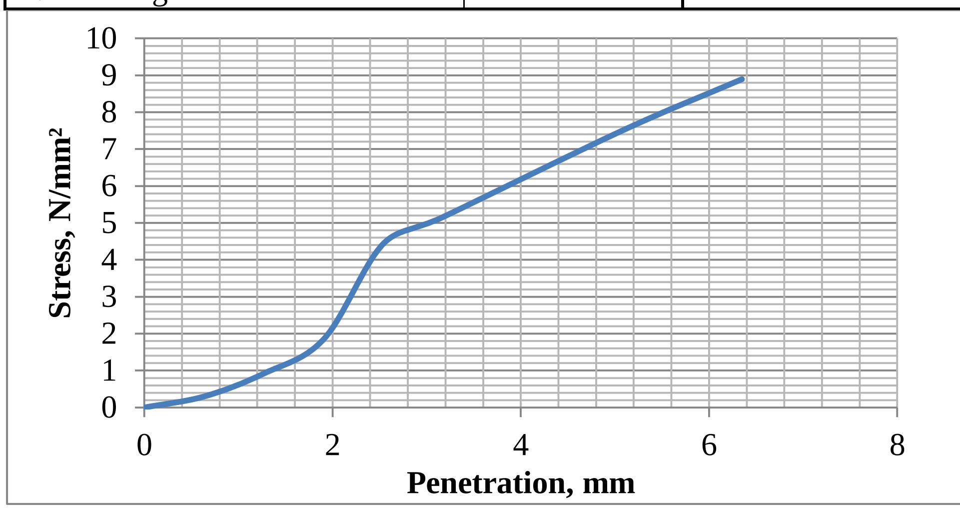

Figure C-10 Stress vs. penetration curve of soaked for 10% pumicite by mass of A’a lava gravel

Table C-11 Un-soaked CBR for 15% pumicite by mass of A’a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	2/7/2018
Material Description	20% Pumicite	Penetration Date	2/7/2018
Test Description	Un-soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5575
Mass of Container + wet soil, gm	111.5	Volume of Soil, cm	1321
Mass of Container +Dry soil, gm	105	Weight of Soil, gm	2511
Mass of Water, gm	6.5	Wet Density, gm/cm³	1.90083
Mass of Dry Soil, gm	45	Moisture Content, %	14.44
Moisture Content, %	14.44	Dry Density, gm/cm³	1.66

Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		4595	1935	2.37	
1.270		9659	1935	4.99	
1.910		21036	1935	10.87	
2.540	6.9	28924	1935	14.95	217
3.180		33752	1935	17.44	
5.080	10.3	47680	1935	24.64	239
6.350		59974	1935	30.99	

Swelling data	
Hright of spacimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For un-soaked sample of 15% pumicite and 85% of lava gravel penetration the CBR value is 239 at 5.08 penetrations.

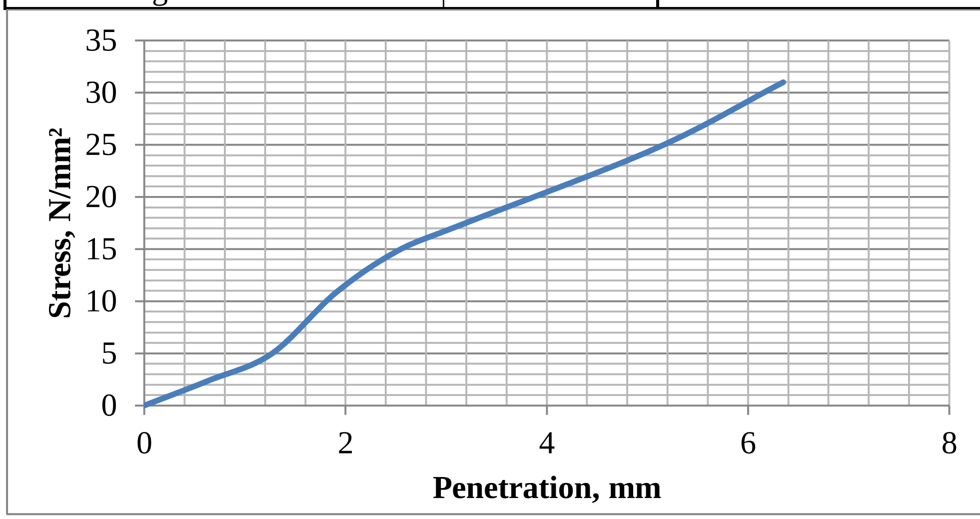

Figure C-11 Stress vs. penetration curve of un-soaked for 15% pumicite by mass of A'a lava gravel

Table C-12 Soaked CBR for 15% pumicite by mass of A'a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	3/7/2018
Material Description	20% Pumicite	Penetration Date	7/7/2018
Test Description	Soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60.5	Weight of Soil + Mold	5970
Mass of Container + wet soil, gm	162.5	Volume of Soil, cm	1321
Mass of Container +Dry soil, gm	134.5	Weight of Soil, gm	2906
Mass of Water, gm	28	Wet Density, gm/cm³	2.19985
Mass of Dry Soil, gm	74	Moisture Content, %	37.84

Moisture Content, %	37.84	Dry Density, gm/cm³			1.60
Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		1297	1935	0.67	
1.270		3285	1935	1.70	
1.910		6593	1935	3.41	
2.540	6.9	10959	1935	5.66	82
3.180		16844	1935	8.70	
5.080	10.3	20671	1935	10.68	104
6.350		24212	1935	12.51	

Swelling data		**Remark:** For soaked sample of 15% pumicite and 85% of lava gravel penetration the CBR value is 104 at 5.08 penetrations.
Height of specimen, mm	125	
No. of blows	56	
Before Soaking	0.00	
After Soaking	0.00	
% Swelling	0	

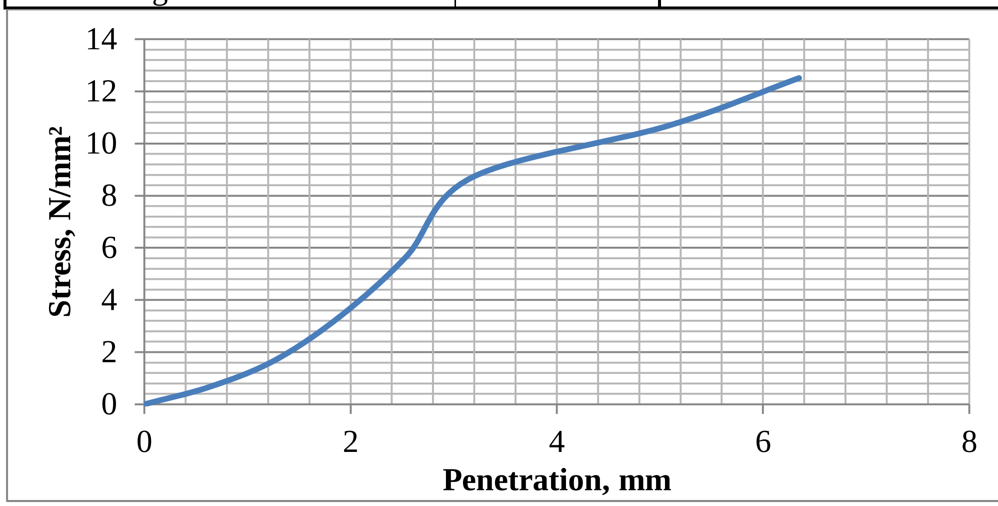

Figure C-12 Stress vs. penetration curve of soaked for 15% pumicite by mass of A’a lava gravel

Table C-13 Un-soaked CBR for 20% pumicite by mass of A’a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	3/7/2018
Material Description	20% Pumicite	Penetration Date	3/7/2018
Test Description	Un-soaked		

Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5656
Mass of Container + wet soil, gm	126	Volume of Soil, cm	1321
Mass of Container +Dry soil, gm	117	Weight of Soil, gm	2592
Mass of Water, gm	9	Wet Density, gm/cm³	1.96215
Mass of Dry Soil, gm	57	Moisture Content, %	15.79

Moisture Content, %	15.79	Dry Density, gm/cm³			1.69
Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		5800	1935	3.00	
1.270		20233	1935	10.46	
1.910		30216	1935	15.62	
2.540	6.9	36690	1935	18.96	275
3.180		42195	1935	21.81	
5.080	10.3	65462	1935	33.83	328
6.350		81164	1935	41.95	

Swelling data		**Remark:** For un-soaked sample of 20% pumicite and 80% of lava gravel penetration the CBR value is 328 at 5.08 penetrations.
Height of specimen, mm	125	
No. of blows	56	
Before Soaking	0.00	
After Soaking	0.00	
% Swelling	0	

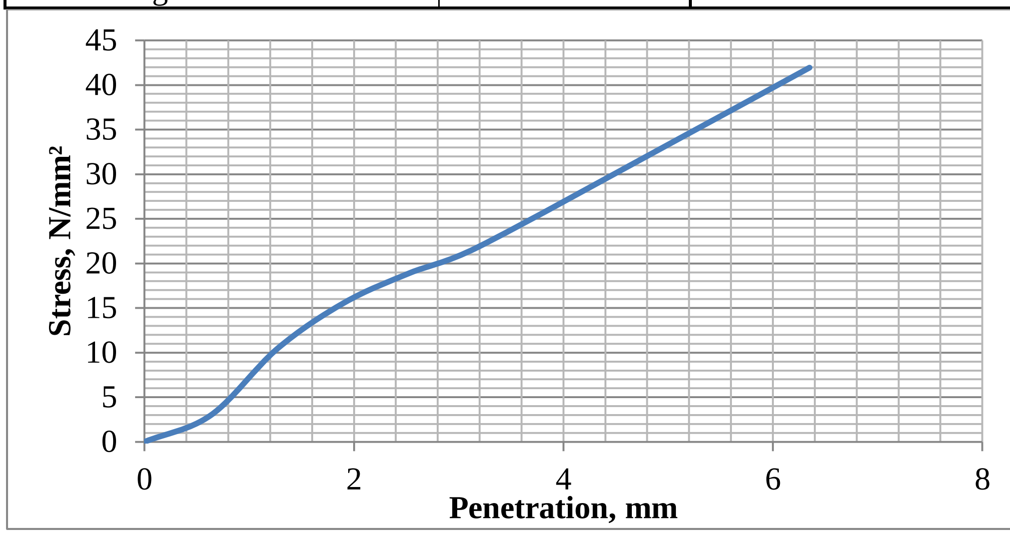

Figure C-13 Stress vs. penetration curve of un-soaked for 20% pumicite by mass of A’a lava gravel

Table C-14 Soaked CBR for 20% pumicite by mass of A’a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	3/7/2018
Material Description	20% Pumicite	Penetration Date	7/7/2018
Test Description	Soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5980
Mass of Container + wet soil, gm	149.5	Volume of Soil, cm	1321
Mass of Container +Dry soil, gm	124	Weight of Soil, gm	2916
Mass of Water, gm	25.5	Wet Density, gm/cm³	2.20742

Mass of Dry Soil, gm	64	Moisture Content, %			39.84
Moisture Content, %	39.84	Dry Density, gm/cm³			1.58
Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		1422	1935	0.73	
1.270		4785	1935	2.47	
1.910		9469	1935	4.89	
2.540	6.9	14789	1935	7.64	111
3.180		19580	1935	10.12	
5.080	10.3	31682	1935	16.37	159
6.350		33966	1935	17.55	
Swelling data		**Remark:** For soaked sample of 20% pumicite and 80% of lava gravel penetration the CBR value is 159 at 5.08 penetrations.			
Height of specimen, mm	125				
No. of blows	56				
Before Soaking	0.00				
After Soaking	0.00				
% Swelling	0				

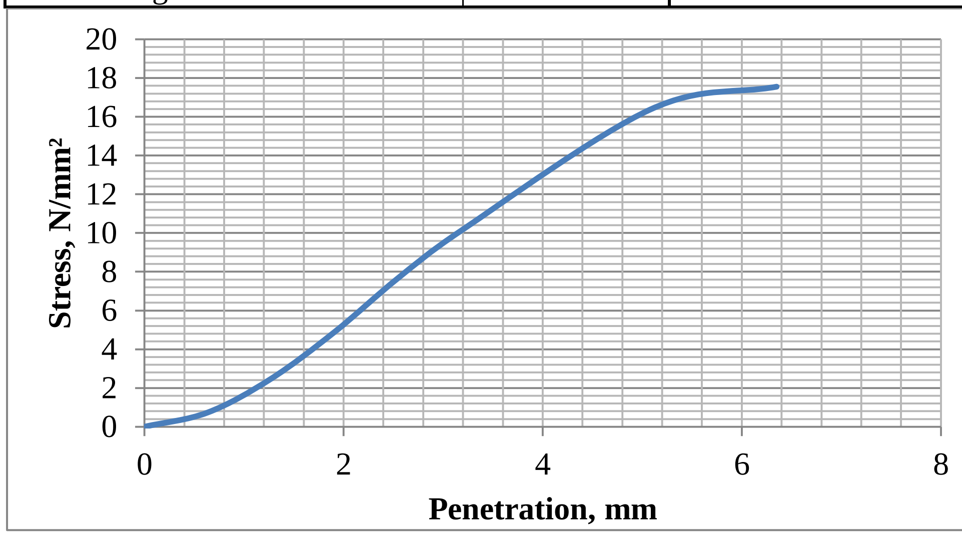

Figure C-14 Stress vs. penetration curve of soaked for 20% pumicite by mass of A'a lava gravel

Table C-15 Un-soaked CBR for 25% pumicite by mass of A'a lava gravel

CALIFORNIA BEARING RATIO TEST **TEST METHOE-AASHO T193**			
Sample Station	Adama	Cast Date	3/7/2018
Material Description	20% Pumicite	Penetration Date	3/7/2018
Test Description	Unsoaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5625
Mass of Container + wet soil, gm	134	Volume of Soil, cm	1321
Mass of Container +Dry soil, gm	120.5	Weight of Soil, gm	2561

Mass of Water, gm	13.5	Wet Density, gm/cm³			1.93868
Mass of Dry Soil, gm	60.5	Moisture Content, %			22.31
Moisture Content, %	22.31	Dry Density, gm/cm³			1.59
Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		5493	1935	2.84	
1.270		13495	1935	6.97	
1.910		23931	1935	12.37	
2.540	6.9	32385	1935	16.74	243
3.180		39942	1935	20.64	
5.080	10.3	47471	1935	24.53	238
6.350		62821	1935	32.47	

Swelling data	
Height of specimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For un-soaked sample of 25% pumicite and 75% of lava gravel penetration the CBR value is 243 at 2.54 penetrations.

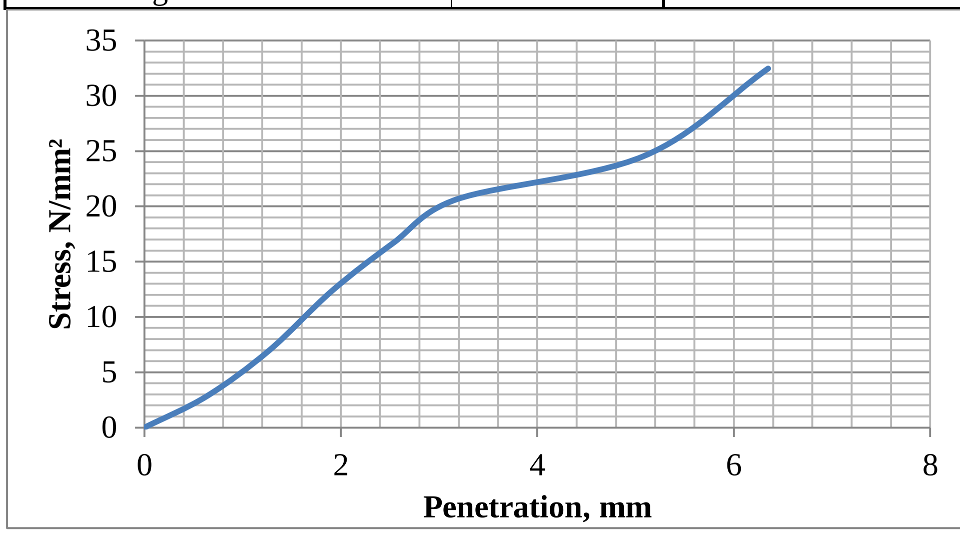

Figure C-15 Stress vs. penetration curve of un-soaked for 25% pumicite by mass of A’a lava gravel

Table C-16 Soaked CBR for 25% pumicite by mass of A’a lava gravel

CALIFORNIA BEARING RATIO TEST TEST METHOE-AASHO T193			
Sample Station	Adama	Cast Date	3/7/2018
Material Description	20% Pumicite	Penetration Date	7/7/2018
Test Description	Soaked		
Moisture Determination		**Density Determination**	
Container No.		Weight of Mould, gm	3064
Mass of Container, gm	60	Weight of Soil + Mold	5774
Mass of Container + wet soil, gm	169.5	Volume of Soil, cm	1321

Mass of Container +Dry soil, gm	145	Weight of Soil, gm			2710
Mass of Water, gm	24.5	Wet Density, gm/cm³			2.05148
Mass of Dry Soil, gm	85	Moisture Content, %			28.82
Moisture Content, %	28.82	Dry Density, gm/cm³			1.59
Loading-Penetration					
Penetration, mm	Standard Load,KN	Load, N	Area, mm²	Penetration stress, Mpa	CBR,%
0.000		0	1935	0.00	
0.635		1396	1935	0.72	
1.270		4174	1935	2.16	
1.910		8338	1935	4.31	
2.540	6.9	12595	1935	6.51	94
3.180		17724	1935	9.16	
5.080	10.3	22813	1935	11.79	114
6.350		26590	1935	13.74	

Swelling data	
Height of specimen, mm	125
No. of blows	56
Before Soaking	0.00
After Soaking	0.00
% Swelling	0

Remark: For soaked sample of 25% pumicite and 75% of lava gravel penetration the CBR value is 114 at 5.08 penetrations.

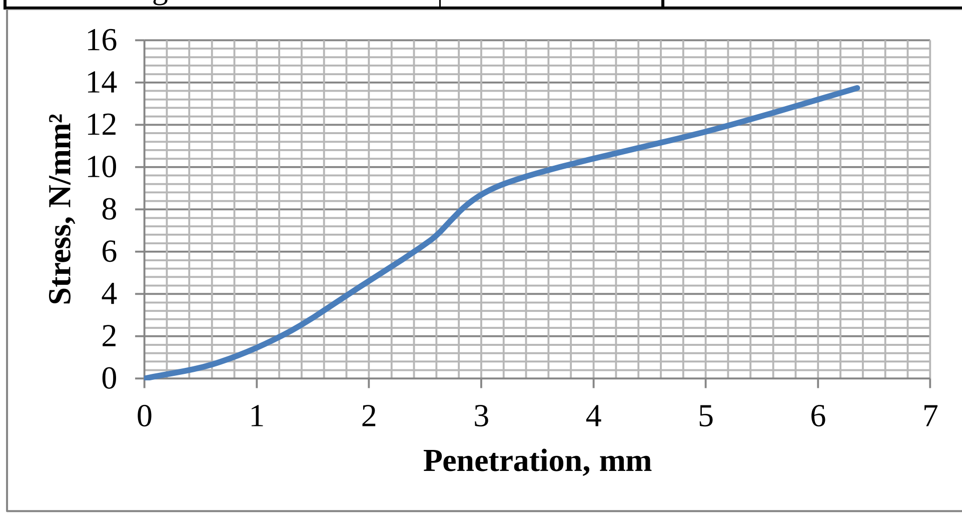

Figure C-16 Stress vs. penetration curve of soaked for 25% pumicite by mass of A'a lava gravel

Table C-17 Particle size distribution of A,a lava gravel with 20% of pumicite by its weight before compaction

Gradation Befor Compaction					
Sieve	Wt. Retained	% Retained	% Pass	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50	0	0	100	100	100
37.5	52	2.1	97.86	80	100
20	477	19.6	78.28	60	80

10	498	20.5	57.82	45	65
5	491	20.2	37.66	30	50
2.36	353	14.5	23.16	20	40
0.425	274	11.3	11.91	10	25
0.075	141	5.8	6.12	5	15
pan	149	6.1	0.00		
Total Weight of sample		2435			

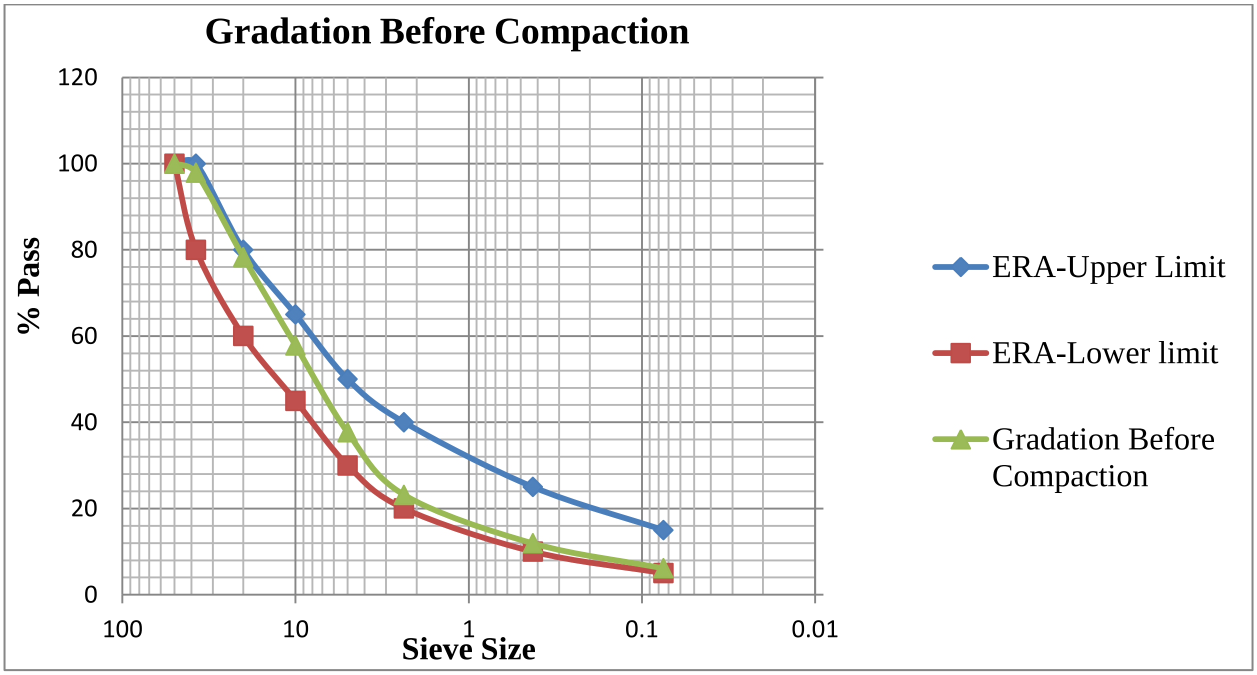

Figure C-17 Particle size distribution curve of A,a lava gravel with 20% of pumicite by its weight before compaction

Table C-18 Particle size distribution of A,a lava gravel with 20% of pumicite by its weight after compaction

Gradation After Compaction					
Sieve	Wt. Retained	% Retained	% Pass	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50	0	0	100	100	100
37.5	0	0.00	100.00	80	100

20	452	18.60	81.40	60	80
10	395	16.26	65.14	45	65
5	564	23.21	41.93	30	50
2.36	364	14.98	26.95	20	40
0.425	284	11.69	15.27	10	25
0.075	168	6.91	8.35	5	15
pan	203	8.35	0.00		
Total Weight of Sample		2430 gm			

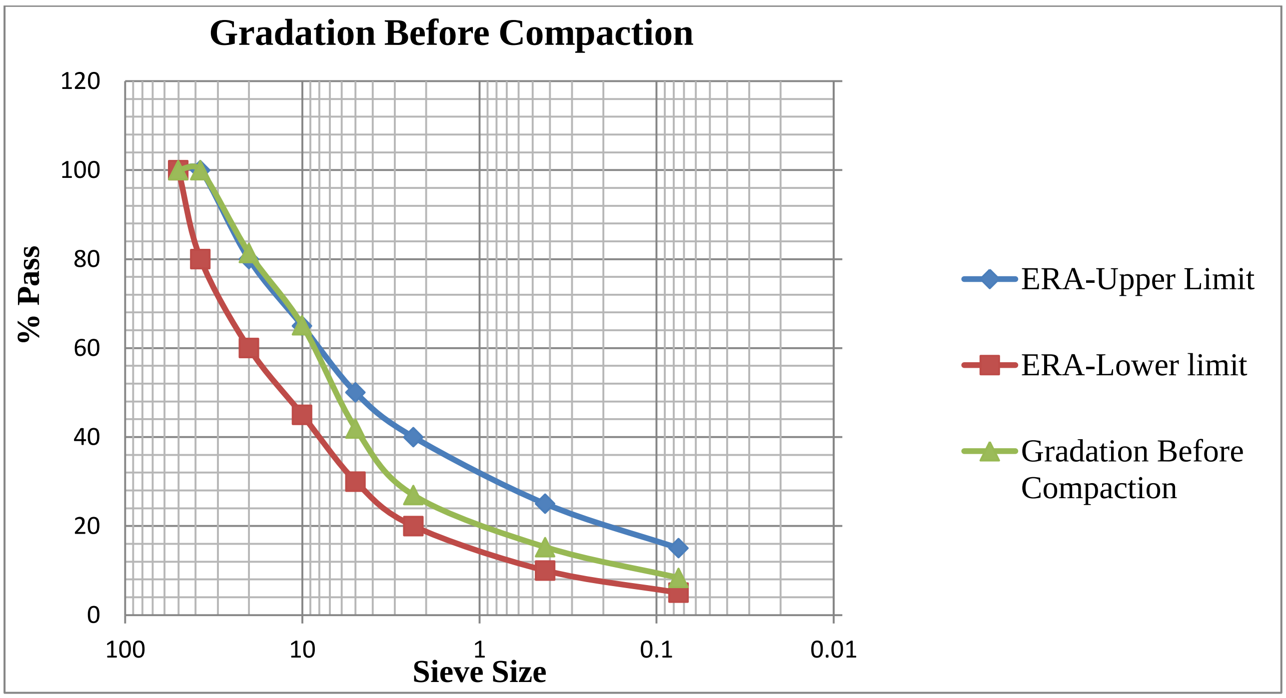

Figure C-18 Particle size distribution curve of A,a lava gravel with 20% of pumicite by its weight after compaction

APPENDIX-D

Cost Comparison

Table D-1 Detail cost breakdown of quarry rock production

Detailed Breakdown of BOQ item Item Unit Rate

Project : Thesis
Item No.
Description: Quarry Rock Production
Quantity

Performance rate: 500m^3/day
Equipment hourly output: 62.5m^3/hr
Resultant : 62.5 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**	**Rate hrly**	**Total**
Explosive	Box	2.200	720.00	1584.00	Foreman	1	1.00	48.08	48.08	Dozer	1.00	0.70	1,002.93	702.05
Blasting Caps	Each	25.00	36.00	900.00	Operator	4	1.00	33.52	134.09	Air Compressor	1.00	0.70	225.47	157.83
					Superintendant	1	1.00	48.08	48.08	Jack Hammer	1.00	0.70	113.84	79.69
					Skilled labour	5	1.00	16.83	84.15	Wagon Drill	1.00	0.70	195.14	136.60
					Unskilled labour	15	1.00	9.65	144.75	Crawler loader	1.00	1.00	729.00	729.00
					Driver	1	1.00	26.44	26.44	Dump truck	2.00	1.00	519.63	1,039.27
Total				2,484.00	**Total**				485.59	**Total**				2,187.70

A = Material Unit Cost 39.74 | B = Manpower Unit Cost 7.77 | C = Equipment Unit Cost : 35.00 62.51

Direct cost of work item =A+B+C 82.52 Birr/m^3

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate of material production = 103.15 ETB/M3

UF : Utilization Factor
* Including west
**including of benefits, travel subsidies and cost of overtime related to the work item

Table D-2 Detail cost breakdown of base course aggregate production

Detailed Breakdown of BOQ Item Unit Rate

Project Thesis
Item No.
Descrip Crushed-Stone (Base Course Aggregate Production)
Quantity

Performance rate: 500m^3/day
Equipment hourly output: 62.5m^3/hr
Resultant : 62.5 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**	**Rate hrly**	**Total**
					Foreman	1	0.50	48.08	24.04	Crushing plant(75 ton/hr)	1.00	1.00	2,737.39	2,737.39
					Operator	3	1.00	33.52	100.56	Loader, Crawler	1.00	0.50	729.00	364.50
					Superintendant	1	1.00	48.08	48.08	Dump Truck	1.00	0.20	519.63	103.93
					Skilled labour	5	1.00	16.83	84.15	Dozer	1.00	0.20	1,002.93	200.59
					Unskilled labour	5	1.00	9.65	48.25					
Total					**Total**				305.08	**Total**				3,406.40

A = Material Unit Cost | B = Manpower Unit Cost 4.88 | C = Equipment Unit Cost : 54.50

Direct cost of work item =A+B+C 59.38 Birr/m^3

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate of material production = 74.23 ETB/M3

UF : Utilization Factor
* Including west
** Including of benefit, travel subsidies and cost of overtime related to the work item

Table D-3 Detail cost breakdown of base course hauling and placing

Detailed Breakdown of BOQ Item Unit Rate

Project : Thesis — Performance rate: 800m³/day

Item No.

Description: Crushed-stone base hauling and placing — 100 m³/hr

Quantity

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	Rate hrly	Total
Creshed Aggergate	m³	1.50	380.55	570.83	Foreman	1.00	0.50	43.25	21.63	Dump truck	9.00	1.00	519.63	4,676.71
					Operator	6.00	1.00	48.08	288.48	Grader	2.00	1.00	697.01	1,394.02
					Driver	10.00	1.00	26.44	264.40	Loader, Wheel	2.00	0.60	686.25	823.50
					labour	3.00	1.00	16.83	50.49	Roller, 12t	2.00	1.00	388.28	776.56
					Unskilled labour	15.00	1.00	9.65	144.75	Water Truck 6×4	1.00	0.20	523.29	104.66
Total				570.83	Total				769.75	Total				7,775.45

A = Material Unit Cost 5.71 Birr/m³ — B = Manpower Unit Co 7.70 Birr/m³ — C = Equipment Unit Cost : 77.75 Birr/m³

Direct cost of work item =A+B+C 91.16 Birr/m³

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 30% of direct cost. Thus :

Unit Rate of material laying = 113.95 Birr/m³

UF : Utilization Factor

* Including west

** Including of benefit, travel subsidies and cost of overtime related to the work item

Table D-4 Detail cost breakdown of Material production of A’a lava gravel and pumice

Detailed Breakdown of BOQ Item Unit Rate

Project : Thesis — Performance rate: 800m³/day

Item No.

Descripti Material Production (A'a Lava gravel and pumice) — 100 m³/hr

Quantity

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	Rate hrly	Total
					Foreman	2.00	0.50	48.08	48.08	Crawler Dozer, d8r	2.00	1.00	1,002.93	2,005.86
					Operator	2.00	1.00	33.52	67.05	Loader	2.00	1.00	437.20	874.40
					Skilled labour	2.00	1.00	16.83	33.66					
					Unskilled labour	4.00	1.00	9.65	38.60					
					Driver	2.00	1.00	26.44	52.88					
Total					Total				240.27	Total				2,880.26

A = Material Unit Cost 0.00 Birr/m³ — B = Manpower Unit Cost 2.40 Birr/m³ — C = Equipment Unit Cost : 28.80 Birr/m³

Direct cost of work item =A+B+C 31.21 Birr/m³

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate of material production = 39.01 Birr/m³

UF : Utilization Factor

* Including west

** Including of benefit, travel subsidies and cost of overtime related to the work item

Table D-5 Detail cost breakdown of Stabilized road base hauling and placing

Detailed Breakdown of BOQ Item Unit Rate

Project : Thesis — Performance rate: 800m^3/day
Item No.
Description: Stabilised Road Base Hauling and Placing — 100 m^3/hr
Quantity

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	Rate hrly	Total
A'a lava gravel	m^3	1.50	53.62	80.43	Foreman	1.00	0.50	43.25	21.63	Dump truck	9.00	1.00	519.63	4,676.71
Pumice	m^3	1.32	48.75	64.35	Operator	6.00	1.00	48.08	288.48	Grader	1.00	1.00	697.01	697.01
					Driver	10.00	1.00	26.44	264.40	Loader, Wheel	2.00	0.60	686.25	823.50
					Skilled labour	3.00	1.00	16.83	50.49	Roller, 12t	2.00	1.00	388.28	776.56
					Unskilled labour	15.00	1.00	9.65	144.75	6×4	1.00	0.20	523.29	104.66
Total				144.78	**Total**				769.75	**Total**				7,078.44

A = Material Unit Cost 1.45 Birr/m^3 — B = Manpower Unit Cost 7.70 Birr/m^3 — C = Equipment Unit Cost : 70.78 Birr/m^3

Direct cost of work item =A+B+C 79.93 **Birr/m^3**

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 30% of direct cost. Thus :

Unit Rate of material laying = 99.91 **Birr/m^3**

UF : Utilization Factor
* Including west
** Including of benefit, travel subsidies and cost of overtime related to the work item

Table D-6 Detail cost breakdown of unsterilized gravel sub base production

Detailed Breakdown of BOQ Item Unit Rate

Project : Thesis — Performance rate: 700m^3/day
Item No.
Descripti Unstabilized gravel sub base Production — 87.5 m^3/hr
Quantity

Material Cost					Labor cost					Equipment cost				
Material type	Unit	Qty	Rate	Cost/un	Title	Qty	UF	Indexed hrly cost	Total hrly cost	Equipment type	Qty	UF	Rate hrly	Total
					Operator	1.00	1.00	33.52	33.52	Dozer	1.00	1.00	1,002.93	1,002.93
					Foreman	1.00	0.50	48.08	24.04	Chain excavator	1.00	1.00	675.32	675.32
					Skilled labour	2.00	1.00	16.83	33.66					
					Unskilled labou	5.00	1.00	9.65	48.25					
Total					**Total**				139.47	**Total**				1,678.25

A = Material Unit Cost 0.00 — B = Manpower Unit Cost 1.59 Birr/m^3 — C = Equipment Unit Cost : 19.18 Birr/m^3

Direct cost of work item =A+B+C 20.77 **Birr/m^3**

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate of material production= 25.97 **Birr/m^3**

UF : Utilization Factor
* Including west
** Including of benefit, travel subsidies and cost of overtime related to the work item

Table D-7 Detail cost breakdown of unsterilized gravel sub base production

Detailed Breakdown of BOQ Item Unit Rate

Project :	Thesis	Performance rate:	700m³/day
Item No.			
Description:	Unstabilized gravel sub base hauling and placing		87.5 m³/hr
Quantity			

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	Rate hrly	Total
					Foreman	1.00	0.50	48.08	24.04	Grader	2.00	1.00	697.7	1,395.40
					Operator	6.00	1.00	33.52	201.12	Water Truck	1.00	0.80	523.29	418.64
					Driver	10.00	1.00	26.44	264.4	Roller	2.00	1.00	388.28	776.56
					Skilled labour	4.00	1.00	16.83	67.32	Dump truck	9.00	1.00	475.89	4,283.01
					Unskilled labour	15.00	1.00	9.65	144.75	Loader, Wheel (2.5 m3)	2.00	0.60	437.2	524.64
Total					Total				701.63	Total				7,398.25

A = Material Unit Cost 0 | B = Manpower Unit Cost 8.02 **Birr/m³** | C = Equipment Unit Cost : 84.55 **Birr/m³**

Direct cost of work item =A+B+C 92.57 **Birr/m³**

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate of sub base placing = 115.713 **Birr/m³**

UF : Utilization Factor

* Including west

** Including of benefit, travel subsidies and cost of overtime related to the work item

Table D-8 Detail cost breakdown of prime coat MC-70 bitumen

Detailed Breakdown of BOQ Item Unit Rate

Project :	Thesis	Labour hourly output :	NA
Item No.		Equipment hourly output:	NA
Description	Prime coat MC-70 bitumen	Resultant :	700 Lt.
Quantity			

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	Rate hrly	Total
Bitumen (MC-30)	Lit	950.00	22.09	15,465.12	Foreman	1.00	0.50	36.93	18.47	Water Truck	1.00	0.10	523.29	52.33
					Driver	2.00	1.00	13.64	27.27	Asphalt Distributer	1.00	1.00	591.63	591.63
					Equipment Operator	2.00	1.00	33.52	67.05	Asphalt Kettle	1.00	1.00	96.98	96.98
					Skilled labour	3.00	1.00	9.30	27.89					
					Unskilled labour	6.00	1.00	3.41	20.45					
Total				15,465.12	**Total**				161.13	**Total**				740.94

A = Material Unit Cost 22.09 Birr/Liter | B = Manpower Unit Cost 0.23 Birr/Liter | C = Equipment Unit Cost : 1.06 Birr/Liter

Direct cost of work item =A+B+C 23.38 **Birr/Liter**

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate = 29.23 **Birr/Liter**

Table D-9 Detail cost breakdown of production and furnishing AC with 15cm thickness

Detailed Breakdown of BOQ Item Unit Rate

Project : Thesis — Performance: 600 m²/hr

Item No.:

Description: Producing and furnishing AC with 15cm thickness

Quantity

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	Rate hrly	Total
Hot mix Asphalt concrete	ton	0.05220	15217.39	794.35	Foreman	1.00	0.50	48.08	46.58	Asphalt Plant	1.00	1.00	3,192.00	3192.00
					Driver	2.00	1.00	26.44	23.44	Paver	1.00	1.00	797.01	697.01
					Equipment Operator	3.00	1.00	33.52	29.52	Dump Truck	2.00	1.00	519.63	103.93
					Skilled labour	3.00	1.00	16.83	12.83	Pneumatic Roller	2.00	1.00	396.11	396.11
					Unskilled labour	5.00	1.00	9.65	3.65					
Total				794.35	**Total**				116.02	**Total**				4,389.04

A = Material Unit Cost 794.35 Birr/m³ — B = Manpower Unit Cost 0.19 Birr/m³ — C = Equipment Unit Cost : 7.32 Birr/m³

Direct cost of work item =A+B+C **801.86** **Birr/m³**

Using 10 % overhead and 15 % profit margin , the total surcharge adopted is 25% of direct cost. Thus :

Unit Rate = **1,002.32** **Birr/m³**