ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

THE POTENTIAL USE OF CINDER GRAVEL AS A BASE COURSE MATERIAL WHEN STABILIZED BY VOLCANIC ASH AND LIME
(The Case of Metehara Area)

A THESIS SUBMITTED TO THE ADDIS ABABA INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES, OF ADDIS ABABA UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIRMENT FOR THE DEGREE OF MASTER SCIENCE IN CIVIL ENGINEERING

BY
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October 2015

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ACKNOWLEDGEMENT

I would like to express my heart felt gratitude to my advisor Professor Alemayehu Teferra without whose advice and encouragement the completion of this thesis work would not be possible. I am also grateful to Dr. Ing Samuel Tadesse and Dr. Ing. Henok Fikre for their comments and suggestions during the progress report which have been invaluable in terms of bringing me to the right track of my thesis work.

I am greatly indebted to Ato Alemayehu Ayele, Director of the Research and Development Directorate of the Ethiopian Roads Authority (ERA), for his professional support and advice from the inception up to the completion of this study. It was because of his good will that I was able to carry out most of the laboratory testing works at the central laboratory of the directorate including sampling from Metehara area. All the staff of this central laboratory deserve my appreciation with special thanks to Ato Asefa Gebeyehu and Ato HenokTsegaye for their helping hand throughout the majority of laboratory works.

The help I got from the staff of the laboratories of both the Addis Ababa City Roads Authority and the Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) during my stay in their laboratories is gratefully acknowledged.

Last but not least my deepest thanks goes to my wife Silu and my children Mihireteab, Rediet, and Shalom for their understanding and the sacrifices they paid during those days they missed me when I should have been with them. All my friends who, in one way or the other, contributed to my thesis work deserve my gratitude.

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USED SYMBOLS AND ABBREVIATION

AACRA – Addis Ababa City Road Authority`

AASHTO – American Association of Highway and Transportation Officials

A.D. –Anno Domini

AIV− Aggregate Impact Value

ASTM – American Society for Testing and Materials

B.C. – Before Christ

CBR – California Bearing Ratio

DD – Dry Density

E.C. –Ethiopian Calendar

ERA – Ethiopia Road Authority

ESA– Equivalent standard Axle

GM – Grading Modules

GPS – Global Position System

LAA – Los Angeles Abrasion

MDD – Maximum Dry Density

m.a.s.l – Mean above sea level

N – Northing

NP – Non-Plastic

NNE – North-North East

OMC – Optimum Moisture Content

PDM – Pavement Design Manual

PDRM −Pavement Design and Rehabilitation Manual

PI – Plastic Index

PP – Plasticity Product

SAI – Strength Activity Index

SSW – South-South West

TFV – Ten Percent Fines Value

TRRL – Transport and Road Research Laboratory

UCS – Unconfined Compressive Strength

UK – United Kingdom

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ABSTRACT

This study has been carried out in order to determine the optimum blending proportion of cinder gravel with volcanic ash and lime. In this regard, an investigation into the improvement of the natural cinder gravel by stabilization technique was conducted using samples collected from Metehara area.

In the first phase of investigation, mechanical stabilization was carried out at various proportions of volcanic ash blended with cinder gravel. Compaction method was used in the determination of the optimum amount of volcanic ash that makes up the deficiency of fine particles. In this method, the optimum amount of volcanic ash has been found to be 22% by weight. CBR values of soaked and unsoaked conditions were determined for cinder gravel stabilized mechanically with the indicated optimum amount of volcanic ash at 3,7,14 and 28 days of wrapping the sample in the mold with a polyethylene sheet. The test results showed that the CBR values for all of these days of wrapping the sample in the mold were more than 80% which is the requirement of ERA specification for road base while that of the cinder gravel alone was found to be 72%.However, the CBR values were, more or less, not affected by the duration of wrapping the sample in the mold. In this phase, the CBR value for the soaked condition has been found to be less than that of the un soaked condition as expected.

In the second phase of investigation, mechanical as well as lime stabilization was carried out simultaneously in which 20% of volcanic ash and 2% of lime were blended with cinder gravel in order to find out how the CBR would be changed. Soaked and un soaked conditions at 3,7,14 and 28 days of wrapping and keeping the sample in the mold indicated that the CBR values in this phase were larger than the corresponding values obtained by blending cinder with volcanic ash only. The CBR value in this scenario was observed to increase with duration of wrapping and keeping the sample in the mold unlike the first phase. Furthermore, the CBR value after four days of soaking was found to be greater than that of the un soaked condition for a given duration of wrapping the sample in the mold.

Although laboratory investigation in the present study has confirmed that the stabilized cinder gravel can be used as base course material, field performance of this stabilized material should be investigated on a pilot project.

CHAPTER 1

INTRODUCTION

1.1General

In civil engineering practice road construction is a major concern. It is an undertaking that is important to the socio economic development of any country. This is because it enables quick and easy movement of people from place to place whereby social interaction is enhanced in addition to transportation of goods and delivery of services [15].

It is in this context that road engineers are involved in trying to obtain materials that are readily available, less costly; and in cases that such materials are not readily available, to devise ways of improving deficiencies of the available materials. Improvement of such materials should be aimed at achieving high qualities in terms of strength, workability and durability at minimum construction costs as well as maintenance costs [15].

Natural gravels are abundant source of road building materials but do not always meet the quality requirements for bases and are frequently rejected in favor of expensive alternatives such as crushed stone. However, these alternatives are often not locally available and hence further cost is incurred as a result of transportation of large quantities in heavy vehicles. If, on the other hand, the properties of locally available materials such as natural cinder gravels can be improved by stabilization techniques, then large financial and environmental benefits can be achieved [12].

1.2 Back Ground of the problem

The quality of the base course material with respect to the pertinent engineering properties is very important in road infrastructure projects. If the required base course material cannot be found at a reasonable distance from the construction site, then very high prices have to be paid in road construction process which causes significant delays or cost increases. In such cases, working with locally available low-quality materials affects the road quality and durability over time and results in very significant losses.

Improving the quality of materials is very important for road construction works in order to ensure that projects meet the necessary cost and quality criteria. If the material found close to the construction site does not meet the specifications, the materials may be improved with suitable chemicals such as lime, cement and fly ash, etc. All the additives may be advantageous to certain type of materials [22].

In many parts of Ethiopia, there is widely distributed cinder gravel. However, this material has the problem of compaction due to its light weight, its rough circular surface and its high porosity. In some parts of Ethiopia, there is a scarcity of a good base course material such as natural gravel, crushed rock or recycled pavement material. Since the distribution of these base course materials is limited only in some parts of the country, using these materials everywhere incurs transportation cost and is time consuming. In those areas where cinder gravels are available, they are used by mixing with fine-grained soils without having any research based output and guideline regarding their proportion. [22]

1.3 Objective of the Study

1.3.1 General objective

- Determination of an acceptable blending proportion of the cinder gravel with volcanic ash and lime to be used as base course materials.

1.3.2 Specific objectives

- Characterization of Cinder gravels.
- Improvement of the compaction property of cinder gravel.
- Determination of the optimum amount of volcanic ash to be used as a stabilizer.
- Investigation of the improvement of gradation as well as CBR as a result of stabilization with volcanic ash and lime.

1.4 Methodology

In order to achieve the objectives of the thesis work, the following methodologies have been employed.

- Literature review.
- Field work in which sampling of cinder gravels and volcanic ash was performed.
- Laboratory testing followed by analysis whereby the engineering properties are determined.

A series of tests carried out include:

- Gradation test.
- Modified Proctor test.
- Atterberg limit test.
- Absorption and Specific gravity test.
- California Bearing Ratio test (CBR) test.
- Los Angeles Abrasion (LAA) test.
- Aggregate Crushing Value (ACV) test.
- Ten Percent Fine Value (TFV) test.
- Aggregate Impact Value (AIV) test.
- Pozzolanicity test.

1.5 Organization of the thesis

This thesis has been organized and presented in five Chapters. In the first Chapter a general description on the use of stabilized locally available natural gravels has been made. Furthermore; the back ground, the objective and methodology have also been discussed in this introductory part of the thesis. The second Chapter deals with the review of published literature on stabilization of naturally occurring gravels with particular emphasis on cinder gravels and volcanic ash. The third Chapter presents a description of the study area as well as the proposed material source. The laboratory test results and related discussions have been included in Chapter four. Under chapter five, conclusions of the thesis work followed by recommendations have been presented. Following Chapter five, reference materials used in the thesis work have been listed properly. The thesis ends with appendices which contain detailed experimental results of laboratory investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 The Location and Engineering Properties of Volcanic Cinder Gravels in Ethiopia.

2.1.1 Introduction

Volcanic cinder gravels which, although widespread in Ethiopia, had only occasionally been used for road construction, even though their use would substantially reduce road construction costs in many instances. The reason for its limited use was mainly because these gravels tend to be deficient in fine material and do not conform to the generally accepted grading specifications. In addition, they were reportedly difficult to compact [6].

As part of a joint research project undertaken by the Ethiopian Road Authority and the United Kingdom Transport and Road Research Laboratory, research has been carried out to provide information on the occurrence and properties of the volcanic cinders with the object of encouraging their wider use in future road construction [6].

This joint research project was commenced in Ethiopia by the Ethiopian Road Authority (ERA) and Transport and Road Research Laboratory (TRRL, UK) in 1975. One of the objectives of the research program was to establish guidelines to enable highway engineers to make full use of locally-available materials for road construction. This was considered to be particularly relevant in Ethiopia and an extensive program of rural road construction is in progress which is expected to continue for a number of years [6, 7].

In a joint research project between the Ethiopian Roads Authority and Transport and Road Research Laboratory (UK), a preliminary investigation on the location and engineering properties and a full-scale road experiment of cinder gravels were undertaken. The preliminary study [6] involved field surveys, laboratory investigation, and investigation of a cinder gravel road. According to the study, the two most important factors that affect the engineering behavior of cinder gravels are grading and the strength of the gravel particles. The particle size analysis carried out on 53 samples collected during the field survey indicated that the grading of natural cinder gravel is deficient in fine particles and do not satisfy the recommended grading limits for base course. The aggregate impact test carried out on 23 samples using a modified procedure for weak aggregates resulted values ranging from 46 to 177 which indicate that the cinder gravel is weak. The main findings from the investigation include:

- The importance of sampling below the weathered zone which can extend to a depth of two meters to obtain representative materials;
- Due to the weak nature of cinder particles, compaction causes the breakdown of particles which improves both grading and strength properties and this is further confirmed on the gravel road study;
- Changes in moisture content do not affect the properties of cinder gravels; and
- The addition of locally available clayey soil to make up for the deficiency of fine materials improves the compactability and stability of cinder gravels.

The full-scale road experiment [7] was comprised of 20 different sections out of which six sections were gravel surfaced and the remaining 14 sections were bitumen surfaced. The results of the gravel surfaced experimental sections showed that improved performance can be obtained by mechanically stabilizing cinder with plastic fines. The findings from the surface dressed sections showed satisfactory performance of cinder gravels whether untreated or mechanically stabilized for use in base course for up to 440,000 ESA when designed according to Road Note 31. The road-mix surfacing was, however, not found to be a satisfactory method of providing a bituminous surface for cinder gravel.

The results of the joint research work should be further taken up to investigate the potential use of these abundantly available natural gravels in base course for heavily trafficked roads by improving their engineering properties. Both pavement design manuals used in Ethiopia, the Ethiopian Roads Authority Pavement Design Manual (ERA-PDM)[9]and the Addis Ababa City Roads Authority Pavement Design and Rehabilitation Manual (AACRA-PDRM),[1] recommend the use of stabilized locally available natural gravels when the cost of importing quality aggregate is expensive and hauling distance is large.[12]

2.1.2 Definition of Volcanic Cinders

Volcanic cinders are pyroclastic materials associated with recent volcanic activity. They occur in characteristically straight sided cone-shaped hills which frequently have large concave depressions in their tops or sides where mixtures of solids and gases were released during the formation of the cone [6]. Cinders vary in color often within the same cone and may be red, brown, grey or black. The cinder particles also vary in size from large irregularly shaped lumps

50 cm in size, to sand and silt sizes. In some cones, however, particles may be more uniform with the largest size not exceeding 3 cm in diameter. Other characteristic features of cinders are their light weight, their rough vesicular surface and their high porosity. Usually they are weak enough to be crushed under the heel [6].

An advantage of cinders as a road construction material is the relative ease with which they can be dug from the quarry; a mechanical shovel or hand tools are usually adequate for their extraction although occasionally a bulldozer may be required to open up a working face [6].

2.1.3 Definition of Pumice

Pumice is amorphous foam produced during volcanic eruptions. It is constituted mostly of silica and alumina in relative amounts varying according to the geological area of origin, and also includes other chemical species, such as different oxides and water. Pumice is a volcanic rock of which porous structure is formed by dissolved gases precipitated during the cooling as the lava hurtles through the air. The connectivity of the pore structure may range from completely closed to completely open.

Pumice is formed during explosive volcanic eruptions when liquid lava is shot into the air as a froth containing masses of gas bubbles. As the lava solidifies, the bubbles are frozen into the rock. Any type of igneous rock—andesite, basalt, dacite or rhyolite—can form pumice given suitable eruptive conditions. When larger amounts of gas are present, the result is a finer-grained variety of pumice known as pumicite. It is considered a glass because it has no crystal structure. Pumice varies in density according to the thickness of the solid material between the bubbles; many samples float in water. The cellular structure of pumice is created by the formation of bubbles or air voids when gases contained in the molten lava flowing from volcanoes become trapped on cooling. The cells are elongated and parallel to one and another and are sometimes interconnected. They may be small and big size [14].

2.1.4 General Location of Cinder Gravel and Volcanic Ash (Pumice) in Ethiopia.

A survey is made under TRRL and ERA which included the examination of aerial photographs and photo-mosaics and the preparation of a map showing the distribution of cinder deposits throughout Ethiopia [6].

Field visits in connection with the survey were all carried out within a distance of 150 km from Addis Ababa. They were concentrated in areas near to Bishoftu, Adama, Ziway, Butajira and Ambo (see Figure 2.1).

Cinder cones rarely support any vegetation other than grasses and examination of the exposed profiles showed that the depth of soil cover was not more than a few centimeters. A weathered cinder zone, however, usually extends down to a depth of about two meters. In some cone deposits of calcium carbonate coats the cinder gravels; this does not persist throughout the cones but in thin white bands parallel to and usually close to the surface [6].

The distinctive shape of the cinder cones made them easily identifiable on aerial photographs and aerial photographs were used both to plan the survey and subsequently in the field work [6].

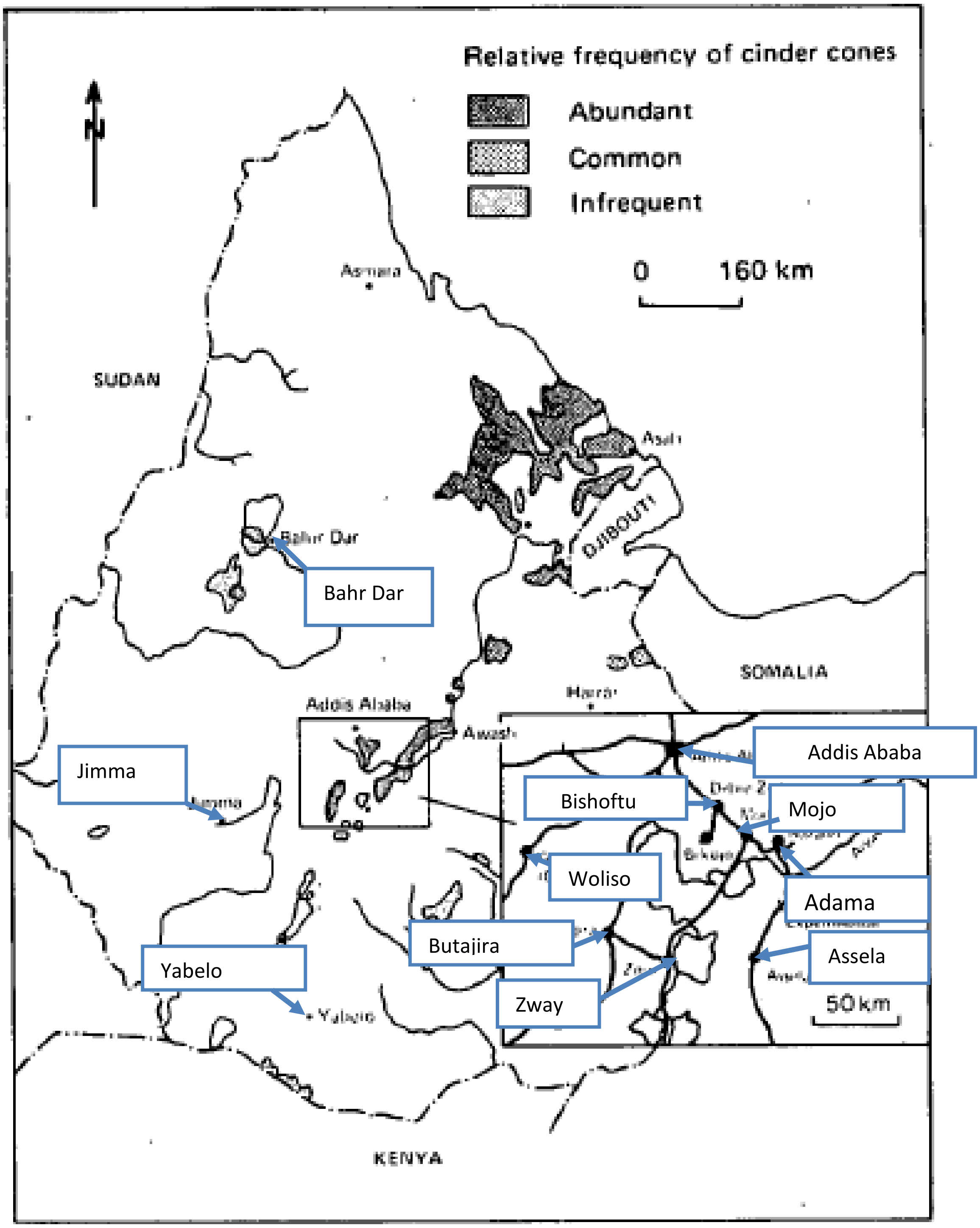

Figure 2.1: Cinder cone distribution in Ethiopia, survey area enlarged [6]

The examination of air-photos and relevant printed materials was extended to cover the whole of Ethiopia and from these and a study of areas of recent (Quaternary) volcanic action on the geological map, a preliminary map was compiled showing the occurrence of cones throughout the country (see Figure 2.1).Cinder gravels were mostly concentrated in the Rift Valley that bisects the country in a SSW−NNE direction; an indication of their frequency for each of the areas that were identified has been given in Figure 2.1. [6]

As pumice is also a volcanic ash, it is commonly found within the rift valley areas alongside the location of cinder gravels. The current study has realized that it is available within the areas of Metehara. Thus, is not surprising to find a hill of pumice at a distance of about one kilometer from cinder cones which is the case observed in this study area.

2.2 Soil Survey for Highway Purposes.

Soil surveys are made in connection with highway location, design and construction. Many sources of information concerning soils generally are available for the area in which a highway project is to be carried out. These sources include geological and topographic maps and reports, agricultural soil maps and reports, aerial photographs, and previous soil survey in the area.

Information of such source is of importance in two general ways. First, a study of this information will aid in sekeeping sample inside CBR mold a broad understanding of soil conditions and associated engineering problems that may be encountered. Second, such information is of great value in planning, conducting and interpreting the results of detailed soil survey that are necessary for design and construction. Modern techniques emphasize the use of all available information about a given area in order to minimize the amount of detailed field and laboratory work necessary [17].

2.2.1 Pumice as a Pozzolanic Material and the Use of Pozzolan in Soil Improvement.

Pumicites are volcanic ashes which are the fine grained variety of pumices. They are amongst the sources from which natural pozzolan are derived.

Pozzolan is an effective agent for chemical and/or mechanical stabilization of soils. The properties of soil which can be changed by using Pozzolan are density, water content, plasticity, strength and compressibility performance of soils, hydraulic conductivity, and so on. Typical applications include: soil stabilization, soil drying, and control of shrink-swell. Pozzolan provides the following advantages when used to improve soil conditions: [20]

- Eliminates the need for expensive borrow materials by stabilizing locally available materials.
- Expedites construction by improving excessively wet or unstable sub grade.
- By improving sub grade conditions, promotes cost savings through reduction in the required pavement thickness.

2.2.2 Definition of Pozzolana.

According to American Concrete Institute (ACI) pozzolan 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 moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [18].”

2.2.3 A Review of Pozzolans in the Construction Industry.

Pozzolans have been in use for many centuries by the Greeks and the Romans. The Greeks started to use pozzolans after noticing that certain types of finely ground volcanic deposits when mixed with lime and sand were highly resistant to the action of water. They obtained their best pozzolans from around the Bay of Naples and particularly in a town called Pozzoli. Consequently these early materials were known as pozzolanas, a word that is now used as the generic term for all such materials [20].

Small scale use of pozzolans has continued through the centuries with widespread use triggered when the economic benefit of using these otherwise waste products was quantified. Their popularity further increased when it was realized that pozzolanic cement has a smaller heat evolution than ordinary Portland cement and was therefore ideal for the manufacture of mass concrete. This resulted in a much slower temperature rise and benefited pavement construction by providing a longer period of time over which to cut the slab joints. Nowadays pozzolans are commonly utilized when the hydration properties of conventional cements may not be appropriate [20].

Natural pozzolans are derived from diatomaceous earth, opaline cherts and shales, tuffs and volcanic ashes or pumicites. The advantages of using natural pozzolans stems from the potentially huge cost savings which can be made by replacing cement or lime in the mix with these low cost alternatives. However, natural pozzolans tend to have variable source properties and may prove too expensive to process. The pozzolanic activity of these materials is dependent on the physical structure of the particles and consequently their potential for reacting and forming cementitious compounds [20].

2.2.4 Engineering behaviour of pozzolans

A thorough investigation of chemical, mineralogical composition, morphology, amount of glassy phase, fineness, and the mechanical properties are required in order to identify pozzolan. Pozzolans are also highly dependent on external factors such as the additional admixtures and thermal treatments they are exposed to. In general, the reactivity of pozzolans with lime or cement is due to the presence of high silicon oxide and aluminium oxide content with a glassy / amorphous structure within them. These properties occur naturally as a result of highly explosive eruptions whereby the molten magma is spewed up into the atmosphere and crystallized into these mineral constituents [20].

The presence of zeolitic compounds that increase pozzolanic potential in volcanic ash makes it slightly different from other natural pozzolans. These zeolitic compounds (such as herchellite, phillipsite, chabacite and analcite) are formed through chemical alteration of the original matter by superheated steam and carbon dioxide (below the earth’s crust) into more chemically reactive matter. [20].

2.2.5 Historical Background of Pozzolan–Lime Mixtures

Long before the invention of Portland cement in 1824, mortars and concretes composed of mixtures and fillers and raw or heat-treated lime were used for construction throughout the world. Lime and limestone are among the oldest materials used by mankind for construction purposes. Structures built of limestone include the pyramids of Egypt. [18].

The mixture of lime and natural pozzolan, a diatomaceous earth from the Persian Gulf oldest was an oldest example of hydraulic binder, dating from 5000-4000 B.C. The next oldest reported use was in the Mediterranean region. The pozzolan was volcanic ash produced from two volcanic eruptions: one, sometime between 1600 and 1500 B.C. on the Aegean Island of Thera, now called Santorin, Greece; the other in 79 A.D. at Mt. Vesuvius on the bay of Naples, Italy. Both are volcanic ashes or pumicites consisting of almost 80% volcanic glass (pumice and obsidian) [18].

Greeks and the Romans were successful in producing cements of superior durability, because "neither waves could break, nor water dissolve" the concrete. In describing the building techniques of masonry construction, he indicated that the Romans developed superior practices of their own from the techniques of the Etruscans and the Greeks. The Greek masons discovered pozzolan-lime mixtures sometime between 700-600 B.C. and later passed their use of concrete along to the Romans in about 150 B.C. During the 600 years of Roman domination, the Romans discovered and developed a variety of pozzolans throughout their empire [18].

An ancient water-storage tank having a capacity of 600 m^3 (785yd^3) was found during archaeological excavations in the 1970s at the ancient city of Camiros on the Island of Rhodes, Greece. It was used until 300 B.C after being built in about 600 B.C.when a new hydraulic system with an underground water tank was constructed. For almost three millennia this water tank has remained in very good condition [18].

Investigation of the materials used for this structure revealed that the concrete blocks and mortar used were made out of a mixture of lime, Santorin earth, fine sand (<2 mm [<0.08 in.]) and siliceous aggregates with sizes ranging between 2 and 20 mm (0.08 and 0.79 in.). The fresh concrete was placed into wooden sidewall molds. The compressive strength of a 20 mm (0.79 in.) cubic specimen was found to be 12 MPa (1740 psi). Mortars like these were known to have a composition of six parts by volume of Santorin earth, two parts by volume of lime, and one part by volume of fine sand. These mortars were used as the first hydraulic cements in aqueducts, bridges, sewers, and structures of all kinds. Some of these structures are still standing along the coasts of Italy, Greece, France, Spain, and in harbors of the Mediterranean Sea. The Greeks and Romans built many such structures over 2000 years ago. Examples of such structures are the Roman aqueducts as well as more recent structures such as the Suez Canal in Egypt (built in 1860), the Corinthian Canal (built in 1880), the sea walls and marine structures in the islands of the Aegean Sea, in Syros, Piraeus,Nauplion, and other cities, and the harbors of Alexandria in Egypt, Fiume, Pola Spalato, Zara on the Adriatic Sea, and Constanta (Romania) on the Black Sea. All of these structures provide evidence of the durability of pozzolan-lime mortar under conditions of mild weathering exposure. Roman monuments in many parts of Europe are in use today, standing as a tribute to the performance of lime-pozzola mortars [18].

2.3 Stabilized Pavement Material

2.3.1 General

Natural soil is both a complex and variable material. Yet, because of its universal availability and its low cost of winning, it offers great opportunities for skillful use as an engineering material. Thus, natural soil that does not meet the requirements of pavement material can be made useful through stabilization technique. The term soil stabilization may be defined as the alteration of the properties of an existing soil either by blending (mixing) two or more material and improving particle size distribution or by the use of stabilizing additive to meet the specified engineering properties.

Quite often soils are stabilized for construction in most parts of the world for the following one or more objectives:

- To improve the strength (stability and bearing capacity) for subgrade, sub base, base, and low-cost road surfaces,
- To improve the volume stability (undesirable properties such as swelling, shrinkage, high plasticity characteristics, and difficulty in compaction, etc. caused by change in moisture are improved).
- To improve durability (increase the resistance to erosion, weathering or traffic) and
- To improve high permeability, poor workability, dust nuisance, frost susceptibility, etc.

Due to their mineralogical composition, soils may be rather complex material. Stabilization is therefore not a straight forward application of a given stabilizing agent, a number of aspects should be taken into account in the selection of the proper stabilization technique the factors that should be consider include physical and chemical composition of the soil to be stabilized, availability and economic feasibility of stabilizing agent, ease of application, site constraint climate, keeping sample inside CBR mold time, and safety such factors should be taken into account in order to select the proper type of stabilization. Basically four techniques of soil stabilization are commonly practiced in pavement construction [11].These are:

- Mechanical Stabilization,
- Cement Stabilization,
- Lime Stabilization, and
- Bitumen Stabilization.

2.3.2 Mechanical Stabilization

A method by which a soil or gravel is mixed with the original soil in order to improve the grading and mechanical characteristics of the soil. Typical material used for mechanical stabilization include river deposited sand, natural gravel, silt sand, sand clays, silt clay, crushed run quarry products and waste quarry products volcanic cinders and scoria, poorly graded laterites and beach sand, etc. The principal properties affecting the stability of compacted base or sub base material are internal friction and cohesion. Internal friction is chiefly dependent on the characteristics of the coarser soil particles, i.e. gravel, sand and silt sizes. The cohesion, shrinkage, swelling and compressibility are mainly associated with the quantity and nature of the clay friction as indicated by plastic properties. Preliminary mix design of mechanical stabilization is based on particle size distribution and plastic properties. It is desirable also the strength test (CBR, etc.) be carried out to verify that the required improvement has been achieved. Stabilized material may be assessed by strength test suitable for this purpose at density and moisture condition prevailing in the pavement during the service life. One of the most commonly used strength test in the laboratory CBR test [11].

2.3.3 Cement Stabilization

Cement is an effective stabilizing agent applicable to a wide range of soils and situation. It has two important effects on soil behaviors:

- It reduces the moisture susceptibility of soil since cement binds the particles greatly and reduces moisture induced volume change (shrinkage and swell) and it also improves strength stability under variable moisture, and
- It develops inter-particle bond in granular materials which results in increased tensile strength and elastic modulus.

Soil properties progressively change with increasing cement content. For practical reason, two categories of cement stabilized material have been identified [11].

Cement modified material: – Cement is used to reduce plasticity, volume change, etc. and the inter-particle bonds are not significantly developed. Such material is evaluated in the same manner as conventional unbound flexible pavement materials [11].

Cement bound material: – Cement is used to sufficiently enhance modulus and tensile strength. Cement bound materials have practical application in stiffening the pavement. There are no established criteria to distinguish between modified and bound materials, but an arbitrary limit of indirect tensile strength of 80 kN or unconfined compressive strength of 800 kPa after seven days moist keeping sample inside CBR mold has been suggested [11].

2.3.4 Lime Stabilization

Stabilization of soil with hydrated lime is broadly similar to cement stabilization in that similar criteria and testing and construction techniques are employed. It differs, however, in two important aspects: first it is applicable to far heavier clayey soils, and is less suitable for granular material, and second, it is used more widely as a construction expedient. That is, to prepare a soil for further treatment or to render a sufficient improvement to support construction traffic. Lime is a broad term which is used to describe calcium oxide (CaO) – quick lime, Calcium hydroxide ($Ca\ (OH)_2$), hydrated lime, and calcium carbonate ($CaCO_3$). Lime is an effective stabilizing agent for clay material to improve both workability & strength. Lime is not effective with cohesion less or low cohesion materials without the addition of secondary (pozzolanic-fine materials which react with lime to form cementitious compounds) additives. The strength of lime stabilized materials is dependent on the amount of lime, the keeping sample inside CBR mold time, keeping sample inside CBR mold temperature and compaction. Lime has more tendencies to produce granular material and consequently their major applications are in the modification of clays, plastic sands, and plastic gravels [11].

The change in plasticity is accompanied by an immediate change in strength of the soil as measured by the CBR. Siliceous and aluminous materials in the soil react with lime to produce a gel of calcium silicates and aluminates. This gel cements the soil particles together in a manner similar to that of hydrated cement. Minerals in the soil that react with lime to produce a cementing compound are known as pozzolans. Lime-cementing action in a soil is usually a slow process; depending on the type of pozzolans, it takes considerably more time than required for hydration of Portland cement. This long term effect on strength, causing continuing strength improvements with time, often called pozzolanic reactions. The cementing action also depends on climatic conditions and a thorough compaction of the mixture. High keeping sample inside CBR mold temperatures have a positive effect on the pozzolanic reactions. Temperatures lower than 13 and 16^0C retard reaction; from this point of view it is obvious that lime stabilization is especially popular in tropical countries [11].

2.3.5 Bituminous Stabilization.

Bituminous stabilization is used with non- cohesive granular materials where the bitumen adds cohesive strength; and with cohesive materials where the bitumen “water proofs” the soil thus reducing loss of strength with increase in moisture content. Both effects take place partly from the formation of bitumen film around the soil particle which bounds them together and prevents the absorption of water and partly from simple blocking of the pores, preventing water from entering the soil mass. Because more care is necessary in bituminous stabilization to achieve satisfactory mixing, its use has not been as wide spread as cement and lime stabilizations [11].

2.4 Previous Works on Cinder Gravels in Road Construction

2.4.1 Experimental use of cinder gravels for roads in Ethiopia

As part of the joint research project between ERA and TRRL, a full scale experiment has been carried out in Ethiopia to examine the performance of volcanic cinder gravels as surfacing material for unpaved roads and as road base under bituminous surfaced roads [5]. Compaction trials were carried out to determine the type of equipment to be used and an experimental road stretch comprising 20 different sections were constructed. Six sections were left unsurfaced and were monitored for 28 months during which they carried approximately 140,000 vehicles. A bitumen surface was provided for the remaining 14 sections and these carried 150-200 vehicles per day for 7 1/2 years giving a total of 440,000 ESA in one direction [7].

Monitoring was carried out by taking quantitative measurements of the performance of the road pavement throughout this period. As a result of the study, recommendations were made for the use of cinders in both paved and unpaved roads. For unpaved roads, recommendations are made for a particle size distribution which provides a road surface that is resistant to corrugations [7].

Improved performance can be obtained by mechanically stabilizing cinders with plastic fines. For paved roads, it is concluded that the types of materials used in this experiment are all capable of carrying in excess of 400,000 ESA when sealed with a surface dressing and designed. Road mixed asphalt is not a suitable surfacing for cinder gravels. In addition to the cinders, other materials also performed satisfactorily including dry bound macadam, agglomerate and tuff. Besides it was recommended that cinders are easier to compact when they are mechanically stabilized with 10 per cent of volcanic ash soil [7].

Preliminary investigation of cinder gravels by TRRL

The main conclusions from the preliminary investigation of cinder gravels by TRRL which covered a field survey, a laboratory study and an examination of a cinder gravel road, are given below [6]:-

(i) Cinder gravels are more widespread in Ethiopia than was originally believed; this showed the importance of using aerial photographs in survey work and enabled a preparation preliminary map which shows the distribution of cinder cones.

(ii) In order to obtain representative material from a cinder cone, it is important that samples are taken from below the weathered zone, which can extend to a depth of two meters.

(iii) Although 'as dug' cinder gravels do not meet the recommended grading requirements for road base materials, the laboratory investigation revealed that, because of the weak nature of the aggregate particles, breakdown under compaction occurred with an improvement in both grading and strength properties.

(iv) In the laboratory investigation, the cinder gravels were not affected by changes in moisture and even complete immersion in water only reduced their strength slightly.

(v) The addition of locally available plastic volcanic ash soil, to make up for the deficiency of fine material in the grading, improved the mechanical stability of cinder gravels and indicated that this could be a valuable construction practice. However, unlike the natural cinders the mixed materials lost some of their strength when they were saturated with water.

(vi)The gravel road study confirmed that an improvement in the grading and the strength of cinder gravels occurred under normal road conditions even when trafficking was used as the means of compaction.

The results from the preliminary investigations indicated that cinders could provide useful road construction materials especially for gravel roads. However, it was necessary to carry out further work under known conditions of traffic and climate in bituminous surfaced roads, as well as in gravel roads, before limits could be recommended for their various uses. It was therefore decided to construct pilot scale compaction trials and then a full-scale road experiment to examine these aspects further.

2.4.2 Stabilizing cinder gravels for heavily trafficked base course.

Investigation into the improvement of natural gravels with the use of stabilization techniques was made using samples collected from quarry sites near Alemgena and Lake Chamo [12].

Mechanical and cement stabilization were investigated in two subsequent phases. In the first phase, optimum amount of fine soils that makes up the deficiency of the fine particles of natural cinder gravels was found to be 12%. In the second phase, natural cinder gravel sample without, and with 12% fine soils were stabilized with 3, 5, 7, and 10% of cement by mass. The result of investigation indicated that the optimum amount of cement required to achieve the minimum UCS of 3.0 MPa as specified in ERA and AACRA pavement design standard for heavily trafficked base course without adding fine soil is found to be 7% cement. However, this high cement requirement was reduced to 5% cement which is practical value by mechanically stabilizing cinder gravel with 12% of fine soils before cement stabilization. Nevertheless, it was recommends that the performance of cement stabilized cinder gravel should be investigated in a full-scale road experiment against cracking due to stresses induced by thermal, shrinkage and traffic [12].

2.4.3 Stabilization of cinder by means of bitumen or cement.

Given the fact that cinder is a troublesome material, Efrem [8] conducted investigations to determine whether or not the characteristics could be enhanced by stabilizing cinder with foam + 1% cement or with cement [8]. The cinder was retrieved from the Addis Ababa – Awash and Nazareth – Assela roads.

Based on this study [8], it was suggested that in general cinder is not suited to act as a surfacing material for un surfaced roads. This is because it lacks fines that act as a binder. Nevertheless it is used in Ethiopia as a surfacing material but those cinder roads are affected by corrugation and rutting in the track wheel as well as a high gravel loss.

Cinder is not considered to be suitable as a base course material because of its lack of crushing resistance [8]. In the late 1970’s, experiments were done in Ethiopia to use cinder as a base course covered with a double surface dressing or a 50 mm thick asphalt layer. It was shown that compaction with a vibratory roller together with a rubber tyre roller produced the best compaction results. The test sections carried 80 – 100 commercial vehicles per day and were designed to carry 0.64 million 80 kN equivalent single axles for a period of 15 years. After 2½ years in service, the test sections were still in good condition although significant crushing of the coarse particles was observed. In late 1999, however the sections were severely damaged by fatigue cracking and for some part the wearing course was totally worn out. The adjacent sections constructed with a conventional crushed stone base were still in a good condition except for some local potholes [8].

It has been concluded that one has to be careful with regard to using cinder as surfacing or as base material. In order to be able to use it as a base, modification of the cinder by means of foam bitumen or cement might be a feasible option [8].

2.4.4 Blending of cinder gravels with fine grained soil to be used as sub base material.

In road construction, the use of locally available materials should be made as much as possible. However, when appropriate material cannot be found in areas close to the construction site, very high prices have to be paid with significant time delays and cost increases [22].

An investigation has been made on the performance of mechanically stabilized natural cinder gravels of Butajira area to be used as road sub-base material. To achieve the Ethiopia Road Authority manual specification, the cinder gravel was blended with some trail proportion of 0, 5, 10, 15, 20, and 25 % of fine-grained soil by mass and different tests including grain size distribution, Atterberg Limit, compaction, CBR, LAA, absorption and linear shrinkage are conducted in the laboratory [22].

Based on the laboratory test results it is shown that, from both MDD- percent of fine-grained soil curve and CBR-percent of fine-grained soil curve, the optimum amount of fine-grained soil required in order to improve its properties is 19 % by mass proportion [22].

CHAPTER 3

GENERAL DESCRIPTION OF THE STUDY AREA

3.1 General Description of the Study Area.

Metehara being the main town of Fentale Woreda is located at a distance of about 196 km from Addis Ababa along the route from Addis Ababa to Djibouti which is one of the most important road links in Ethiopia. The latitude and longitude of Metehara are 08°54′N and 39°55′E respectively while the altitude is 947m above sea level [13].

As Metehara area is found within a region where volcanic eruption had taken place, cone shaped volcanic hills are seen sporadically within a radius of about 50-60 km from Metehara Town particularly alongside the route from Wolenchiti to Metehara. Wolenchiti is a Town which is found at a distance of 122 km from Addis Ababa. These volcanic hills have cinder deposits whose color varies from brownish red to black; and also have concave depressions on their tops or sides where mixtures of solids and gases were released during the formation of the cone.

The volcanic hill of cinder gravel from which samples have been taken for the present study is about 160 km from Addis Ababa with an offset of 50m to the left of the main route to Djibouti. This hill of cinder gravel is covered by shrubs as shown in Fig 3.1.

There is a typical cinder cone adjacent to the site of sampling as shown in Fig 3.2. This cone shaped hill is known by the people living in the vicinity as “Genfo Terara” due to the concave depression at the top.

The volcanic ash which has been used to stabilize the cinder gravel is shown in Fig 3.3. It is located at a distance of about 161km from Addis Ababa with an offset of 100 m to the left. The sampling sites of the volcanic ash (pumice) and the cinder gravel are almost 1km far apart.

Figure 3.1: Material site for black cinder gravel.

Figure3.: Typical cinder cone (Cone shaped hill where cinder gravel is deposited adjacent to the hill where sampling took place)

Figure 3.3: Material site for volcanic ash (pumice)

3.2 Overview of FentaleWoreda

Locational Setting and Population:-FentaleWoreda is located in Oromiya regional state of East Shoa zone. This Woreda is bounded by Afar National Regional State and Amhara National Regional State in the north, Afar National Regional State and Harerge Zone in the east ; Arsi Zone in the south; and by three Woredas of east Shoa Zone in the west. Currently this Woreda is divided into eighteen Kebeles (Peasant Associations). The total population and area of this woreda is about 58906 (31,143 is male and 27,763 is female) and 1339.64 km^2 (133963.66 hectares) respectively. This gives an average density of about 43.97 persons per sq. km. The average household size is 6 [19].

The economy of the woreda: -The economy of the Woreda is predominantly agricultural, based on animal husbandry. Husbandry is the mainstay for over 80 percent of the population in the Woreda. For the last several decades pastoralists and agro-pastoralist have been following traditional livestock husbandry. The Kereyu and Ittu tribes are the principal livestock owners of the Woreda. Other livestock owners include the town people, plantation laborers, the Argobba and Arsi- Oromos[14].

According to Rural and Agricultural Development Office of Fentale Woreda, currently the Woreda has 15,101.5- hectare of cultivated land (out of which about 11,000 hectare is under the State Farm), 22,809-hectare cultivable land, 11,397-hectare of pastureland, 457- hectare forest and bush and about 84,199.16- hectares are other land use and waste land. Major crops grown in the area are maize, sorghum and wheat [19].

Accessibility: -Accessibility of Fentale Woreda is limited. Metehara, the main town of the Woreda, is connected with Zeway, the capital city of east Shoa Zone, by all weather roads with the length of 200 km. The accessibility and mobility problems in the Woreda are immense creating severe constraints in carrying out rural development in the Woreda [19].

3.3 Climatic Condition around Metehara Area

The climatic condition of the country is classified into five temperature zones on the basis of temperature-altitude relationships [16].

Table 3.1: Climatic category with the corresponding altitude and mean annual temperature.

Climatic category	Altitude	Mean Annual Temperature
"Wirch" which is cold moist temperature	Above 3300 m. a.s.l	below 10ºC).
"Dega" which is cool to cold humid	2300–3300 m a.s.l.	10 to 15ºC
"Weina-Dega" which is warm to cool semi-humid	1500–2300 m a.s.l.	15 to 20ºC
"Kola" which is warm to hot semi-arid	500–1500 m a.s.l.	20 to 30ºC
"Berha" which is hot arid	below 500 m a.s.l.	30 to 40ºC

From the above classification, Metehara area is found within the "Kola" climatic zone as its altitude lies between 500 and 1500 m a.s.l.

Furthermore, the mean annual rain fall and temperature of the area are in the range of 410-820mm and 20-27^{o}C respectively while the humidity is 50% [19].

CHAPTER 4

LABORATORY TEST RESULTS AND DISCUSSIONS

4.1 General

Soil aggregates obtained from different sources vary considerably in their constitution as well as in their engineering properties. Laboratory tests are instrumental in determining the various engineering properties of soils from different sources so that their classification and grouping can be used in order to enhance planning, design and construction of roads [22].

Observations made during the field survey in relation to cinder gravel indicated that the two most important factors likely to affect the engineering behavior of this material were the grading and the strength of the gravel particles.

The aims of the laboratory investigation were to:

- characterize the cinder gravel(classification and strength),
- determine the optimum amount of locally available volcanic ash which is blended with cinder in order to make up for the deficiency of fine materials, and
- observe the improvement in CBR when 2% by weight of lime is blended with cinder and volcanic ash.

4.2 Laboratory Test Result for Unstabilized Cinder Gravel.

4.2.1Grain Size Distribution

This method is used primarily to determine the grading of materials proposed for use as aggregates or being used 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 [22].

A key property of aggregate used for highway bases and surfaces is distribution of particles sizes in the aggregate mix. The gradation of cinder gravel, that is, the blend of the particle sizes in the mix, affects the density, strength, and economy of the pavement structure.

Detailed procedures for performing a grain size analysis of coarse and fine aggregates are given in AASHTO Method T-27 [3].

The particle size distribution requirement depends on the nominal maximum particle size as shown in Table 4.1.

Table 4.1: Recommended particle size distributions according to ERA for natural gravels and weathered rocks for use as base course material (GB2, GB3) [10].

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve	
	Nominal maximum particle size	
	37.5mm	20mm
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	30 -50
0.425	10 – 25	12 – 27
0.075	5 – 15	5 – 15

When we refer to Table 4.1, two options of grain size distribution are presented depending on the nominal maximum particle size. In this study, grain size distribution test for the nominal maximum particle size of 37.5mm was carried out before and after compaction on the cinder gravel and the results are as shown in Fig 4.1 and Fig 4.2.

(The details are indicated in Appendix A).

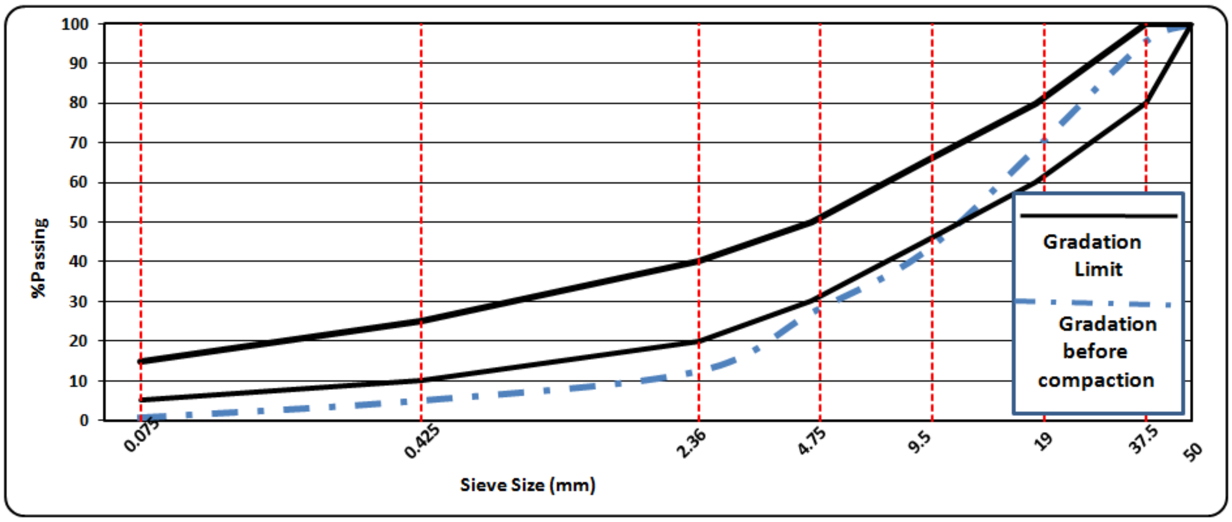

Figure 4.1: Gradation of natural cinder gravel before compaction.

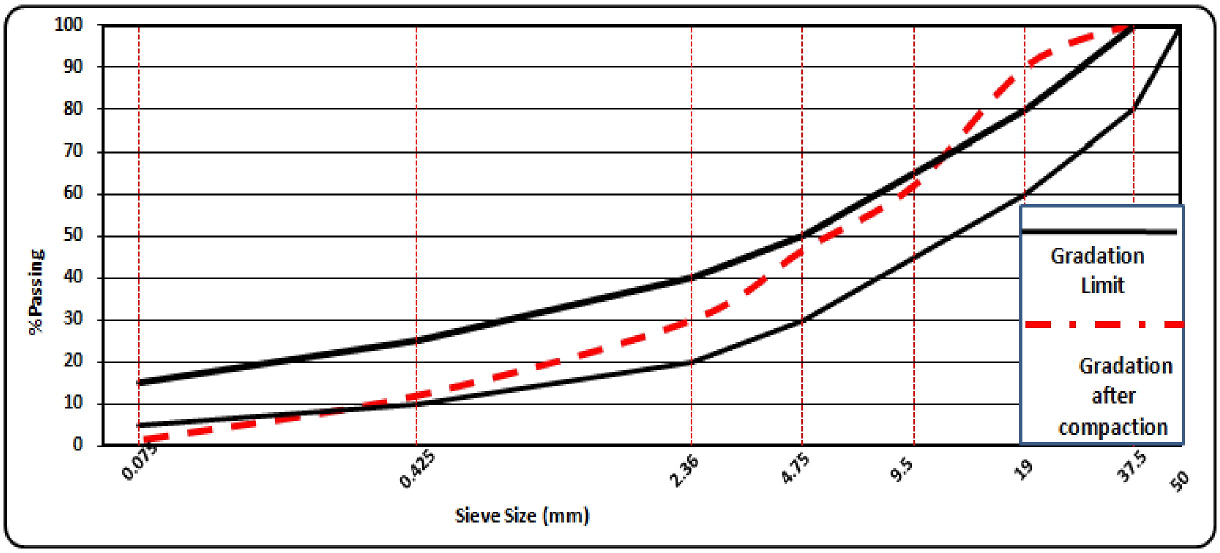

Figure 4.2: Gradation of natural cinder gravel after compaction.

Comparison of the gradation curves in the preceding figures clearly shows that the gradation of cinder gravel changes significantly upon compaction due to its weakness to resist crushing which is attributed to the porosity in the cinder.

The grading modulus values,as indicated in Tables A-3 and A-4 of AppendixA, have been found to be greater than two before and after compaction. The techincal specification of ERA requires that the minimum value of grading modulus should be two.Thus,the requirement has been satisfied.

4.2.3Atterberg Limits

Plasticity is an important factor in the performance of a gravel wearing course for the following reasons. Material with too low plasticity 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 [22].

Following T-90 standards, Laboratory test results showed that the cinder gravel is a non-plastic material both before and after compaction. This result satisfies the requirement of ERA technical specification in which the plasticity index shall not exceed 6 [10].

4.2.4 Absorption and specific gravity.

In order to know some of the special characteristics of cinder gravel, it is important to determine the of absorption potential and specific gravity of natural cinder gravel [22].

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 and other mixtures that are proportioned or analyzed on an absolute volume basis. The bulk specific gravity determined on the saturated surface-dry basis is used if the aggregates is wet, that is, if its absorption has been satisfied [3, 22].

Since cinder gravel is lightweight aggregate, the pores may or may not become essentially filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without most of the aggregates' absorption potential when AASHTO T-85 method is followed.

Therefore, AASHTO T-84 method which is used for the determination of absorption and specific gravity of grain size less than 4.75mm was followed instead of AASHTO T-85 [3, 22].

Accordingly, laboratory test results revealed that the absorption & specific gravity of the cinder gravels that pass sieve 4.75 mm are12.4 % and 2.3 respectively as indicated in Table A-1 of Appendix A. Therefore, the cinder gavel has high water absorption capacity because of its high porosity.

4.2.5 Moisture – Density relations By Modified Proctor Test.

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.

Accordingly, the test was carried out which produced that the maximum dry density (MDD) of the cinder gravel is 1.51g/cc at the optimum moisture content (OMC) of 8.3% as indicated in the curve shown below. The details of this test are found in the annex of this study (Appendix -A, Table A-8).

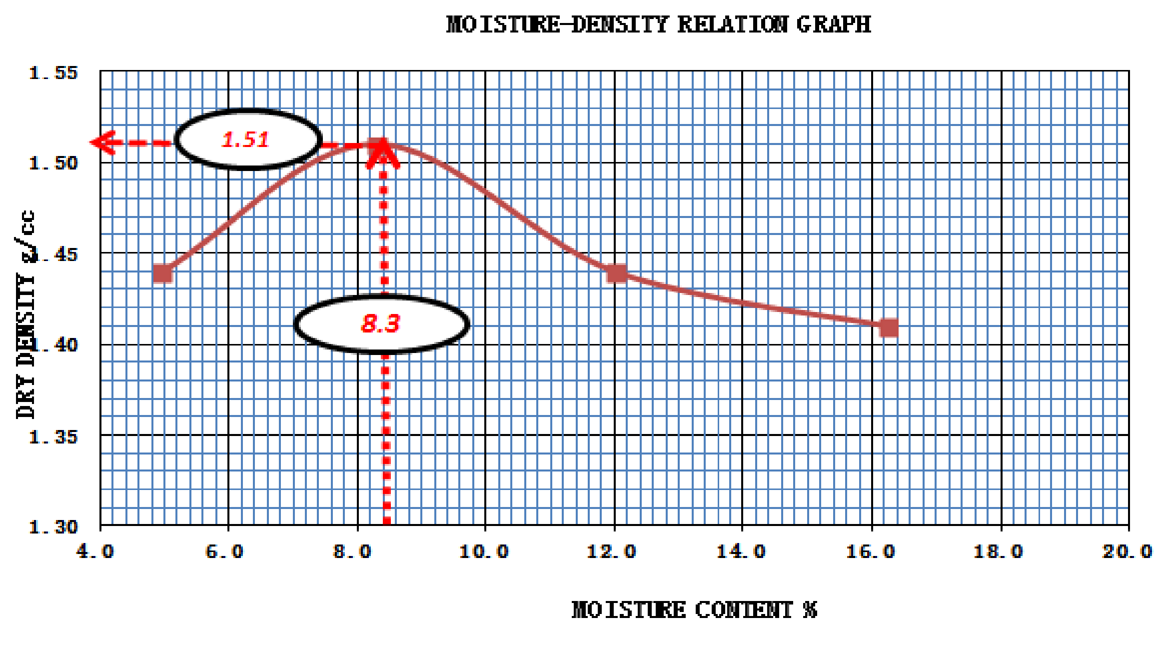

Figure 4.3: Moisture Density Relationship for cinder gravel only.

From the above graph, we can see that the MDD and OMC of natural cinder gravel are 1.51g/cc and 8.3% respectively.

4.2.6 California Bearing Ratio (CBR) Tests.

According to ERA manual, the minimum soaked California Bearing Ratio (CBR) for the base course material shall be 80% when determined in accordance with the requirements of AASHTO T-193. 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 AASHTO T-180 method D [2, 10].

Laboratory Test Result for Unstabilized Cinder Gravel

The details of the following test results are found in Table A-9 of Appendix A.

Table 4. 2: Determination of dry density before and after soaking.

Blows	Before Soaking		After Soaking	
	DD(g/cc)	Moisture (%)	DD(g/cc)	Moisture (%)
10	1.16	7.1	1.1	16.8
30	1.42	6.8	1.33	17.5
65	1.53	8.5	1.46	17.6

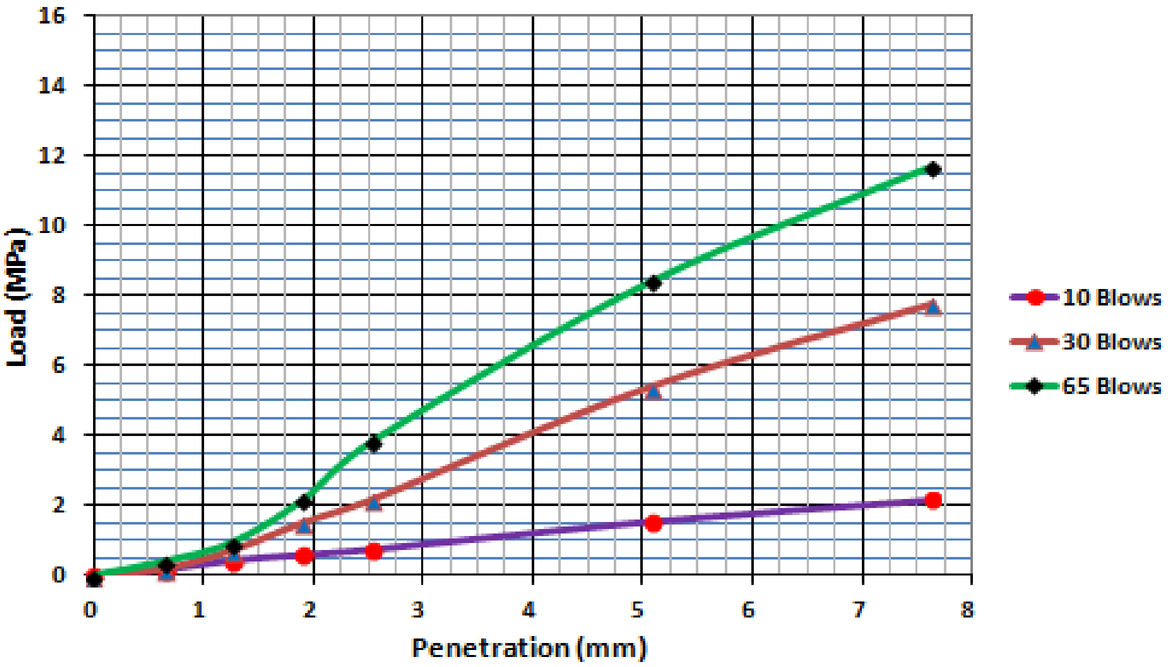

Figure 4.4: Load-penetration curves of unstabilized cinder gravel.

The curve having concave upward shape near the origin has been corrected in order to obtain the true stress-strain relationships by adjusting location of origin which is done by extending the straight line portion of the curve having concave downward until it intersect the abscissa.

Table 4.3: Determination of CBR and swell.

Blows	**Load(MPa)**		**CBR (%)**		**Swell (%)**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**	
10	0.74	1.54	10.67	14.88	0
30	1.81	3.91	26.18	37.85	0.03
65	6.4	10.5	92.75	91.88	0.04

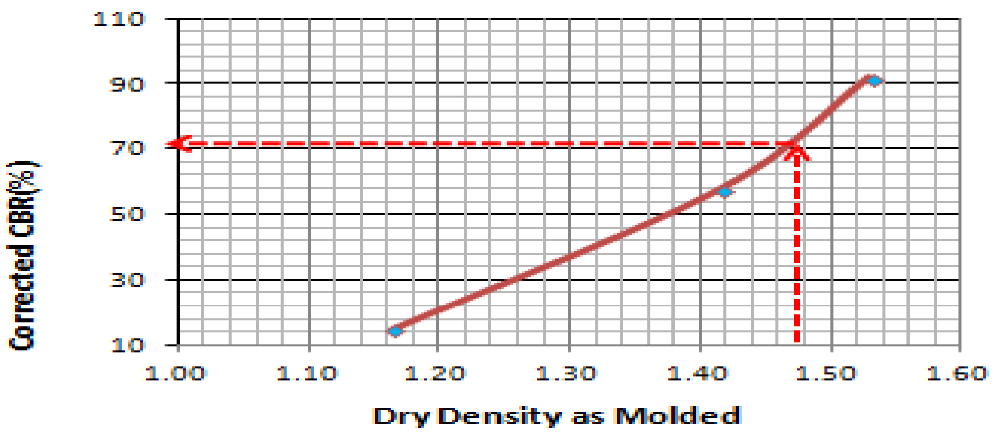

Figure 4.4: Dry Density Vs Percent CBR

Table 4.4: Determination of CBR at 98 % of MDD of cinder gravel.

Blow	Dry Density(g/cc)	CBR(%)
10	1.16	14.88
30	1.42	37.85
65	1.53	91.88
CBR at 98% of MDD		**72**

4.2.7 Abrasion Resistance.

Abrasion test is the test used to know how the aggregate is sufficiently hard to resist the abrasive effect of traffic over its service life.

The Ethiopia Road Authority standard technical specifications manual recommends that the Los Angeles Abrasion value shall not exceed 45% when determined in accordance with the requirements of AASHTO T-96[10].

The test was carried out accordingly and Los Angeles Abrasion value (LAAV) has been found to be 41% which meets the requirement of the standard technical specification. The details of this test are indicated in Table A-5 of appendix A.

4.2.8 Ten Percent Fines Value (TFV).

To ensure that the materials are sufficiently durable, the minimum soaked Ten percent Fines Value (TFV) according to BS 812, Part 111 shall be 50 kN [10].However the Ten Percent Fines Value (TFV) of the cider gravel was found to be 23 kN as indicated in Table A-6 of Appendix A. Thus, it has failed to satisfy the requirement of the technical specification of ERA.

4.2.9 Aggregate Impact Test

The test method that is followed in this regard is BS812 part112.This test is a means of evaluating the resistance of aggregates to sudden impact loading.

Accordingly, the test was carried out producing a result of 48.3% while the desired limit of the aggregate impact value (AIV) is a maximum of 35% revealing that the cinder gravel has failed to meet the requirement [12]. The details of the test are presented in Table A-7 of Appendix A.

4.3 Laboratory Test Results for Volcanic Ash (Pumice) Only.

4.3.1 Atterberg Limit.

The liquid limit test was carried out in which it was observed that the groove of the volcanic ash sample on the Casagrande cup closed in less than ten blows for three trials in which case it was impossible to determine the liquid limit. In addition to this, the ash was also observed to crumble before reaching a thickness of 3.2mm when rolled.

What was observed in the determination of both liquid limit and plastic limit brings us in to a conclusion that the volcanic ash is considered as non-plastic (NP) according to section 7.3.1 of AASHTO T–90 [3].

4.3.2 Specific Gravity and Absorption of Volcanic Ash.

The standard method that is followed for determining the specific gravity and absorption of volcanic ash with aggregate size less than 4.75mm is AASHTO T-84.The test results, as indicated in table A-2 of Appendix-A , showed that the absorption and specific gravity of the volcanic ash are 8% and 1.4 respectively.

4.3.3 Testing for Pozzolanicity.

Test methods for the evaluation of the pozzolans are still undergoing development. At present the American Standard Test Methods (ASTM) categorizes a pozzolan by its chemical and physical characteristics. These tests can be used to rank a selection of pozzolans in order of the potential strength development but do not indicate the ability of a pozzolan to perform in the field. Both the British and American specifications also outline a mechanical method of investigation. This evaluates the strength development of a pozzolan against that of Portland cement by considering the strength of a standard mortar cube made from sand, Portland cement and aggregate with a cube in which 20% of the Portland cement is replaced by the test pozzolan material as outlined below. The ratio of the strength of the test cube to the control cube is then presented as the strength activity index (SAI), which for a material to be considered pozzolanic should exceed 75% according to ASTM C-618[4, 20].

Pozzolanicity is evaluated using the procedures outlined in ASTM C311, 'Standard test methods for sampling and testing fly ash or natural pozzolans for use as a mineral admixture in Portland-cement concrete'. The pozzolanic potential of a material is determined by means of the 'strength activity index' with Portland cement [20].

Common amongst all pozzolans is the slow rate of hardening of pozzolan mixes compared to cement mixes. If tested after the same time period, pozzolans will show much lower strengths than the corresponding cement mix, yet the pozzolan strengths will continue to develop over a much longer time period. Grinding 15-20% of the pozzolan to the same fineness as cement can increase the rate of strength development but even then the lag between cement and pozzolanic mix strengths will continue to exist. Therefore the 7-day strengths of pozzolanic mixes and cement mixes should not be directly compared. Instead, where possible, the tests should consider the long-term strength of the two materials by studying the strength development over a period long enough to identify the strength lag between the two samples. Typically, this would require testing at 7, 14, 28 and 56 days [20].

The Guide line for the preparation of the test samples is provided as indicated below according to ASTMC311 [3, 21].

Table 4.5: Constituents for both control and test mortar.

Control mortar cube	Test mortar cube
500g Portland cement	400g Portland cement
1375g graded standard sand	100g test sample(volcanic ash)
242mL water.	1375g graded standard sand
	Variable amount of water to give a flow ±5of the control mixture.

The preparation of two types of mortar for the purpose of both control and test cubes was carried out by following C 305 which is the standard practice for mechanically mixing of hydraulic cement pastes and mortars of plastic consistency[4].

The determination of the strength of mortars from each type is conducted by following ASTM C109 which is the standard method for compressive strength of hydraulic cement mortars using 50mm (2in) cube specimens [4].

Based on the preceding guide lines of, twelve mortar cubes were prepared out of which the first six are for the control and the remaining six are for test purposes. The 7^{th} day and the 28^{th} day strengths are determined by considering three cubes from each type so that their strengths are averaged before the evaluation of the strength activity index (SAI).

The table indicated below shows the strength of the 50-mm cube mortars from both control sample and test sample.

Table 4.6: Test result of pozzolanicty test

		DURATION of KEEPING SAMPLE INSIDE CBR MOLD					
		7 days			28 days		
CONTROL MORTAR CUBE	sample Code	C1	C2	C3	C4	C5	C6
	strength (kgf)	4100	4050	4150	5600	5500	5550
	strength(MPa)	16.09	15.89	16.28	21.97	21.58	21.78
	Average	**16.09**			**21.78**		
TEST MORTAR CUBE	sample Code	P1	P2	P3	P4	P5	P6
	strength (kgf)	2700	2600	2650	4250	4150	4350
	strength(MPa)	10.59	10.20	10.40	16.68	16.28	17.07
	Average	**10.40**			**16.68**		
STRENGTH ACTIVITY INDEX (SAI) in %		**64.6**			**76.6**		

The test results indicate that the strength activity indices (SAI's) after 7 and 28days of keeping sample inside CBR mold are 64.6 % and 75.9% respectively. The slow rate of hardening of pozzolans is a very good reason for the SAI to exceed 75% after 28 days of keeping sample inside CBR mold while it is less than 75% after 7 days of keeping sample inside CBR mold.

4.4 Laboratory Test Results of Cinder Blended with Volcanic Ash and Lime.

4.4.1 Determination of the Optimum Amount of Volcanic Ash.

The proportion of volcanic ash that produces maximum density is the optimum amount volcanic ash that was needed to be determined. To this end, compaction was carried out by blending cinder gravels with volcanic ash at various proportions of 10%, 14%, 18%, 20%, 22% and 26% by weight of the cinder gravel. The method of compaction that was followed in this regard was AASHTO-T180 method D (Modified Proctor Test).The moisture density relations for various blending proportions of volcanic ash are presented in Appendix- B.

The summary of the test results of compaction of cinder gravel blended with volcanic ash at various proportions are indicated below by a table as well as a graph.

Table 4.7: Determination of optimum volcanic ash proportion

Optimum Pumice Content (%)	MDD (g/cc)	OMC (%)
0	1.51	8.3
10	1.52	13.8
14	1.53	17.8
18	1.55	18.2
20	1.56	18.5
22	1.58	18.9
26	1.54	24.4

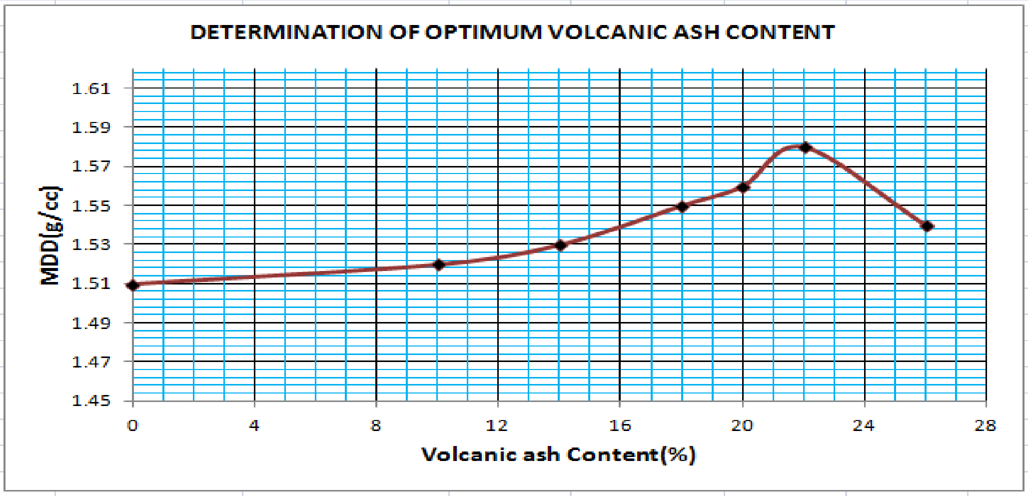

Figure 4.7: Maximum dry density versus volcanic ash content.

It is clearly seen in the above graph that the optimum proportion of volcanic ash content is 22% at which a maximum dry density (MDD) of 1.58g/cc is attained.

4.4.2 Grain Size Distribution of Natural Cinder Gravel Blended with the Optimum Amount of Volcanic Ash.

The natural cinder gravel which is blended with volcanic ash was sieved both before and after compaction. The sieve analysis showed that the gradation curve is within the envelope of ERA specification before compaction while it lies outside the envelope for the 19mm sieve after compaction. The details of the test are presented in Tables B-8 and B-9 of Appendix B.

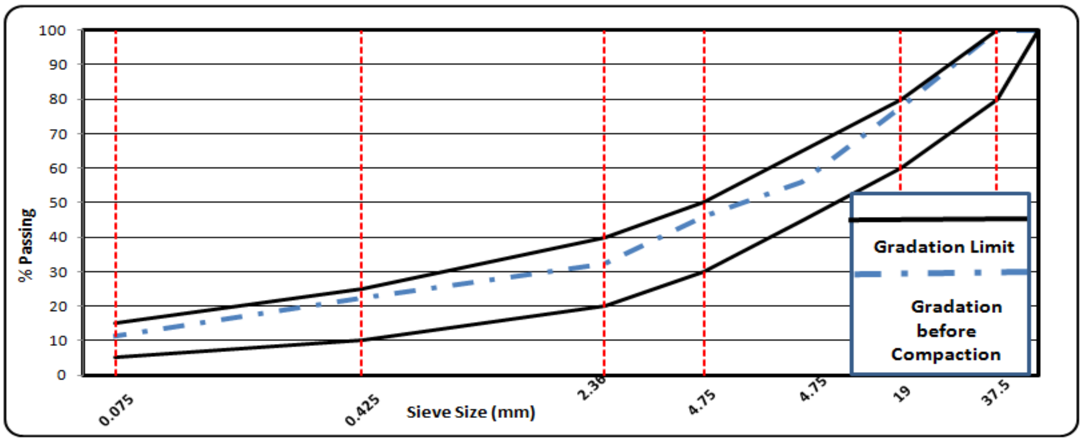

Figure 4.8: Gradation before compaction of natural cinder gravel blended with the optimum amount of volcanic ash.

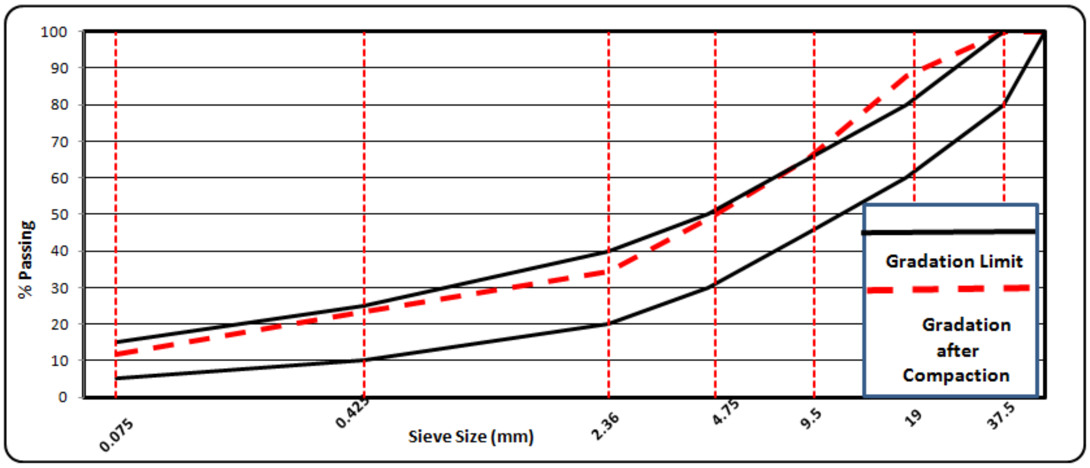

Figure 4.9: Gradation after compaction of natural cinder gravel blended with the optimum amount of volcanic ash.

Although the gradation curve after compaction lies outside the gradation envelope for 19mm sieve, the CBR of the stabilized cinder has been observed to be improved significantly as discussed in the next section.

4.4.3 California Bearing Ratio Test for Natural Cinder Gravels Blended With Volcanic Ash Only.

The California Bearing Ratio (CBR) test was conducted after blending the natural cinder gravels with the 22% by weight of volcanic ash which was found to be the optimum blending proportion as discussed in section 4.4.1.

The discussion made in section 4.2.6 in relation to CBR test applies in the determination of the CBR of the blending of cinder with volcanic ash (Pumice) except that a one point CBR was determined in this scenario.

Before the determination of a one point CBR, the samples were kept in CBR molds by wrapping with a polyethylene sheet for the durations of 0, 3,7,14 and 28 days.

In this case, two samples were prepared in CBR molds for each of the indicated durations in which one of them is for unsoaked condition while the other is for soaked condition. For the unsoaked condition, the durations after which the penetration test took place were 0, 3,7,14, and 28 days; whereas for the soaked condition a further 4 days of soaking were required in addition to the indicated durations.

The test results obtained are provided in Appendix−C. As can be seen in the graphs, correction of the CBR values was made by extending the straight line portion of the graph whenever it starts with a shape of concave opening upward. The reason for the graph to start with a concave upward is the irregularity of the surface of the sample in a CBR mold.

It can be easily seen from Table 4.8 and Fig 4.10 that the CBR value of the natural cinder gravel has increased from 72% to more than 80% when stabilized by 22% by weight of volcanic ash which makes up the deficiency of fines in cinder gravels. However, it was observed that the CBR value of the stabilized cinder gravel is not affected by the duration of keeping the sample in the mold by wrapping with polyethylene sheet .What one can understand from this is that the volcanic ash, which has been used to stabilize the natural cinder gravel, has no cementitious property.

Although the volcanic ash under consideration has no cementitious property in itself, it was tested to be pozzolanic as discussed in section 4.3.3. As a pozzolanic material, it possesses cementitious property when mixed with hydrated lime in the presence of moisture.

Table 4.8: CBR values for both soaked and unsoaked conditions of cinder gravels blended with volcanic ash only.

Days of keeping sample in CBR mold	Codition of Soaking	CBR cinder + pumice
0	Soaked	145.04
	Unsoaked	174.08
3	Soaked	130.62
	Unsoaked	174.17
7	Soaked	145.14
	Unsoaked	172.71
14	Soaked	130.62
	Unsoaked	174.17
28	Soaked	130.62
	Unsoaked	170.12

Fig 4.10 shows that natural cinder gravel blended with volcanic ash has more or less closer values for different days that the samples are kept in the CBR mold.

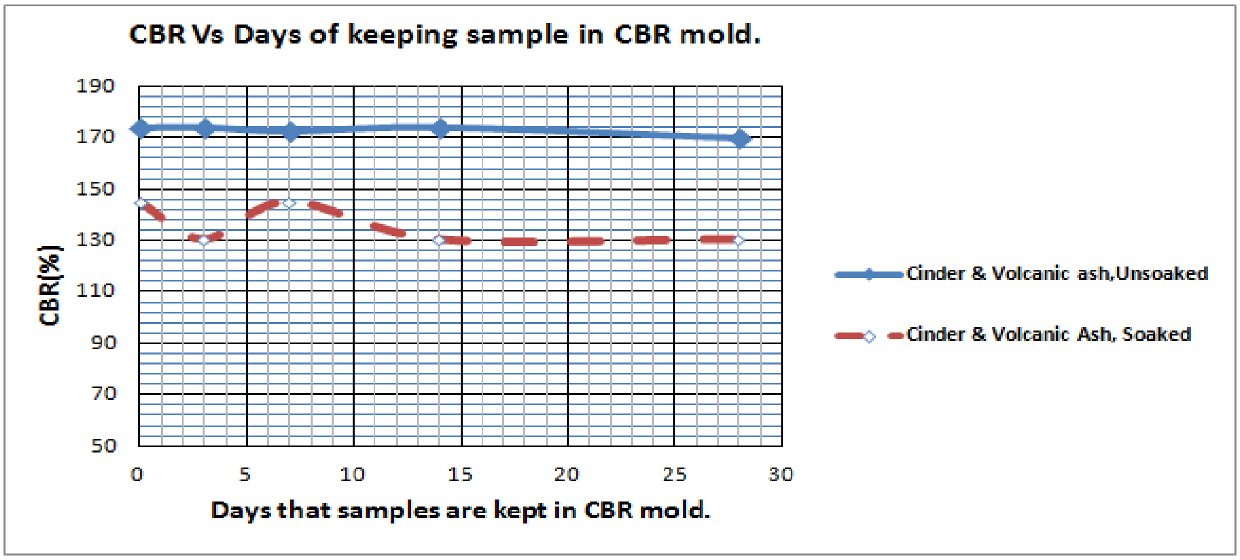

Figure 4.10: CBR Versus days that sample is kept in the CBR mold for both soaked &un soaked conditions.

It is clearly seen in Fig 4.10 that the CBR values have shown reduction after 4 days of soaking as expected.

In order to investigate how the CBR value changes upon the addition of lime, further tests were carried. The following section provides the test results obtained when the natural cinder gravel was blended with 20% by weight of volcanic ash and 2% by weight of lime. As the long term reaction (pozzolanic reaction) takes place when there is sufficient lime added, any amount less than 2% was not considered.

4.4.4 California Bearing Ratio Test for Natural Cinder Gravels Blended With Volcanic Ash and Lime.

In a similar manner to what was conducted on the blending of natural cinder gravel with volcanic ash, two samples were prepared in a CBR are mold in which one of them is for the soaked condition while the other is for the un soaked condition.

The optimum moisture used for compaction in the CBR mold was found to be 19.4% at the maximum dry density of 1.61g/cc as determined according to AASHTO-T180, method D for the blending of cinder gravel with 20% by weight of volcanic ash and 2% by weight of lime. The moisture density relation in this regard is presented in Table D-1 and Fig D-1 of Appendix D. As more water is needed for reaction when lime is added, the optimum moisture content has increased from 18.9% as indicated in Table 4.7 to 19.4%.

In this case too, penetration tests were carried out after durations of 0, 3,7,14 and 28 days during which the samples were kept inside CBR molds by wrapping with a polyethylene sheet. For the soaked condition, penetration test took place upon the completion of the indicated durations while for the soaked condition, additional 4 days of soaking were required.

The test results obtained are provided in Appendix-D.As can be seen in the graphs, correction of the CBR values were made by extending the straight line portion of the graph whenever it starts with a shape of concave opening upward. The test results are summarized in Table 4.9.

Table 4.9: CBR values for both soaked and un soaked conditions of cinder gravels blended with volcanic ash and lime.

Days of keeping sample in CBR mold	Codition of Soaking	CBR cinder+pumice+lime
0	Soaked	183.75
	Unsoaked	174.08
3	Soaked	195.94
	Unsoaked	188.68
7	Soaked	203.19
	Unsoaked	193.42
14	Soaked	217.6
	Unsoaked	203.19
28	Soaked	225.82
	Unsoaked	217.71

The observation made so far is also presented graphically in Fig 4.11.

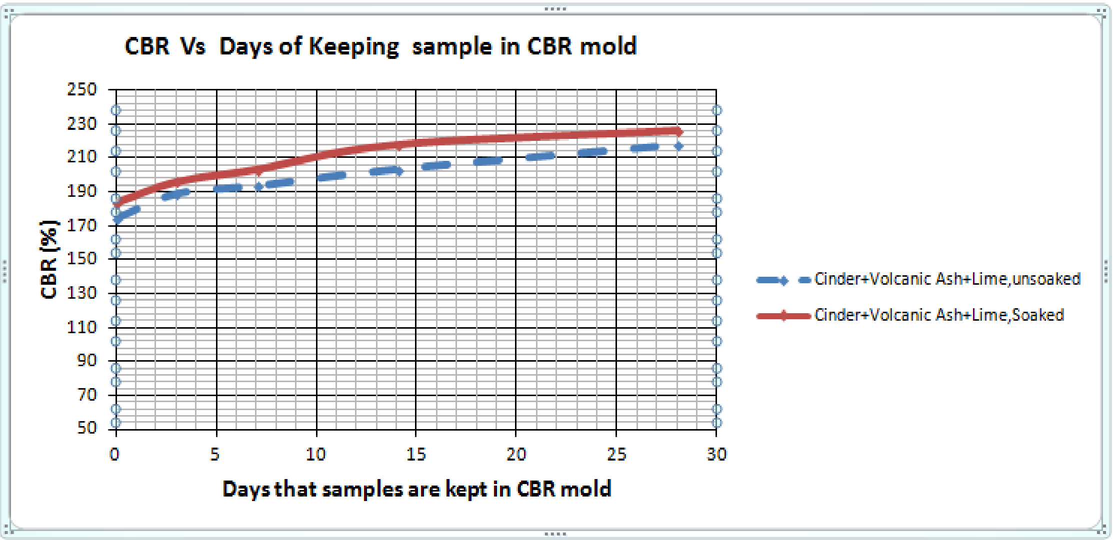

Figure 4.11: CBR Versus days that sample is kept in the CBR mold for both soaked &un soaked conditions.

What can be observed from the above graphs is that the CBR values are affected by the duration of keeping the samples in CBR molds. This means that as the duration of keeping the samples in

CBR mold increases, the CBR values were also observed to increase. Furthermore, unlike what has been observed in the case of cinder gravels blended with volcanic ash, the CBR values after 4 days of soaking were observed to be greater than that in the unsoaked condition for the same duration of keeping sample in CBR mold. The increase in CBR for the soaked is due to the presence of sufficient moisture which facilitates the cementation process through curing.

For example, two samples were kept in two CBR molds by wrapping with a polyethylene sheet for 28 days. The CBR value of one of them was determined right after the completion of the indicated duration which was found to be 217.2% for the unsoaked condition. The CBR value for the other sample was determined after a further 4 days of soaking which was found to be 225.8%.

The increase in the CBR value with duration that the sample is kept in CBR mold is attributed to the pozzolanic reaction. This phenomenon has taken place as the result of a long term chemical reaction between the volcanic ash which was found to be a pozzolanic material and the hydrated lime.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions.

This thesis work has attempted to investigate whether natural cinder gravels of Metehara area would be used as a base course material when stabilized by volcanic ash and lime.

In the course of carrying out the study, the following conclusions have been drawn.

1. The sieve analysis, which was conducted after the compaction of natural cider gravels, has shown that a significant amount of these materials have been broken down into fine grained sizes. However, the gradation requirement of ERA specification has not been satisfied.
2. The optimum amount of volcanic ash to be blended with cinder gravel was found to be 22% as determined through compaction method.
3. Atterberg limit tests indicated that both cinder gravel and volcanic ash are non-plastic.
4. The sieve analysis, which was carried out by blending natural cinder gravel with volcanic ash, has shown that the gradation curves, before and after compaction, fall within the envelope of ERA specification.
5. The volcanic ash which was used to stabilize the cinder gravel has been found to be pozzolanic which is a very important property for the development of cementitious material when mixed with lime in the presence of water.
6. The CBR value of cinder gravel has been significantly improved to the extent of being more than double when blended with the optimum amount volcanic ash. However, this CBR value of the stabilized cinder has not shown an increment with the duration of keeping the samples in CBR mold regardless of the soaking condition.
7. The CBR values obtained by blending cinder gravel with volcanic ash (20% by weight) and lime (2% by weight) showed increment with the duration of keeping the samples in CBR mold. Furthermore, the CBR values obtained in a soaked condition have been found to be greater than those obtained in an unsoaked condition for a given duration of keeping the samples in CBR mold.

5.2 Recommendations.

As cinder gravel deposits are widely distributed in Ethiopia, a feasible stabilization of these naturally occurring gravels to be used as a base course material is of paramount importance.

The following recommendations are made based on the study of the potential use of cinder gravels as a base course material when stabilized with volcanic ash and lime.

1. A special gradation requirement should be provided for natural gravels such as cinder gravel whose gradation changes significantly upon compaction.
2. Chemical test should also be conducted on the volcanic ash in order to obtain a complete confirmation of its pozzolanicity.
3. Laboratory investigation has revealed that cinder gravel stabilized by volcanic ash (pumice) and lime has achieved the required strength as a base course material. However, the field performance of this stabilized material should be investigated on a pilot project
4. Guidelines on the blending proportion of cinder gravel with volcanic ash and lime should be prepared for cinder gravels and volcanic ash (pumice) found in different areas of our country.
5. The findings in this study can be used as a basis for further researches in the field of cinder gravels found in different parts of the country.

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APPENDICES

Appendix–A

Test results of cinder gravels

&

volcanic ash

Table A−1: Absorption and specific gravity of cinder gravel for grain size <4.75mm.

Trial No	1	2
Pycnometer no	P_1	P_2
Mass of saturated surface dry test sample in air,(A)(g)	500	500
Mass of pycnometer+soil+ water(M_2)(g)	1565	1563
Mass of pycnometer+ water(M1)(g)	1280.5	1281.6
Mass of oven dry test sample in air (B)(g)	445	443.6
Absorption(%) = (A-B)/B	12.4	12.7
Average Absorption(%)	**12.5**	
Specific gravity of cinder at 23°C = A/(M1+A-M2)	2.3	2.3
Average specific gravity of cinder at 23°C	**2.3**	

Table A−2: Absorption and specific gravity of volcanic ash for grain size <4.75mm.

Trial No	1	2
Pycnometer no	P_1	P_2
Mass of saturated surface dry test sample in air,(A)(g)	500	500
Mass of pycnometer+soil+ water(M_2)(g)	1383	1395
Mass of pycnometer+ water(M1)(g)	1248.5	1257
Mass of oven dry test sample in air (B)(g)	460.8	465.5
Absorption(%) = (A-B)/B	8.5	7.4
Average Absorption(%)	**8.0**	
Specific gravity of cinder at 23°C = A/(M1+A-M2)	1.4	1.4
Average specific gravity of cinder at 23°C	**1.4**	

Table A−3: Sieve analysis for cinder gravel before compaction.

PARTICLE SIZE DISTRIBUTION BY SIEVING

TEST METHOD: AASHTO T 27

Location:	Mthara /Gorera	REQ. NO.:	
Source:	Mthara /Gorera	REF. NO.:	
Material type:	Cinder Gravel	DATE SAMPLED:	10/1/2015
Sample from:	Stock pile	DATE TESTED:	10/2/2015

No of sample		1			2		Grading modulas	PP	Specification limt	
Dry sample weight Before Washing (g)		5146.1			5587.9					
Dry sample weight After Washing (g)		5014.1			5457.9		2.78			
Inch	Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Passing (%)		
2.00	50	0	5034.9	97.8	0.0	5587.9	100.0	98.9	100.0	100.0
1.50	37.5	528	4507.4	87.6	690.0	4897.9	87.7	87.6	80.0	100.0
3/4	19	1369.2	3138.3	61.0	1582.4	3315.5	59.3	60.2	60.0	80.0
3/8	9.5	1309.5	1828.7	35.5	1439.8	1875.7	33.6	34.6	45.0	65.0
NO 4	4.75	764.0	1064.7	20.7	829.2	1046.5	18.7	19.7	30.0	50.0
NO 10	2.36	436.0	628.7	12.2	350.8	695.8	12.5	12.3	20.0	40.0
NO 40	0.425	382.9	245.8	4.8	278.3	417.5	7.5	6.1	10.0	25.0
NO 200	0.075	105.0	140.8	2.7	132.3	285.2	5.1	3.9	5.0	15.0
pan		120.0	0.0		155.3	0.0				
Wash lose		132	0.0	0.0	130.0	0.0				
Total		5146.1			5587.9					

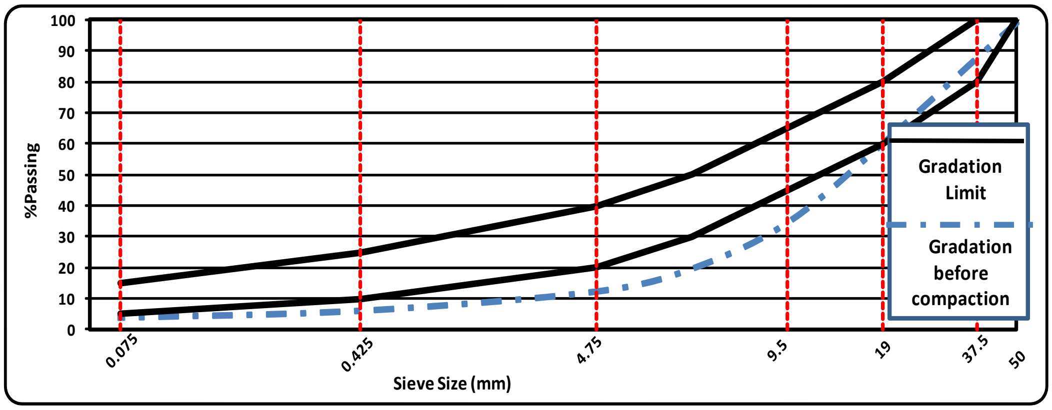


Figure A-1: Sieve analysis for cinder gravel before compaction.

Table A−4: Sieve analysis for cinder gravel after compaction.

PARTICLE SIZE DISTRIBUTION BY SIEVING

TEST METHOD: AASHTO T 27

Location:	Mthara /Gorera	REQ. NO.:	
Source:	Mthara /Gorera	REF. NO.:	
Material type:	Cinder Gravel	DATE SAMPLED:	10/1/2015
Sample from:	Stock pile	DATE TESTED:	10/2/2015

No of sample		1			2			Grading modulas	PP	Specification limt	
Dry sample weight Before Washing (g)		6169.0			6304.0						
Dry sample weight After Washing (g)		6119.1			6287.2			2.57			
Inch	Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Passing (%)			
2.00	50	0	6169.0	100.0	0.0	6304.0	100.0	100.0		100.0	100.0
1.50	37.5	0	6169.0	100.0	0.0	6304.0	100.0	100.0		80.0	100.0
3/4	19	603	5566.3	90.2	629.3	5674.7	90.0	90.1		60.0	80.0
3/8	9.5	1722.5	3843.8	62.3	1764.8	3910.0	62.0	62.2		45.0	65.0
NO 4	4.75	946.2	2897.6	47.0	977.6	2932.4	46.5	46.7		30.0	50.0
NO 10	2.36	1033.8	1863.8	30.2	1065.0	1867.4	29.6	29.9		20.0	40.0
NO 40	0.425	1108.5	755.3	12.2	1142.3	725.1	11.5	11.9		10.0	25.0
NO 200	0.075	648.0	107.3	1.7	675.0	50.1	0.8	1.3		5.0	15.0
pan		57.5	0.0		33.3	0.0					
Wash lose		50	0.0	0.0	16.8	0.0					
Total		6169.0			6304.0						

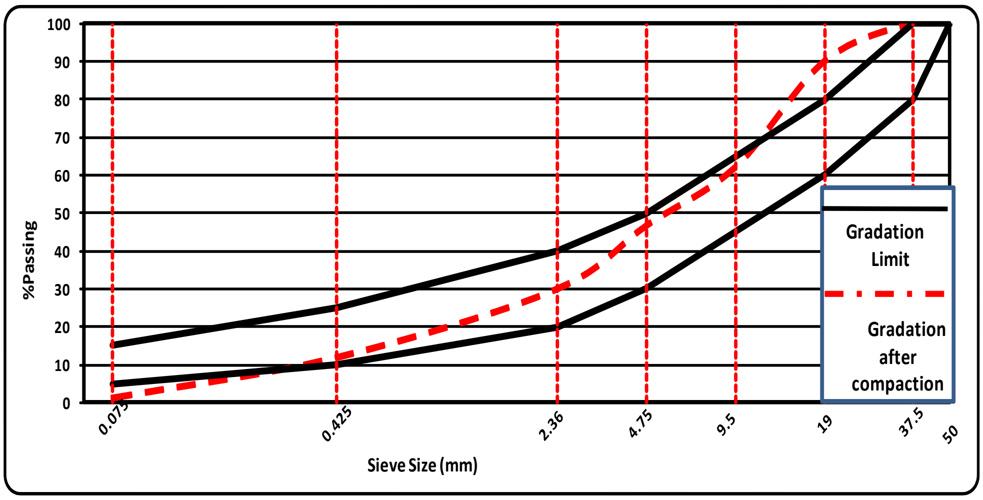


Figure A-2: Sieve analysis for cinder gravel after compaction.

TableA−5: Determination of Los Angeles abrasion value.

RESISTANCE TO ABRASION OF SMALL SIZE COARSE AGGREGATE

BY USE OF THE LOS ANGELES MACHINE

TEST METHOD : AASHTO T 96-94

Location:	**Mthara /Gorera**	**Lab.Ref.No :**	**0**
Source:	**Mthara /Gorera**	**Request.No:**	
Material type:	**Cinder Gravel**	**Date sample:**	**10/1/2015**
Sample from:	**Volcainc hill**	**Date test:**	**22/01/2015**

MATERIAL DESCRIPTION :	**Volcanic material**

SIEVE SIZES	1 1/2 - 1"	1 - 3/4 "	3/4 - 1/2 "	1/2 - 3/8 "	3/8 - 1/4 "	1/4" - No.4	No.4-No.8
GRADE	A				C		D
NUMBER OF BALLS	12 BALLS				8 BALLS		6 BALLS
WT. OF INDICATED SIZE	1250 ± 25	1250 ± 25	1250 ± 10	1250 ± 10	2500 ± 10	2500 ± 10	5000 ± 10
WT.OF TESTED SAMPLE							
GRADE			B				
NUMBER OF BALLS			12 BALLS				
WT. OF INDICATED SIZE			2500 ± 10	2500 ± 10			
WT.OF TESTED SAMPLE							

TEST RESULTS

TRIAL	1	2	3	Average
NUMBER OF REVOLUTION	500	500		
TOTAL WT. OF SAMPLE TESTED, (g)	5000	5000		
WT. OF TESTED SAMPLE RETAINED ON No. 12 SIEVE (g)	2929	2929		
PERCENT LOSS (%)	**41**	**41**		**41**

Table A−6: Determination of ten percent fines value (TPFV) for soaked condition.

Lab. Test No. :-
Location Sampled:- Gorera
Type of material:- Cinder Gravel

Date sample **10/1/2015**
Date Tested
Sample no. : **15/03/2015**

TEN PER CENT FINES VALUE (TPFV)

BS 812 Part 111 : 1990

Condition of Aggregate Tested	**Soaked**	
Sample No.	**1**	**2**
Mass of aggregate passing **14 mm** and retained on **10 mm** ,gm. /**before compression**/	1398.8	1404.8
Mass of aggregate,retained on **2.36** mm sieve size, gm. / **after compression**/	1279.8	1296.6
% of material passing **2.36** mm (m)	8.51	7.70
Duration of testing, min.	10.3	10.4
Maximum load, f (KN)	19.60	19.50
Force required to produce 10% fines in (KN)= 14x f /(m+4)	21.94	23.33
AVERAGE FORCE TFV IN KN,	**23**	

Remarks:	Percent passing 2.36mm should be between 7.5% and 12.5% F=14xf / (m+4) Penetration of plunger 15mm rounded or partially rounded aggregates 20mm for normal crushed aggregates 24mm for vesicular (honeycombed) aggregates

TableA−7: Determination of aggregate impact value (AIV).

AGGREGATE IMPACT VALUE (AIV) TEST METHOD:BS812 Part112:1990

Location : Road Research Center(ERA)
Source : Volcanic Hill
Material type:Cinder Gravel

Date Sampled: 10/1/2015
Date Tested : 15/03/2015

TEST No	1	2
Mass of aggregate before test, Passing 14mm and retained on 10mm sieves,M_1 (g)	173.8	169.5
Mass of aggregate after impact loading passing 2.36mm sieve,M_2 (g)	91.9	85.7
AIV (%)=(M_2/M_1)X100	52.877	50.560
Average AIV (%)	**51.72**	

Table A−8: Relationship between moisture and density for cinder gravel only.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.N	
Source:	Methehara /Gorera	Request.N	
Material type:	Cider Gravel	Date samp	10/1/2015
Sample from:	Volcanic Hilll	Date test:	7/5/2015

Weight mold+sample(g)	9668	9928	9885	9928		
Weight of mold(g)	6475	6475	6475	6475		
Weight of Wet sample(g)	3193	3453	3410	3453		
Volume of mold(cm)³	2108.6	2108.6	2108.55	2108.55		
Wet density (g/cc)	1.51	1.64	1.62	1.64		
tare No	B12	B1	B2	B7		
Weight tare+sample(g)	614.61	602.78	579.19	502.04		
Wet tare+dry sample(g)	589.27	562.73	524.59	442.70		
Wet of water(g)	25.34	40.05	54.6	59.34		
Wet of tare(g)	78.6	79.2	69.7	77.5		
Wet of dry sample(g)	510.72	483.55	454.93	365.21		
Moisture content(g/cc)	5.0	8.3	12.0	16.2		
Dry density(g/cc)	1.44	1.51	1.44	1.41		

DIA. Of mould(mm	Rammer Wt(kg	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.51	8.3	5

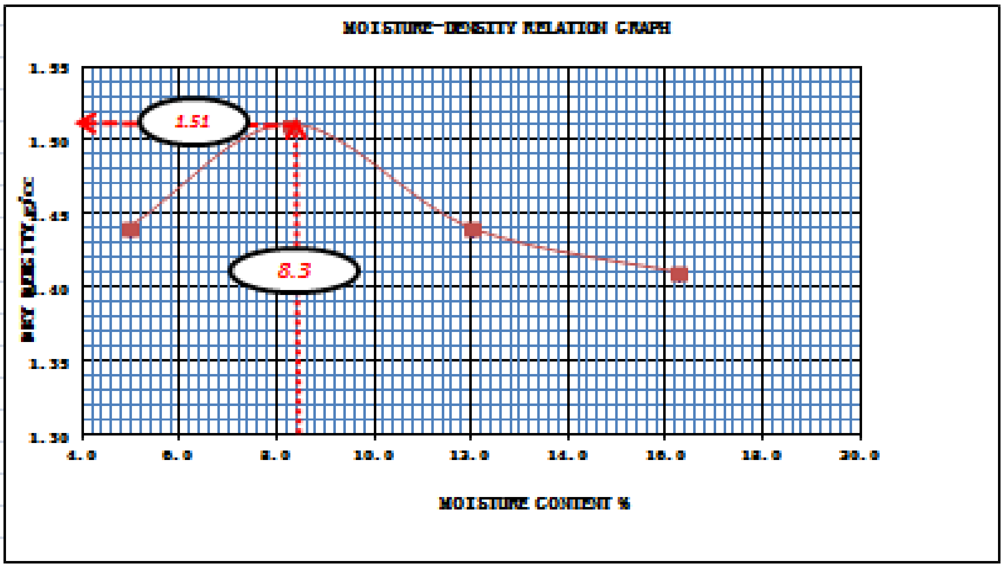


Figure A-3: Relationship between moisture and density for cinder gravel only.

Table A–9: Determination of CBR of natural cinder gravel only.

ETHIOPIAN ROADS AUTHORITY

ROAD RESEARCH CENTER

CALIFORNIA BEARING RATIO TEST

TEST METHOD : AASHTO T 193-99

Source:	Volcanic Hill	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel	Date of soaking:	10/5/2015
MDD (g/cc):	1.51	Date of Penetration:	14/05/2015
OMC %:	8.3%	Test ID:	

DENSITY DETERMINATION

		10 Blows		30 Blows		65 Blows	
		Before	After	Before	After	Before	After
Moulder No.		60		59		54	
Weight of Soil + Mold, g	a	8657.0	8740.0	9392.0	9505.5	9974.0	10092.5
Weight of Mold, g	b	6030.0	6030.0	6200.0	6200.0	6475.0	6475.0
Weight of Soil, g	d=a-b	2627.0	2710.0	3192.0	3305.5	3499.0	3617.5
Volume of Mold, cc	e	2108.5	2108.5	2108.5	2108.5	2108.5	2108.5
Wet Density of Soil, g/cc	f=d/e	1.25	1.29	1.51	1.57	1.66	1.72
Dry Density of Soil, g/cc	=f/(1+w) **	1.16	1.10	1.42	1.33	1.53	1.46

** w is moisture content in fraction

MOISTURE DETERMINATION

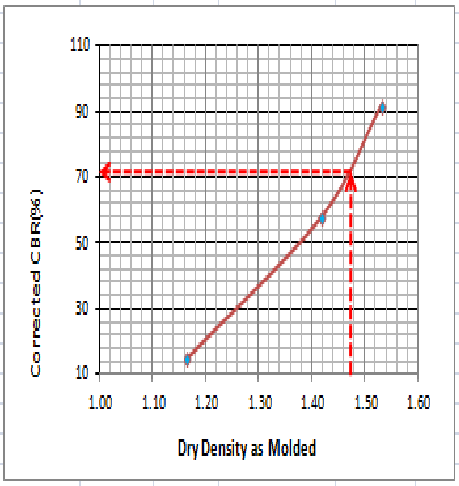
	10 Blows			30 Blows			65 Blows		
	Before	After		Before	After		Before	After	
		Top	middle		Top	middle		Top	middle
Container No.	B14	P10	P11	B2	P13	P15	B14	P15	P16
Wet Soil + Container, g A	590.63	2071.0	2111.0	586.64	2367.0	2712.0	604.1	2463.0	2820.0
Dry Soil + Container, g B	556.62	1910.0	1921.0	553.6	2161.0	2425.0	562.9	2242.0	2513.0
Weight of Water, g C=A-B	34.01	161.0	190.0	33.0	206.0	287.0	41.2	221.0	307.0
Weight of Container, g D	75.93	892.0	855.0	69.64	905.0	878.0	75.9	902.0	869.0
Weight of Dry Soil,g E=B-D	480.69	1018.0	1066.0	484.0	1256.0	1547.0	487.0	1340.0	1644.0
Moisture Content, % w=C/E*100	7.1	15.8	17.8	6.8	16.4	18.6	8.5	16.5	18.7
Average Moisture Content %	7.1	16.8		6.8	17.5		8.5	17.6	

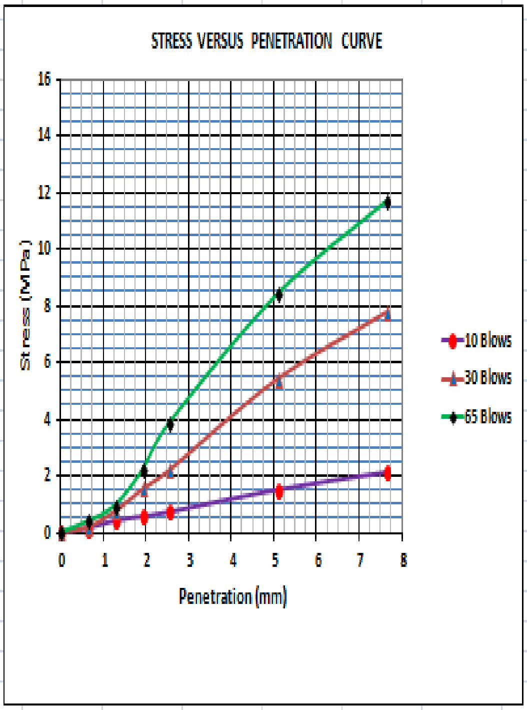
Ring factor=21.58 N/Div

PENETRATION TEST DATA

Penetration	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %	Dial Rdg	Load,Mpa	COR Load	CBR %	Dial Rdg	Load,Mpa	COR Load	CBR %
0	0	0.00			0	0.00			0	0.00		
0.64	14	0.16			16	0.18			35	0.39		
1.27	38	0.42			65	0.72			85	0.95		
1.91	52	0.58			135	1.51			195	2.17		
2.54	66	0.74	0.74	10.67	195	2.17	2.17	31.51	345	3.85	5.50	79.71
5.08	138	1.54	1.54	14.88	485	5.41	6.00	58.03	755	8.42	9.50	91.88
7.62	194	2.16			695	7.75			1048	11.69		

SWELL			
No. of Blows	10	30	65
RDG. (Before Soaking)	500	400	1000
RDG. (After Soaking)	500	404	1005
Percent Swell	0.00	0.03	0.04





At 98% AASHTO Modified Maximum Dry Density, CBR = 72%
CBR Value Should Be Grater than or Equal to 80%

Figure A-4: Three point CBR determination and the determination of CBR at 98% MDD for cinder gravel only.

Appendix–B

Compaction and gradation test results of the blending of cinder & volcanic ash.

Table B−1: Relationship between moisture and density for cinder gravel blended with 10%by weight of volcanic ash.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.No :	
Source:	Methehara /Gorera	Request.No:	
Material type:	Cider blended with Volcanic ash	Date sample:	10/1/2015
Sample from:	Volcanic Hilll	Date test:	5/5/2015

Wet mold+sample(g)	9878	9998	10115	10119		
Wet of mold(g)	6475	6475	6475	6475		
Wet of sample(g)	3403	3523	3640	3644		
Volume of mold(cm)³	2108.6	2108.6	2108.55	2108.55		
Wet density (g/cc)	1.61	1.67	1.73	1.73		
tare No	B2	B1	B2	B7		
Wet tare+sample(g)	614.61	602.78	581.19	512.04		
Wet tare+dry sample(g)	571.27	549.73	520.59	451.70		
Wet of water(g)	43.34	53.05	60.6	60.34		
Wet of tare(g)	69.64	79.18	81.61	77.64		
Wet of dry sample(g)	501.63	470.55	438.98	374.06		
Moisture content(g/cc)	8.6	11.3	13.8	16.1		
Dry density(g/cc)	1.49	1.50	1.52	1.49		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.52	13.8	5

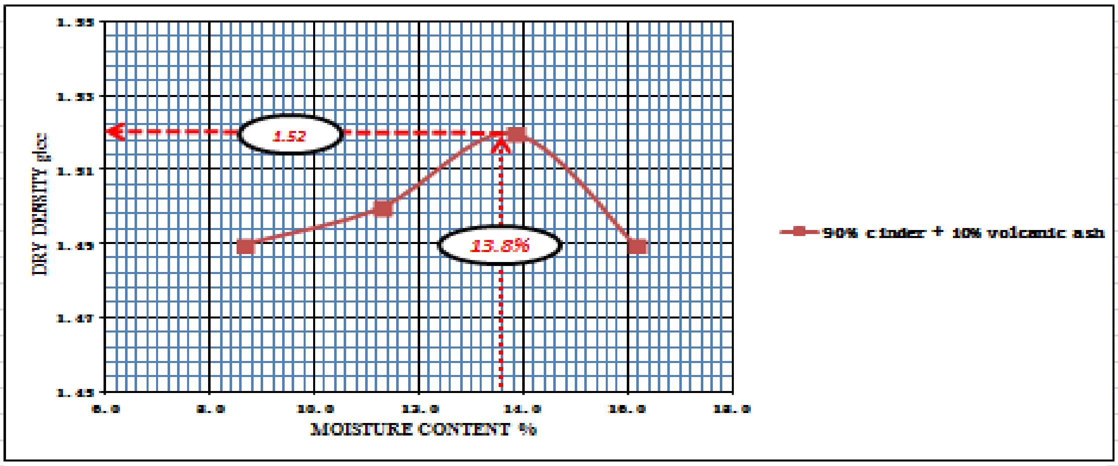


Figure B-1: Relationship between moisture and density for cinder gravel blended with 10%by weight of volcanic ash.

Table B‒2: Relationship between moisture and density for cinder gravel blended with 14%by weight of volcanic ash.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.N	
Source:	Methehara /Gorera	Request.N	
Material type:	Cider blended with Pun	Date samp	10/1/2015
Sample from:	Volcanic Hilll	Date test:	21/5/2015

Wt mold+sample(g)	10145	10275	10298	10341		
Wt of mold(g)	6475	6475	6475	6475		
Wt of sample(g)	3670	3800	3823	3866		
Volume of mold(cm)³	2108.6	2108.6	2108.55	2108.55		
Wet density (g/cc)	1.741	1.802	1.813	1.833		
tare No	B10	B12	B1	B6		
Wt tare+sample(g)	617.22	609.57	611.49	608.41		
Wt tare+dry sample(g)	542	529.53	521.53	508.8		
Wet of water(g)	75.22	80.04	89.96	99.61		
Wet of tare(g)	74.6	78.55	79.2	68.98		
Wet of dry sample(g)	467.4	450.98	442.33	439.82		
Moisture content(%)	16.1	17.7	20.3	22.6		
Dry density(g/cc)	1.50	1.53	1.51	1.49		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.53	17.7	5

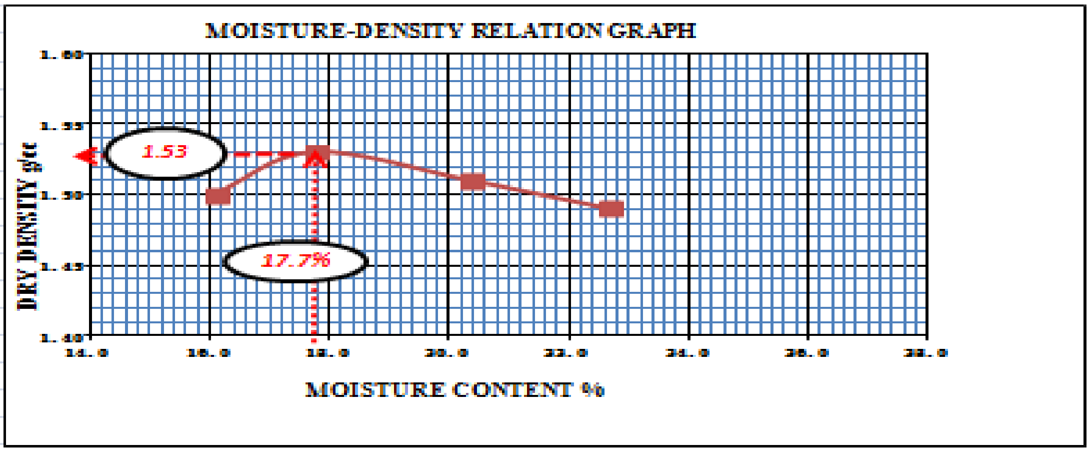


Figure B-2: Relationship between moisture and density for cinder gravel blended with 14%by weight of volcanic ash.

Table B−3: Relationship between moisture and density for cinder gravel blended with 18%by weight of volcanic ash.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.N	
Source:	Methehara /Gorera	Request.N	
Material type:	Cider blended with Pun	Date samp	10/1/2015
Sample from:	Volcanic Hilll	Date test:	10/5/2015

Wt mold+sample(g)	10198	10349	10365	10445		
Wt of mold(g)	6475	6475	6475	6475		
Wt of sample(g)	3723	3874	3890	3970		
Volume of mold(cm)³	2108.6	2108.6	2108.55	2108.55		
Wet density (g/cc)	1.766	1.837	1.845	1.883		
tare No	B7	B12	B8	B6		
Wt tare+sample(g)	617.22	612.57	611.43	608.41		
Wt tare+dry sample(g)	542.74	530.53	521.53	501.8		
Wet of water(g)	74.48	82.04	89.9	106.61		
Wet of tare(g)	77.64	78.55	69.5	68.98		
Wet of dry sample(g)	465.1	451.98	452.03	432.82		
Moisture content(%)	16.0	18.2	19.9	24.6		
Dry density(g/cc)	1.52	1.55	1.54	1.51		

DIA. Of mould(mm	Rammer Wt(kg	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.55	18.2	5

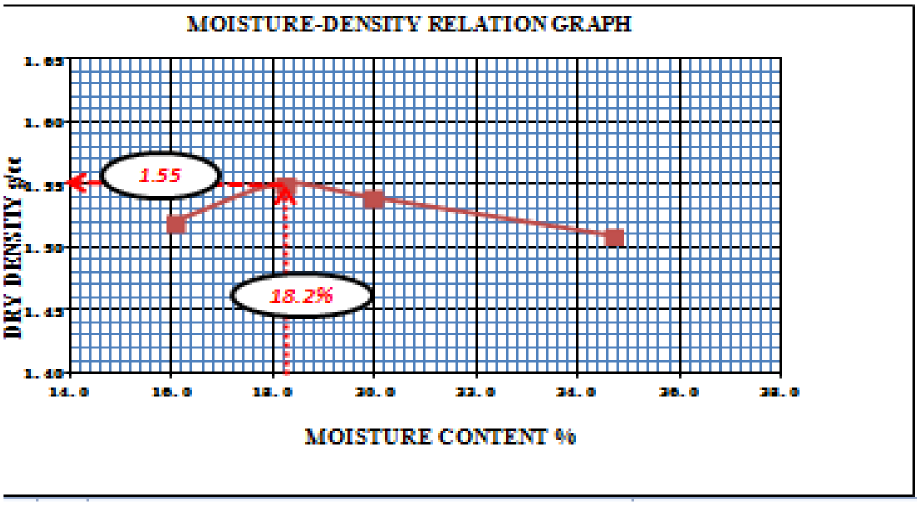


Figure B-3: Relationship between moisture and density for cinder gravel blended with 18%by weight of volcanic ash.

Table B−4: Relationship between moisture and density for cinder gravel blended with 20% by weight of volcanic ash.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.N	
Source:	Methehara /Gorera	Request.N	
Material type:	Cider blended with Pun	Date samp	10/1/2015
Sample from:	Volcanic Hilll	Date test:	20/5/2015

Wt mold+sample(g)	10240	10378	10528			
Wt of mold(g)	6475	6475	6475			
Wt of sample(g)	3765	3903	4053			
Volume of mold(cm)³	2108.6	2108.6	2108.55			
Wet density (g/cc)	1.786	1.851	1.922			
tare No	B3	B10	B15			
Wt tare+sample(g)	639	650	678			
Wt tare+dry sample(g)	558	560	558			
Wet of water(g)	81	90	120			
Wet of tare(g)	81.62	74.56	71.57			
Wet of dry sample(g)	476.38	485.44	486.43			
Moisture content(%)	17.0	18.5	24.7			
Dry density(g/cc)	1.53	1.56	1.54			

DIA. Of mould(mm	Rammer Wt(kg	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.56	18.5	5

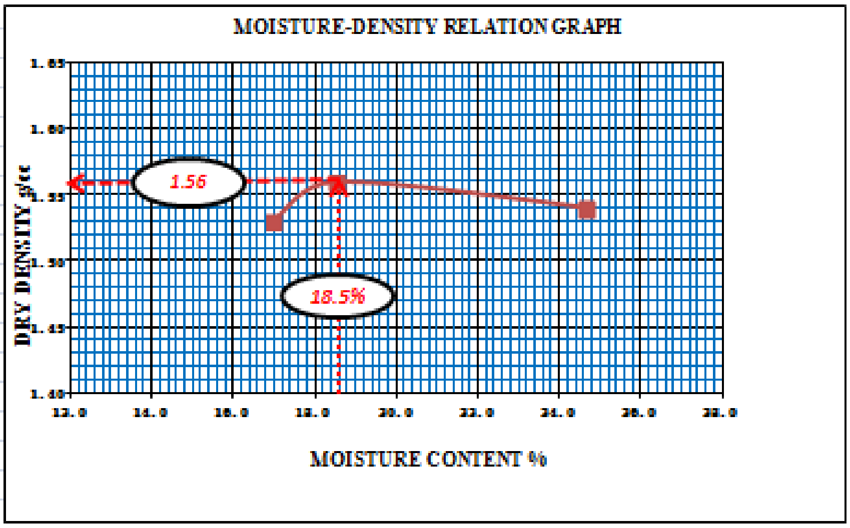


Figure B-4: Relationship between moisture and density for cinder gravel blended with 20% by weight of volcanic ash.

Table B−5: Relationship between moisture and density for cinder gravel blended with 22% by weight of volcanic ash.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.N	
Source:	Methehara /Gorera	Request.N	
Material type:	Cider blended with Pun	Date samp	10/1/2015
Sample from:	Volcanic Hilll	Date test:	7/5/2015

Wt mold+sample(g)	10121	10447	10514	10507		
Wt of mold(g)	6475	6475	6475	6475		
Wt of sample(g)	3646	3972	4039	4032		
Volume of mold(cm)³	2108.6	2108.6	2108.55	2108.55		
Wet density (g/cc)	1.729	1.884	1.916	1.912		
tare No	B7	B12	B11	B9		
Wt tare+sample(g)	605.35	578.48	567.83	574.62		
Wt tare+dry sample(g)	542.3	499.09	472.4	466.25		
Wet of water(g)	63.05	79.39	95.43	108.37		
Wet of tare(g)	77.64	78.55	67.59	68.77		
Wet of dry sample(g)	464.66	420.54	404.81	397.48		
Moisture content(%)	13.6	18.9	23.6	27.3		
Dry density(g/cc)	1.52	1.58	1.55	1.5		

DIA. Of mould(mm	Rammer Wt(kg	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.58	18.9	5

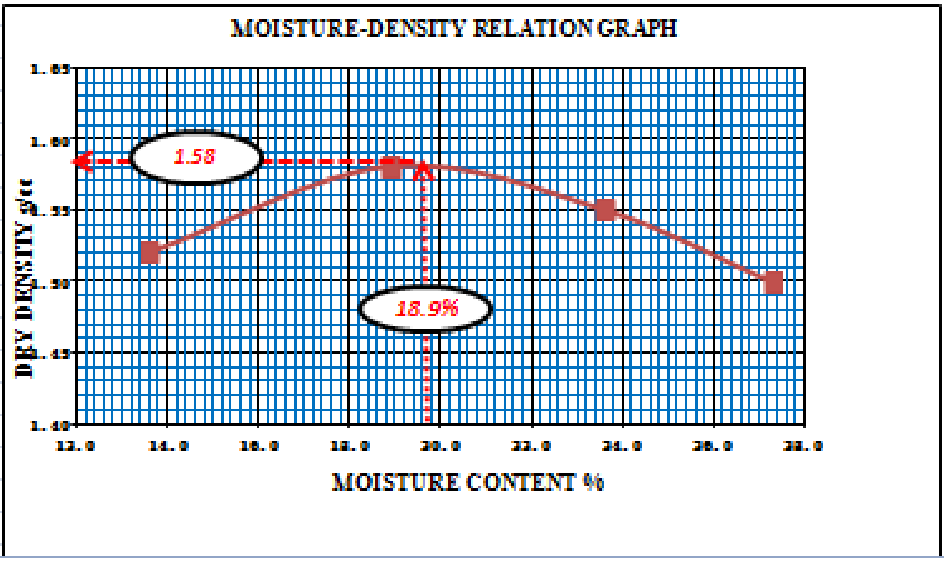


Figure B-5: Relationship between moisture and density for cinder gravel blended with 22% by weight of volcanic ash.

Table B−6: Relationship between moisture and density for cinder gravel blended with 22% by weight of volcanic ash.

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	Lab.Ref.N	
Source:	Methehara /Gorera	Request.N	
Material type:	Cider blended with Pun	Date samp	10/1/2015
Sample from:	Volcanic Hilll	Date test:	13/5/2015

Wt mold+sample(g)	9863	9981	10087	10095		
Wt of mold(g)	6060	6060	6060	6060		
Wt of sample(g)	3803	3921	4027	4035		
Volume of mold(cm)³	2098.4	2098.4	2098.42	2099.42		
Wet density (g/cc)	1.812	1.869	1.919	1.922		
tare No	B2	B3	B6	B7		
Wt tare+sample(g)	618.03	617.64	614.52	613.15		
Wt tare+dry sample(g)	524.33	519.14	507.68	500.68		
Wet of water(g)	93.7	98.5	106.84	112.47		
Wet of tare(g)	69.64	81.61	68.97	77.64		
Wet of dry sample(g)	454.69	437.53	438.71	423.04		
Moisture content(%)	20.6	22.5	24.4	26.6		
Dry density(g/cc)	1.50	1.53	1.54	1.52		

DIA. Of mould(mm	Rammer Wt(kg	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.54	24.4	5

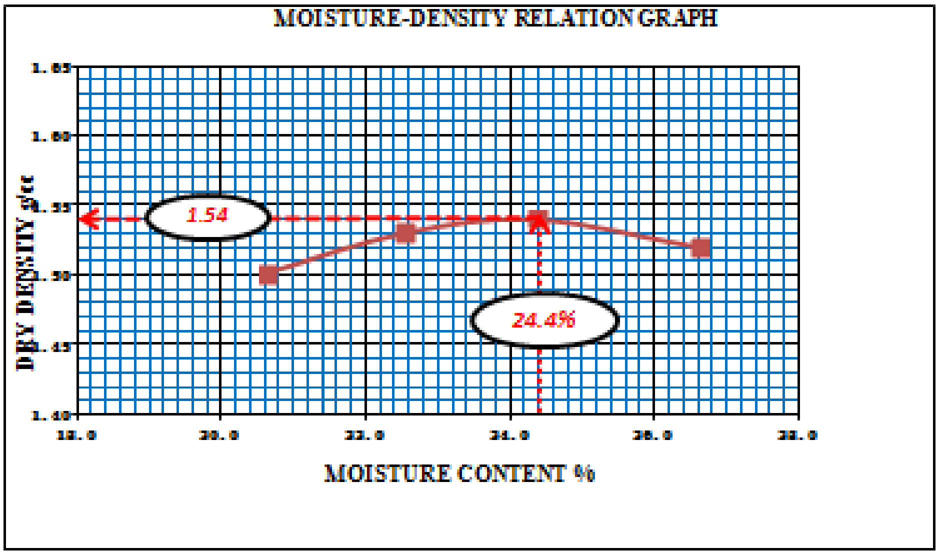


Figure B-6: Relationship between moisture and density for cinder gravel blended with 22% by weight of volcanic ash.

Table B−7: Determination of optimum volcanic ash content.

DETERMINATION OF OPTIMUM PUMICE CONTENT

Optimum Pumice Content (%)	MDD (g/cc)	OMC (%)
0	1.51	8.28
10	1.52	13.80
14	1.53	17.75
18	1.55	18.15
20	1.56	18.54
22	1.58	18.88
26	1.54	24.35

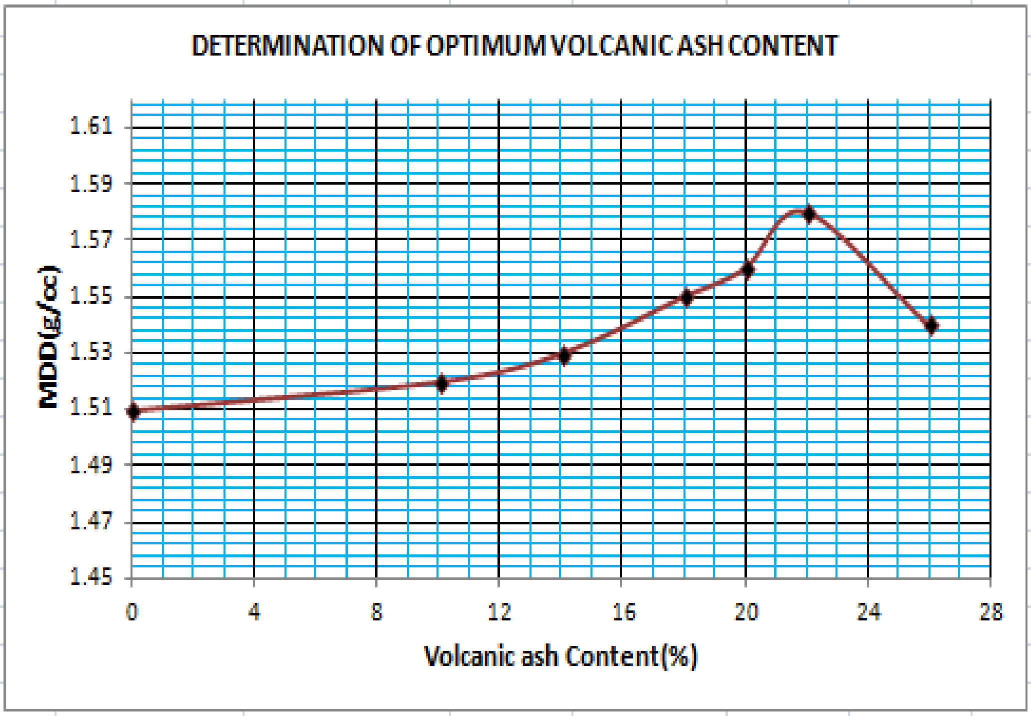


Figure B-7: Determination of optimum volcanic ash content.

Table B–8: Sieve analysis for the blending of cinder gravel with 22% by weight of volcanic ash before compaction.

PARTICLE SIZE DISTRIBUTION BY SIEVING

TEST METHOD: AASHTO T 27

Location:	Mthara /Gorera	REQ. NO.:	
Source:	Volcanic Hill	REF. NO.:	
Material type:	Cinder gravel and Pumice	DATE SAMPLED:	10/1/2015
Sample from:	Volcanic Hill	DATE TESTED:	15/05/2015

No of sample		1			2		Grading modulas	PP	Specification limt	
Dry sample weight Before Washing (g)		6800.0			6701.0					
Dry sample weight After Washing (g)		6388.0			6335.9		2.34			
Inch	Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Passing (%)		
2	50	0.0	6800.0		0.0	6701.0	100.0	100.0	100.0	100.0
1.50	37.5	0.0	6800.0	100.0	0.0	6701.0	100.0	100.0	80.0	100.0
3/4	19	1613.5	5186.6	76.3	1413.6	5287.5	78.9	77.6	60.0	80.0
3/8	9.5	1479.0	3707.6	54.5	1431.4	3856.1	57.5	56.0	45.0	65.0
NO 4	4.75	654.5	3053.1	44.9	690.1	3166.0	47.2	46.1	30.0	50.0
NO 10	2.36	852.0	2201.0	32.4	995.7	2170.3	32.4	32.4	20.0	40.0
NO 40	0.425	705.7	1495.3	22.0	654.5	1515.8	22.6	22.3	10.0	25.0
NO 200	0.075	716.1	779.2	11.5	756.5	759.3	11.3	11.4	5.0	15.0
pan		367.2	0.0		394.1	0.0				
Wash lose		412.0	0.0	0.0	365.2	0.0				
Total		6800.0			6701.0					

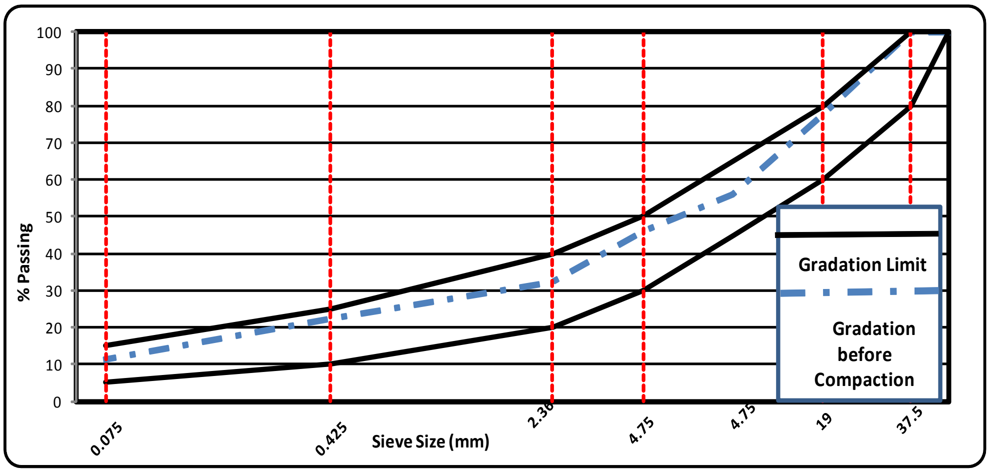


Figure B-8: Sieve analysis for the blending of cinder gravel with 22% by weight of volcanic ash before compaction.

Table B–9: Sieve analysis for the blending of cinder gravel with 22% by weight of volcanic ash after compaction.

PARTICLE SIZE DISTRIBUTION BY SIEVING

TEST METHOD: AASHTO T 27

Location:	Mthara /Gorera	REQ. NO.:	
Source:	Mthara /Gorera	REF. NO.:	
Material type:	Cinder gravel and pumice	DATE SAMPLED:	10/1/2015
Sample from:	Volcanic Hill	DATE TESTED:	16/05/2015

No of sample		1			2		Grading modulas	PP	Specification limt	
Dry sample weight Before Washing (g)		6621.0			7423.0					
Dry sample weight After Washing (g)		6350.6			6970.4		2.30			
Inch	Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Passing (%)		
2.00	50	0.0	6621.0		0.0	7423.0	100.0	100.0	100.0	100.0
1.50	37.5	0.0	6621.0	100.0	0.0	7423.0	100.0	100.0	80.0	100.0
3/4	19	853.3	5767.7	87.1	862.0	6561.0	88.4	87.7	60.0	80.0
3/8	9.5	1539.4	4228.3	63.9	1645.2	4915.8	66.2	65.0	45.0	65.0
NO 4	4.75	1039.3	3189.0	48.2	1217.9	3697.9	49.8	49.0	30.0	50.0
NO 10	2.36	929.9	2259.1	34.1	1109.1	2588.8	34.9	34.5	20.0	40.0
NO 40	0.425	731.2	1527.9	23.1	826.0	1762.8	23.7	23.4	10.0	25.0
NO 200	0.075	771.1	756.8	11.4	868.2	894.6	12.1	11.7	5.0	15.0
pan		486.4	0.0		442.0	0.0				
Wash lose		270.4	0.0	0.0	452.6	0.0				
Total		6621.0			7423.0					

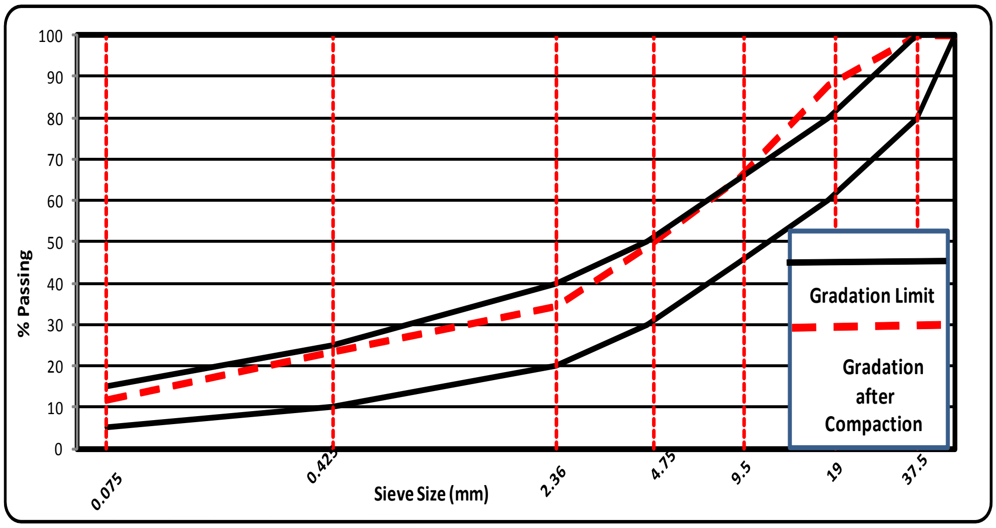


Figure B-9: Sieve analysis for the blending of cinder gravel with 22% by weight of volcanic ash after compaction.

Appendix – C

CBR test results of the blending of cinder & volcanic ash.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 22 % Volcanic ash	Date of soaking:	UNSOAKED
MDD (g/cc):	1.59	Date of Penetration:	24/7/2015
OMC %:	18.2	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		1
		BEFORE
Weight of Soil + Mold, g	a	10265.0
Weight of Mold, g	b	6367.0
Weight of Soil, g	d=a-b	3898.0
Volume of Mold, cc	e	2077.3
Wet Density of Soil, g/cc	f =d/e	1.88
Dry Density of Soil, g/cc	=f/(1+w) **	1.59

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		BY
Wet Soil + Container, g	A	610.06
Dry Soil + Container, g	B	528.50
Weight of Water, g	C=A-B	81.56
Weight of Container, g	D	81.59
Weight of Dry Soil,g	E=B-D	446.91
Moisture Content, %	w=C/E*100	18.2

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration (mm)	56 Blows Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	22	0.49		
1.27	85	1.89		
1.91	225	5.00		
2.54	350	7.78	11.50	166.91%
5.08	740	16.46	18.00	174.08%
7.62	905	20.12		

SWELL

No. of Blows	56		
RDG. (Before Soaking)	345		
RDG. (After Soaking)	351		
Percent Swell	0.05		

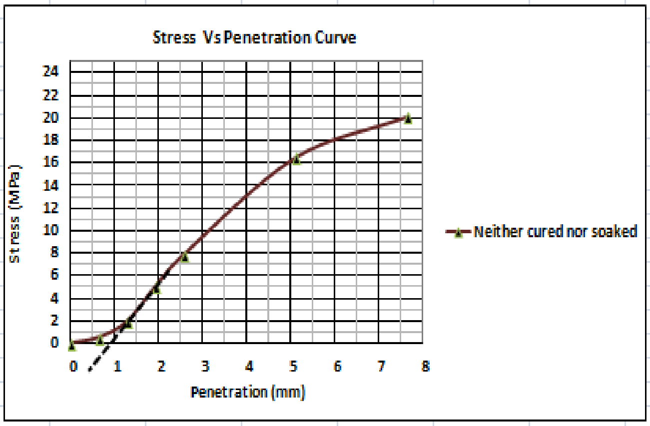


Figure C-1: CBR value for cinder gravel blended with 22% by weight of volcanic ash in which the CBR reading was taken right after the completion of compaction.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel & 22% Volcanic ash	Date of soaking:	14/7/2015
MDD (g/cc):	1.59	Date of Penetration:	18/7/2015
OMC %:	19.1	Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		6	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10193.0	10300.0
Weight of Mold, g	b	6317.0	6317.0
Weight of Soil, g	d=a-b	3876.0	3983.0
Volume of Mold, cc	e	2077.3	2106.7
Wet Density of Soil, g/cc	f =d/e	1.87	1.89
Dry Density of Soil, g/cc	=f/(1+w) **	1.58	1.59

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		B2	P14	P55
Wet Soil + Container, g	A	613.62	2991	2842
Dry Soil + Container, g	B	528.89	2643	2535
Weight of Water, g	C=A-B	84.73	348.00	307.00
Weight of Container, g	D	69.58	856	894
Weight of Dry Soil,g	E=B-D	459.31	1787.00	1641.00
Moisture Content, %	w=C/E*100	18.4	19.5	18.7
			19.1	

Ring Factor 43.04 N/div

PENETRATION TEST DATA				
Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	40	0.89		
1.27	122	2.71		
1.91	228	5.07		
2.54	347	7.72	9.00	130.62%
5.08	630	14.01	15.00	145.07%
7.62	854	18.99		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)	245		
RDG. (After Soaking)	253		
Percent Swell	0.07		

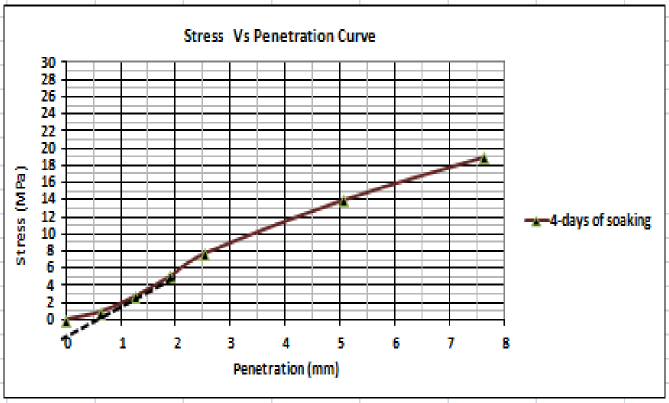


Figure C-2: CBR value for cinder grave blended with 22% by weight of volcanic ash after 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic Hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,22% Volcanic ash.	Date of soaking:	UNSOAKED
MDD (g/cc):	1.58	Date of Penetration:	19/06/2015
OMC %:	18.8	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		56
Weight of Soil + Mold, g	a	10100.0
Weight of Mold, g	b	6144.0
Weight of Soil, g	d=a-b	3956.0
Volume of Mold, cc	e	2110.5
Wet Density of Soil, g/cc	f =d/e	1.87
Dry Density of Soil, g/cc	=f/(1+w) **	1.58

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		B6
Wet Soil + Container, g	A	612.68
Dry Soil + Container, g	B	526.56
Weight of Water, g	C=A-B	86.12
Weight of Container, g	D	69.02
Weight of Dry Soil,g	E=B-D	457.54
Moisture Content, %	w=C/E*100	18.8

Ring Factor 21.58 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	23	0.26		
1.27	245	2.73		
1.91	570	6.36		
2.54	805	8.98	12.00	174.17%
5.08	1435	16.00	17.70	171.18%
7.62	1795	20.01		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

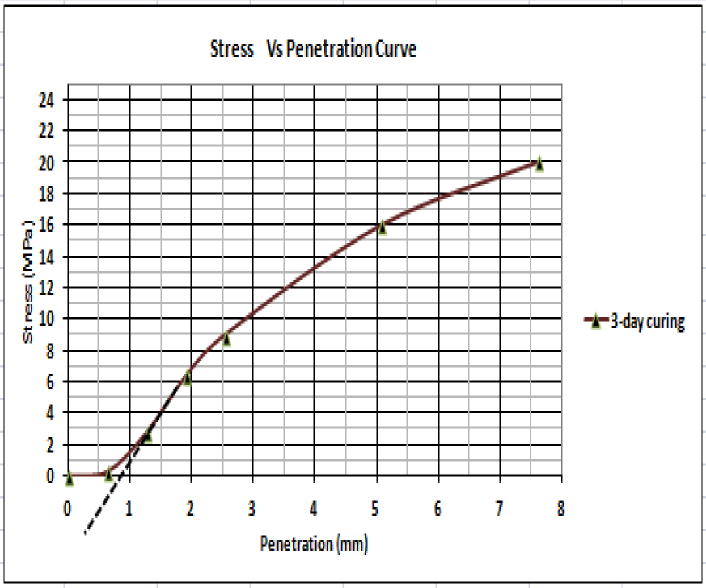


Figure C-3: CBR value for cinder grave blended with 22% by weight of volcanic ash after 3 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic Hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,22% Volcanic ash.	Date of soaking:	19.06.2015
MDD (g/cc):	1.59	Date of Penetration:	23/06/2015
OMC %:	18.7	Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		1	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10232.0	10293.0
Weight of Mold, g	b	6367.0	6367.0
Weight of Soil, g	d=a-b	3865.0	3926.0
Volume of Mold, cc	e	2077.3	2077.3
Wet Density of Soil, g/cc	f=d/e	1.86	1.89
Dry Density of Soil, g/cc	=f/(1+w) **	1.57	1.59

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		B8	P12	P11
Wet Soil + Container, g	A	605.40	3701.00	3057.00
Dry Soil + Container, g	B	522.88	3352.00	2813.00
Weight of Water, g	C=A-B	82.52	349.00	244.00
Weight of Container, g	D	69.50	1497	1496
Weight of Dry Soil,g	E=B-D	453.38	1855.00	1317.00
Moisture Content, %	w=C/E*100	18.2	18.8	18.5
Average Moisture Content(%)			18.7	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	60	1.33		
1.27	145	3.22		
1.91	265	5.89		
2.54	368	8.18	9.00	130.62%
5.08	505	11.23	12.00	116.05%
7.62	645	14.34		

SWELL	
No. of Blows	56
RDG. (Before Soaking)	248
RDG. (After Soaking)	356
Percent Swell	0.93

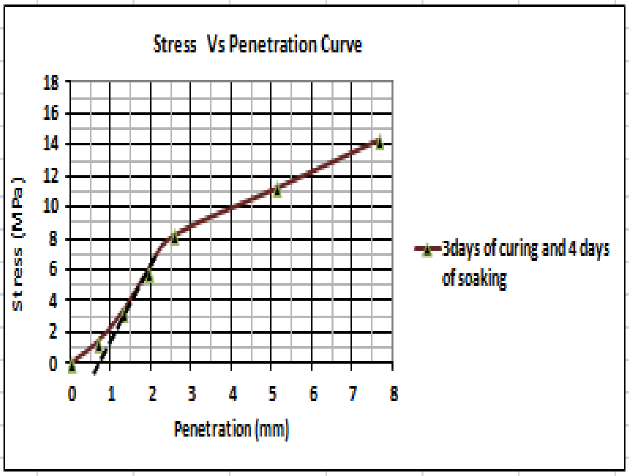


Figure C-4: CBR value for cinder grave blended with 22% by weight of volcanic ash after 3 days of keeping sample inside CBR mold and a further 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic Hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,22% Volcanic ash.	Date of soaking:	UNSOAKED
MDD (g/cc):	1.59	Date of Penetration:	3/7/2015
OMC %:	18.4	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		1
Weight of Soil + Mold, g	a	10278.0
Weight of Mold, g	b	6367.0
Weight of Soil, g	d=a-b	3911.0
Volume of Mold, cc	e	2077.3
Wet Density of Soil, g/cc	f =d/e	1.88
Dry Density of Soil, g/cc	=f/(1+w) **	1.59

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		P12
Wet Soil + Container, g	A	2480.00
Dry Soil + Container, g	B	2327.00
Weight of Water, g	C=A-B	153.00
Weight of Container, g	D	1497.00
Weight of Dry Soil,g	E=B-D	830.00
Moisture Content, %	w=C/E*100	18.4

Ring Factor	43.04 N/div			
PENETRATION TEST DATA				
Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	53	1.18		
1.27	265	5.89		
1.91	415	9.23		
2.54	500	11.12	11.90	172.71%
5.08	657	14.61	15.50	149.90%
7.62	831	18.48		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

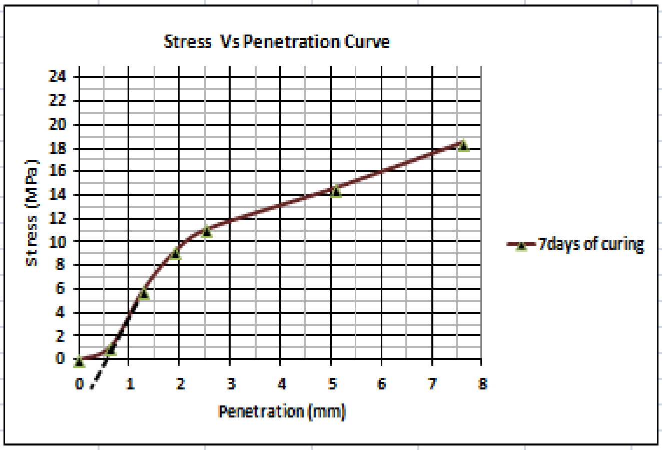


Figure C-5: CBR value for cinder grave blended with 22% by weight of volcanic ash after 7 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,22% Volcanic ash.	Date of soaking:	3/1/2015
MDD (g/cc):	1.59	Date of Penetration:	7/7/2015
OMC %:	18.3	Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		59	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10135.0	10166.0
Weight of Mold, g	b	6210.0	6211.0
Weight of Soil, g	d=a-b	3925.0	3955.0
Volume of Mold, cc	e	2108.6	2109.6
Wet Density of Soil, g/cc	f=d/e	1.86	1.87
Dry Density of Soil, g/cc	=f/(1+w) **	1.57	1.59

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		P11	P13	P33
Wet Soil + Container, g	A	2414.00	2861	2840
Dry Soil + Container, g	B	2270.00	2561	2535
Weight of Water, g	C=A-B	144.00	300.00	305.00
Weight of Container, g	D	1496.00	905	878
Weight of Dry Soil,g	E=B-D	774.00	1656.00	1657.00
Moisture Content, %	w=C/E*100	18.6	18.1	18.4
			18.3	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	48	1.07		
1.27	98	2.18		
1.91	189	4.20		
2.54	315	7.00	10.00	145.14%
5.08	550	12.23	13.50	130.56%
7.62	705	15.68		

SWELL

No. of Blows	56
RDG. (Before Soaking)	1244
RDG. (After Soaking)	1238
Percent Swell	0.05

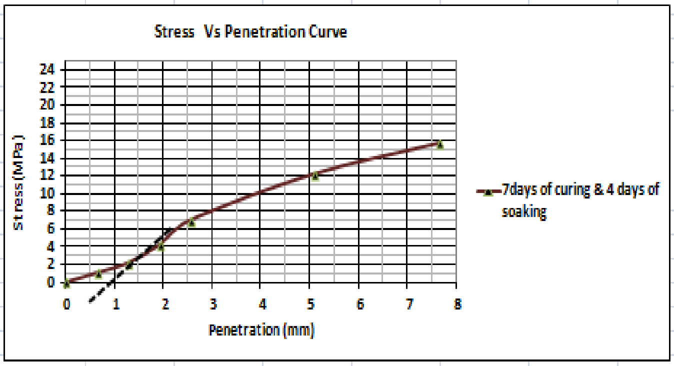


Figure C-6: CBR value for cinder grave blended with 22% by weight of volcanic ash after 7 days of keeping sample inside CBR mold and a further 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel & 22 % Volcanic ash.	Date of soaking:	UNSOAKED
MDD (g/cc):	1.57	Date of Penetration:	7/7/2015
OMC %:	18.4	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		2
Weight of Soil + Mold, g	a	10020.0
Weight of Mold, g	b	6169.0
Weight of Soil, g	d=a-b	3851.0
Volume of Mold, cc	e	2077.3
Wet Density of Soil, g/cc	f =d/e	1.85
Dry Density of Soil, g/cc	=f/(1+w) **	1.57

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		B3
Wet Soil + Container, g	A	614.93
Dry Soil + Container, g	B	531.94
Weight of Water, g	C=A-B	82.99
Weight of Container, g	D	81.63
Weight of Dry Soil,g	E=B-D	450.31
Moisture Content, %	w=C/E*100	18.4

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	53	1.18		
1.27	145	3.22		
1.91	317	7.05		
2.54	445	9.90	12.00	174.17%
5.08	695	15.45	17.00	164.41%
7.62	839	18.66		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

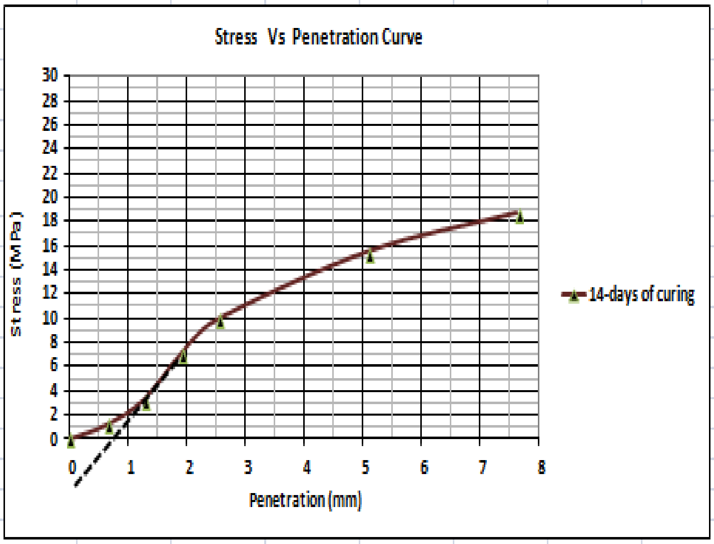


Figure C-7: CBR value for cinder grave blended with 22% by weight of volcanic ash after 14 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel &22% volcanic ash	Date of soaking:	7/7/2015
MDD (g/cc):	1.59	Date of Penetration:	11/7/2015
OMC %:	19.0	Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		5	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10290.0	10315.0
Weight of Mold, g	b	6395.0	6395.0
Weight of Soil, g	d=a-b	3895.0	3920.0
Volume of Mold, cc	e	2077.3	2077.3
Wet Density of Soil, g/cc	f =d/e	1.88	1.89
Dry Density of Soil, g/cc	=f/(1+w) **	1.58	1.59

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		B3	P2	P1
Wet Soil + Container, g	A	614.93	3015	3845
Dry Soil + Container, g	B	531.94	2763.00	3485.00
Weight of Water, g	C=A-B	82.99	252.00	360.00
Weight of Container, g	D	81.63	1496.00	1497.00
Weight of Dry Soil,g	E=B-D	450.31	1267.00	1988.00
Moisture Content, %	w=C/E*100	18.4	19.89	18.11
			19.0	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	49	1.09		
1.27	120	2.67		
1.91	215	4.78		
2.54	325	7.23	9.00	130.62%
5.08	525	11.67	12.50	120.89%
7.62	613	13.63		

SWELL	
No. of Blows	56
RDG. (Before Soaking)	935
RDG. (After Soaking)	938
Percent Swell	0.03

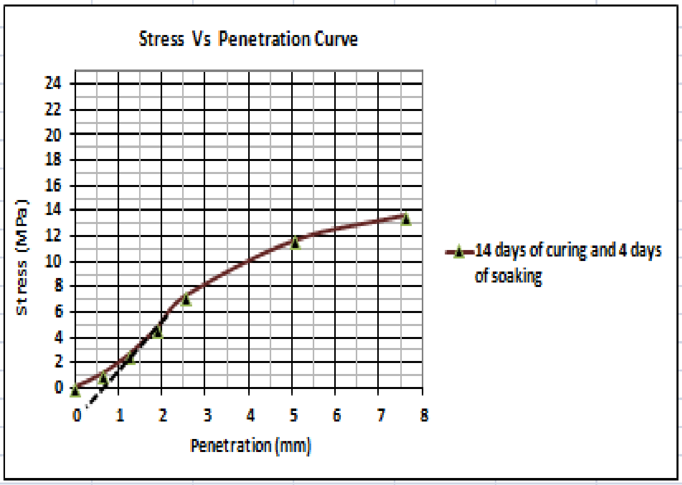


Figure C-8: CBR value for cinder grave blended with 22% by weight of volcanic ash after 14 days of keeping sample inside CBR mold and a further 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,22% Volcanic ash.	Date of soaking:	UNSOAKED
MDD (g/cc):	1.58	Date of Penetration:	2/7/2015
OMC %:	18.4	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		4
Weight of Soil + Mold, g	a	10400.0
Weight of Mold, g	b	6509.0
Weight of Soil, g	d=a-b	3891.0
Volume of Mold, cc	e	2077.3
Wet Density of Soil, g/cc	f =d/e	1.87
Dry Density of Soil, g/cc	=f/(1+w) **	1.58

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		R8
Wet Soil + Container, g	A	616.14
Dry Soil + Container, g	B	530.83
Weight of Water, g	C=A-B	85.31
Weight of Container, g	D	68.05
Weight of Dry Soil,g	E=B-D	462.78
Moisture Content, %	w=C/E*100	18.4

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	100	2.22		
1.27	200	4.45		
1.91	304	6.76		
2.54	404	8.98	8.98	130.33%
5.08	791	17.59	17.59	170.12%
7.62	959	21.33		

SWELL

No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

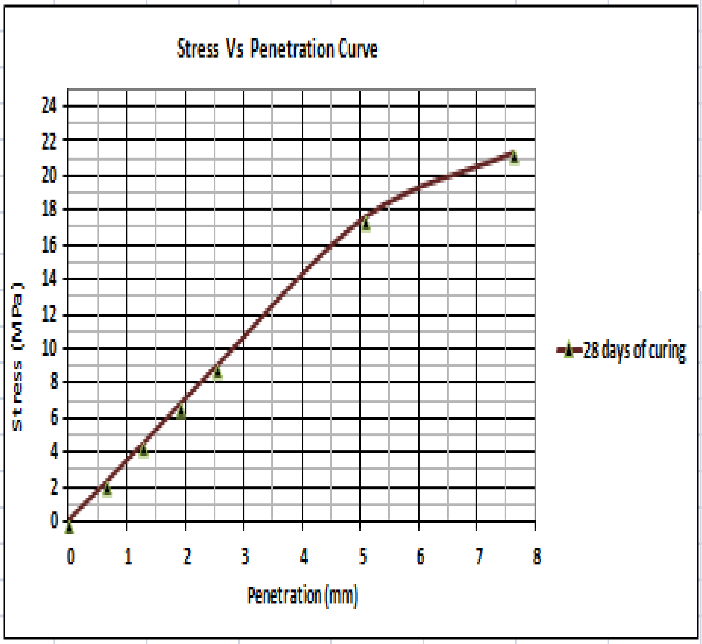


Figure C-9: CBR value for cinder grave blended with 22% by weight of volcanic ash after 28 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,22% Volcanic ash.	Date of soaking:	2/7/2015
MDD (g/cc):	1.58	Date of Penetration:	6/7/2015
OMC %:	18.6	Test ID:	

DENSITY DETERMINATION

		56Blows	
		BEFORE	AFTER
Moulder No.		50	
Weight of Soil + Mold, g	a	10065.0	10095.0
Weight of Mold, g	b	6142.0	6142.0
Weight of Soil, g	d=a-b	3923.0	3953.0
Volume of Mold, cc	e	2111.3	2111.3
Wet Density of Soil, g/cc	f =d/e	1.86	1.87
Dry Density of Soil, g/cc	-f/(1+w) **	1.57	1.58

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		D1	P13	P14
Wet Soil + Container, g	A	618.25	2961.00	2681
Dry Soil + Container, g	B	532.83	2637.00	2395
Weight of Water, g	C=A-B	85.42	324.00	286.00
Weight of Container, g	D	70.74	905.00	856.00
Weight of Dry Soil,g	E=B-D	462.09	1732.00	1539.00
Moisture Content, %	w=C/E*100	18.5	18.7	18.6
			18.6	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	23	0.51		
1.27	62	1.38		
1.91	170	3.78		
2.54	295	6.56	9.00	130.62%
5.08	485	10.79	13.00	125.73%
7.62	717	15.94		

SWELL

No. of Blows	56
RDG. (Before Soaking)	665
RDG. (After Soaking)	667
Percent Swell	0.02

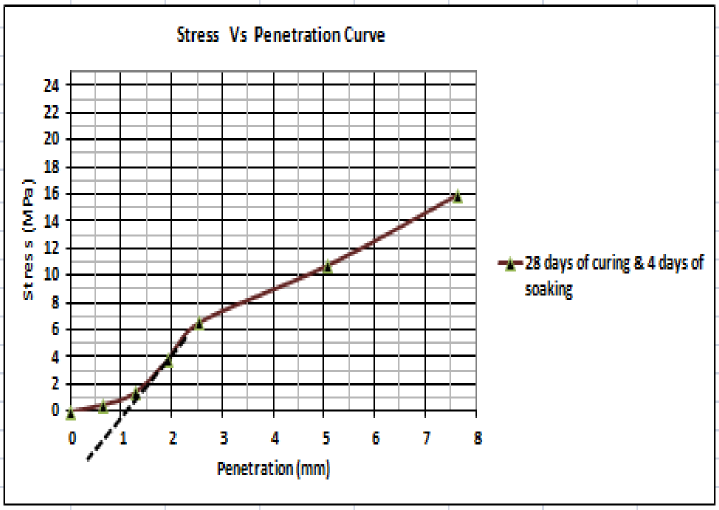


Figure C-10: CBR value for cinder grave blended with 22% by weight of volcanic ash after 28 days of keeping sample inside CBR mold and a further 4 days of soaking.

Table C-1: Investigation of the effect of duration of keeping sample inside CBR mold on CBR value.

	Cinder +Volcanic Ash	
Days of keeping sample inside CBR mold	Unsoaked	Soaked
0	174.1	145.1
3	174.2	130.6
7	172.7	145.1
14	174.2	130.6
28	170.1	130.6

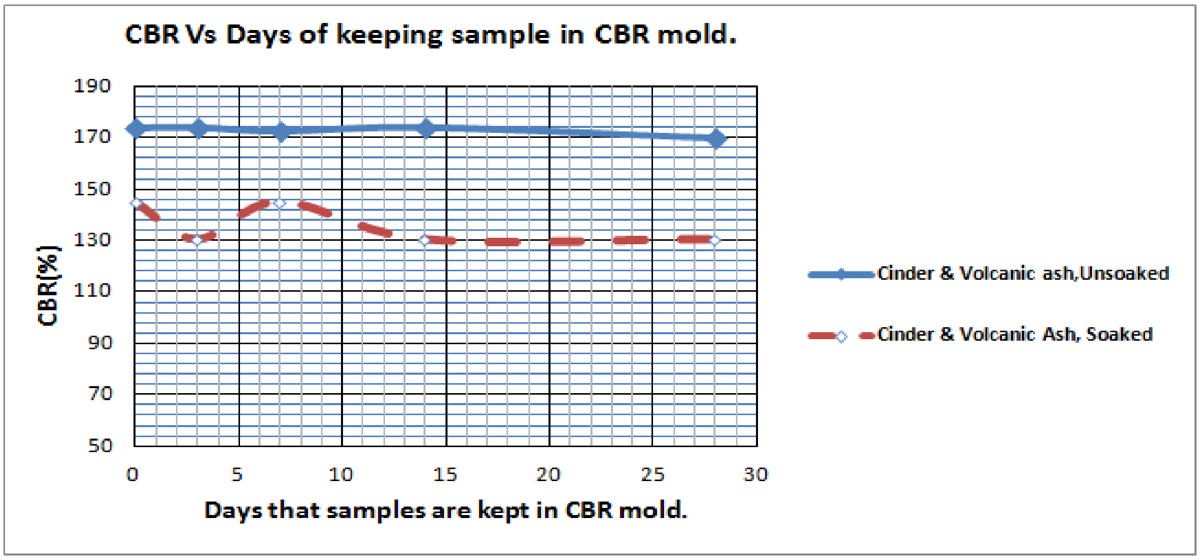


Figure C-11: Investigation of the effect of duration of keeping sample inside CBR mold on CBR.

Appendix –D

CBR test results of the blending of Cinder, volcanic ash& lime.

Table D–1: Relationship between moisture and density for cinder gravel blended with 20%by weight of volcanic ash and 2% by weight of lime.

ETHIOPIAN ROADS AUTHORITY
ROAD RESEARCH CENTER

MOISTURE DENSITY RELATIONS OF THE SOIL

TEST METHOD : AASHTO T 180-97, Method D

Location:	Methehara /Gorera	**Lab.Ref.No :**	
Source:	Methehara /Gorera	**Request.No:**	
Material type:	Cider blended with Pumice & Lime	**Date sample:**	10/1/2015
Sample from:	Volcanic Hilll	**Date test:**	10/6/2015

Wt mold+sample(g)	10250	10425	10525	10507		
Wt of mold(g)	6475	6475	6475	6475		
Wt of sample(g)	3775	3950	4050	4032		
Volume of mold(cm)^3	2108.55	2108.55	2108.55	2108.55		
Wet density (g/cc)	1.79	1.873	1.921	1.912		
tare No	B1	B10	B9	B12		
Wt tare+sample(g)	603.25	650	570.83	574.62		
Wt tare+dry sample(g)	530.3	560	489.4	480.25		
Wet of water(g)	72.95	90	81.43	94.37		
Wet of tare(g)	79.2	74.56	68.77	78.55		
Wet of dry sample(g)	451.1	485.44	420.63	401.7		
Moisture content(%)	16.2	18.5	19.4	23.5		
Dry density(g/cc)	1.54	1.58	1.61	1.55		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.61	19.4	5

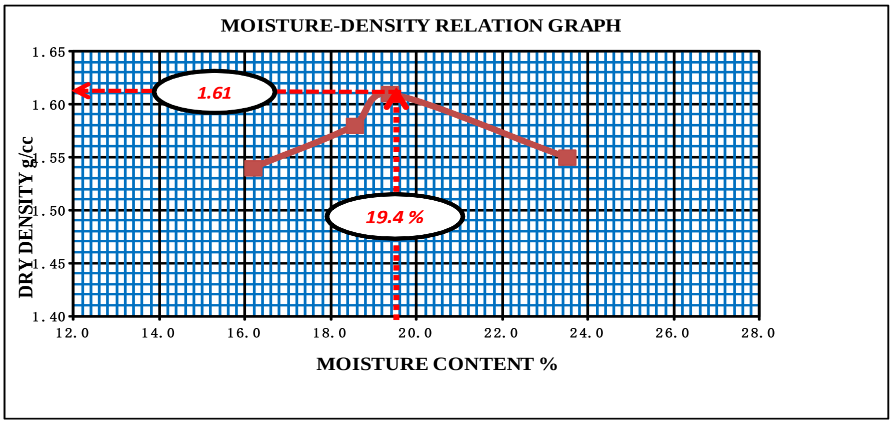


Figure D-1: Relationship between moisture and density for cinder gravel blended with 20% by weight of volcanic ash and 2% by weight of lime.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 20 %Pumice & 2% Lime	Date of soaking:	UNSOAKED
MDD (g/cc):	1.61	Date of Penetration:	29/7/2015
OMC %:	19.5	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		4
		BEFORE
Weight of Soil + Mold, g	a	10558.0
Weight of Mold, g	b	6569.0
Weight of Soil, g	d=a-b	3989.0
Volume of Mold, cc	e	2077.3
Wet Density of Soil, g/cc	f =d/e	1.92
Dry Density of Soil, g/cc	=f/(1+w) **	1.61

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
		BEFORE
Container No.		BY
Wet Soil + Container, g	A	618.06
Dry Soil + Container, g	B	530.59
Weight of Water, g	C=A-B	87.47
Weight of Container, g	D	81.59
Weight of Dry Soil,g	E=B-D	449.00
Moisture Content, %	w=C/E*100	19.5

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	18	0.40		
1.27	78	1.73		
1.91	180	4.00		
2.54	305	6.78	10.00	145.14%
5.08	750	16.68	18.00	174.08%
7.62	905	20.12		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

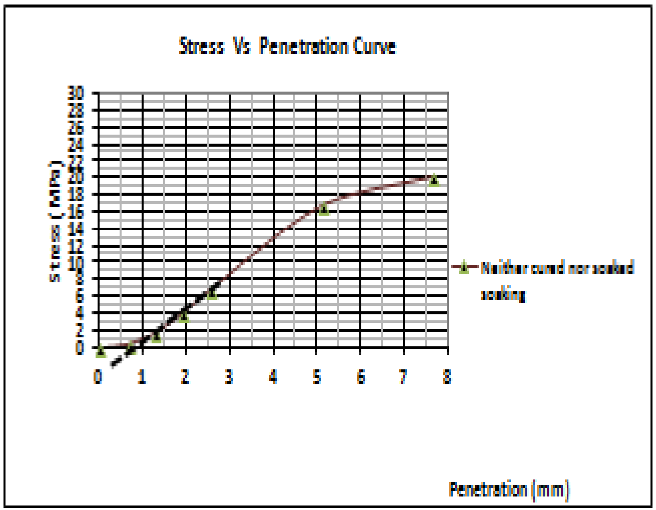


Figure D-2: CBR value for cinder gravel blended with 20% by Wt of volcanic ash and 2% by Wt of lime in which the CBR reading was taken right after the completion of compaction.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 20 % Volcanic ash & 2% Lime	Date of soaking:	14/7/2015
MDD (g/cc): 1.60		Date of Penetration:	18/7/2015
OMC %: 19.0		Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		3	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10305.0	10315.0
Weight of Mold, g	b	6366.0	6366.0
Weight of Soil, g	d=a-b	3939.0	3949.0
Volume of Mold, cc	e	2077.3	2077.3
Wet Density of Soil, g/cc	f =d/e	1.90	1.90
Dry Density of Soil, g/cc	=f/(1+w) **	1.59	1.60

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		BY	P13	P33
Wet Soil + Container, g	A	619.92	3161	2755
Dry Soil + Container, g	B	530.59	2800	2455
Weight of Water, g	C=A-B	89.33	361.00	300.00
Weight of Container, g	D	70.96	905	878
Weight of Dry Soil,g	E=B-D	459.63	1895.00	1577.00
Moisture Content, %	w=C/E*100	19.4	19.1	19.0
			19.0	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	13	0.29		
1.27	55	1.22		
1.91	138	3.07		
2.54	265	5.89	10.50	152.39%
5.08	710	15.79	19.00	183.75%
7.62	1015	22.57		

SWELL	
No. of Blows	56
RDG. (Before Soaking)	345
RDG. (After Soaking)	354
Percent Swell	0.08

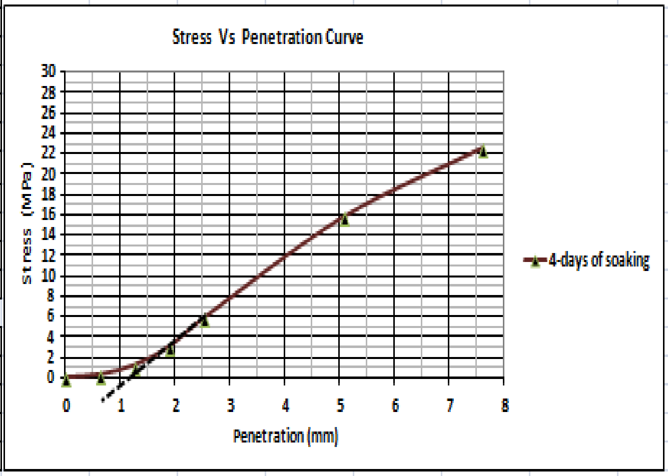


Figure D-3: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,20% Volcanic ash &2% Lime	Date of soaking:	UNSOAKED
MDD (g/cc):	1.60	Date of Penetration:	2/7/2015
OMC %:	19.20	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		62
Weight of Soil + Mold, g	a	10205.0
Weight of Mold, g	b	6235.0
Weight of Soil, g	d=a-b	3970.0
Volume of Mold, cc	e	2077.3
Wet Density of Soil, g/cc	f =d/e	1.91
Dry Density of Soil, g/cc	=f/(1+w) **	1.60

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		B7
Wet Soil + Container, g	A	616.17
Dry Soil + Container, g	B	529.36
Weight of Water, g	C=A-B	86.81
Weight of Container, g	D	77.48
Weight of Dry Soil,g	E=B-D	451.88
Moisture Content, %	w=C/E*100	19.2

Ring Factor 21.58 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	75	0.84		
1.27	490	5.46		
1.91	850	9.48		
2.54	1115	12.43	13.00	188.68%
5.08	1395	15.55	16.00	154.74%
7.62	1490	16.61		

SWELL

No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

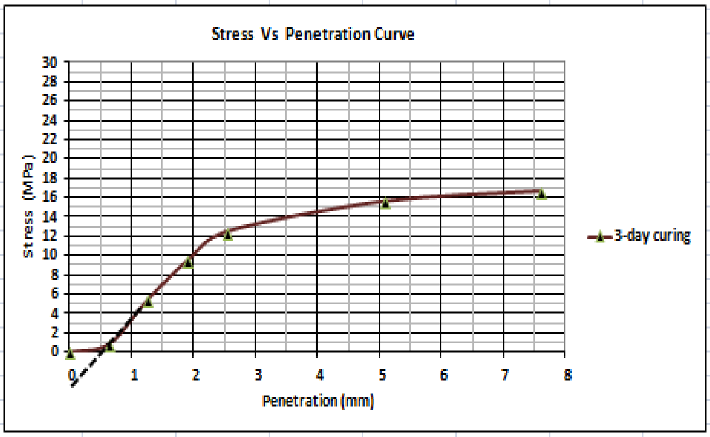


Figure D-4: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 3 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,20% Volcanic ash & 2% Lime	Date of soaking:	04.07.2015
MDD (g/cc):	1.61	Date of Penetration:	11/7/2015
OMC %:	19.4	Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		4	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10500.0	10520.0
Weight of Mold, g	b	6509.0	6509.0
Weight of Soil, g	d=a-b	3991.0	4011.0
Volume of Mold, cc	e	2077.31	2077.31
Wet Density of Soil, g/cc	f =d/e	1.92	1.93
Dry Density of Soil, g/cc	=f/(1+w) **	1.61	1.62

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		B12	P13	P31
Wet Soil + Container, g	A	617.32	2992.00	3306.00
Dry Soil + Container, g	B	530.38	2650.00	3022.00
Weight of Water, g	C=A-B	86.94	342.00	284.00
Weight of Container, g	D	78.56	905.00	1538.00
Weight of Dry Soil,g	E=B-D	451.82	1745.00	1484.00
Moisture Content, %	w=C/E*100	19.2	19.6	19.1
			19.4	

Ring Factor 21.58 N/div

PENETRATION TEST DATA

Penetration (mm)	56 Blows Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	145	1.62		
1.27	590	6.58		
1.91	910	10.15		
2.54	1120	12.49	13.50	195.94%
5.08	1620	18.06	18.00	174.08%
7.62	1990	22.19		

SWELL

No. of Blows	56
RDG. (Before Soaking)	1000
RDG. (After Soaking)	1003
Percent Swell	0.03

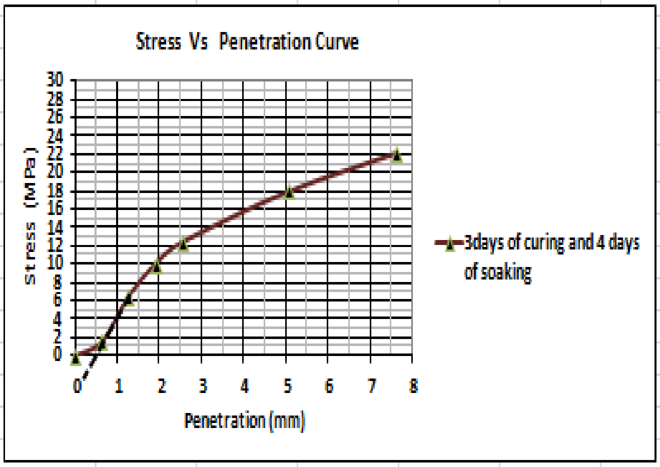


Figure D-5: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 3 days of keeping sample inside CBR mold and a further 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 20 % Volcanic ash & 2% Lime	Date of soaking:	UNSOAKED
MDD (g/cc):	1.61	Date of Penetration:	18/06/2015
OMC %:	19.3	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		62
Weight of Soil + Mold, g	a	10285.0
Weight of Mold, g	b	6235.0
Weight of Soil, g	d=a-b	4050.0
Volume of Mold, cc	c	2104.9
Wet Density of Soil, g/cc	f =d/c	1.92
Dry Density of Soil, g/cc	=f/(1+w) **	1.61

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		B7
Wet Soil + Container, g	A	613.17
Dry Soil + Container, g	B	526.36
Weight of Water, g	C=A-B	86.81
Weight of Container, g	D	77.48
Weight of Dry Soil,g	E=B-D	448.88
Moisture Content, %	w=C/E*100	19.3

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	60	1.33		
1.27	138	3.07		
1.91	228	5.07		
2.54	323	7.18	12.00	174.17%
5.08	849	18.88	20.00	193.42%
7.62	912	20.28		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

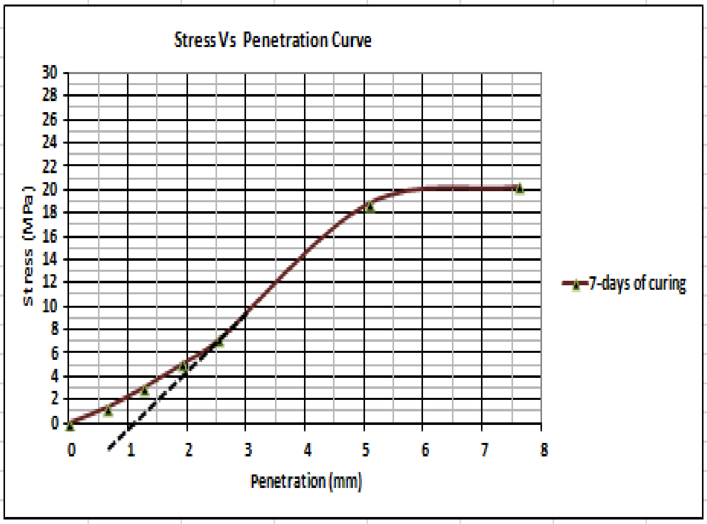


Figure D-6: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 7 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 20 % Volcanic ash & 2% Lime	Date of soaking:	7/7/2015
MDD (g/cc):	1.61	Date of Penetration:	11/7/2015
OMC %:	19.4	Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		60	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10100.0	10122.0
Weight of Mold, g	b	6040.0	6040.0
Weight of Soil, g	d=a-b	4060.0	4082.0
Volume of Mold, cc	e	2108.55	2108.55
Wet Density of Soil, g/cc	f =d/e	1.93	1.94
Dry Density of Soil, g/cc	=f/(1+w) **	1.61	1.62

** w is moisture content in fraction

MOISTURE DETERMINATION

			56 Blows	
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		B12	P13	P14
Wet Soil + Container, g	A	614.42	3034.00	2739.00
Dry Soil + Container, g	B	525.38	2685.00	2443.00
Weight of Water, g	C=A-B	89.04	349.00	296.00
Weight of Container, g	D	78.56	905.00	907.00
Weight of Dry Soil,g	E=B-D	446.82	1780.00	1536.00
Moisture Content, %	w=C/E*100	19.9	19.6	19.3
			19.4	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	95	2.11		
1.27	275	6.12		
1.91	445	9.90		
2.54	560	12.45	14.00	203.19%
5.08	845	18.79	20.00	193.42%
7.62	1035	23.02		

SWELL

No. of Blows	56		
RDG. (Before Soaking)	251		
RDG. (After Soaking)	253		
Percent Swell	0.02		

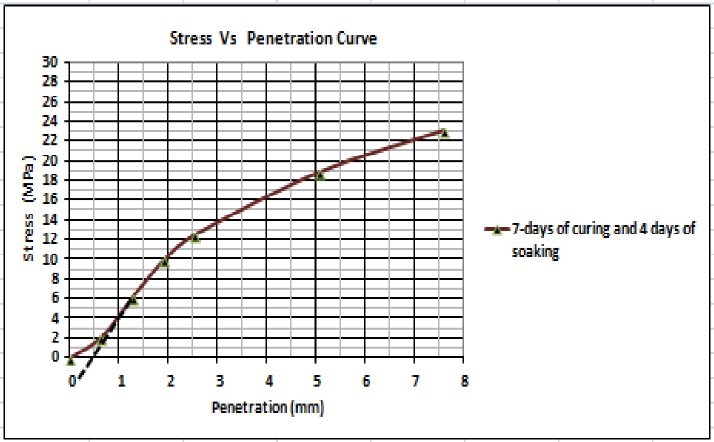


Figure D-7: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 7 days of keeping sample inside CBR mold and a further 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,20% Volcanic ash & 2% Lime	Date of soaking:	UNSOAKED
MDD (g/cc):	1.61	Date of Penetration:	4/7/2015
OMC %:	19.0	Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		6
Weight of Soil + Mold, g	a	10225.0
Weight of Mold, g	b	6235.0
Weight of Soil, g	d=a-b	3990.0
Volume of Mold, cc	c	2077.3
Wet Density of Soil, g/cc	f =d/c	1.92
Dry Density of Soil, g/cc	=f/(1+w) **	1.61

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		B3
Wet Soil + Container, g	A	615.12
Dry Soil + Container, g	B	529.92
Weight of Water, g	C=A-B	85.20
Weight of Container, g	D	81.63
Weight of Dry Soil,g	E=B-D	448.29
Moisture Content, %	w=C/E*100	19.0

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	85	1.89		
1.27	275	6.12		
1.91	475	10.56		
2.54	590	13.12	14.00	203.19%
5.08	825	18.35	19.00	183.75%
7.62	945	21.01		

SWELL

No. of Blows			
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

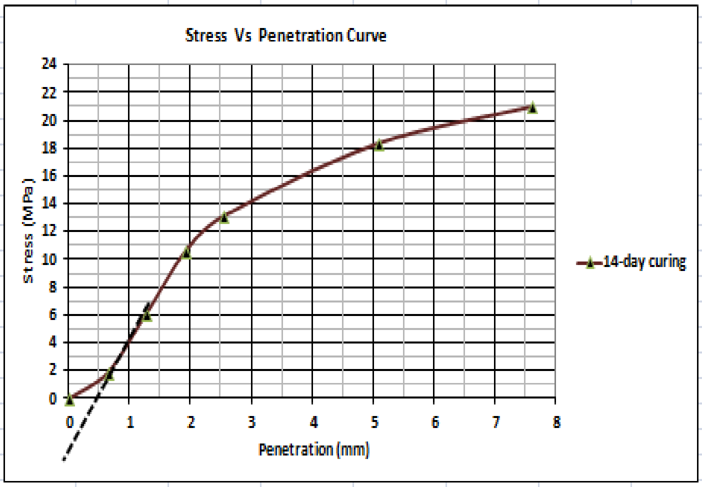


Figure D-8: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 14 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel,20%Volcanic ash &2% Lime	Date of soaking:	30/0./2015
MDD (g/cc):	1.62	Date of Penetration:	4/7/2015
OMC %:	19.6	Test ID:	

DENSITY DETERMINATION

		56Blows BEFORE	56Blows AFTER
Moulder No.		3	
Weight of Soil + Mold, g	a	10325.0	10342.0
Weight of Mold, g	b	6317.0	6317.0
Weight of Soil, g	d=a-b	4008.0	4025.0
Volume of Mold, cc	e	2077.3	2077.3
Wet Density of Soil, g/cc	f =d/e	1.93	1.94
Dry Density of Soil, g/cc	=f/(1+w) **	1.61	1.62

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows BEFORE	56 Blows AFTER TOP	56 Blows AFTER BOTTOM
Container No.		BY	P12	P11
Wet Soil + Container, g	A	617.25	3161	3679
Dry Soil + Container, g	B	529.78	2885	3325
Weight of Water, g	C=A-B	87.47	276.00	354.00
Weight of Container, g	D	81.63	1496	1497
Weight of Dry Soil,g	E=B-D	448.15	1389.00	1828.00
Moisture Content, %	w=C/E*100	19.5	19.9	19.4
Average Moisture Content(%)			19.6	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration (mm)	56 Blows Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	32	0.71		
1.27	103	2.29		
1.91	203	4.51		
2.54	344	7.65	11.00	159.65%
5.08	897	19.95	22.50	217.60%
7.62	1137	25.28		

SWELL

No. of Blows	56
RDG. (Before Soaking)	1261
RDG. (After Soaking)	1264
Percent Swell	0.03

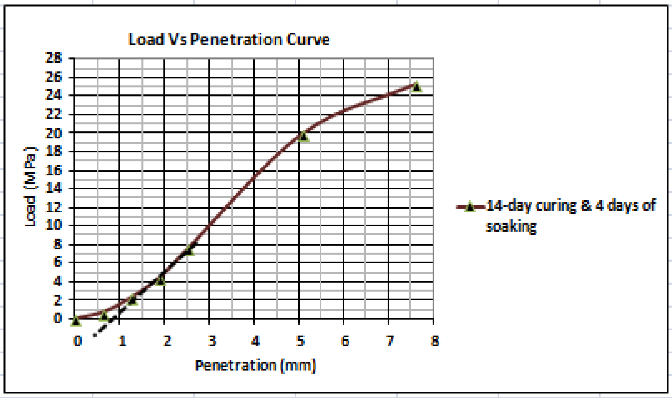


Figure D-9: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 14 days of keeping sample inside CBR mold and a further 4 days of soaking.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 20 % Volcanic ash & 2% Lime	Date of soaking:	UNSAOKED
MDD (g/cc): 1.61		Date of Penetration:	6/7/2015
OMC %: 19.3		Test ID:	

DENSITY DETERMINATION

		56Blows
Moulder No.		54
Weight of Soil + Mold, g	a	10535.0
Weight of Mold, g	b	6475.0
Weight of Soil, g	d=a-b	4060.0
Volume of Mold, cc	e	2108.6
Wet Density of Soil, g/cc	f =d/e	1.93
Dry Density of Soil, g/cc	=f/(1+w) **	1.61

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows
Container No.		R8
Wet Soil + Container, g	A	617.09
Dry Soil + Container, g	B	528.40
Weight of Water, g	C=A-B	88.69
Weight of Container, g	D	68.05
Weight of Dry Soil,g	E=B-D	460.35
Moisture Content, %	w=C/E*100	19.3

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	65	1.45		
1.27	170	3.78		
1.91	345	7.67		
2.54	530	11.79	15.00	217.71%
5.08	915	20.35	22.00	212.77%
7.62	1154	25.66		

SWELL			
No. of Blows	56		
RDG. (Before Soaking)			
RDG. (After Soaking)			
Percent Swell			

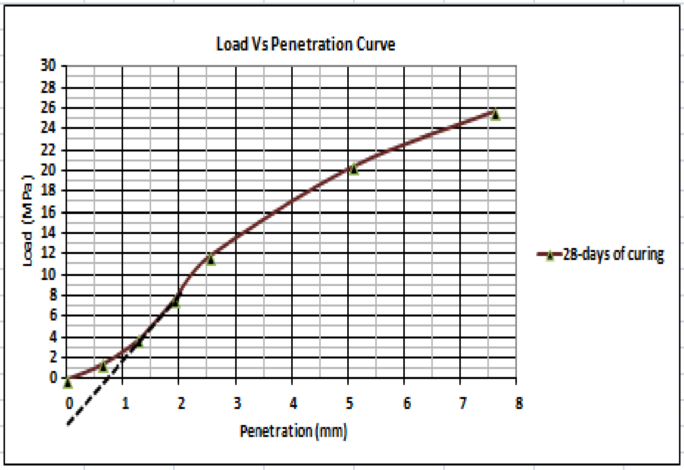


Figure D-10: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 28 days of keeping sample inside CBR mold.

TEST METHOD : AASHTO T 193-99

Source:	Volcanic hill around Methehara	Date Sampled:	10/1/2015
Material Description:	Cinder Gravel , 20 % Volcanic ash & 2% Lime	Date of soaking:	2/7/2015
MDD (g/cc): 1.62		Date of Penetration:	6/7/2015
OMC %: 19.3		Test ID:	

DENSITY DETERMINATION

		56Blows	
Moulder No.		57	
		BEFORE	AFTER
Weight of Soil + Mold, g	a	10242.0	10268.0
Weight of Mold, g	b	6200.0	6200.0
Weight of Soil, g	d=a-b	4042.0	4068.0
Volume of Mold, cc	e	2106.7	2106.7
Wet Density of Soil, g/cc	f =d/e	1.92	1.93
Dry Density of Soil, g/cc	=f/(1+w) **	1.60	1.62

** w is moisture content in fraction

MOISTURE DETERMINATION

		56 Blows		
		BEFORE	AFTER	
			TOP	BOTTOM
Container No.		R8	P15	P14
Wet Soil + Container, g	A	607.09	2306.00	3429.00
Dry Soil + Container, g	B	518.40	2075.00	3012.00
Weight of Water, g	C=A-B	88.69	231.00	417.00
Weight of Container, g	D	68.05	870.00	856.00
Weight of Dry Soil,g	E=B-D	450.35	1205.00	2156.00
Moisture Content, %	w=C/E*100	19.7	19.17	19.34
			19.3	

Ring Factor 43.04 N/div

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Rdg.	Load,Mpa	COR.Load	CBR %
0	0	0.00		
0.64	127	2.82		
1.27	290	6.45		
1.91	420	9.34		
2.54	555	12.34	12.34	179.10%
5.08	1050	23.35	23.35	225.82%
7.62	1260	28.02		

SWELL

No. of Blows	56
RDG. (Before Soaking)	452
RDG. (After Soaking)	454
Percent Swell	0.02

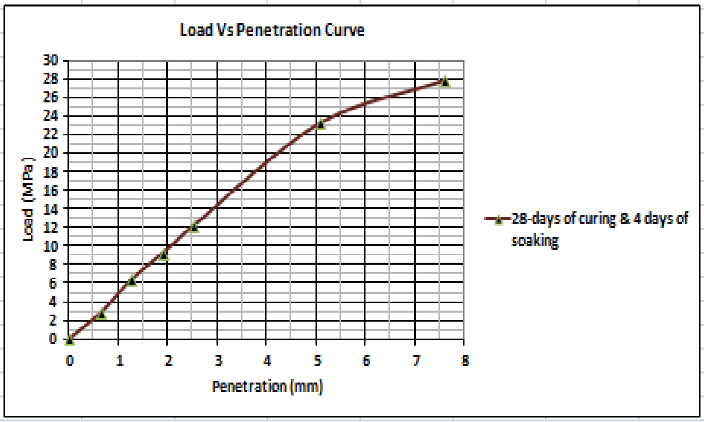


Figure D-11: CBR value for cinder grave blended with 20% by weight of volcanic ash and 2% by weight of lime after 28 days of keeping sample inside CBR mold and a further 4 days of soaking.

Table D-2: Effect of duration of keeping sample inside CBR mold on CBR value of cinder gravel blended with 20% by weight of volcanic ash and 2% by weight of lime.

	Cinder +Volcanic Ash +Lime	
Days of keeping sample inside CBR mold	Unsoaked	Soaked
0	174.1	183.8
3	188.7	195.9
7	193.4	203.2
14	203.2	217.6
28	217.7	225.8

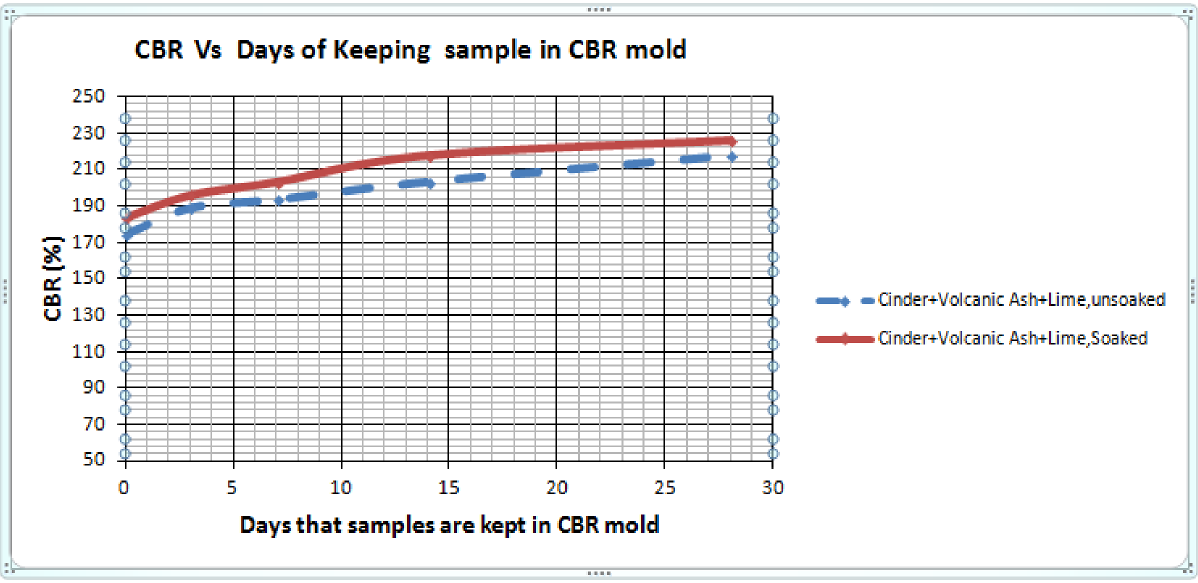


Figure D-12: Effect of duration of keeping sample inside CBR mold on CBR of cinder gravel blended with 20% by weight of volcanic ash and 2% by weight of lime.

Appendix–E

Screen shot and picture

Figure E-1: Metehara area, a screen shot taken at 8:00pm on the 16th of November 2015.

Figure E-2: Cinder cone in which black and reddish brown cinder gravels are observed in layers.

DECLARATION

I hereby declare that the work which is being presented in this thesis entitles **"THE POTENTIAL USE OF CINDER GRAVELS AS A BASECOURSE MATERIAL WHEN STABILIZED BY VOLCANIC ASH AND LIME. (The case of Metehara area)"** is original work of my own, has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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Zerai Hadera Date

(Candidate)

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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Prof. Alemayehu Teferra Date

(Thesis Advisor)