



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
School of Civil and Environmental Engineering

The Use of Natural Pozzolana (Volcanic Ash) to Stabilize Cinder
Gravel for a Road Base
(Along Modjo - Ziway Route)

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the
Requirement for Degree of Masters of Science in Geotechnical Engineering

By

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Advisor

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Addis Ababa

Ethiopia

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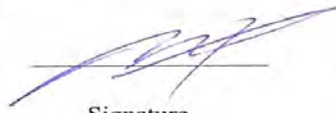
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A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirement
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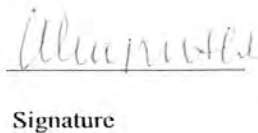
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SYMBOLS AND ABBREVIATION

| | |
|--------|--|
| AACRA | Addis Ababa City Road Authority |
| AASHTO | American Association of Highway and Transportation Officials |
| ASTM | American Society for Testing and Materials |
| CBR | California Bearing Ratio |
| DD | Dry Density |
| E | Easting |
| ERA | Ethiopia Road Authority |
| ESA | Equivalent Axle Load |
| GPS | Global Position System |
| GB | Granular Base |
| LAA | Los Angeles Abrasion |
| MDD | Maximum Dry Density |
| N | Northing |
| NNE | North-North East |
| NP | Non-Plastic |
| OMC | Optimum Moisture Content |
| ONRS | Oromia National Regional State |
| PI | Plastic Index |
| PM | Plastic Modulus |
| SAI | Strength Activity Index |
| TRRL | Transport and Road Research Laboratory |
| UCS | Unconfined Compressive Strength |
| UK | United Kingdom |
| VPD | Vehicles per Day |

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ABSTRACT

In road construction using locally available materials plays a significant role in cost and time saving of road construction projects.

Cinder gravel is abundantly available in different parts of Ethiopia. However, its use has been to limited purposes due to its light weight, rough surfaces and high porosity. In this study two types of Natural Pozzolana's were collected from Ziway Area. One was Pumice (coarser) and the other was volcanic ash (Pumicite). Pozzolanicity test was conducted on both samples using strength activity index test. For the Pumice the strength activity index value was 89.17% while for the volcanic ash (Pumicite) it was 76.43%. Since the volcanic ash (Pumicite) satisfies the minimum requirement for pozzolanicity and is finer, it was used as a stabilizer. From the unconfined compression test conducted on two specimens of the volcanic ash (Pumicite), the average UCS value increases from 84.65 kPa to 266.63 kPa for 3 and 7 curing days, respectively.

The cinder gravel is blended with 0, 4, 8, 12, 16, 20, and 24% by mass of volcanic ash (Pumicite). Compaction, California Bearing Ratio, Gradation, Atterberg limit, Los Angeles Abrasion, Aggregate Crushing Value, Ten Percent Fines Value, Absorption and Specific gravity tests were conducted in the laboratory.

From the laboratory test results of moisture content vs. density relationship, it has been observed that the optimum amount of natural pozzolana (volcanic ash) is 20% by mass proportion at a density of 1.76g/cc. Air curing technique was used for the soaked and unsoaked condition where the stabilized samples were covered with a polyethylene sheet and kept in a normal air temperature and out of water intrusion during the a curing period of zero, three, seven, fourteen and twenty eight days. For the optimum blending proportion; the range of soaked CBR increases from 98% to 245% whereas for the unsoaked condition the CBR increases from 118% to 307%, for 0 to 28 days curing.

Key Words: Air Curing, CBR, Cinder Gravel, Compaction, Natural Pozzolana, Unconfined Compression

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Cinder is a volcanic, non-cohesive and weak gravel material which is widely available in the main rift valley of Ethiopia. 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. 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 0.5m in diameter to sand and silt sizes. In some cones, however, particles may be more uniform with the largest size not exceeding 30mm in diameter. Other characteristic features of cinder are their light weight, their rough vascular surface and their high porosity. Usually they are weak enough to be crushed under the heel [12]. An advantage 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 [12]. But cinder gravels are deficient of fine material, as a result of this, they are porous materials with non-conformity to conventional gradations for sub-base and road base and they are difficult to compact. Previous researches have been conducted on cinder gravels jointly by Ethiopian Transport Construction Authority and Road research laboratory (UK) to devise a specification to use as a road construction material for light traffic roads [13]. Recent researches conducted to improve the property of cinder gravel to use as road construction material include; stabilizing cinder gravel heavy trafficked base course, blending cinder gravel with fine grained soil to use as a sub base material (The case of Butajira-Gubre Road), blending cinder gravel with coarse aggregate and fine grained soil for road sub base on the area Addis Ababa- Adama and Stabilization of cinder gravel with cement and clay.

In this research cinder gravel has been stabilized using natural Pozzolana (volcanic ash) from samples collected between Modjo and Ziway. Grading, Atterberg limits, absorption, specific gravity, compaction, California Bearing Ratio and unconfined

compressive strength tests have been conducted in the laboratory. Then strength tests have been conducted on the stabilized material to check the improvement in the compaction characteristics of cinder gravel and to check its conformity with ERA's standard technical specification for road base and recommended as a proper blending proportion for use as a road base material.

1.2 Objective

The general objective of this thesis is to determine a good blending proportion of the cinder gravel with the natural Pozzolana (volcanic ash) in order to use it as road base material based on ERA specification. The specific objective is to improve the compaction property of the cinder gravel and study its engineering property.

1.3 Problem Statement

Research has shown that the use of bitumen, lime or cement is effective. Unfortunately, the costs of these stabilizers are on the higher side making them economically unattractive as stabilizing agents. Recent trend in research works in the field of geotechnical engineering and construction materials focuses more on the search of cheap and locally available material such as natural Pozzolana, bagasse ash, fly ash , blast furnace slag etc. as stabilizing agents for the purpose of full or partial replacement of traditional stabilizers.

This thesis therefore attempts to provide an alternative solution to the current practice. The alternative is to mix the natural pozzolana with the cinder gravel so that it will be used as a base material. The principle is that the Natural Pozzolana is cementitious in presence of water hence no swelling and shrinkage properties are observed. The Natural Pozzolana also performs a separation function thereby restraining the aggregates from mixing at the boundary between the sub-base and the base. Lateral and upward movements of the sub-grade soil are also restrained by the natural pozzolana.

Currently, research is conducted worldwide to find road construction material that will be both economically feasible as well as environmentally friendly. The use of in-situ and non-industrial material in road construction was observed to be the best solution especially by including various stabilization techniques and chemicals. These stabilization methods has proved to be useful and more so economical in improving the

quality of material initially regarded as being marginal, despite the high costs associated with cement and other chemical stabilizer.

The problem of cost is a factor since the current materials (cement and lime) are relatively expensive. Therefore the introduction of volcanic Pozzolana ash which is readily available and cheap will go a long way into more savings in the construction industry. Besides, Environmental pollution (CO₂) is greatly reduced due to industrial emissions during processing of cement.

1.4 Methodology

To achieve the objectives of this thesis, the following methodologies have been followed. Different Literatures have been reviewed in relation to cinder stabilization. Disturbed Samples were collected from the two different quarries for the cinder gravel and the natural pozzolana (volcanic ash). The cinder gravel was collected from Mojo whereas the natural pozzolanas were collected from Ziway area. The appropriate natural pozzolana (volcanic ash) for this test was selected based on strength activity index test conducted in the laboratory. The cinder gravel was blended with the natural pozzolana (volcanic ash) and modified proctor test was conducted in different trial proportion until the optimum proportion was identified. For the optimum blending proportion, strength tests were conducted to check if the blended material achieves requirement of the specifications of Ethiopian Road Authority (ERA).

The series of tests conducted include:

- Strength Activity Index
- Gradation
- Atterberg Limit
- Compaction
- California Bearing Ratio
- Unconfined Compression Test
- Los Angeles Abrasion
- Specific Gravity and Absorption
- Ten Percent Fines Value
- Aggregate Crushing Value

1.5 Organization of the Thesis

This thesis has five Chapters. The first Chapter contains a general introduction about the study, the objective of the study and the problem statement of the study. In the second Chapter, a comprehensive literature review on the origin and formation of Cinder gravel and Pozzolanic material is discussed in addition to stabilization techniques and function of base course. The third Chapter is about the general description of the study area. Chapter four presents the laboratory test results and discussions. In Chapter five, Conclusion and recommendations are presented.

CHAPTER TWO

2 LITERATURE REVIEW

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

2.1.1 –Introduction

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.

Volcanic cinder gravels occur extensively in Ethiopia, but in the past they have been used in road construction only to a limited extent, even though their use would substantially reduce road construction costs in many instances. One of the reasons is lack of fine material and also failure to conform to the grading specification for conventional crushed rock bases.

As part of a joint research project undertaken by the Ethiopian Road Authority and the United Kingdom Transport and Road Research Laboratory (TRRL, UK) in 1975, research has been carried out previously to provide information on the occurrence and properties of the volcanic cinders with the objective of encouraging their wider use in road construction and establishing guidelines to enable highway engineers to make fuller use of locally available materials for road construction. This was considered important particularly in Ethiopia as extensive rural road projects are in progress as in many developing countries [12].

2.1.2- Definition of Volcanic Cinders

Volcanic cinders are primarily pyroclastic (fragmental) products of volcanic eruptions. Volcanic cinders are volcanic rocks characterized by a cellular structure. They form as gases (primarily water) dissolved in molten rock (magma), generating a froth that cools and solidifies into rigid foam. The cells or bubbles are referred to as vesicles and range in size from a few thousandths of a millimeter to several centimeters. Because of their vesicular character, Cinder gravels have lower density and higher porosity than most other rock types. As their vesicle walls are broken, sharp cutting edges are continually generated. These properties are the basis for their commercial value as lightweight aggregates, insulators,

absorbents, and abrasives [8]. 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. 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 [12].

2.1.3- General Location of Cinder Gravel in Ethiopia

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

Samples were obtained either from existing borrow pits from which material had previously been extracted or by digging pits where cinder cones had not been disturbed. Existing borrow pits provided the opportunity to obtain deeper profile samples which were more representative of the cone as a whole [12].

2.1.4– Geologic Formation of Cinder Gravels

2.1.4.1 - Composition and Physical Characteristics of Scoria

Scoria is a dark colored igneous rock with abundant round bubble –like cavities known as vesicles. It ranges from black or dark grey to deep reddish brown. Scoria usually has a composition similar to Andesite.

Many people believe that small pieces of scoria look like the ash produced in a coal furnace. That gas resulted in particles of scoria bring called “Cinder” and the small volcanoes that erupt scoria to be called “Cinder Cones” [6].Scoria and cinder are typically basaltic to andesitic with a composition of approximately 50% to 60% SiO₂. Pumice and cinder may contain phenocrysts of feldspars and various ferromagnesian minerals that crystallized in magma before eruption. Fragments of rock through which the magma has passed may be entrained in the melt and wall rock may be fragmented and admixed during an explosive eruption. Some scoria fragments have lithic fragment cores. Cinder typically is heavier than pumice and has a higher crushing strength. In Volcanology, the term *Scoria* refers to a dark vesicular material throughout a wide size range. Common commercial practice is to use the term scoria for larger fragments usually greater than 2.5cm) and cinder for smaller fragments [8].

2.1.4.2 – Formation of Scoria

Scoria forms when a magma containing abundant dissolved gas flows from a volcano or is blown out during an eruption. As the molten rock emerges from the Earth the pressure upon it is reduced and the dissolved gas starts to escape in the form of bubbles. If the molten rock solidifies before the gas has escaped the bubbles become small rounded or elongated cavities in a rock with the trapped bubbles known as scoria.

When some volcanoes erupt, a rush of gas blows out of the vent. This gas was once dissolved in the magma below. The gas often blows out small bodies of magma that solidify as they fly through the air. This action can produce a ground cover of scoria all around the volcanic vent with the heaviest deposit on the downwind side [6].

2.1.4.3 - Cinder Cones

As the name suggests, Cinder cones (also called scoria) are built from ejected lava fragments that take on the appearance of cinders or clinkers as they begin to harden while in flight. These fragments range in size from fine ash to bombs but consist mostly of pea-walnut-size lapilli [6]. Cinder cones formed from a single vent can be nearly circular, but elongate forms can develop under strong prevailing wind conditions or from fissure eruptions or multiple vent eruptions. Variations in color from red to black are often concentric around the vent. Cinders are black initially, but those deposited near the vent are subject to heating after deposition, causing oxidation of iron to shades of brown and red [8].

Recall that these vesicular fragments are called Scoria. Occasionally an eruption of silica rich magma will generate a light-colored cinder cone composed of ash and pumice fragments.

Cinder cones have a very simple distinctive shape determined by the slope that loose pyroclastic material maintains as it comes to rest. Because cinders have a high angle of repose, young cinder cones are steep sided, having stopes between 30 and 40 degrees. In addition, cinder cones have large, deep craters in relation to the overall size of the structure. Although relatively symmetrical, many cinder cones are elongated and higher on the side that was downwind during the eruptions.

Cinder cones are usually the product of a single eruptive episode that sometimes lasts only a few weeks and rarely exceeds a few years. Once this vent ceases, the magma in the pipe connecting the vent to the magma chamber solidifies, and the volcano never erupts again. As a consequence of this short lifespan, cinder cones are small, usually between 30 meters and 300 meters, and rarely exceed 700 meters in height [6].

2.2 Cinder as a Road Construction Material

2.2.1 Experimental Use of Cinder Gravel in Ethiopia

The occurrence of the cinder gravel in Ethiopia was mapped with the aid of aerial photographs. From the laboratory tests conducted on the range of the materials; it showed that they typically have weak particles, deficient in fine material and upon compaction breakdown of large particles occurs producing a better grading and a higher strength. It was also found that the addition of fines improves the strength and density of the compacted

cinder gravels. The Road examination confirmed that the action of traffic produces the same breakdown effect in gravel roads as was observed in the laboratory compaction tests [12].

A full scale experiment has been carried out in Ethiopia to examine the performance of volcanic cinder gravels as the surfacing material for unpaved roads and as the road base under bituminous surfaced roads as a joint road research project by the Ethiopian Transport Construction Authority and the Transport and Road Research Laboratory (UK)

Compaction trials were carried out to determine the type of plant to be used and an experimental road comprising 20 different sections was then 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 vpd (Vehicles per day) for 7.5 years giving a total of 440,000 esa in one direction. 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 are made for the use of cinders in both paved and unpaved roads [13].

For unpaved roads, recommendations are made for a particle size distribution which provides a road surface that is resistant to corrugations. 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 according to Road Note 31. 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 a tuff. Cinders are easier to compact when they are mechanically stabilized with 10 percent of volcanic ash soil [13].

2.2.2 – Preliminary Investigation of Cinder Gravel by TRRL

Conclusions were drawn from the preliminary investigation after conducting field survey, laboratory study and examination of a cinder gravel road as a joint research project by the Ethiopian Road Authority and Transport and Road Research Laboratory (UK) in 1975.

From the investigation it was realized that cinder gravels were abundantly available throughout Ethiopia by making use of aerial photographs in survey work which enabled preparation of preliminary map depicting the distribution of cinder gravels. Before

Conducting the laboratory investigation on cinder gravels, representative samples were taken from the weathered zone which usually extended up to 2 m. In their in-situ condition cinder gravels do not conform to the grading requirement of road base material but after compaction cinder gravel showed an improvement in gradation and strength properties due to the weak nature of its aggregate particles.

During the laboratory investigation cinder gravels were not affected by change in moisture with a slight reduction in strength upon complete immersion in water. Addition of plastic volcanic ash soils to fill up their deficiency of fine material improved the mechanical stability of cinder gravel and indicated that it could be a valuable road construction material but unlike the natural cinder gravels the mixed materials lost some of their strength when they were saturated with water [13].

From the gravel road study, improvement in the grading and strength of cinder gravels was observed under normal road conditions even when traffic was a means of compaction.

The results from the preliminary investigation indicated that cinders could be a useful road construction material 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 [13].

2.2.3 – Cinder Blended with Fine Clay as a Sub Base Material

In road construction, it would be more appropriate to use locally available. However, these materials may not always be suitable and 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 increments. In many parts of Ethiopia, there is widely distributed cinder gravel. However, this material has the problem of compaction due to its light weight, rough circular surface and its high porosity.

Investigating the performance of mechanically stabilized natural cinder gravels to be used as road sub-base material has been done to achieve the Ethiopian 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 were conducted in the laboratory. From the laboratory investigation, an improvement in the gradation was observed though not satisfying ERA's specification due to deficiency of fine grained soil.

Cinder gravels showed significant amount of breakdown after compaction due to their weak nature. While blending arithmetic proportioning was used to minimize time and effort. The blended sub-base material has no plasticity characteristics with zero plasticity products. 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 [16].

2.2.4 – Cinder Blended with Clay and Coarse Aggregate

In road Construction, the use of locally available material should be made in order to reduce time and cost. Stabilization may be defined as a process by which construction material is improved and made suitable for the intended purpose which it would fail under normal conditions. Among many soil stabilization techniques mechanical / Blending is one. For the case of road sub base, cinder gravel, does not meet the conventional road base specification [11].

Research was conducted to prepare the optimum blending proportion of cinder with coarse aggregate and fine grained soil for road base in the area Addis-Adama. To achieve both ERA and AACRA specifications, the cinder gravel was blended with some trial proportion of fine grained soil and coarse aggregate by mass and different tests including grain size distribution, Atterberg limit, Compaction, CBR, LAA and Absorption are conducted in the laboratory. From the laboratory test results it is shown that, from MDD-percent of fine grained soil and coarse aggregate curve, CBR percent of fine grained soil and coarse aggregate curve and gradation before and after compaction; the optimum amount of fine grained soil and coarse aggregate required in order to improve its properties is 20% each by mass proportion. The blended sub base material has no plasticity and has zero plastic products. Blending cinder gravel with an optimum fine grained soil and coarse aggregate improves the CBR of cinder gravels and fulfilled the specification for sub base material [11].

2.2.5 – Cinder Stabilized by Cement and Clay

The location of the road construction can affect the material that can be used for the construction. If the material found at the construction site can not satisfy the requirement the material has to be stabilized [4].

Sample of cinder gravel was collected from Nazareth area and routine test like gradation, Impact test, Crushing test and specific gravity were conducted. The clay needed to stabilize

the cinder gravel was taken from Addis Ababa around „Addisu Gebeya”. 10-15% of clay of the total weight was taken to conduct CBR and Proctor test to find out the suitable clay content and the optimum clay content was taken from the CBR result. Optimum moisture content was taken for 3%, 5%, 7% and 10% of cement and mechanically stabilized cinder gravel to find out the durability of the molded mixture. Based on the 12 cycles of wetting and drying results were compared for 3%, 5%, 7% and 10% cement stabilized cinders. The 3% cement was excluded because of its small values in the durability and unconfined compression strength tests and 10% was also excluded from the point of construction cost. The optimum value became between 5% and 7%. Stabilized cinder gravel with 7% cement is selected for its 3.0 MPa unconfined compression strength and 17.80% wet and dry loss as compared to 0.6 MPa compressive strength and 20.65% wet and dry loss of 5% cement stabilized cinder [4].

2.2.6 – Stabilizing Cinder 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 [7]. 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 investigations 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 recommended 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 [7].

2.3 – Pozzolanic Materials

2.3.1 Definition of Pozzolana

Pozzolana is defined in ACI 116R as a siliceous or siliceous and aluminous material, which in itself possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Natural Pozzolana is defined as either raw or calcined natural material that has Pozzolanic properties (for example, volcanic ash or Pumicite, opaline chert and shales, tuffs and some diatomaceous earths. The natural pozzolans in the raw or calcined state are designated as Class N pozzolans and are described in ASTM C 618 specifications as “ Raw or calcined natural pozzolans that comply with the applicable requirements for the class given herein, such as some diatomaceous earth; opaline chert and shales; tuffs and volcanic ashes or Pumicites, any of which may or may not be processed by calcination; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales” [14].

Pumicite is a finely divided volcanic ash composed of angular and porous particles of siliceous glass and varying proportions of crystal fragments differing from pumice only in grain size. Pumicites are mainly rhyolitic or dacites in composition. They occur as stratified or massive deposits, commonly as lake beds [14].

2.3.2 Types of Pozzolana

Pozzolana are classified based in their origin (Hewlett, 1988) namely natural Pozzolanas and artificial Pozzolanas. Natural Pozzolanas represent all those naturally occurring materials such as volcanic ash or Pumicite, Diatomaceous earth, Shales, opaline, Chert, and tuffs. Artificial Pozzolans represents all those Pozzolans formed from processing of materials originally without Pozzolanic properties such as fly ash, blast furnace slag, burned clay or shale, micro silica or silica fumes. Furthermore, Lea classified natural Pozzolans into three groups based on their origin, namely volcanic origin, sedimentary origin and those of mixed origin [2].

Although there are many methods of classifications of Pozzolans currently in practice, Pozzolans may differ in the following respects

- Composition(Chemical, mineralogical, physical)
- Geographical Distribution,
- Amount of processing required
- Properties(Cementitious, Pozzolanic)
- Economics
- Methods of use, and
- Specification requirements [2]

Today, volcanic tuffs and Pumicite are still used as Pozzolans throughout the world and are often referred to as Pozzolana in the literature.

Deposits of volcanic ash are likely to be found wherever there are active or recently active volcanoes, for example in the Mediterranean, the Pacific region, and central and eastern Africa. The physical condition of volcanic ashes may range from loose fine material to coarse deposits containing quite large particles. Deposits may be loose, with an appearance and texture similar to a compacted coal or wood ash. Other deposits are cemented, sometimes with appearance and properties similar to stone, and in this form they are normally referred to as tuffs or trassy. The colour of deposits can vary from off-white to dark grey [10].

Once the deposits have been excavated most volcanic ashes will require only minor processing before use as a pozzolana. Many ashes are only loosely cemented and can easily be excavated by hand, although others may need mechanical or pneumatic equipment. Some lithic tuffs may require blasting with explosives. The ash may require drying, and in dry sunny climates this can simply be achieved by spreading the ash in a thin layer on a specially prepared drying floor, similar to those commonly used to dry crops. Alternatively, in wet climates, and for large quantities, inclined rotary driers are normally used.

If the ash is cemented it will need to be crushed before entering the dryer. Some volcanic ashes will already be in a very fine, loose powdered form and may not require crushing or grinding. Other ashes may be of sufficient fineness but be cemented together. These will require milling or crushing. Coarse ashes and lithic tuffs will need to be ground in a ball mill or similar [10].

2.3.3 Uses of Pozzolana

There is evidence that the use of pozzolan in the construction industry is dated back to the 1500-200 B.C with Minoan structures of Crete Island, which contained potsherds (i.e., calcined clay) in a lime mortar.

Pozzolans are in worldwide use as a cement replacement material due to the fact that they improve the durability of cement, reduce the cement production costs and also reduces the environmental degradation associated with cement production as well as disposal of various industrial wastes effectively. Common Pozzolanic materials that have been utilized are fly ash, sludge and in some countries, natural Pozzolans. Fly ash is in wide use whereas the addition of natural Pozzolans of volcanic origin is used to a lesser extent [2].

2.3.4 Pozzolana as Road Construction Material

Traditional strengthening methods for roads in developing countries require large quantities of high quality aggregates, or hydraulic binders such as Portland cement, which may cause undesirable environmental effects. Alternative binders, such as natural Pozzolanic materials (e.g. volcanic ash) can alleviate many of these effects, and lead to significant import savings for the countries where these materials are found.

Based on experiences from a recent road construction project in Tanzania and a pilot study relating to the suitability of locally available Pozzolanic materials, a research project was proposed which was hoped to establish a theoretical model for the structural and functional deterioration of pavements with pozzolan-stabilized bases. The pilot study showed that the major part demonstrates good strength properties, utilization of the resources is considered highly viable, economically and environmentally friendly, Pozzolan resources can be utilized in several sectors-road, housing and cement industry as a substitute for high energy consuming, ordinary binder materials as well as for other purposes in the building sector, several natural pozzolans investigated in the pilot study show higher strength results for similar binder dosages than in blast furnace slag-sand mixtures. Further recommendations from this pozzolan pilot study include developing new strategies for road works to promote innovative and appropriate road construction technology, to develop design guidelines and technical specifications and to develop maintenance for repair of pozzolan bases in the case of possible failures or repair after excavations for example pipes. [9].

2.4. The Function of Base Course

The principal function of a base course and sub base in a flexible pavement, is to provide sufficient cover over the sub grade, to limit the stresses and strains induced by wheel loading such that sub grade shear failures do not occur and the sub grade does not densify significantly, thus contributing to a loss of shape of the pavement surface.

To perform satisfactorily, a base course must have a number of attributes, namely: Stability, Resistance to wear, Impermeability, and Workability.

2.5. Stabilization

2.5.1 Methods of Stabilization

2.5.1.1 Mechanical Stabilization

Not all natural gravels are suitable for use in road construction and some form of improvement may be required to achieve adequate strength and to limit permeability. In some cases, natural gravels can be improved by blending with sand, crusher dust or other inert material, a process referred to as mechanical stabilization.

2.5.1.2 Cement Stabilization

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

2.5.1.3 Lime Stabilization

Lime can be used in a similar way to cement for improving the strength of pavement layers, but in order to develop cementitious bonds, natural Pozzolans must be present. In Western Australia lime is most commonly used to reduce plasticity and therefore reduce a materials' moisture sensitivity.

2.5.1.4 Bitumen Stabilization

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

2.5.1.5 Chemical Stabilization

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

CHAPTER THREE

3 GENERAL DESCRIPTION OF THE STUDY AREA

3.1 Modjo-Ziway Area

Mojo and Ziway towns are located in the southern part of Ethiopia, particularly in the Oromia National Regional State (ONRS). The road corridor traverses five administrative weredas in the ONRS (Lome, Liben, Dugda Bora, Adami Tulu and Jido kombolcha). The main road lies in a North-South direction along the axis of the rift valley. The main access route from the north is the asphalt road from Mojo to Hawassa which continues south through the Ziway town as a gravel-surfaced all weathered road. Modjo-Ziway Road starts at Modjo town in Oromia National Regional State (ONRS) by making connection with the Adama-Addis Ababa Highway Road having a total length of 93 km. The geographic coordinates are 515964.35E 949152.25N & 465818.80E 878018.17N at the start and end, respectively.

The Modjo-Ziway road has also quite significant national and international tourist flows using the road to visit important tourist attraction sites in the Southern National Nationality People Regional State (SNNPRS) and Oromia National Regional State (ONRS); the known destination are Abjata Shalla Lakes National Park (ASLNP), and generally the lakes strip that include Hawassa, Ziway, Shalla, Langano and Abjata. The proposed road project will give momentum to the already accelerating tourism industry.

3.2 Description of the Project Environment

The project road directly traverses weredas located in Oromia Region, East Shoa zone, in Lume, Bora, and Adami Tulu Jido Kombolcha weredas.

3.2.1 Topography

The road project traverses through two major river basins of the country, majority of the first section from the starting point at Modjo town up to Alem Tena area falls in Awash River Basin & the remaining section fall in the Rift Valley Lakes Basin (RVLB). Majority of the land form is characterized by flat land and depressions that formed the lakes, run off from the highlands drains through stream channels. Generally, the elevation in the road project area ranges from 1600 m to 2000 m above sea level.

3.2.2 Climate

The project is located in a warm temperate zone, and the mean daily temperature ranges from 12.5 °C to 31.5 °C area-wide, with 6.6 to 21 °C excursion in Modjo and 8-31 °C in Hawassa. Annual rainfall varies from 750mm to 1250mm area-wide increasing from 875 mm at Modjo to 1,100 mm in Hawassa. Two rainy seasons are experienced annually, the main rainy season lasts from the end of June to the end of September, the lesser rainy season from the end of February to the middle of May, the rest of the months in the year being generally dry.

3.2.3 Soil and Geology

The soils in most part of the road corridor are light reddish and light gray soils with varying proportions of sand gravel silt and clay, and they are dominantly used for crop cultivation. The project road crosses mainly Quaternary Deposits and Rocks of Volcanic Origins. The geology in the project road route corridor from the start to the end is made of two litho-stratigraphic units. It's made of Alluvial & Lacustrine Deposits with Volcanic which consist mainly of sand, silt and clay with thick deposits of Volcanic Ashes and Tuff.

3.3 Proposed Material Source

Selection of appropriate material is important with respect to ensuring long term service of the road and optimizing cost of the construction. An important prerequisite for selecting the best of the locally available materials for road construction is knowledge of their properties and behavior and how these vary in time and space. Conventional selection criteria based on general classification could be adequate to exclude almost all unsatisfactory materials but have a disadvantage of excluding some materials capable of giving satisfactory performance.

The samples in this research were collected from Modjo and Ziway. The cinder gravel was collected from Modjo town from a quarry which is located right at the entrance of Modjo from the Addis-Adama expressway exit. The location from GPS indicates N=0833000, E=0391700. The volcanic ash was collected from Ziway, around Bulbulla River. The volcanic ash, in this research, is used as a stabilizer for the cinder gravel so that the appropriate blending proportion that meets road base requirement is determined.

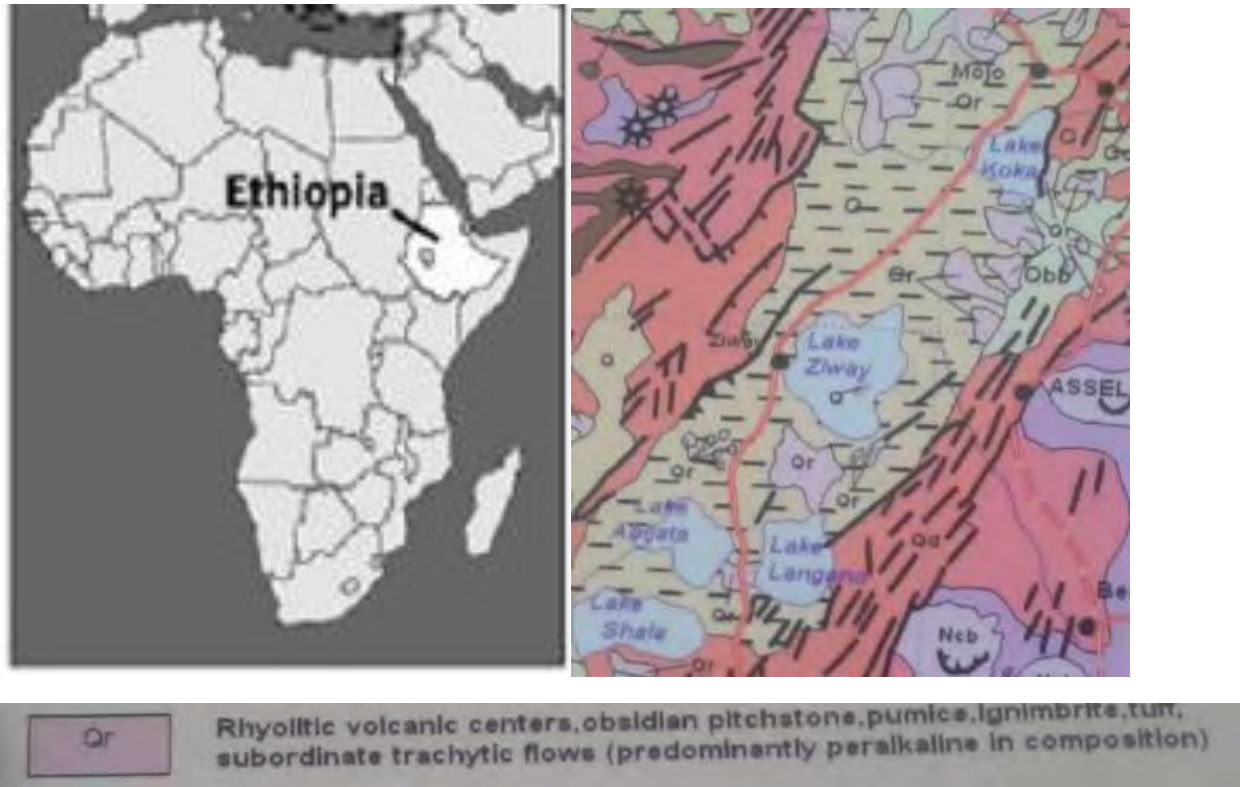


Figure 3-1 Locations of Modjo and Ziway (Source: Ethiopian Geologic Map)



Figure 3-2 Material Site for the Cinder Gravel, picture taken from Modjo (a)



Figure 3-3 Material Site for the Cinder Gravel (b)



Figure 3-4 Material Site for the Volcanic Ash/Pumicite, picture taken from Ziway Area (a)



Figure 3-5 Material Site for the Volcanic Ash/Pumicite (b)



Figure 3-6 Material Site for the Volcanic Ash/Pumicite (c)

CHAPTER FOUR

4 LABORATORY TESTS AND RESULTS

In this section a description of the testing procedures followed while conducting this research will be discussed. Standard procedures of AASHTO and ASTM have been used wherever appropriate.

4.1 Materials Used

Road base is the most important structural layer in bituminous pavement. It is designed to take up the function of distributing the traffic loads so as not to exceed the bearing capacity of sub grade. Selection of appropriate material affects service life of a project and cost. Using locally available construction materials goes a long way into more savings in the construction industry. In this research locally available Pozzolanic material was blended with cinder gravel to fill in the deficiency of cinder gravels with objective of using it as a road base material. Descriptive test results are shown below for the Pozzolanic material and cinder gravel used in this research.

4.2 Characterization of the Cinder Gravel

4.2.1 Particle Size Distribution and Gradation

This method covers the determination of the particle size distribution of fine and coarse grained aggregates by sieving. 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.

A grain size analysis is used to determine the relative distribution of various particle sizes in cinder gravels. To do this analysis, a wet preparation method is performed which is given in AASHTO T-146 and weighed sample of dried aggregate is shaken over a nest of sieves having selected sizes of square openings. The cinder sample is shaken with a mechanical sieve shaker, and the weight of material retained on each sieve is determined and expressed as a percentage of the original sample. Detailed procedures for performing a grain size analysis of coarse and fine aggregates are given in AASHTO Method T-27 [1].

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

Table 4-1 ERA grading limits for Mechanically Stable Natural Gravels and Weathered Rocks for Use as Base Course Material (GB2, GB3)

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

From sampling it is observed that the nominal maximum size of the cinder gravel is 37.5 mm. Since cinder gravel is coarser and falls short of fine material GB2 Particle size distribution is used throughout this thesis work.

The specification of grain size analysis of grade GB2 data is plotted on an aggregate grading chart, exemplified by Figure 4.1.

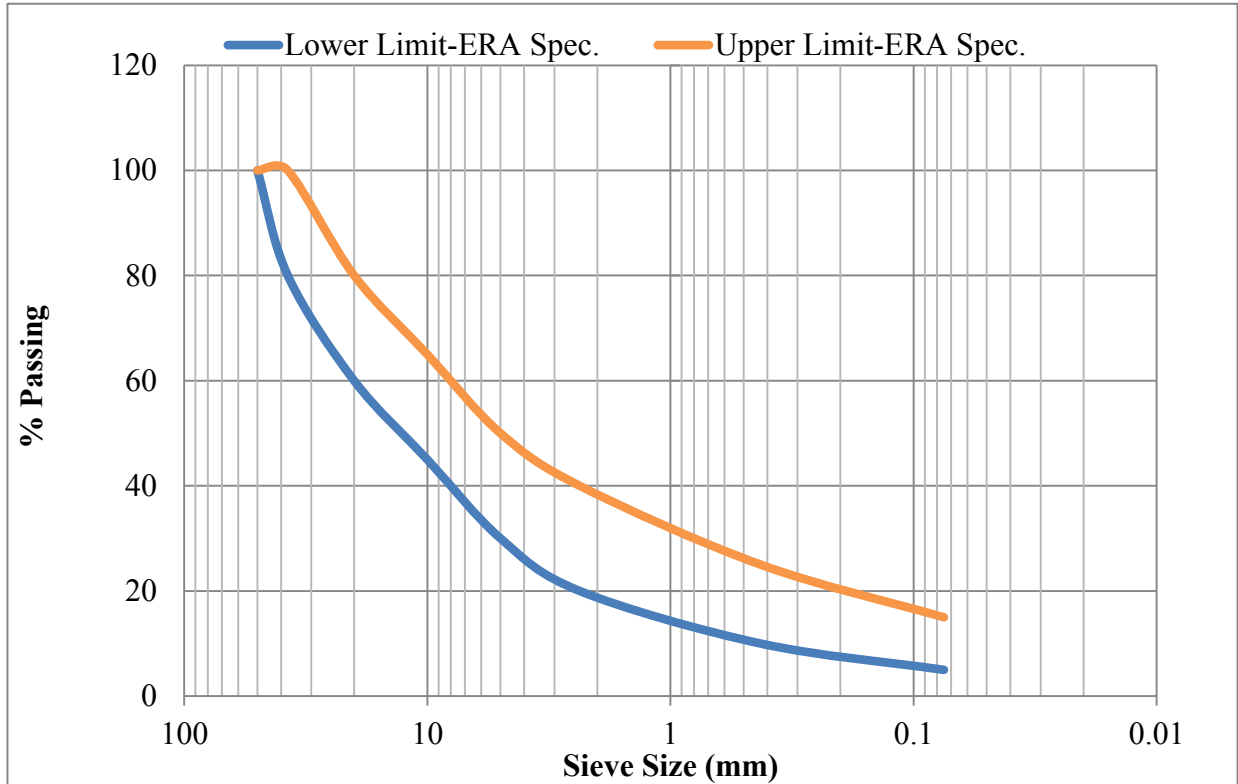


Figure 4-1 ERA Specification grade limits for grade GB2

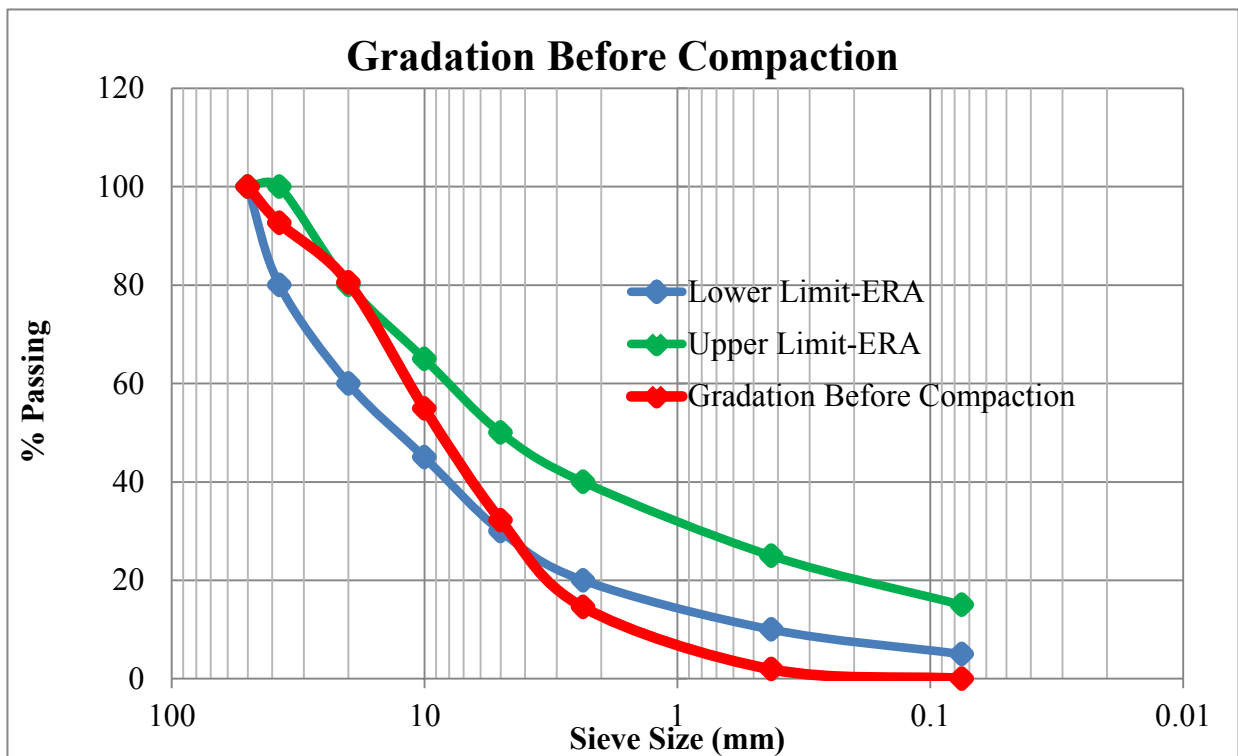


Figure 4-2 Gradation before Compaction of Natural Cinder Gravel only

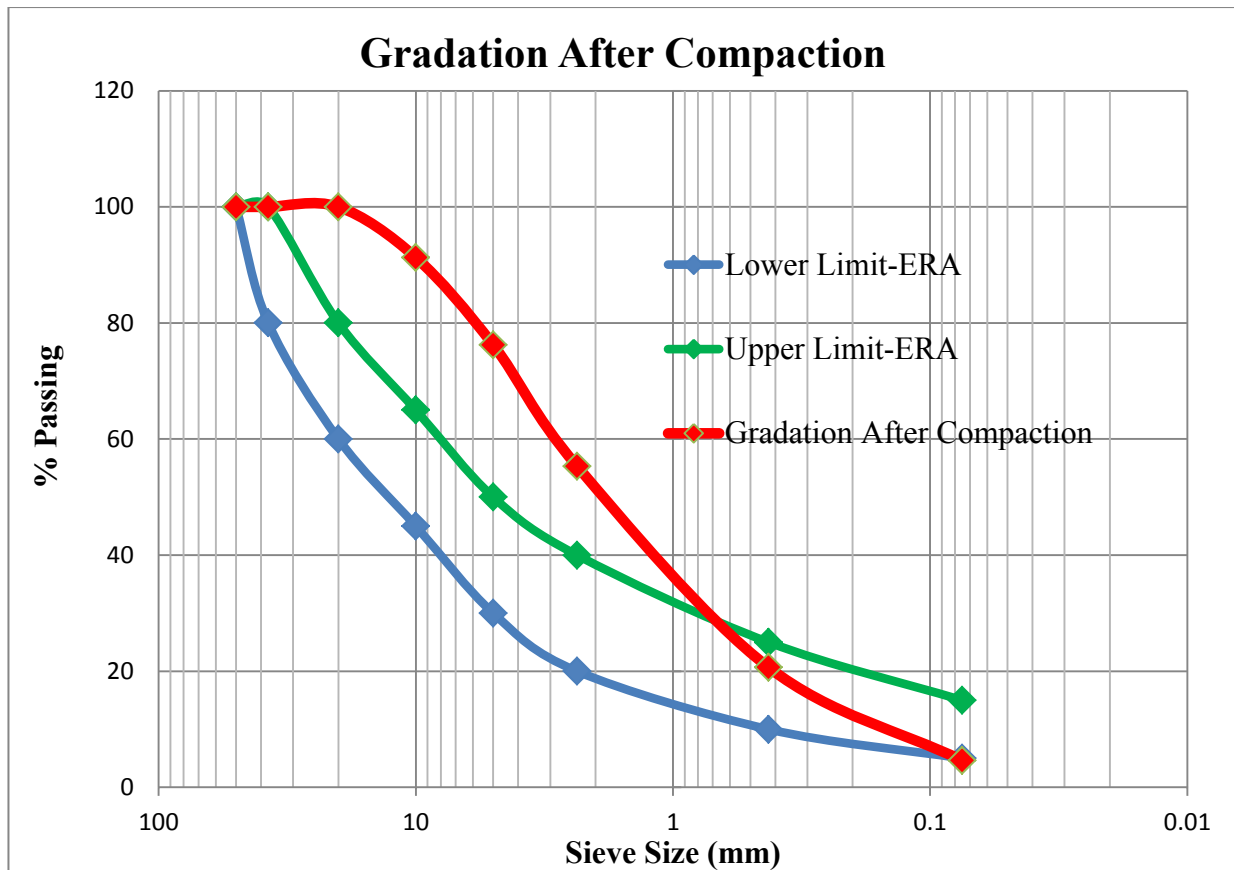


Figure 4-3 Gradation after Compaction of Natural Cinder Gravel only

4.2.2 Specific gravity and Absorption

The determination of absorption and specific gravity of natural cinder gravel is important to know some of the special characteristics cinder gravel.

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

determined by deducting the absorption from the total moisture content determined by AASHTO T-255[1].

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

Since cinder gravel is lightweight aggregate, the pores may 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. Therefore, this method for both Absorption and Specific gravity is intended for coarser cinder gravel that are retained on 4.75 mm sieve size.

Laboratory test results showed that the water absorption of the cinder gravel is 12.97% as shown in Table A-6, Appendix-A. Table 4.2 shows the specific gravity of cinder gravel.

Table 4-2 Specific gravity of cinder gravel

| Description | | Samples | |
|---|--------|---------|--------|
| | | I | II |
| Weight of Surface Dry Sample in Air | A (gm) | 500 | 500 |
| Weight of Pycnometer filled with Water | B (gm) | 1280.5 | 1287.2 |
| Weight of Pycnometer with sample and water calibration mark | C (gm) | 1589.4 | 1596.4 |
| Specific Gravity = $500 / (B + 500 - C)$ | | 2.616 | 2.621 |
| Average Bulk Specific Gravity (Saturated Surface Dry Basis) | | 2.62 | |

4.2.3 Los Angeles Abrasion

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact and grinding in

a rotating drum containing a specified number of steel spheres, the number depending upon the grading of the test sample [1].

Abrasion resistance applies only to coarse aggregates. Aggregates vary in their resistance from fracturing under impact (toughness) and from breaking down into smaller pieces from abrasive action (hardness). The acceptable limits are set by the Los Angeles Abrasion Test AASHTO T-96. The limits vary from 30.0 to 50.0 percent, depending on the classification of the aggregate. The percentage is a measure of the degradation or loss of material as a result of impact and abrasive actions. It is widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions. The Los Angeles Abrasion test is an empirical test; it is not directly related to field performance of aggregates. Field observations do not generally show a good relationship between Los Angeles abrasion values and field performance. Specifically, the test may not be satisfactory for some types of aggregates. Some aggregates such as slag and some lime stones, tend to have high Los Angeles Abrasion loss but perform adequately in the field. Table 4-3 shows the resistance to abrasion of the cinder gravel by the Los Angeles abrasion machine.

Table 4-3 Resistance of Abrasion of cinder by use of the Los Angeles Abrasion machine

| Designation | Trail 1 | Trail 2 |
|---|---------|--------------|
| No. of revolution | 500 | 500 |
| Total Wt. of sample tested(gm) | 5000 | 5000 |
| Wt. of tested sample retained on 12mm sieve | 2554 | 2558 |
| Percent Loss (%) | 48.92 | 48.84 |
| Average | | 48.88 |

4.2.4 Aggregate Crushing Value (ACV)

As described in BS 812, ACV gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. The method is applicable to aggregate passing a 14.0 mm test sieve and retained on 10.0 mm test sieve.

The method is not suitable for testing aggregates with an aggregate crushing value higher than 30, and in such cases the method for ten per cent fines value described in BS 812-111 is applicable.

For the cinder gravel, the aggregate crushing value is found to be 50.77kN which is greater than 30kN. The results are presented in Table A-8, Appendix-A. Therefore, the ten percent fines value is applicable as described in BS 812.

4.2.5 Ten Percent Fines Value (TFV)

As described in BS 812, TFV gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.

Two procedures are described, one in which the aggregate is tested in a dry condition and the other in a soaked condition. The methods are applicable to both weak and strong aggregates passing a 14.0 mm test sieve and retained on a 10.0 mm test sieve.

For the cinder gravel, the ten percent fines value is found to be 32.13kN tested in accordance to BS 812-111:1990. The results are presented in Table A-7, Appendix A.

4.2.6 Aggregate Impact value

This method gives a relative measure of the resistance of an aggregate to sudden shock or impact. The property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breakdown into smaller pieces. The aggregates should therefore have sufficient toughness to resist the disintegration due to impact. This method is applicable to aggregates passing 14.0 mm test sieve and retained on a 10.0 mm test sieve.

The aggregate impact value of the natural cinder gravel is 42.68% as shown in Table A-9, Appendix A.

4.2.7 Modified Proctor Test

Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their

engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

During design of an engineered fill, shear, consolidation, permeability, or other tests require preparation of test specimens by compacting at some water content to some unit weight. It is common practice to first determine the optimum water content (w_o) and maximum dry unit weight (γ_{dmax}) by means of a compaction test. Test specimens are compacted at selected water content (w), either wet or dry of optimum (w_o) or at optimum (w_o), and at a selected dry unit weight related to a percentage of maximum dry unit weight (γ_{dmax}). The selection of water content (w), either wet or dry of optimum (w_o) or at optimum (w_o) and the dry unit weight (γ_{dmax}) may be based on past experience, or a range of values may be investigated to determine the necessary percent of compaction.

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

In this research, a heavily trafficked asphalt road was considered hence the modified proctor test is used. The Ethiopian Road Authority recommends using ASTM D1557-91. In this test, a specimen is prepared by compacting soil in 152.4 mm mold in five approximately equal layers to give a total compacted depth of about 127 mm, each layer being compacted by 56 uniformly distributed blows from the rammer.

Maximum Dry Density and corresponding optimum Moisture content for four, eight, twelve, sixteen, twenty, and twenty four percent of volcanic ash are presented in Table C-1 to C-6 of Appendix C, respectively. Summary of maximum dry density and corresponding optimum moisture content for different volcanic ash/pumicite percentage are presented in Table 4-4 and Figure 4-4 from the compaction test.

Table 4-4 Determination of MDD & OMC for Different Volcanic Ash/ Pumicite Percentage

| Volcanic Ash (%) | MDD(g/cc) | OMC (%) |
|------------------|-----------|---------|
| 0 | 1.57 | 5.55 |
| 4 | 1.58 | 13.61 |
| 8 | 1.60 | 14.55 |
| 12 | 1.65 | 15.45 |
| 16 | 1.72 | 16.23 |
| 20 | 1.76 | 13.01 |
| 24 | 1.70 | 18.10 |

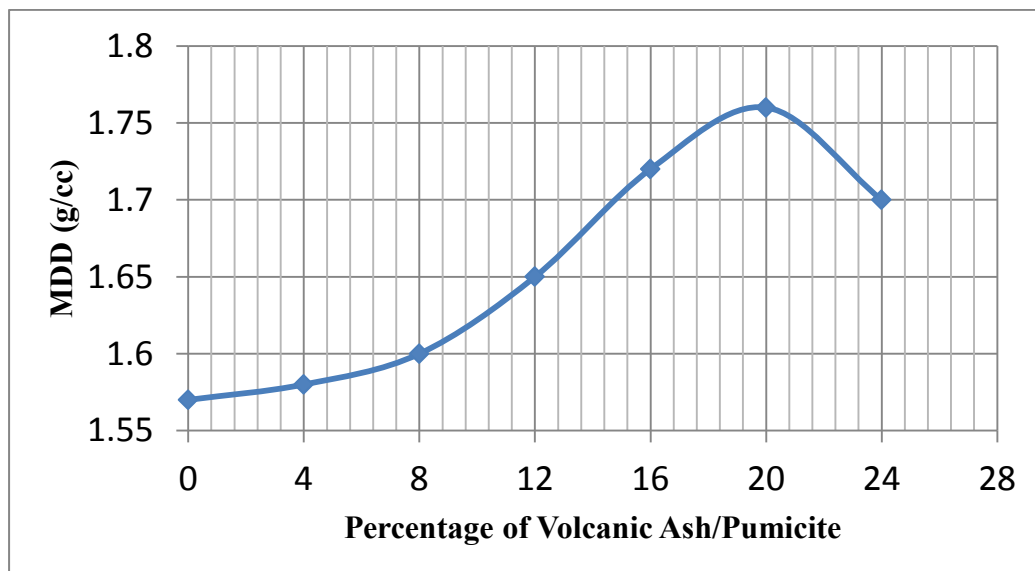


Figure 4-4 Variation of MDD with percentage of Volcanic Ash/Pumicite

4.2.8 California Bearing Ratio (CBR) Test

This test method covers the determination of the CBR of pavement sub-grade, sub-base, and base course materials from laboratory compacted specimens. It is also used to evaluate the potential strength of sub grade, sub base, and base course material, including recycled materials for use in road and airfield pavements.

For applications where the effect of compaction water content on CBR is small, such as cohesion less, coarse grained materials, or where an allowance is made for the effect of

differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort.

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

The criteria for test specimen preparation of self-cementing (and other) materials which gain strength with time must be based on a geotechnical engineering evaluation. Self-cementing materials shall be properly cured until bearing ratios representing long term service conditions can be measured.

According to ERA manual, for road-base material, when compacted to its maximum dry density in the laboratory, the material should have a minimum CBR of 80% after four days immersion in water. The Californian Bearing Ratio (CBR) shall be determined at a density of 98% of the maximum dry density when determined in accordance with the requirements of ASTM test method D 1557 [1]. The three point CBR of the natural cinder gravel according to this method was 59% at 98% maximum dry density.

Table 4-5 Determination of dry density before & after soaking

| Blows | Before Soaking | | After Soaking | |
|-------|----------------|--------------|---------------|--------------|
| | DD(g/cc) | Moisture (%) | DD(g/cc) | Moisture (%) |
| 10 | 1.27 | 4.54 | 1.44 | 12.72 |
| 30 | 1.34 | 4.54 | 1.48 | 20.26 |
| 65 | 1.54 | 5.67 | 1.56 | 20.47 |

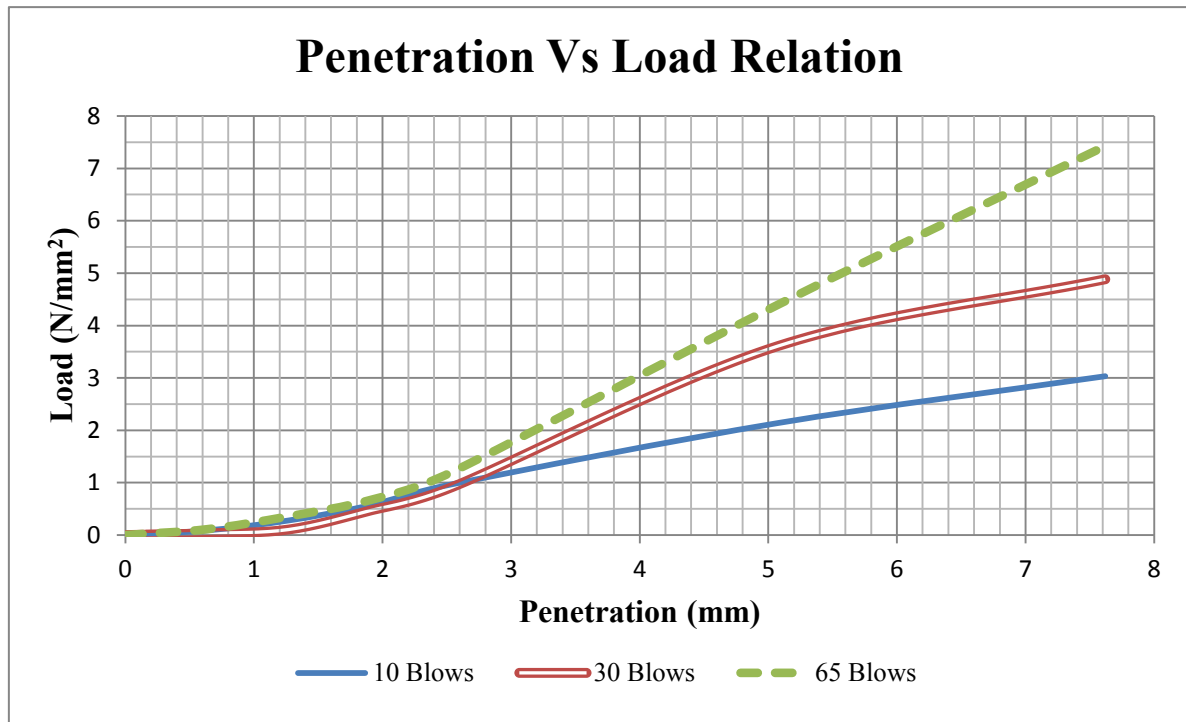


Figure 4-5 Load vs. penetration relation of cinder gravel @10, 30 and 65 blows

For the stabilized sample, Air curing technique was used in which the samples were kept in normal air temperature covered with a polyethylene sheet and out of reach of water intrusion during the curing period. Air curing technique was used to strengthen the stabilized material by gradual moisture content reduction, instead of the usual water curing technique or water submergence technique which has been a common practice in past experiments. By using this technique, the stabilized material gradually loses its moisture content through the curing period and become drier and harder [3]. In order to investigate the soaked CBR of the stabilized sample material i.e. at the optimum blending proportion of 20% volcanic ash/pumicite by mass proportion, the samples were cured in air for zero, three, seven, fourteen and twenty eight days and then soaked in water for a period of 96 hours and penetrated.

Table 4-6 Determination of CBR for different Curing times for the 20% Volcanic Ash

| Curing Time (Days) | CBR | |
|-----------------------|--------|----------|
| | Soaked | Unsoaked |
| 0 | 98 | 118 |
| 3 | 128 | 165 |
| 7 | 178 | 210 |
| 14 | 181 | 221 |
| 28 | 245 | 307 |

CBR value vs. curing time is plotted in Figure 4.6 & Figure 4.7 for the unsoaked and soaked condition.

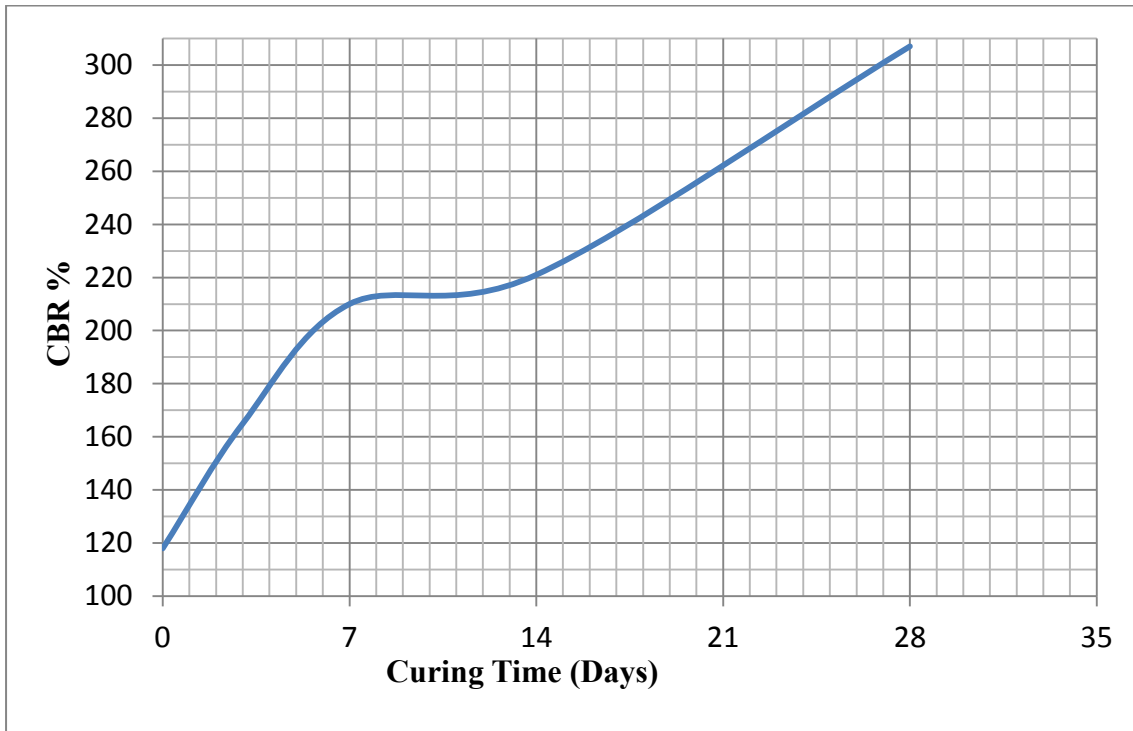


Figure 4-6 CBR vs. Curing time plot for Unsoaked Condition

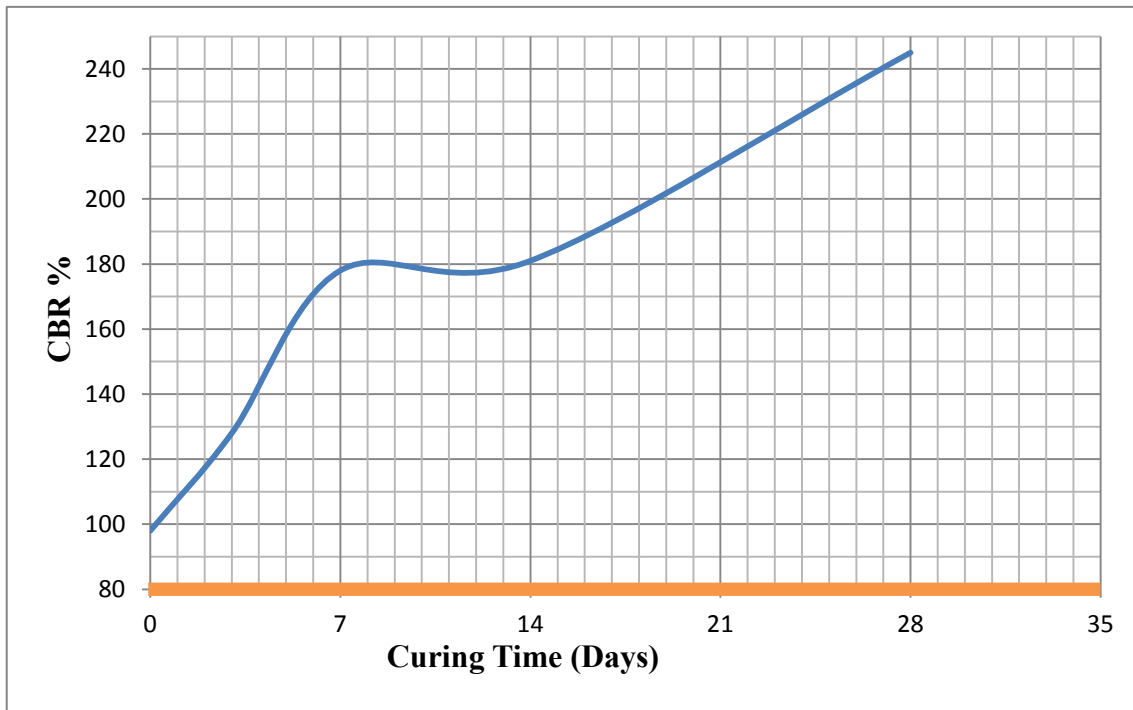


Figure 4-7 CBR vs. Curing time plot for Soaked Condition

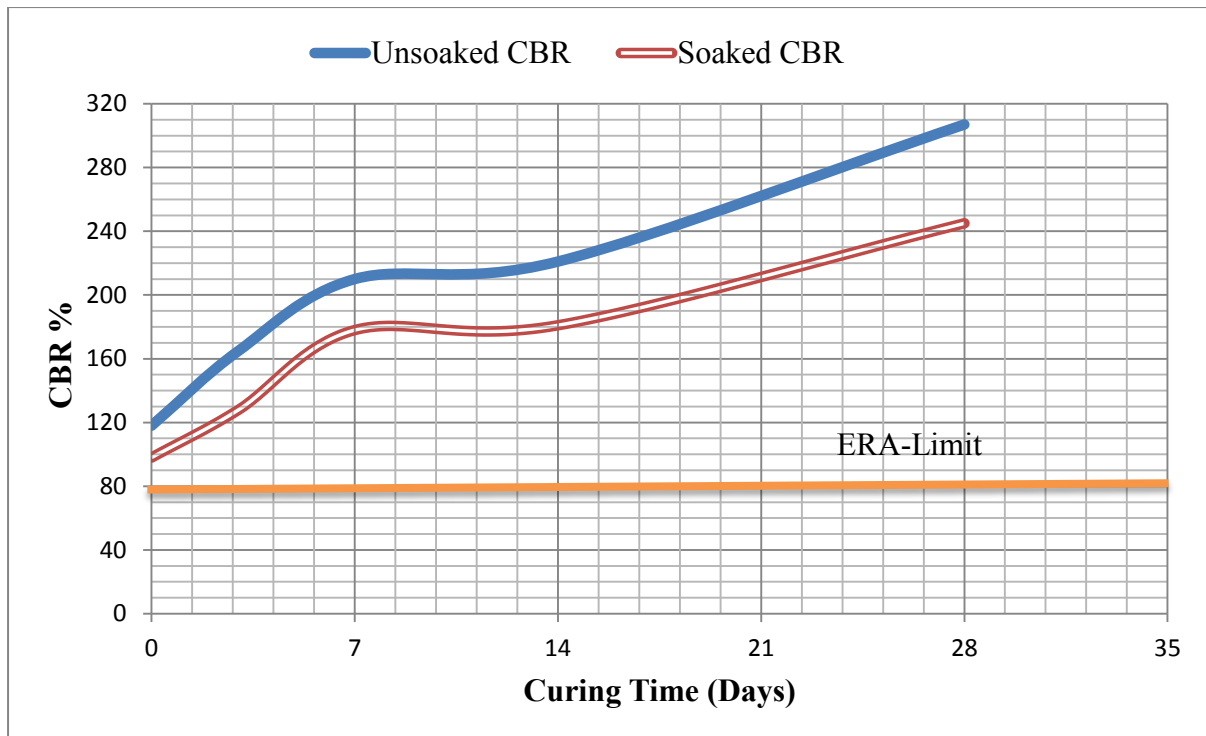


Figure 4-8 CBR vs. Curing time plot for Soaked/Unsoaked Condition



Figure 4-9 Cured and penetrated CBR Sample during Extraction (Left) and after Extraction (Right)

4.3 Characterization of the pozzolana material

4.3.1 Strength Activity Index

This test method cover procedures for sampling and testing fly ash and raw or calcined Pozzolans for use as a mineral admixture in Portland-cement concrete as stated in ASTM C311. The test for strength activity index is used to determine whether a mineral admixture results in an acceptable level of strength development when used with hydraulic cement in concrete. Since the test is performed with mortar, the results may not provide a direct correlation of how the mineral admixture will contribute to strength in concrete. SAI 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%. The test can be used as a guide of field performance but as with the other test methods, it is best used to rank different Pozzolans against each other. 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.

In this research two types of pozzolanic materials were collected from Ziway area. Both samples were tested for pozzolanicity following the above test method and the pumice (coarser) showed a higher SAI value of 89.17% while the volcanic ash/pumicite, which is finer, showed a result of 76.43% as shown in Table 4-7. The following picture shows the mortar cube samples and compression test on one of the samples.



Figure 4-10 Mortar Cube samples (Left) and Compression Test (Right)

Table 4-7 Strength activity index of pumice-coarser and volcanic ash/pumicite

| Sample No | Date Poured | Date Tested | Age in Day | Dimensions (cm) | | | Vol (dm ³) | Weight (g) | Press Area (Cm ²) | Total Load Tons | Compressive strength (Kg/cm ²) | Compressive strength (KPa) | Strength Activity Index |
|-----------|-------------|-------------|------------|-----------------|---|---|------------------------|------------|-------------------------------|-----------------|--|----------------------------|-------------------------|
| | | | | L | B | H | | | | | | | |
| C | 24/01/2015 | 21/02/2015 | 28 | 7 | 7 | 7 | 343 | 652.80 | 49 | 5 | 102.04 | 10.40 | |
| C | 24/01/2015 | 21/02/2016 | 28 | 7 | 7 | 7 | 343 | 697.22 | 49 | 6 | 122.45 | 12.48 | |
| C | 24/01/2015 | 21/02/2017 | 28 | 7 | 7 | 7 | 343 | 642.80 | 49 | 4.7 | 95.92 | 9.78 | |
| Average | | | | | | | | | | | 106.80 | 10.89 | |
| P1 | 24/01/2015 | 21/02/2015 | 28 | 7 | 7 | 7 | 343 | 689.00 | 49 | 5 | 102.04 | 10.40 | 89.17% |
| P1 | 24/01/2015 | 21/02/2016 | 28 | 7 | 7 | 7 | 343 | 703.30 | 49 | 4 | 81.63 | 8.32 | |
| P1 | 24/01/2015 | 21/02/2017 | 28 | 7 | 7 | 7 | 343 | 681.80 | 49 | 5 | 102.04 | 10.40 | |
| Average | | | | | | | | | | | 95.24 | 9.71 | |
| P2 | 24/01/2015 | 21/02/2015 | 28 | 7 | 7 | 7 | 343 | 671.20 | 49 | 4 | 81.63 | 8.32 | 76.43% |
| P2 | 24/01/2015 | 21/02/2016 | 28 | 7 | 7 | 7 | 343 | 677.30 | 49 | 4 | 81.63 | 8.32 | |
| P2 | 24/01/2015 | 21/02/2017 | 28 | 7 | 7 | 7 | 343 | 678.30 | 49 | 4 | 81.63 | 8.32 | |
| Average | | | | | | | | | | | 81.63 | 8.32 | |

Note:- Sample C represents a cube mixed with Cement and Sand only

- Sample P1 represents a cube mixed with 20% Pumice-coarser,80%cement and Sand

- Sample P2 represents a cube mixed with 20% Volcanic ash/pumicite,80%cement and Sand

4.3.2 Unconfined Compressive Strength Test

This test method covers the determination of the unconfined compressive strength of cohesive soils in the undisturbed, remolded, or compacted condition, using strain-controlled

application of the axial load. This method is applicable only to cohesive materials which will not expel or bleed water (water expelled from soil due to deformation or compaction) during the loading portion of the test and which will retain intrinsic strength after removal of confining pressures, such as clays or cemented soils.

In this research the sample is remolded using optimum moisture content and density obtained from standard compaction. After the samples were extracted from the mold they were covered with soft paper and sprinkled with water twice a day for three and seven days. The samples were penetrated on the third and seventh day. The average UCS values for three and seven days curing of Volcanic Ash/Pumicite are presented in Table 4-8.

Table 4-8 Average UCS values for three and seven days curing of Volcanic Ash/Pumicite

| Curing Days | UCS (Kpa) | | Average-UCS (Kpa) |
|-------------|------------|------------|-------------------|
| | Specimen-1 | Specimen-2 | |
| 3 | 82.32 | 86.98 | 84.65 |
| 7 | 253.02 | 280.24 | 266.63 |

The following figure shows the samples during the curing period.



Figure 4-11 three and seven days Cured UCS samples of Volcanic Ash/ Pumicite

4.3.3 Specific Gravity

This method covers the determination of the specific gravity of soils by means of Pycnometer. The specific gravity of a soil is used in almost every equation expressing the

phase relationship of air, water, and solids in a given volume of material. Specific gravity is defined as the ratio of the mass in air of a given material at a stated temperature to the mass in air of the same volume of gas free distilled water at a stated temperature.

Table 4-9 Specific Gravity of Volcanic Ash/ Pumicite

| | | |
|--|----------|----------|
| Pycnometer No. | A-5 | B-7 |
| Mass of dry soil (Ms), g | 25 | 25 |
| Mass of Pycnometer + water + soil (M1), g | 159 | 158.6 |
| Test temperature, °C | 20.2 | 20.4 |
| Mass of Pycnometer + water (M2), g | 144.4 | 144.0 |
| Specific gravity of soil at test temperature (G_{atT}) | 2.4038 | 2.4038 |
| Correction factor, K | 0.999958 | 0.999916 |
| Specific gravity of soil at 20°C | 2.40 | 2.40 |
| Average specific gravity of soil at 20°C | 2.40 | |

The laboratory test result shows that the specific gravity of the volcanic Ash/Pumicite is 2.40.

4.3.4 Atterberg Limit

This method covers the determination of the liquid limit, plastic limit, and the plasticity index of soils. The liquid limit may be defined as the minimum moisture content at which the soil will flow under the application of a very small shear force. At this moisture content the soil is assumed to behave practically as a liquid. The plasticity limit may be defined in general terms, as the minimum moisture content at which the soil remains in plastic condition. The plastic limit is further described as the lowest moisture content at which the soils can be rolled in to thread of 3.2mm diameter without crumbling. The liquid and plastic limit of a soil can be used with the natural water content of the soil to express its relative consistency or liquidity index. The “Plasticity index” (PI) of a soil is defined as the numerical difference between the liquid and plastic limits. It thus indicates the range of moisture content over which the soil is in a plastic condition.

Plasticity is an important factor in the performance of a gravel wearing course for the following reasons. Material with plasticity that is too low tends to loosen quickly as a result of diminished bonding and the rate of gravel losses 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 loss 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.

In the liquid limit test, the volcanic ash/Pumicite closes in 8 or 9 blows for repeated trials. In the test procedure stated in AASHTO T 089-96, no trial requiring more than 35 blows or less than 15 blows shall be recorded. In the plastic limit test, the volcanic Ash/Pumicite crumbles before it rolls into a thread of 3.2mm. AASHTO T090-96 recommend to report a material non-plastic when the liquid limit or plastic limit cannot be determined. Therefore, the volcanic Ash/Pumicite is a non-plastic material. Figure 4-12 shows the liquid and plastic limit of the Volcanic Ash/Pumicite.



Figure 4-12 Liquid and Plastic limit of Volcanic Ash/Pumicite

The Plasticity Modulus ($PM = PI \times \text{percentage passing the } 0.425 \text{ mm sieve}$) shall not be greater than 90% and the Plastic Product ($PM = PI \times \text{percentage passing the } 0.075 \text{ mm sieve}$) shall not be greater than 60% [5]. Since both material are non-plastic materials the plasticity index and the plastic product of the blended material is zero as shown in Table 4-10.

Table 4-10 Determination of plastic index and plastic product for the blended material

| Percentage of Volcanic Ash/ Pumicite | Plasticity Index | Plasticity Product |
|--------------------------------------|------------------|--------------------|
| 0 | NP | Zero |
| 4 | NP | Zero |
| 8 | NP | Zero |
| 12 | NP | Zero |
| 16 | NP | Zero |
| 20 | NP | Zero |
| 24 | NP | Zero |

4.3.5 Moisture – density relations by standard proctor test

This method is intended for determining the relation between the moisture content and density of soils compacted in a mold of a given size with a 2.5 Kg rammer dropped from a height of 305 mm. This method applies to soils that have 305 or less by weight of particles retained on the $\frac{3}{4}$ inch (19.0 mm) sieve. A soil at a selected water content is placed in three layers in to a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 5.5 lbf (24.4 N) rammer dropped from a distance of 12 in. (305-mm), subjecting the soil to a total compactive effort of about 12,400 ft.-lbf/ft. (600) KN-m/m³).The resulting dry unit weight is determined. The procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

For the volcanic ash/pumicite, the optimum moisture content is 38.82% and a maximum dry density 1.13 g/cc. The optimum moisture content obtained from this test was used while conducting UCS test for the same material. Figure 4-13 shows the moisture density relation of the volcanic ash or pumicite by the standard compaction method.

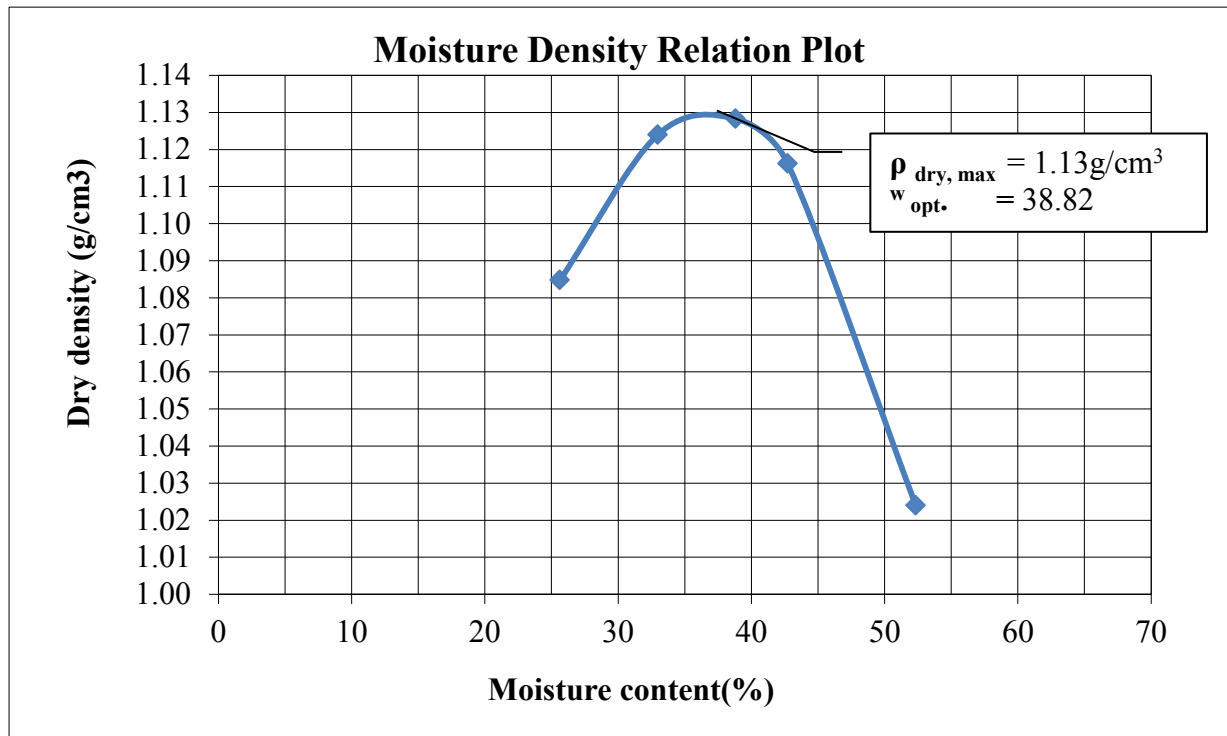


Figure 4-13 Moisture density relation of the volcanic ash or Pumicite

4.3.6 Moisture content determination

This test method covers the laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water. This standard requires the drying of material in an oven at high temperatures. The following table shows the moisture content of the volcanic Ash/Pumicite.

Table 4-11 Moisture content determination of volcanic ash/pumicite

| | |
|--------------------------|-------|
| Container number | 4 |
| Wet soil + container (g) | 559.3 |
| Dry soil + container (g) | 549.6 |
| Weight of container (g) | 228.9 |
| Weight of dry soil (g) | 320.7 |
| Moisture content % | 3.02 |

4.4 Additional Tests

4.4.1 Gradation

The gradation of the blended material is checked whether it falls in ERA upper and lower limit boundary. The gradation curves before and after compaction of the blended material is shown in Figure 4.12 and 4.13 respectively.

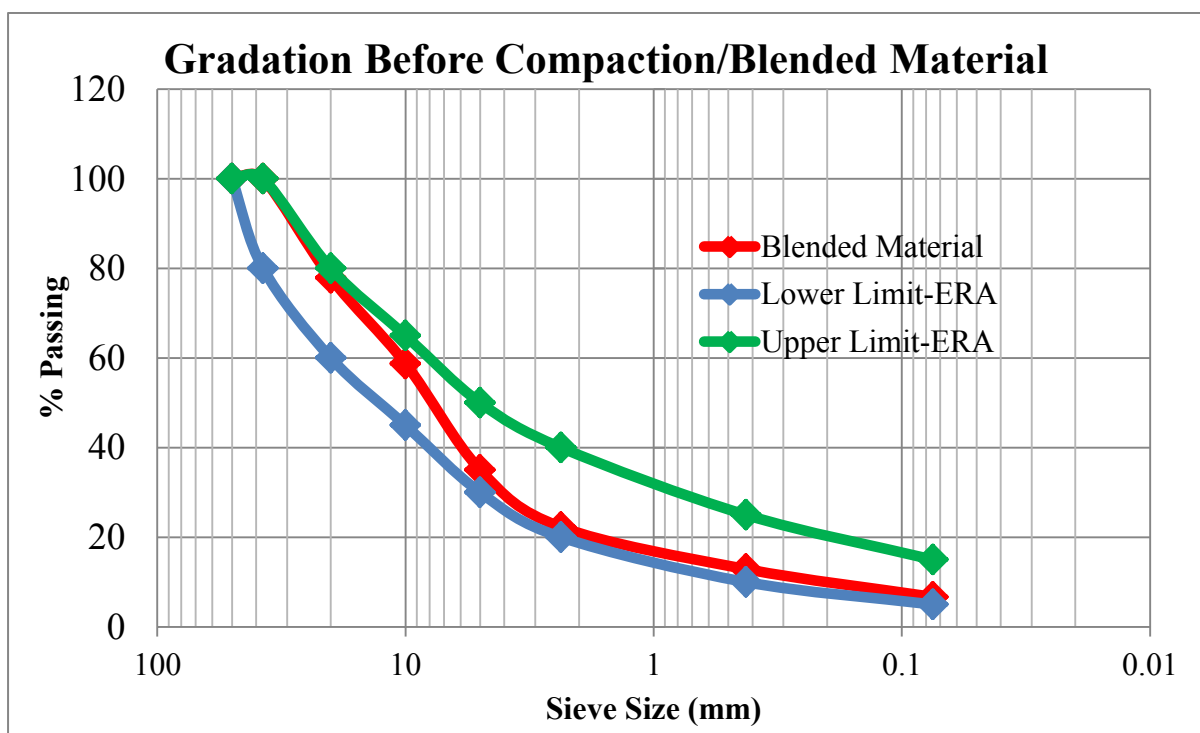


Figure 4-14 Gradation before Compaction of the blended material

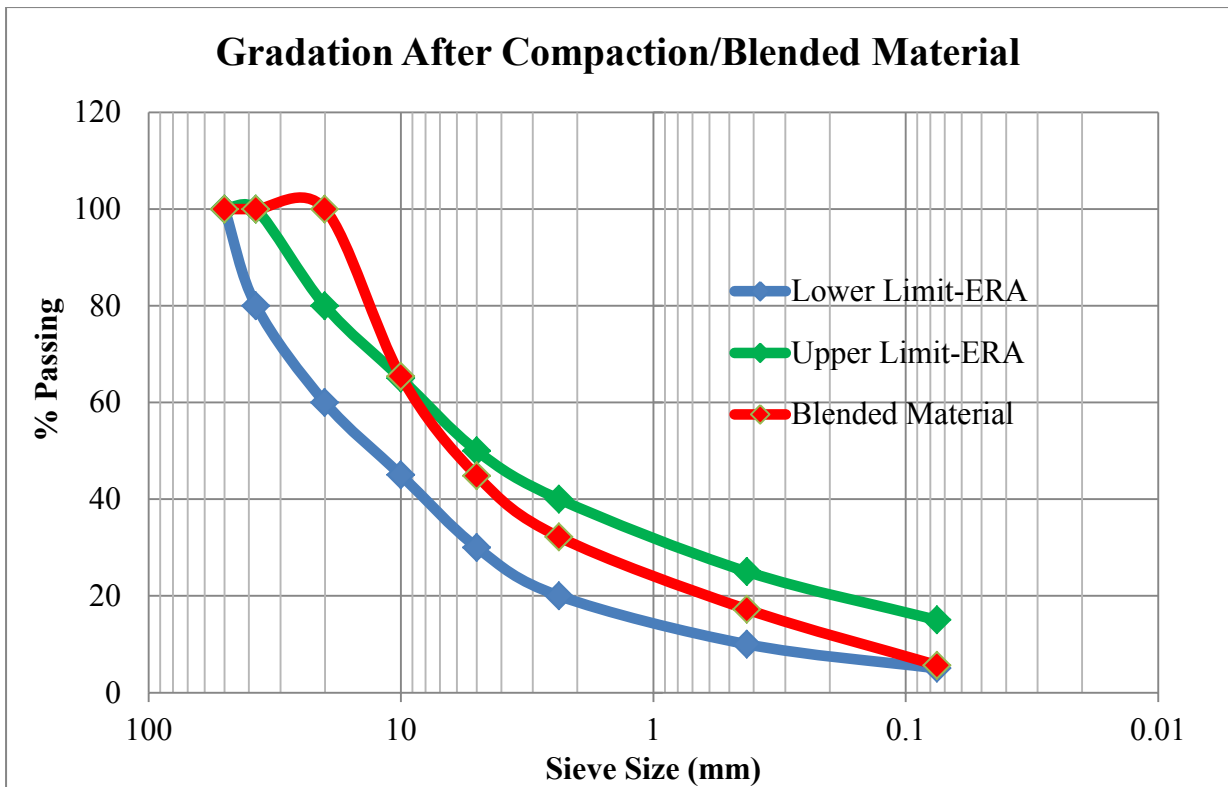


Figure 4-15 Gradation after compaction of the blended material

CHAPTER 5

5 DISCUSSION OF THE TEST RESULTS

5.1 Discussion on Los Angeles abrasion test

The average calculated values LAA for natural cinder by use of the Los Angeles Abrasion machine is 48.88% as shown in table 4-3. The Ethiopia Road Authority Manual Specification recommends that the Los Angeles Abrasion value shall not exceed 45% at 500 revolutions unless specified in the project specification when determined in accordance with the requirements of AASHTO T-96 [15]. The Los Angeles Abrasion result of the cinder gravel shows that it is weak in resistance to abrasion. Even though cinder gravel is weak in resistance to abrasion according to the Los Angeles abrasion test, it does not necessarily tell its field performance as the test is an empirical test.

5.2 Discussion on Aggregate crushing value test

The aggregate crushing value of the natural cinder gravel is 50kN but for values greater than 30kN the British Standard recommends to express it in terms of the ten percent fines value. The Ten percent fines value of the natural cinder gravel becomes 32.13kN. According to ERA specification the ten percent fines value should not be less than 50kN. The result obtained shows that cinder is weak in resistance to gradually applied crushing load as it failed in crushing under a small load. Another approach was also used to determine the resistance of cinder gravel against impact load using the aggregate crushing value test. According to the test method stated in British Standard the aggregate impact value should be less than 35% in order to say that an aggregate has good resistance to impact. However, the result obtained was 42.68% which showed that cinder has insufficient toughness to resist disintegration due to impact.

5.3 Discussion on specific gravity and Absorption

From the laboratory test conducted on the natural cinder gravel the water absorption value was 12.97% .This high water absorption capacity of the cinder gravel is due to the fact that cinder is light weight aggregate and highly porous at its natural state. The specific gravity of the cinder gravel is 2.62 as shown in Table 4-2 and the specific gravity of the volcanic ash/pumicite is 2.40 as shown in Table 4-9. The specific gravity of the volcanic ash is lower

than that of the cinder gravel due to the fineness of the pozzolan mineral and is light weight. Several studies have shown that the pozzolanicity of a material is dependent on the fineness of the particles with the strength rising for increasingly fine material. [15]

5.4 Discussion on the test result of strength activity index

In this study two materials which were believed to be pozzolanic were brought from Ziway area. Indirect test or physical test was conducted to determine the pozzolanicity of both materials. Pozzolanicity test was conducted using strength activity index test on both materials. From the result shown in Table 4-7; the pumice, which is a coarser one, had a strength activity index value of 89.17% whereas the volcanic ash/pumicite, which is finer, had a strength activity index value of 76.43%. The results showed that both materials were pozzolanic in nature but in this research the volcanic Ash/Pumicite was selected as a stabilizer for the reason that the material fulfills the minimum requirement for pozzolanicity. In addition, since cinder is short of fine material, using this material is ultimately believed to improve the gradation and subsequently the density.

5.5 Discussion on the test result of compaction

In this research heavy traffic asphalt road was considered, as a result, modified compaction effort was used for the natural cinder gravel as well as for all blending proportions that were investigated. By using the compaction method, it was believed that the high porosity of the cinder gravel would be filled up by the volcanic ash/pumicite and higher density would be obtained. A 4% increment of the volcanic ash/pumicite was made until the density dropped at 24% of volcanic ash/pumicite. Table C-1 to Table C-7 in Appendix C shows the moisture density relationship for 4% up to 24% of volcanic ash/pumicite, respectively. From the summary of maximum dry density and corresponding optimum moisture content for different volcanic ash/pumicite percentage presented in Table 4-4, one can see that the maximum dry density and the corresponding optimum moisture content increases along with the increase in volcanic ash/pumicite percentage. at zero percent of volcanic ash/pumicite i.e. for the natural cinder gravel the maximum dry density was 1.57g/cc at an optimum moisture content of 5.55%. From 4% to 16% of volcanic ash/pumicite the maximum dry density and the corresponding optimum moisture content increases linearly due to the addition of fine material. After adding the volcanic ash/pumicite the moisture content has significantly increased when compared with that of the natural cinder gravel i.e. at zero percent volcanic

ash/pumicite. But at the 20% volcanic ash/pumicite the optimum moisture content decreases relatively while the density still increases. By adding 24% volcanic ash/pumicite the optimum moisture content increases highly when compared with the 20% volcanic ash/pumicite and also the density decreases significantly. The objective of compaction is to achieve a maximum density at optimum moisture content.

From the plot of the maximum dry density vs. percentage of Volcanic Ash/Pumicite plot shown in Figure 4-4, one can see that the maximum dry density increases from zero up to 20% of volcanic ash/Pumicite by mass and a further increase in the percentage of volcanic ash/ Pumicite bring a decrement in the maximum dry density. By adding 20% of volcanic ash/pumicite, the maximum dry density of the natural cinder gravel has improved from 1.57g/cc to 1.76 g/cc at optimum moisture content of 13.01%.

Stability of a material is obtained from good interlocking between its grains. Cinder gravel is short of fine material; as a result, it has a relatively low density. Adding volcanic ash/Pumicite, which is a fine material, fills up the voids in the cinder gravel and increases the grain-to-grain contact making it dense up to an optimum point. At the optimum volcanic ash/pumicite i.e. at 20% the density is high as all the voids are sealed at this point. A further increase in the volcanic ash/Pumicite brings a decrement in the maximum density.

The cinder gravel has little fine-grained soil content and gains its stability from grain-to-grain contact; consequently it usually has relatively low density. Adding fine-grained soil to the cinder gravel still gains its strength from grain-to-grain contact and leads to the increment of density up to an optimum point. The cinder gravel that contains optimum amount of fine-grained soil fills all the voids. This resulted in a relatively higher density. Beyond this optimum fine-grained soil, say at 24%, grain-to-grain contact gradually decreases leading to the decrement of density.

5.6 Discussion on the test result of CBR

Strength test on the natural cinder gravel and the blended material was made to check the improvement in strength and also to check the whether the blended material meets the minimum CBR requirement stated in ERA specification. From the California Bearing Ratio Test on the natural cinder gravel the three point CBR value was 59% at 98% maximum dry density. This shows that the CBR of the cinder gravel is small. After knowing the optimum content of the volcanic ash/pumicite was 20% by mass at an optimum moisture content of

13.01%, CBR test was conducted considering soaked and unsoaked condition. Air curing technique was used for the soaked and unsoaked condition where the stabilized samples were covered with a polyethylene sheet and kept in a normal air temperature and out of water intrusion during the curing period. After air curing the samples for zero, three, seven, fourteen, and twenty eight days, the samples prepared for the unsoaked condition were penetrated whereas the samples prepared for the soaked condition were immersed in water for 96 hours before penetration.

From the CBR vs. Curing time plot for Soaked/Unsoaked Condition shown in Figure 4-8 one can see that the CBR value increased for both conditions linearly and that soaking has decreased the CBR for all curing days. The plot of the CBR vs. curing time showed higher values of CBR. By introducing 20% of the volcanic ash/Pumicite the CBR value of the cinder was improved from 59% to 98%. Table 4-6 shows the CBR values for the soaked and unsoaked condition for zero, three, seven, fourteen and twenty eight curing days at the optimum i.e. at 20% volcanic ash content. It shows that the range of soaked CBR increases from 98% to 245% whereas for the unsoaked condition the CBR increases from 118% and 307%, for 0 to 28 days curing period. It was observed that the rate of increment in the CBR value for the soaked and unsoaked condition for seven to fourteen curing days is relatively small relative to the other curing periods. This could be an indicator that this period was not enough for expedited chemical reaction to take place as compared with the other curing periods. For periods of fourteen to twenty eight curing days, the CBR value for both conditions increased significantly which could imply that higher reactions were taking place during this period as indicated from the CBR values. The slow chemical reaction during this period could have been further understood had there been certain chemical tests conducted on the volcanic ash/pumicite. From the picture shown in Figure 4-9 one can see how the cured and penetrated sample is stable and intact during and after penetration. It shows that the penetrated sample was stable without disintegration which indicates that pozzolanic reaction was taking place during the curing period. The increase in strength along with the curing period is attributed to the fact that the material used as a stabilizer i.e. the volcanic ash/pumicite exhibits pozzolanic or cementation property. The minimum soaked CBR as recommended in ERA specification is 80% when determined in accordance with ASTM D 1883. The result shows that the minimum soaked CBR meets the minimum requirements of the specification. Besides, as the sample gets more curing time the CBR value for both soaked and unsoaked condition increases. The overall results confirms that the blended

material is best material when used as a road base material because even at the worst scenario i.e. at the soaked condition, the material shows a strength development and that water is not a treat to it at all.

5.7 Discussion on Unconfined compression test

From the strength test conducted on the blended material higher CBR values were obtained when longer curing periods were given. To further check whether this increment in strength along with the curing period was due to the cementation or pozzolanic property of the material, an indirect test was conducted using the unconfined compression strength test on two samples cured for three and seven days which were compacted at a density obtained from standard compaction test conducted on the volcanic ash/pumicite. The density and the moisture content used to prepare the samples are shown in Figure 4-13. The results showed an increment in the UCS value with longer curing period. For the three days curing an average UCS value of 84.65 kPa was obtained and for seven days curing the average UCS value was 266.63 kPa as presented in Table 4-8.

From the unconfined compressive strength test results one can see that the volcanic ash/Pumicite increases in strength as more curing time was given. This shows that the cementation property of the material is enhanced along with the curing period and proves that the material is self-cementing. This material is non- plastic material and yet exhibits cementation property, which is an indicator that the material is pozzolanic.

5.8 Discussion on Atterberg limit test

According to ERA specification, all road-base materials shall have a maximum plasticity index of 6 when determined in accordance with AASHTO T-90. A maximum plasticity product of 60 is recommended or plasticity modulus of 90 is recommended alternatively. Table 4-10 shows that 0, 4, 8, 12, 16, 20 and 24 % of the blending proportion of material by mass with cinder has no plasticity characteristics and the plastic product is also zero. This is due to the non-plastic nature of the cinder gravel and the volcanic ash or pumicite. Figure 4-12 shows the liquid and plastic limit of the volcanic ash/pumicite. From the figure one can see that the material crumbles before it rolls into a 3.2mm rod. Besides in the liquid limit test, the volcanic ash/pumicite closes in 8 or 9 blows for repeated trials. Since the liquid limit and the plastic limit cannot be determined the material is reported to be a non plastic material. For a material to perform very well as a road base, its plasticity should be between zero and

six and yet for this blended material, it has no plasticity at all and as a result the plastic product and the plasticity modulus is zero. Therefore; all the blending proportions satisfy the ERA manual specification.

5.9 Discussion on the test result of gradation

Based on field observation, the nominal size of the cinder gravel was 37.5mm. For this nominal size the appropriate grading limit is GB2 which is shown in Figure 4-1. Grading of the natural cinder gravel and the material blended with the cinder gravel and natural pozzolana was made against this grading limit. From the grading chart of the natural cinder gravel shown in Figure 4-2 deficiency in fine material is clearly observed. It is out of ERA specification. From Figure 4-3 one can see that the modified AASHTO compaction has resulted in large amount of crushing. There is a certain improvement in the gradation due to breakdown of cinder gravel under compaction which is attributed to its weak nature. This shows the need to add fine material in order to achieve ERA's specification.

From the gradation curves for the optimum blending proportion shown in Figures 4-14 and 4-15; one can see that the gradation before compaction falls within ERA specification Limit. For the coarser sieves, particularly sieve No.10 and above the percentage retained is small which makes it closer to ERA's specification upper limit for the naturally occurring granular base. For Sieves less than No.10 addition of 20% volcanic ash has improved the gradation of the natural cinder gravel by filling up its deficiency of fine material as was observed from the gradation curve of the natural cinder gravel.

From the gradation after compaction plot of the optimum blending proportion the curve falls out of ERA specification limit starting from sieve No. 10 and above. This is due to the modified compaction effort used and the weak resistance to crushing of the aggregates of cinder gravel. Under laboratory conditions, the grading parameter falls outside of the limits set by ERA specifications. The grading of a material is used as an indicative measure of a material's capability to achieve a desired performance. Hence, the laboratory testing demonstrated that the stabilized material still achieved the strength requirements without having the correct grading then this should not be seen as a reason for rejection.

CHAPTER 6

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Although Cinder gravel is abundantly available in Ethiopia, it had not been widely used as a road construction material because of its failure to meet specification requirements. This thesis attempted to use Natural Pozzolana to stabilize Cinder gravel for a road base. The under listed conclusions are made from the thesis work:

- 1- The gradation after compaction shows significant breakdown of Coarser cinder gravel particles.
- 2- The blended road base material has no plasticity characteristics and the plastic product and the plastic modulus is zero.
- 3- The property of cinder gravel is improved when blended with Natural Pozzolana, i.e. volcanic ash/pumicite.
- 4- From the maximum dry density vs. percentage volcanic ash/pumicite plot, the optimum amount of Natural Pozzolana is 20%.
- 5- The Volcanic Ash/Pumicite exhibits Pozzolanic property as shown from the physical tests i.e. Strength Activity Index and Unconfined Compression Strength tests.
- 6- The Unconfined Compression Strength of the volcanic Ash/Pumicite increases significantly for 7 days when compared to 3 days while covered with a soft paper and sprinkled with water.
- 7- Soaking has decreased the CBR for 0, 3, 7, 14 and 28 curing days when compared with the Unsoaked CBR value.
- 8- The minimum soaked CBR is 98% at 4 days soaking and the peak soaked CBR value is 245% at 28 days for the optimum blending proportion.
- 9- The blended material, i.e. 80% cinder gravel with 20% volcanic ash/pumicite could be used as a road base material.
- 10- The rate of increment of CBR for the soaked condition is lower when compared to that of the unsoaked condition.
- 11- The gradation before compaction of the optimum blending proportion falls within ERA specification limit.
- 12- Curing plays an important role in the strength development of the blended material.

6.2 Recommendations for future work

This thesis attempted to stabilize cinder gravel with natural pozzolana (volcanic ash) from Ziway. Since both materials are volcanic products and that Ethiopia had volcanic activity along the rift valley, different natural Pozzolana could be used to stabilize cinder gravel at other parts of the country. In light of this, the following recommendations are made.

- 1- Field performance evaluation should be conducted at a pilot section.
- 2- Durability Tests should be conducted on the blended material.
- 3- Samples of cinder gravel should be taken from other part of the country for further study.
- 4- Composition of natural pozzolanas should be carried out using chemical analysis for its detailed classification.
- 5- Standard should be developed to make use of natural pozzolana and cinder gravel as a road construction material across Ethiopia.

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APPENDICES

APPENDIX - A

Test Results of Cinder Gravel Only

Table A- 1 Particle Size Distributions for Base Course Material (GB2), ERA Specification

| Test Sieve (mm) | Lower Limit-ERA Spec. | Upper Limit-ERA Spec. |
|-----------------|-----------------------|-----------------------|
| 50.00 | 100 | 100 |
| 37.50 | 80 | 100 |
| 20.00 | 60 | 80 |
| 10.00 | 45 | 65 |
| 5.00 | 30 | 50 |
| 2.360 | 20 | 40 |
| 0.425 | 10 | 25 |
| 0.075 | 5 | 15 |

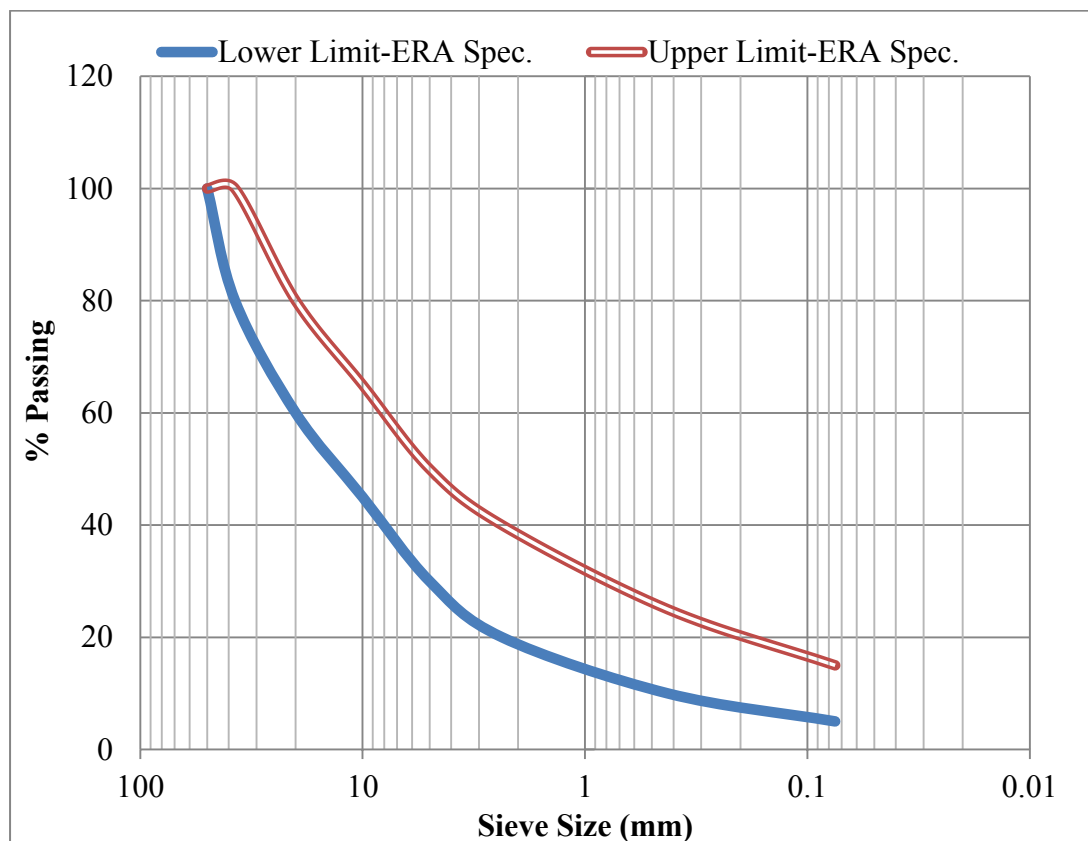


Figure A-1 Ethiopian Roads Authority grading Limit for base course Material (GB2)

Table A- 2 Particle Size Distributions of Cinder before compaction

| Washed Gradation Before Compaction | | | | | |
|------------------------------------|--------------|------------|-----------|-----------------------|-----------------------|
| Sieve | Wt. Retained | % Retained | % Passing | Lower Limit-ERA Spec. | Upper Limit-ERA Spec. |
| 50 | 0 | 0 | 100 | 100 | 100 |
| 37.5 | 260.9 | 7.39 | 92.61 | 80 | 100 |
| 20 | 426.6 | 12.08 | 80.53 | 60 | 80 |
| 10 | 905.5 | 25.64 | 54.89 | 45 | 65 |
| 5 | 800.4 | 22.66 | 32.23 | 30 | 50 |
| 2.36 | 623.9 | 17.67 | 14.56 | 20 | 40 |
| 0.425 | 446.1 | 12.63 | 1.93 | 10 | 25 |
| 0.075 | 68.1 | 1.93 | -2E-15 | 5 | 15 |

| | |
|-------------------------|----------|
| Weight Before Wash(gm.) | 3,531.50 |
|-------------------------|----------|

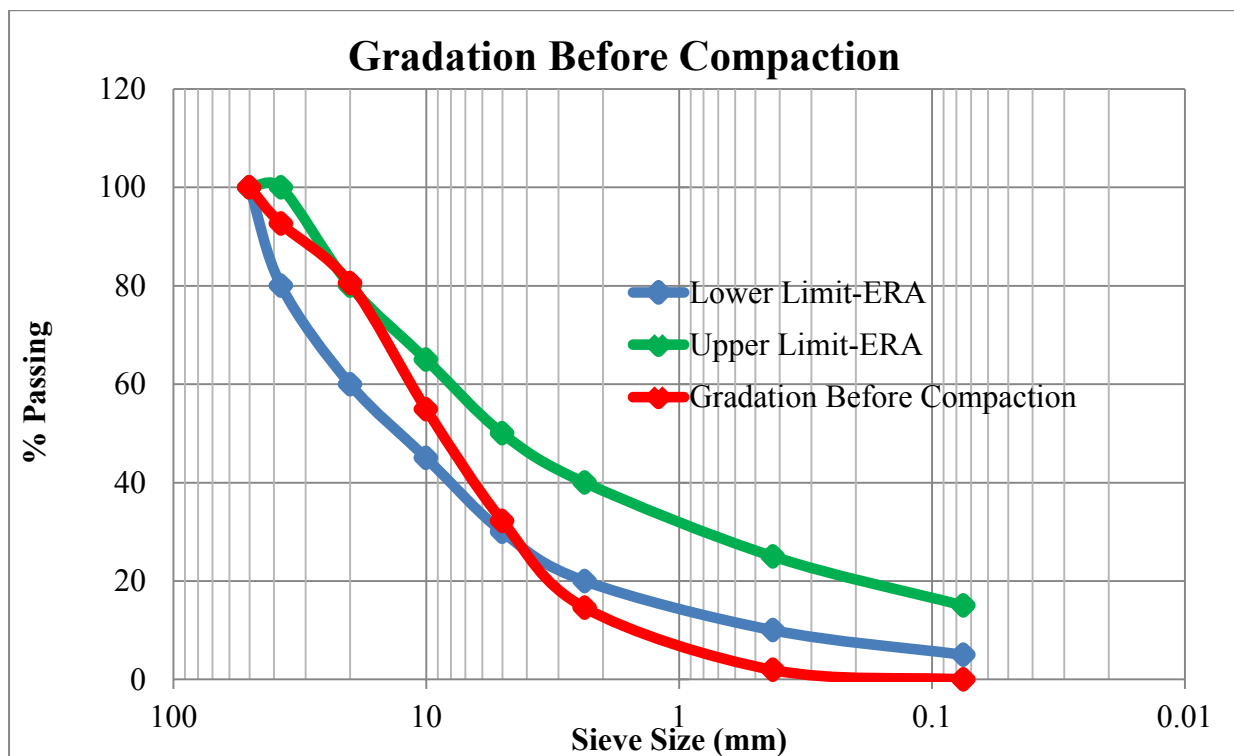


Figure A-2 Washed Gradation of Cinder before Compaction

Table A- 3 Particle Size Distributions of Cinder after compaction

| Washed Gradation After Compaction | | | | | |
|--|---------------------|-------------------|------------------|------------------------------|------------------------------|
| Sieve | Wt. Retained | % Retained | % Passing | Lower Limit-ERA Spec. | Upper Limit-ERA Spec. |
| 50 | 0 | 0 | 100 | 100 | 100 |
| 37.5 | 0 | 0.00 | 100.00 | 80 | 100 |
| 20 | 0 | 0.00 | 100.00 | 60 | 80 |
| 10 | 275.8 | 8.72 | 91.28 | 45 | 65 |
| 5 | 475.8 | 15.05 | 76.22 | 30 | 50 |
| 2.36 | 660.3 | 20.89 | 55.34 | 20 | 40 |
| 0.425 | 1095.6 | 34.66 | 20.68 | 10 | 25 |
| 0.075 | 507.2 | 16.05 | 4.63 | 5 | 15 |

| | |
|-------------------------|----------|
| Weight Before Wash(gm.) | 3,161.10 |
|-------------------------|----------|

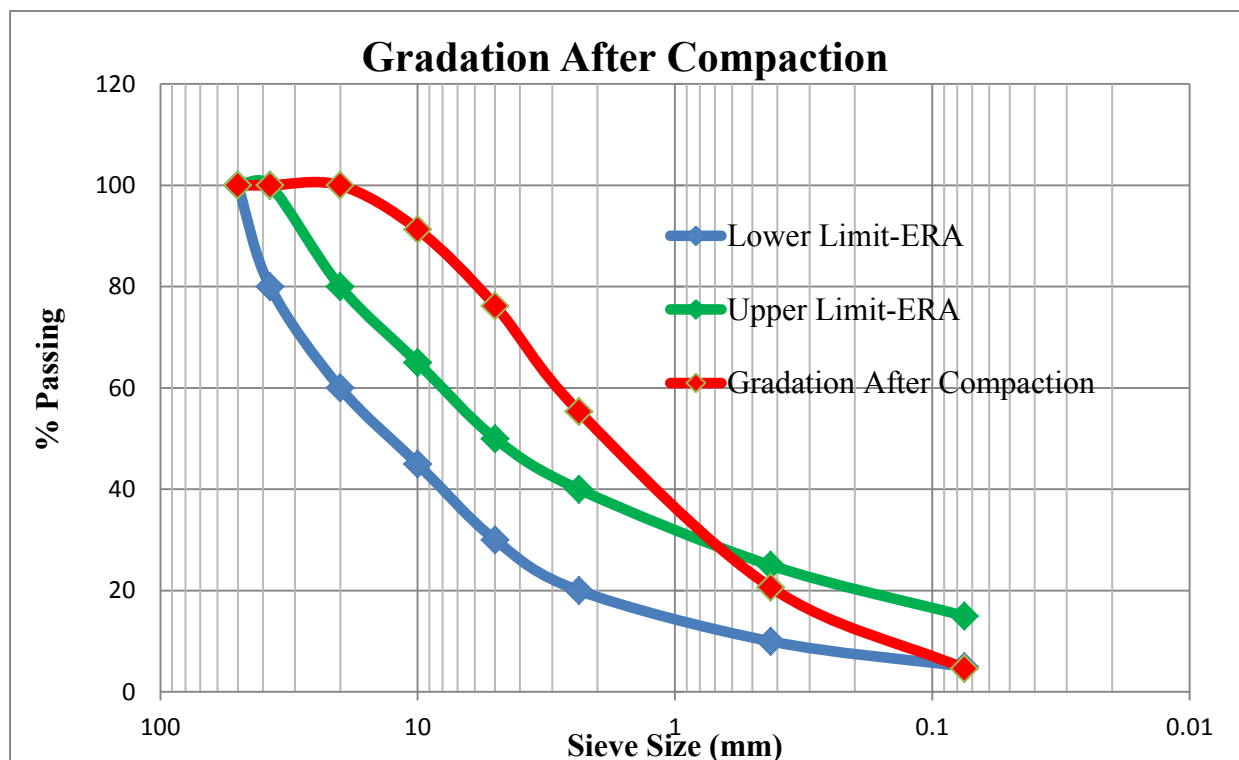


Figure A-3 Washed Gradation of Cinder after Compaction

Table A- 4 Moisture Content Vs Density Relation of Cinder

| | | | |
|----------------------------------|---------|---------|---------|
| Determination No. | 1.0 | 2.0 | 3.0 |
| Mass of Mold, g | 4727.3 | 4727.3 | 4727.3 |
| Mass of mold + Compacted Soil, g | 7999.1 | 8135.9 | 8158.5 |
| Mass of Compacted soil, g | 3271.8 | 3408.6 | 3431.2 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.60 | 1.66 | 1.67 |
| Water Content, % | 2.67 | 5.55 | 8.62 |
| Dry density, g/cm ³ | 1.55 | 1.57 | 1.54 |
| Water Content Determination | | | |
| Container No | C-01 | C-02 | C-03 |
| Mass of container, g | 230.00 | 227.90 | 224.80 |
| Mass of container + wet soil, g | 526.40 | 587.30 | 557.40 |
| Mass of container + Dry soil, g | 518.70 | 568.40 | 531.00 |
| Mass of Water, g | 7.70 | 18.90 | 26.40 |
| Mass of Dry soil, g | 288.70 | 340.50 | 306.20 |
| Water content, % | 2.67 | 5.55 | 8.62 |

| | |
|---|------|
| Opt. moisture content, (%)= | 5.55 |
| Max.dry density, (g/cm ³) = | 1.57 |

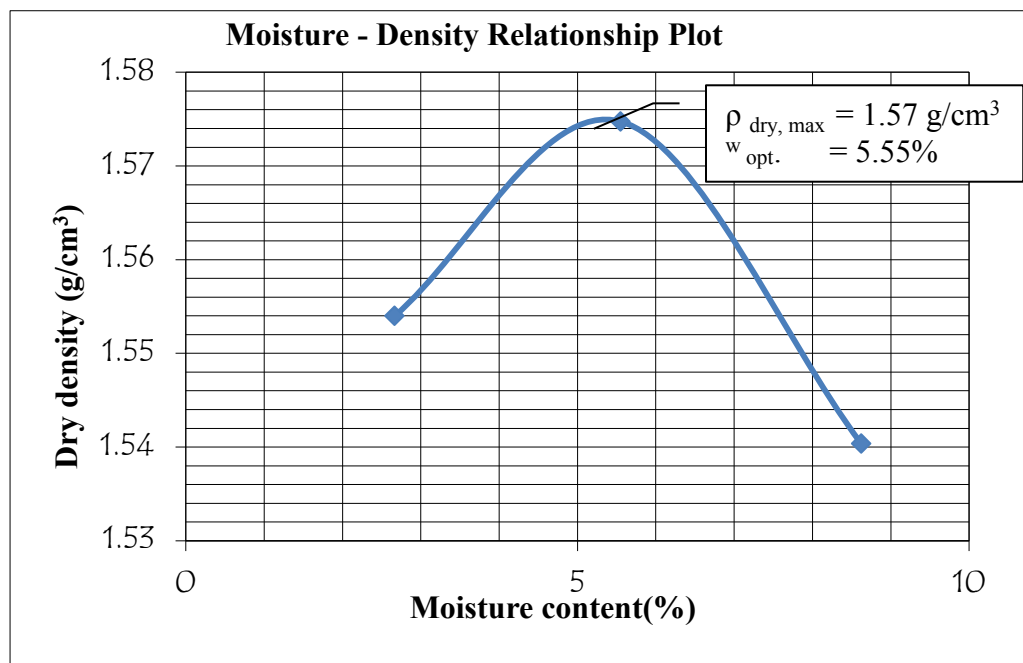


Figure A-4 Moisture Content Vs. Density Plot of the Cinder Gravel

Table A-5 Resistance to Abrasion of Small size coarse Aggregate

| RESISTANCE TO ABRASION OF SMALL SIZE COARSE AGGREGATE BY USE OF THE LOS ANGELES MACHINE TEST METHOD : <u>AASHTO T 96-94</u> | | | | | | | |
|---|---------------|--------------|----------------|----------------|----------------|----------------|---------------|
| Location: | Mojo | | | | | | |
| Material type: | Cinder Gravel | | | Date sample: | | | |
| Sample from: | Quarry | | | Date test: | | | |
| MATERIAL DESCRIPTION : | | | | | | | |
| 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) | | | 2554 | 2558 | | | |
| PERCENT LOSS (%) | | | 48.92 | 48.84 | | 48.88 | |

Table A-6 Specific Gravity and Water Absorption Test

| SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE | | | |
|--|---------------------------------|--------------|---------|
| Test Method: ASTM C 127 | | | |
| Location: | Mojo | | |
| Material type: | Cinder Gravel | Date sample: | |
| Sample from: | Quarry | Date test: | |
| MATERIAL SAMPLE No. | | A | B |
| A | DRY WEIGHT(g) | 1774.30 | 1783.00 |
| B | SATURATED SURFACE DRY WEIGHT(g) | 2009.90 | 2008.90 |
| C | WEIGHT IN WATER(g) | 984.60 | 1009.20 |
| D | (A-C) (g) | 789.70 | 773.80 |
| E | (B-C) (g) | 1025.30 | 999.70 |
| APPARENT SPECIFIC GRAVITY (g/cm ³) | A/D | 2.25 | 2.30 |
| | AVERAGE | 2.28 | |
| BULK SPECIFIC GRAVITY (SSD) SATURATED SURFACE DRY (g/cm ³) | B/E | 1.96 | 2.01 |
| | AVERAGE | 1.98 | |
| BULK SPECIFIC GRAVITY (g/cm ³) | A/E | 1.73 | 1.78 |
| | AVERAGE | 1.76 | |
| WATER ABSORPTION*100% | (B-A)/A | 13.28 | 12.67 |
| | AVERAGE | 12.97 | |

Table A-7 Ten percent Fines Value (TFV)

| TEN PERCENT FINES VALUE (TPV) | | |
|--|---------------|--------------------|
| Test Method: BS 812-111 : 1990 | | |
| Location: | Mojo | |
| Material type: | Cinder Gravel | Date sample: _____ |
| Sample from: | Quarry | Date test: _____ |
| Test No | 1 | 2 |
| Mass of Aggregate Before test, Pass 14mm and Retain 10mm sieves, (M1) (gm.) | 1465 | 1442.9 |
| Mass of Aggregate Before test, Pass 14mm and Retain 10mm sieves, (M1) (gm.) | 98.4 | 98.9 |
| Percent Fine, m (%) | 7.80 | 9.00 |
| Maximum Load, f (KN) | 30.2 | 26.4 |
| TFV = $14 \cdot f / (m + 4)$, KN | 39.45 | 34.05 |
| Average TPV,KN | 32.13 | |

Table A-8 Aggregate Crushing Value (ACV)

| AGGREGATE CRUSHING VALUE (ACV) | | |
|--|---------------|--------------------|
| Test Method: BS 812-112 : 1990 | | |
| Location: | Mojo | |
| Material type: | Cinder Gravel | Date sample: _____ |
| Sample from: | Quarry | Date test: _____ |
| Test No | 1 | 2 |
| Mass of Aggregate Before test, Pass 14mm and Retain 10mm sieves, (M1) (gm.) | 1411.5 | 1432.4 |
| Mass of Aggregate after compression, Passing 2.36 sieves , (M2) (gm.) | 721 | 722.8 |
| ACV(%) = (M2/M1)*100 | 51.08 | 50.46 |
| Average TFV,KN | 50.77 | |

Table A-9 Aggregate Impact Value (AIV)

| | | |
|---|--------------|-------|
| Test No | 1 | 2 |
| Mass of Aggregate Before test, Pass 14mm and Retain 10mm sieves, (M1) (gm) | 171.1 | 167.5 |
| Mass of Aggregate after compression, Passing 2.36 sieves , (M2) (gm) | 72.6 | 71.9 |
| AIV(%) = (M2/M1)*100 | 42.43 | 42.93 |
| Average AIV, | 42.68 | |

Table A-10 California Bearing Ratio (CBR)

| CALIFORNIA BEARING RATIO (CBR) | | | | | | | | | | |
|--------------------------------|--------------|------------|-------------|----------------|----------------|----------------|---------------|-----------------|---------------|--|
| TEST METHOD AASHTO T-193 | | | | | | | | | | |
| Sample Location | Modjo | | | Sampled From | | Quarry | | | | |
| Ring factor (N/mm) | 21.58N/mm | | | Date Sampled | | Feb 24,2015 | | | | |
| Material Description | Cinder | | | Date tested | | | | | | |
| Density Determination | | | | | | | | | | |
| | | | | 10 blows | | 30 blows | | 65 blows | | |
| Soaked □ | | Unsoaked □ | | Before soaking | | Before soaking | | Before soaking | | |
| Mold No. | | | 54 | | 62 | | 54 | | | |
| Weight of soil + mould g | | | 9285 | 9890 | 9180 | 10220 | 9915 | 10445 | | |
| Weight of mould g | | | 6475 | 6475 | 6225 | 6475 | 6475 | 6475 | | |
| Weight of soil g | | | 2810 | 3415 | 2955 | 3745 | 3440 | 3970 | | |
| Volume of mould g | | | 2108.6 | 2108.55 | 2104.94 | 2104.94 | 2108.55 | 2108.55 | | |
| Wet density of soil g/cc | | | 1.33 | 1.62 | 1.40 | 1.78 | 1.63 | 1.88 | | |
| Dry density of soil g/cc | | | 1.27 | 1.44 | 1.34 | 1.48 | 1.54 | 1.56 | | |
| Moisture Determination | | | | | | | | | | |
| | | | | 10 blows | | 30 blows | | 65 blows | | |
| | | | | Before soaking | After soaking | Before soaking | After soaking | Before soaking | After soaking | |
| Container number | | | | B-3 | x1 | B-3 | G1 | B-5 | P-22 | |
| Wet soil + container (g) | | | | 537.8 | 460.66 | 537.8 | 496.91 | 372.55 | 457.22 | |
| Dry soil + container (g) | | | | 517.98 | 417.06 | 517.98 | 425.84 | 356.8 | 392.33 | |
| Weight of container (g) | | | | 81.66 | 74.3 | 81.66 | 75.92 | 78.96 | 76.01 | |
| Weight of dry soil (g) | | | | 436.32 | 342.76 | 436.32 | 349.92 | 277.84 | 316.32 | |
| Moisture content % | | | | 4.54 | 12.72 | 4.54 | 20.26 | 5.67 | 20.47 | |
| Load - Penetration Data | | | | | | | | | | |
| | | 10 blows | | | 30 blows | | | 65 blows | | |
| Penetration (mm) | Dial reading | Load (MPa) | Corr. CBR % | Dial reading | Load (MPa) | Corr. CBR % | Dial reading | Load (MPa) | Corr. CBR % | |
| 0 | 0 | 0 | | 0 | 0 | | 0 | 0 | | |
| 0.635 | 8 | 0.089 | | 3 | 0.033 | | 10 | 0.111 | | |
| 1.27 | 25 | 0.279 | | 9.5 | 0.106 | | 32 | 0.357 | | |
| 1.905 | 51 | 0.569 | | 42 | 0.468 | | 60 | 0.669 | | |
| 2.54 | 87 | 0.970 | 1.25 | 82 | 0.914 | 3.91 | 108 | 1.204 | 46 | |
| 5.08 | 192 | 2.141 | 2.38 | 324 | 3.612 | 4.35 | 395 | 4.404 | 61 | |
| 7.62 | 272 | 3.033 | | 438 | 4.884 | | 666 | 7.426 | | |
| Swelling Data | | | | | | | | | | |
| Height of specimen(mm) | 125 | | | No. of blows | Before soaking | After soaking | % swell | Average % swell | | |
| | | | | 10 | 116 | 116 | 0.00 | 0.00% | | |
| | | | | 30 | 328 | 328 | 0.00 | | | |
| | | | | 65 | 400 | 400 | 0.00 | | | |

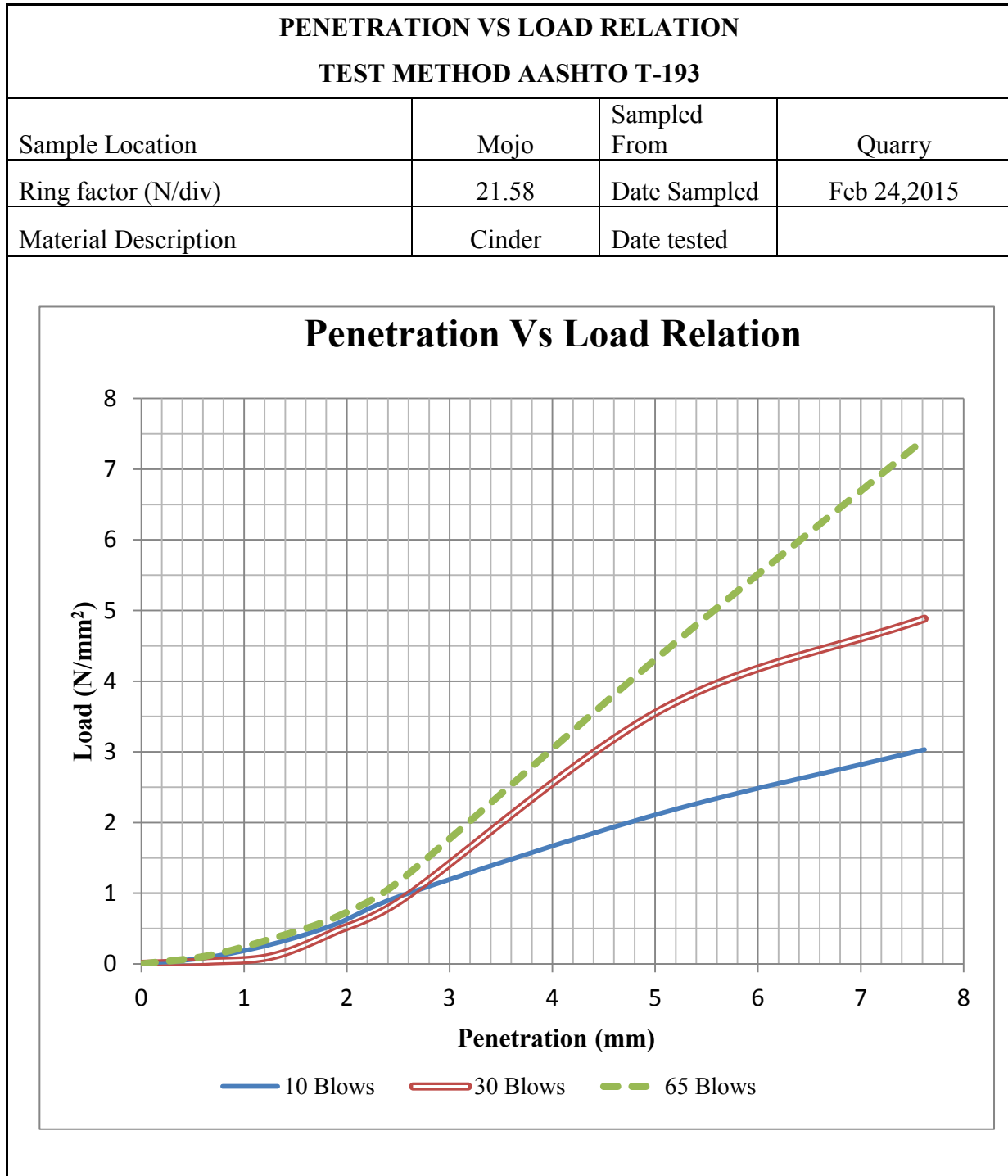


Figure A- 5 Penetration and load relation of cinder only

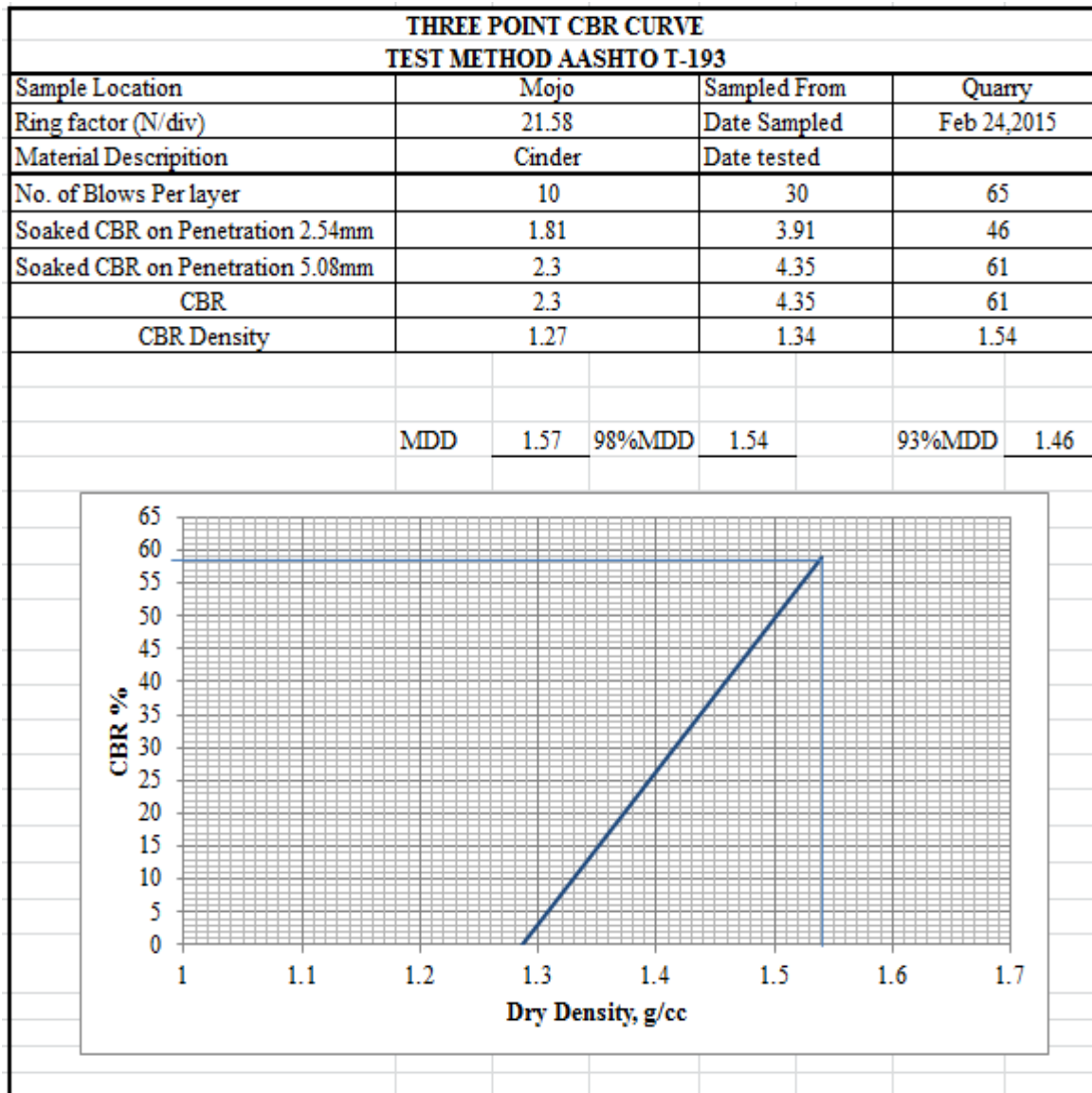


Figure A- 6 Three-point CBR curve of cinder only

APPENDIX - B

Test Results of Natural Pozzolana (Volcanic Ash)

Table B- 1 Moisture Content Vs Density Relation of Volcanic Ash/Pumicite

| Determination No. | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|----------------------------------|--------|--------|--------|--------|--------|
| Mass of Mold, g | 3160.0 | 3160.0 | 3160.0 | 3160.0 | 3160.0 |
| Mass of mold + Compacted Soil, g | 4432.0 | 4555.0 | 4622.0 | 4647.0 | 4616.0 |
| Mass of Compacted soil, g | 1272.0 | 1395.0 | 1462.0 | 1487.0 | 1456.0 |
| Volume of Mold, cm ³ | 933.38 | 933.38 | 933.38 | 933.38 | 933.38 |
| Bulk density, g/cm ³ | 1.36 | 1.49 | 1.57 | 1.59 | 1.56 |
| Water Content, % | 25.63 | 32.97 | 38.82 | 42.73 | 52.34 |
| Dry density, g/cm ³ | 1.08 | 1.12 | 1.13 | 1.12 | 1.02 |

| | |
|---|-------|
| Opt. moisture content, (%) = | 38.82 |
| Max.dry density, (g/cm ³) = | 1.13 |

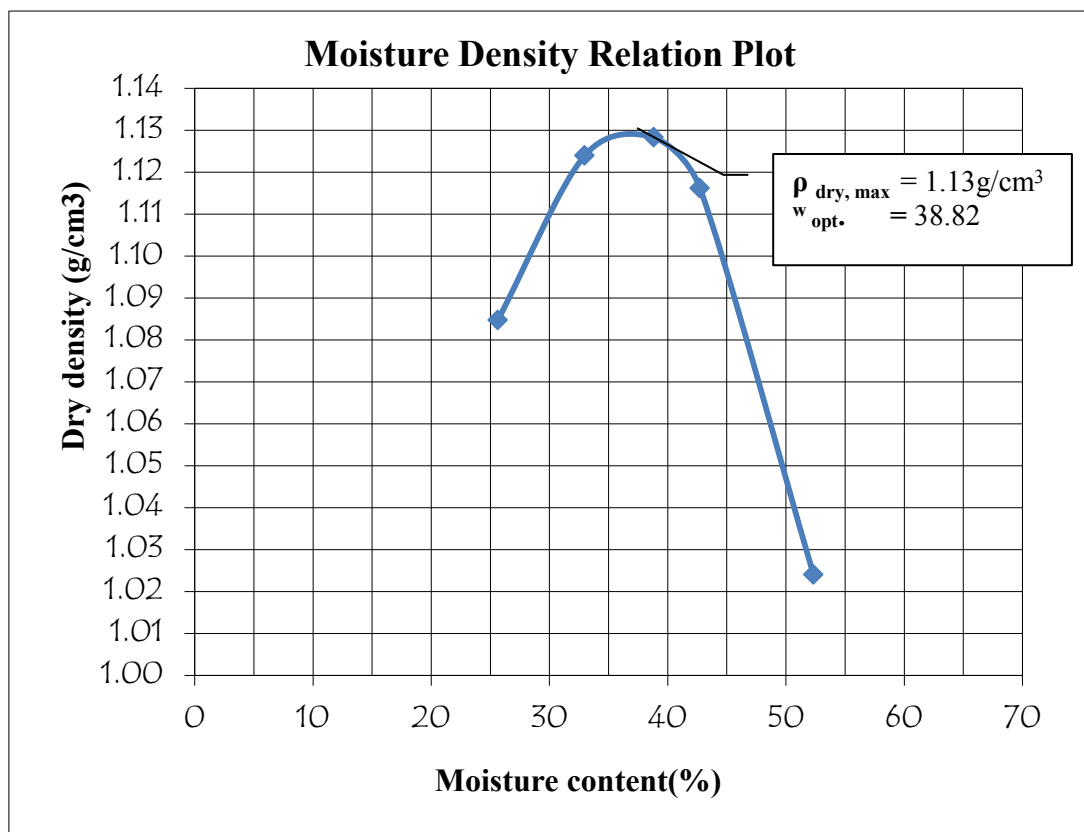


Table B-2 Unconfined Compression Test of Volcanic Ash/Pumicite- 3 days Cured/Specimen-1

| UNCONFINED COMPRESSION TEST | | | | | |
|---------------------------------|-----------------------|--|-----------------------|----------------------------------|--------------------|
| TEST METHOD-ASTM D2166 | | | | | |
| Sample Station | Zeway | Cast Date | May 26,2015 | | |
| Material Description | Volcanic Ash/Pumicite | Penetration Date | June 2,2015 | | |
| Diameter of sample , cm | 10 | Ring Calibration Factor, KN/div | 0.02158 | | |
| Moisture Determination | | | Density Determination | | |
| Container No. | | Initial Area of Specimen,cm ² | 78.5714 | | |
| Mass of Container,gm | 35.51 | Initial Height of Specimen, cm | 20.00 | | |
| Mass of container + wet soil, g | 94.65 | Volume of Specimen,cm ³ | 1571.43 | | |
| Mass of container + Dry soil, g | 78.53 | Weight of Specimen, g | 2363.00 | | |
| Mass of Water, g | 43.02 | Wet Density, g/cm ³ | 1.50 | | |
| Moisture Content | 54.78% | Moisture Content | 54.78% | | |
| | | Dry Density, g/cm ³ | 0.97 | | |
| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [KN] | Corrected Area [m ²] | Axial Stress [Kpa] |
| 0 | 0.00 | 0 | 0.0000 | 0.0078570 | 0 |
| 0.44 | 0.2200 | 6 | 0.1295 | 0.0100731 | 12.854 |
| 0.54 | 0.2700 | 14 | 0.3021 | 0.0107630 | 28.070 |
| 0.59 | 0.2950 | 21 | 0.4532 | 0.0111447 | 40.663 |
| 0.63 | 0.3150 | 29 | 0.6258 | 0.0114701 | 54.561 |
| 0.645 | 0.3225 | 37 | 0.7985 | 0.0115970 | 68.850 |
| 0.655 | 0.3275 | 40 | 0.8632 | 0.0116833 | 73.883 |
| 0.665 | 0.3325 | 43 | 0.9279 | 0.0117708 | 78.834 |
| 0.668 | 0.3340 | 45 | 0.9711 | 0.0117973 | 82.315 |
| 0.678 | 0.3390 | 44 | 0.9495 | 0.0118865 | 79.882 |
| 0.684 | 0.3420 | 40 | 0.8632 | 0.0119407 | 72.290 |

Axial Stress Vs Axial Strain

The graph plots Axial Stress (kPa) on the y-axis (0 to 80) against Axial Strain (%) on the x-axis (0.2000 to 0.4000). The data points form a curve that rises to a peak of 82.315 kPa at 0.3340% strain before slightly declining.

Unconfined Compressive Strength(q_u),kP **82.315**

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

| UNCONFINED COMPRESSION TEST | | | | | |
|---------------------------------|-----------------------|--|-----------------------|----------------------------------|--------------------|
| TEST METHOD-ASTM D2166 | | | | | |
| Sample Station | Ziway | Cast Date | May 26,2015 | | |
| Material Description | Volcanic Ash/Pumicite | Penetration Date | June 2,2015 | | |
| Diameter of sample , cm | 100 | Ring Calibration Factor, KN/div | 0.02158 | | |
| Moisture Determination | | | Density Determination | | |
| Container No. | | Initial Area of Specimen,cm ² | 78.5714 | | |
| Mass of Container, gm | 35.51 | Initial Height of Specimen, cm | 20.00 | | |
| Mass of container + wet soil, g | 94.65 | Volume of Specimen,cm ³ | 1571.43 | | |
| Mass of container + Dry soil, g | 78.53 | Weight of Specimen, g | 2363.00 | | |
| Mass of Water, g | 43.02 | Wet Density, g/cm ³ | 1.50 | | |
| Moisture Content | 54.78% | Moisture Content | 54.78% | | |
| | | Dry Density, g/cm ³ | 0.97 | | |
| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [KN] | Corrected Area [m ²] | Axial Stress [Kpa] |
| 0 | 0.00 | 0 | 0.0000 | 0.0078570 | 0 |
| 0.41 | 0.2050 | 5.5 | 0.1187 | 0.0098830 | 12.009 |
| 0.51 | 0.2550 | 13 | 0.2805 | 0.0105463 | 26.601 |
| 0.56 | 0.2800 | 20.5 | 0.4424 | 0.0109125 | 40.540 |
| 0.59 | 0.2950 | 28 | 0.6042 | 0.0111447 | 54.218 |
| 0.6 | 0.3000 | 34 | 0.7337 | 0.0112243 | 65.369 |
| 0.615 | 0.3075 | 38.5 | 0.8308 | 0.0113458 | 73.228 |
| 0.625 | 0.3125 | 43 | 0.9279 | 0.0114284 | 81.196 |
| 0.635 | 0.3175 | 45.5 | 0.9819 | 0.0115121 | 85.292 |
| 0.638 | 0.3190 | 46.5 | 1.0035 | 0.0115374 | 86.975 |
| 0.643 | 0.3215 | 44 | 0.9495 | 0.0115800 | 81.997 |
| 0.648 | 0.3240 | 42 | 0.9064 | 0.0116228 | 77.981 |

| |
|---|
| <p style="text-align: center;">Axial Stress Vs Axial Strain</p> <p style="text-align: center;">Unconfined Compressive Strength(q_u),kPa = 86.975</p> |
|---|

Table B-4 Unconfined Compression Test of Volcanic Ash/Pumicite- 7 days cured/Specimen-1

| UNCONFINED COMPRESSION TEST | | | | | |
|---------------------------------|-----------------------|--|-----------------------|----------------------------------|--------------------|
| TEST METHOD-ASTM D2166 | | | | | |
| Sample Station | Zeway | Cast Date | May 26,2015 | | |
| Material Description | Volcanic Ash/Pumicite | Penetration Date | June 2,2015 | | |
| Diameter of sample , mm | 100 | Ring Calibration Factor, KN/div | 0.02158 | | |
| Moisture Detremination | | | Density Determination | | |
| Container No. | | Initial Area of Specimen,cm ² | 78.5714 | | |
| Mass of Container, gm | 35.51 | Initial Height of Specimen, cm | 20.00 | | |
| Mass of container + wet soil, g | 110.99 | Volume of Specimen,cm ³ | 1571.43 | | |
| Mass of container + Dry soil, g | 90.24 | Weight of Specimen, g | 2291.00 | | |
| Mass of Water, g | 54.73 | Wet Density, g/cm ³ | 1.46 | | |
| Moisture Content | 60.65% | Moisture Content | 60.65% | | |
| | | Dry Density, g/cm ³ | 0.91 | | |
| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [KN] | Corrected Area [m ²] | Axial Stress [Kpa] |
| 0 | 0.00 | 0 | 0.0000 | 0.0078570 | 0 |
| 0.32 | 0.1600 | 20 | 0.4316 | 0.0093536 | 46.143 |
| 0.33 | 0.1650 | 47 | 1.0143 | 0.0094096 | 107.790 |
| 0.337 | 0.1685 | 72 | 1.5538 | 0.0094492 | 164.433 |
| 0.342 | 0.1710 | 88 | 1.8990 | 0.0094777 | 200.370 |
| 0.345 | 0.1725 | 100 | 2.1580 | 0.0094949 | 227.281 |
| 0.35 | 0.1750 | 109 | 2.3522 | 0.0095236 | 246.988 |
| 0.355 | 0.1775 | 112 | 2.4170 | 0.0095526 | 253.016 |
| 0.36 | 0.1800 | 111 | 2.3954 | 0.0095817 | 249.995 |
| 0.365 | 0.1825 | 110 | 2.3738 | 0.0096110 | 246.988 |

Axial Stress Vs Axial Strain

The graph plots Axial Stress (kPa) on the y-axis (ranging from 40 to 250) against Axial Strain (%) on the x-axis (ranging from 0.1600 to 0.1850). The data points form a curve that rises linearly until approximately 175% strain, then curves to a peak of 253.016 kPa at 177.5% strain, and finally slightly declines.

Unconfined Compressive Strength(q_u),kPa **253.016**

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

| UNCONFINED COMPRESSION TEST | | | | | |
|---------------------------------|-----------------------|--|-----------------------|----------------------------------|--------------------|
| TEST METHOD-ASTM D2166 | | | | | |
| Sample Station | Zeway | Cast Date | May 26,2015 | | |
| Material Description | Volcanic Ash/Pumicite | Penetration Date | June 2,2015 | | |
| Diameter of sample , mm | 100 | Ring Calibration Factor, KN/div | 0.02158 | | |
| Moisture Detremination | | | Density Determination | | |
| Container No. | | Initial Area of Specimen,cm ² | 78.5714 | | |
| Mass of Container,gm | 35.51 | Initial Height of Specimen, cm | 20.00 | | |
| Mass of container + wet soil, g | 100.44 | Volume of Specimen,cm ³ | 1571.43 | | |
| Mass of container + Dry soil, g | 81.93 | Weight of Specimen, g | 2185.00 | | |
| Mass of Water, g | 46.42 | Wet Density, g/cm ³ | 1.39 | | |
| Moisture Content | 56.66% | Moisture Content | 56.66% | | |
| | | Dry Density, g/cm ³ | 0.89 | | |
| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [KN] | Corrected Area [m ²] | Axial Stress [Kpa] |
| 0 | 0.00 | 0 | 0.0000 | 0.0078570 | 0 |
| 0.16 | 0.0800 | 20 | 0.4316 | 0.0085402 | 50.537 |
| 0.162 | 0.0810 | 47 | 1.0143 | 0.0085495 | 118.634 |
| 0.166 | 0.0830 | 72 | 1.5538 | 0.0085682 | 181.341 |
| 0.17 | 0.0850 | 88 | 1.8990 | 0.0085869 | 221.156 |
| 0.172 | 0.0860 | 100 | 2.1580 | 0.0085963 | 251.039 |
| 0.175 | 0.0875 | 109 | 2.3522 | 0.0086104 | 273.183 |
| 0.178 | 0.0890 | 112 | 2.4170 | 0.0086246 | 280.241 |
| 0.179 | 0.0895 | 111 | 2.3954 | 0.0086293 | 277.586 |
| 0.183 | 0.0915 | 108 | 2.3306 | 0.0086483 | 269.490 |

Axial Stress Vs Axial Strain

The graph plots Axial Stress (kPa) on the y-axis (ranging from 40 to 290) against Axial Strain (%) on the x-axis (ranging from 0.0800 to 0.0900). A pink curve shows the relationship, peaking at 280.241 kPa at approximately 0.0895% strain. The peak is labeled 'Unconfined Compressive Strength (q_u), kPa 280.241'.

Unconfined Compressive Strength (q_u), kPa **280.241**

Table B-6 Strength Activity Index Test- Pozzolanicity Test of Pumice-Coarser

| STRENGTH ACTIVITY INDEX TEST METHOD - ASTM C311 | | | | | | | | | | | | | | |
|--|--------------------|--------------------------------|-----------------|------------|-------|-----------------------------|------------------------|------------|-------------------------------|-----------------|--|----------------------------|-------------------------|--------|
| Sample Station | | | Zeway | | | Material Description | | | | Pumice- Coarser | | | | |
| Control Mortar Cube | | | | | | Test Mortar Cube | | | | | | | | |
| * 500g Portland Cement | | | | | | * 500g Portland Cement | | | | | | | | |
| *1375g graded standard sand | | | | | | * 100g Test Sample | | | | | | | | |
| * 242 ml water | | | | | | *1375g graded standard sand | | | | | | | | |
| | | | | | | * 242 ml water | | | | | | | | |
| Sample No | Date Poured | Date Tested | Age in Day | Dimensions | | | Vol (dm ³) | Weight (g) | Press Area (Cm ²) | Total Load Tons | Compressive strength (Kg/cm ²) | Compressive strength (KPa) | Strength Activity Index | |
| | | | | L (cm) | B (c) | H (cm) | | | | | | | | |
| C | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 679.00 | 49 | 5 | 102.04 | 10.40 | | |
| C | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 659.50 | 49 | 4 | 81.63 | 8.32 | | |
| C | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 670.40 | 49 | 5 | 102.04 | 10.40 | | |
| Average | | | | | | | | | | | 95.24 | 9.71 | | |
| C | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 652.80 | 49 | 5 | 102.04 | 10.40 | | |
| C | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 697.22 | 49 | 6 | 122.45 | 12.48 | | |
| C | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 642.80 | 49 | 4.7 | 95.92 | 9.78 | | |
| Average | | | | | | | | | | | 106.80 | 10.89 | | |
| P1 | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 653.20 | 49 | 3 | 61.22 | 6.24 | | 50.00% |
| P1 | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 660.60 | 49 | 2 | 40.82 | 4.16 | | |
| P1 | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 659.30 | 49 | 2 | 40.82 | 4.16 | | |
| Average | | | | | | | | | | | 47.62 | 4.85 | | |
| P1 | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 689.00 | 49 | 5 | 102.04 | 10.40 | 89.17% | |
| P1 | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 703.30 | 49 | 4 | 81.63 | 8.32 | | |
| P1 | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 681.80 | 49 | 5 | 102.04 | 10.40 | | |
| Average | | | | | | | | | | | 95.24 | 9.71 | | |
| Strength Activity Index Test Result for the Pumice-Coarser | | | | | | | | | | | | | | |
| Sample No | Sample Description | Percentage of Control Strength | | | | | | | | | | | | |
| | | 7-day Strength | 28-day Strength | | | | | | | | | | | |
| C | Cement Mortar | 9.71 | 10.89 | | | | | | | | | | | |
| P1 | Pumice-Coarser | 4.85 | 9.71 | | | | | | | | | | | |
| Strength Activity Index (SAI) | | 50.00% | 89.17% | | | | | | | | | | | |
| Note:- Sample C represents a cube mixed with Cement and Sand only | | | | | | | | | | | | | | |
| - Sample P1 represents a cube mixed with 20% Pumice,80%cement and Sand | | | | | | | | | | | | | | |

Table B-7 Strength Activity Index Test- Pozzolanicity Test of Volcanic Ash/Pumicite

| STRENGTH ACTIVITY INDEX TEST METHOD - ASTM C311 | | | | | | | | | | | | | |
|---|--------------------|--------------------------------|-----------------|------------|--------|------------------------------|------------------------|------------|-------------------------------|-----------------|-----------------------|----------------------------|-------------------------|
| Sample Station | | | Ziway | | | | Material Description | | | | Volcanic Ash/Pumicite | | |
| Control Mortar Cube | | | | | | Test Mortar Cube | | | | | | | |
| • 500g Portland Cement | | | | | | • 500g Portland Cement | | | | | | | |
| • 1375g graded standard sand | | | | | | • 100g Test Sample | | | | | | | |
| • 242 ml water | | | | | | • 1375g graded standard sand | | | | | | | |
| | | | | | | • 242 ml water | | | | | | | |
| Sample No | Date Poured | Date Tested | Age in Day | Dimensions | | | Vol (dm ³) | Weight (g) | Press Area (Cm ²) | Total Load Tons | Compressive strength | Compressive strength (KPa) | Strength Activity Index |
| | | | | L (cm) | B (cm) | H (cm) | | | | | | | |
| C | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 679.00 | 49 | 5 | 102.04 | 10.40 | |
| C | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 659.50 | 49 | 4 | 81.63 | 8.32 | |
| C | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 670.40 | 49 | 5 | 102.04 | 10.40 | |
| Average | | | | | | | | | | | 95.24 | 9.71 | |
| C | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 652.80 | 49 | 5 | 102.04 | 10.40 | |
| C | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 697.22 | 49 | 6 | 122.45 | 12.48 | |
| C | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 642.80 | 49 | 4.7 | 95.92 | 9.78 | |
| Average | | | | | | | | | | | 106.80 | 10.89 | |
| P1 | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 666.70 | 49 | 3 | 61.22 | 6.24 | |
| P1 | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 665.50 | 49 | 2 | 40.82 | 4.16 | |
| P1 | 24-Jan-15 | 31-Jan-15 | 7 | 7 | 7 | 7 | 343 | 664.50 | 49 | 3 | 61.22 | 6.24 | |
| Average | | | | | | | | | | | 54.42 | 5.55 | |
| P1 | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 671.20 | 49 | 4 | 81.63 | 8.32 | 76.43% |
| P1 | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 677.30 | 49 | 4 | 81.63 | 8.32 | |
| P1 | 24-Jan-15 | 21-Feb-15 | 28 | 7 | 7 | 7 | 343 | 678.30 | 49 | 4 | 81.63 | 8.32 | |
| Average | | | | | | | | | | | 81.63 | 8.32 | |
| Strength Activity Index Test Result for the Volcanic Ash/Pumicite | | | | | | | | | | | | | |
| Sample No | Sample Description | Percentage of Control Strength | | | | | | | | | | | |
| | | 7-day Strength | 28-day Strength | | | | | | | | | | |
| C | Cement Mortar | 9.71 | 10.89 | | | | | | | | | | |
| P1 | Pumice-Coarser | 5.55 | 8.32 | | | | | | | | | | |
| Strength Activity Index (SAI) | | 57.14% | 76.43% | | | | | | | | | | |
| Note:- Sample C represents a cube mixed with Cement and Sand only | | | | | | | | | | | | | |
| - Sample P2 represents a cube mixed with 20% Volcanic Ash/Pumicite,80%cement and Sand | | | | | | | | | | | | | |

APPENDIX - C

Test Results of Cinder Gravel Blended with Natural Pozzolana (Volcanic Ash)

Table C - 1 Moisture Content Vs Density Relation of Cinder (96%)
blended With Volcanic Ash/Pumicite (4%)

| | | | | | |
|----------------------------------|---------|---------|---------|---------|---------|
| Determination No. | 1.0 | 5.0 | 2.0 | 3.0 | 4.0 |
| Mass of Mold, g | 4730.6 | 4730.6 | 4730.6 | 4730.6 | 4730.6 |
| Mass of mold + Compacted Soil, g | 7965.2 | 8144.6 | 8417.9 | 8344.3 | 8317.1 |
| Mass of Compacted soil, g | 3234.6 | 3414.0 | 3687.3 | 3613.7 | 3586.5 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.58 | 1.66 | 1.80 | 1.76 | 1.75 |
| Water Content, % | 9.18 | 12.50 | 13.61 | 14.29 | 15.12 |
| Dry density, g/cm ³ | 1.44 | 1.48 | 1.58 | 1.54 | 1.52 |
| Water Content Determination | | | | | |
| Container No | 1.00 | 5.00 | 2.00 | 3.00 | 4.00 |
| Mass of container, g | 237.20 | 229.10 | 230.00 | 227.90 | 224.80 |
| Mass of container + wet soil, g | 658.20 | 684.60 | 683.30 | 638.30 | 690.10 |
| Mass of Container + Dry soil, g | 622.80 | 634.00 | 629.00 | 587.00 | 629.00 |
| Mass of Water, g | 35.40 | 50.60 | 54.30 | 51.30 | 61.10 |
| Mass of Dry soil, g | 385.60 | 404.90 | 399.00 | 359.10 | 404.20 |
| Water content, % | 9.18 | 12.50 | 13.61 | 14.29 | 15.12 |

| | |
|---|-------|
| Opt. moisture content, (%)= | 13.61 |
| Max.dry density, (g/cm ³) = | 1.58 |

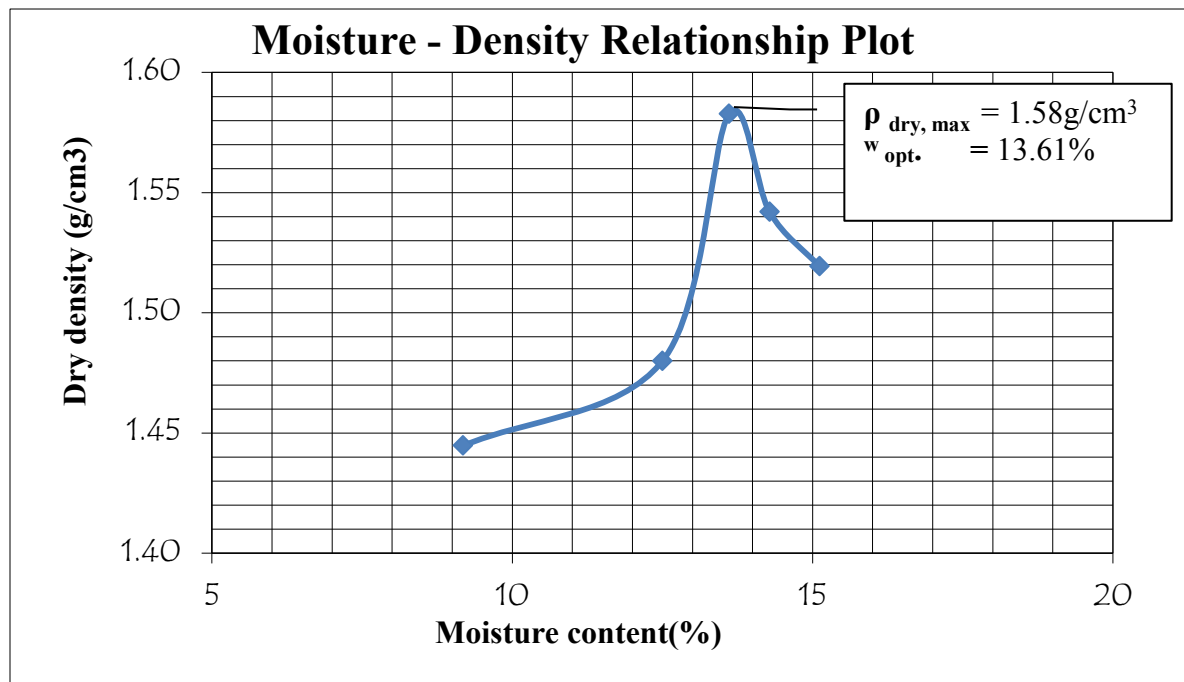


Table C - 2 Moisture Content Vs. Density Relation of Cinder (92%)
blended With Volcanic Ash/Pumicite (8%)

| | | | | | |
|----------------------------------|---------|---------|---------|---------|---------|
| Determination No. | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
| Mass of Mold, g | 4730.6 | 4730.6 | 4730.6 | 4730.6 | 4730.6 |
| Mass of mold + Compacted Soil, g | 8034.3 | 8387.1 | 8444.6 | 8404.6 | 8374.9 |
| Mass of Compacted soil, g | 3303.7 | 3656.5 | 3714.0 | 3674.0 | 3644.3 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.61 | 1.78 | 1.81 | 1.79 | 1.78 |
| Water Content, % | 11.19 | 13.14 | 14.55 | 15.93 | 16.98 |
| Dry density, g/cm ³ | 1.45 | 1.56 | 1.60 | 1.56 | 1.52 |
| Water Content Determination | | | | | |
| Container No | 3 | 4 | 5 | 2 | 1 |
| Mass of container, g | 227.9 | 229.1 | 224.8 | 230 | 237.2 |
| Mass of container + wet soil, g | 638.3 | 684.6 | 690.1 | 683.3 | 658.2 |
| Mass of Container + Dry soil, g | 597 | 631.7 | 631 | 621 | 597.1 |
| Mass of Water, g | 41.3 | 52.9 | 59.1 | 62.3 | 61.1 |
| Mass of Dry soil, g | 369.1 | 402.6 | 406.2 | 391 | 359.9 |
| Water content, % | 11.19 | 13.14 | 14.55 | 15.93 | 16.98 |

| | |
|---|-------|
| Opt. moisture content, (%)= | 14.55 |
| Max.dry density, (g/cm ³) = | 1.60 |

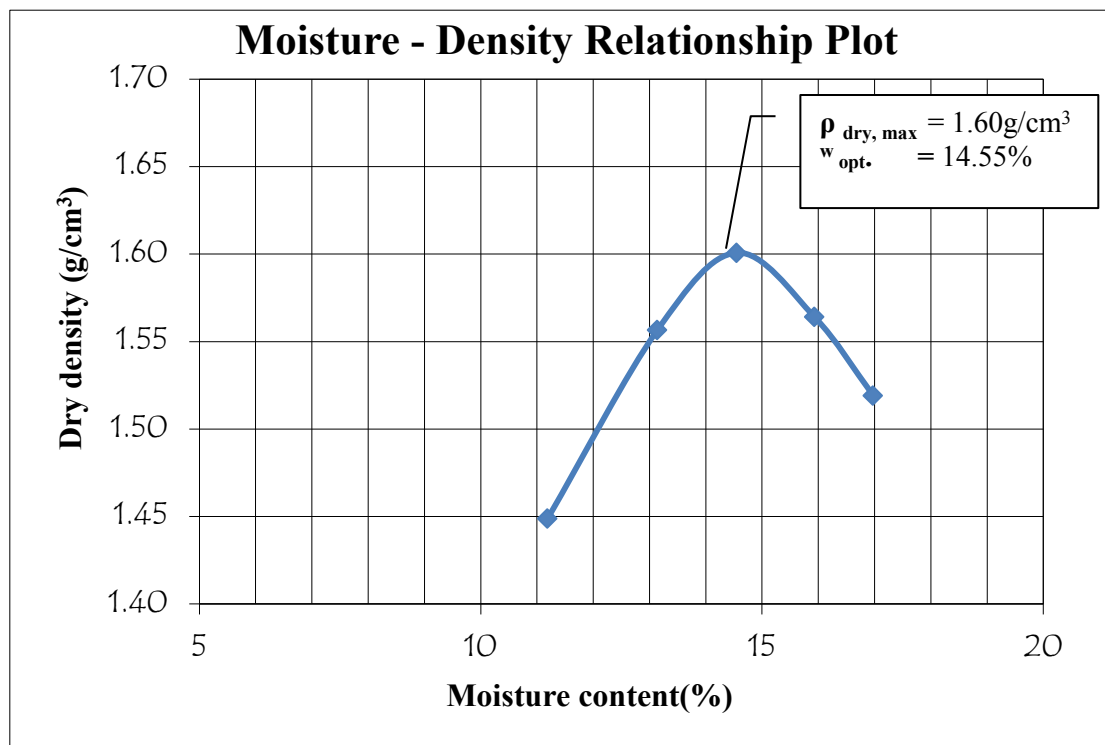


Table C - 3 Moisture Content Vs. Density Relation of Cinder (88%)
blended With Volcanic Ash/Pumicite (12%)

| | | | | |
|----------------------------------|---------|---------|---------|---------|
| Determination No. | 2.0 | 3.0 | 4.0 | 5.0 |
| Mass of Mold, g | 4724.0 | 4724.0 | 4724.0 | 4724.0 |
| Mass of mold + Compacted Soil, g | 8216.3 | 8469.2 | 8627.9 | 8619.9 |
| Mass of Compacted soil, g | 3492.3 | 3745.2 | 3903.9 | 3895.9 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.70 | 1.83 | 1.90 | 1.90 |
| Water Content, % | 8.86 | 13.14 | 15.45 | 20.23 |
| Dry density, g/cm ³ | 1.56 | 1.61 | 1.65 | 1.58 |
| Water Content Determination | | | | |
| Container No | 2 | 3 | 4 | 5 |
| Mass of container, g | 229.2 | 230.8 | 230 | 237.3 |
| Mass of container + wet soil, g | 616.4 | 690.6 | 626.8 | 696.1 |
| Mass of container + Dry soil, g | 584.9 | 637.2 | 573.7 | 618.9 |
| Mass of Water, g | 31.5 | 53.4 | 53.1 | 77.2 |
| Mass of Dry soil, g | 355.7 | 406.4 | 343.7 | 381.6 |
| Water content, % | 8.86 | 13.14 | 15.45 | 20.23 |

| | |
|---|-------|
| Opt. moisture content, (%)= | 15.45 |
| Max.dry density, (g/cm ³) = | 1.65 |

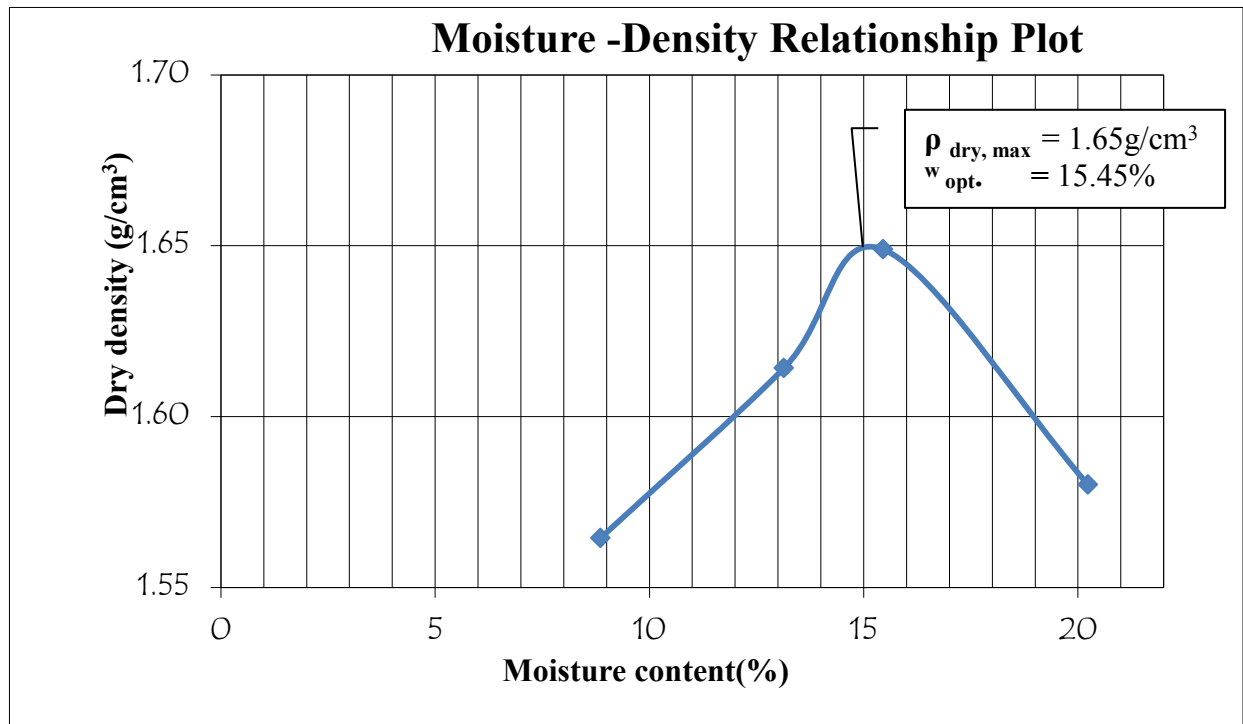


Table C - 4 Moisture Content Vs. Density Relation of Cinder (84%)
blended With Volcanic Ash/Pumicite (16%)

| | | | | |
|----------------------------------|---------|---------|---------|---------|
| Determination No. | 4.0 | 5.0 | 6.0 | 7.0 |
| Mass of Mold, g | 4729.0 | 4729.0 | 4729.0 | 4729.0 |
| Mass of mold + Compacted Soil, g | 8586.0 | 8832.4 | 8904.5 | 8865.2 |
| Mass of Compacted soil, g | 3857.0 | 4103.4 | 4175.5 | 4136.2 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.88 | 2.00 | 2.04 | 2.02 |
| Water Content, % | 13.25 | 16.23 | 19.20 | 20.62 |
| Dry density, g/cm ³ | 1.66 | 1.72 | 1.71 | 1.67 |
| Water Content Determination | | | | |
| Container No | 4.0 | 5.0 | 6.0 | 7.0 |
| Mass of container, g | 229.1 | 237.2 | 192.2 | 217.7 |
| Mass of container + wet soil, g | 785.7 | 851.6 | 915.5 | 989.2 |
| Mass of container + Dry soil, g | 720.60 | 765.80 | 799.00 | 857.30 |
| Mass of Water, g | 65.10 | 85.80 | 116.50 | 131.90 |
| Mass of Dry soil, g | 491.50 | 528.60 | 606.80 | 639.60 |
| Water content, % | 13.25 | 16.23 | 19.20 | 20.62 |

| | |
|---|-------|
| Opt. moisture content, (%) = | 16.23 |
| Max.dry density, (g/cm ³) = | 1.72 |

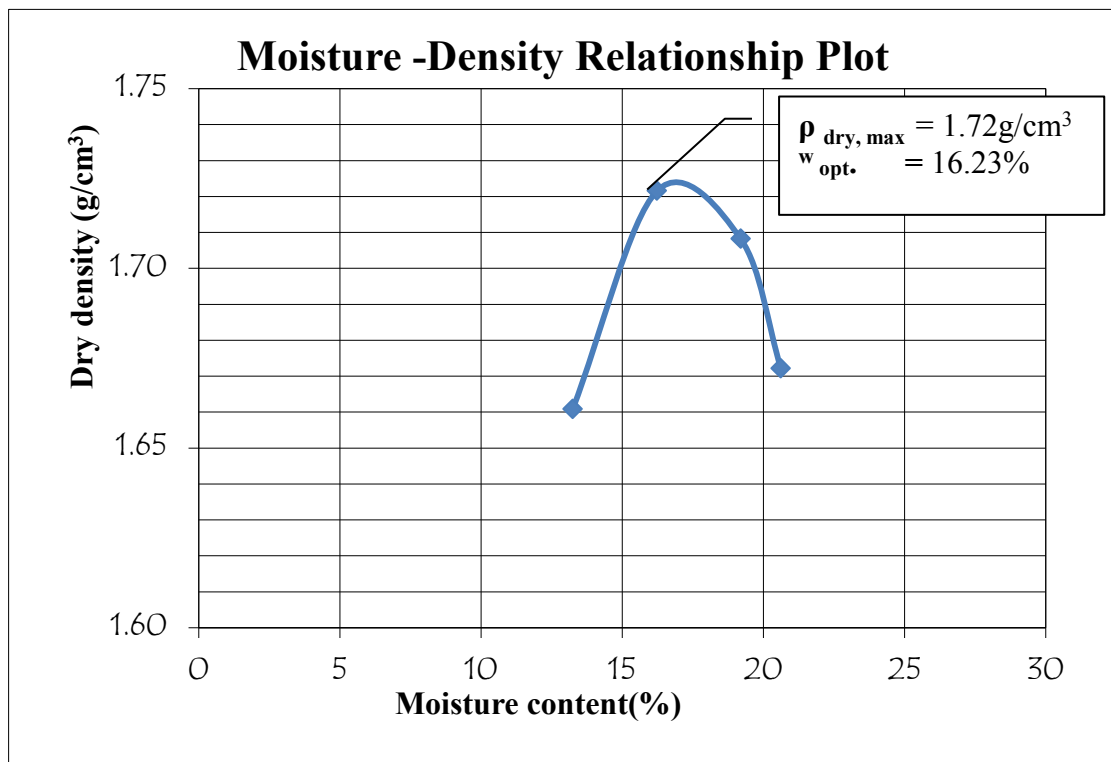


Table C - 5 Moisture Content Vs. Density Relation of Cinder (80%)
blended With Volcanic Ash/Pumicite (20%)

| | | | | | |
|----------------------------------|---------|---------|---------|---------|---------|
| Determination No. | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
| Mass of Mold, g | 4730.5 | 4730.5 | 4730.5 | 4730.5 | 4730.5 |
| Mass of mold + Compacted Soil, g | 8299.3 | 8540.3 | 8806.0 | 8858.3 | 8890.0 |
| Mass of Compacted soil, g | 3568.8 | 3809.8 | 4075.5 | 4127.8 | 4159.5 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.74 | 1.86 | 1.99 | 2.01 | 2.03 |
| Water Content, % | 4.22 | 9.29 | 13.01 | 19.42 | 22.10 |
| Dry density, g/cm ³ | 1.67 | 1.70 | 1.76 | 1.69 | 1.66 |
| Water Content Determination | | | | | |
| Container No | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
| Mass of container, g | 227.8 | 229.2 | 229.5 | 237.1 | 231.0 |
| Mass of container + wet soil, g | 696.7 | 635.1 | 641.2 | 803.4 | 1027.2 |
| Mass of container + Dry soil, g | 677.7 | 600.6 | 593.8 | 711.3 | 883.1 |
| Mass of Water, g | 19.00 | 34.50 | 47.40 | 92.10 | 144.10 |
| Mass of Dry soil, g | 449.90 | 371.40 | 364.30 | 474.20 | 652.10 |
| Water content, % | 4.22 | 9.29 | 13.01 | 19.42 | 22.10 |

| | |
|---|-------|
| Opt. moisture content, (%) = | 13.01 |
| Max.dry density, (g/cm ³) = | 1.76 |

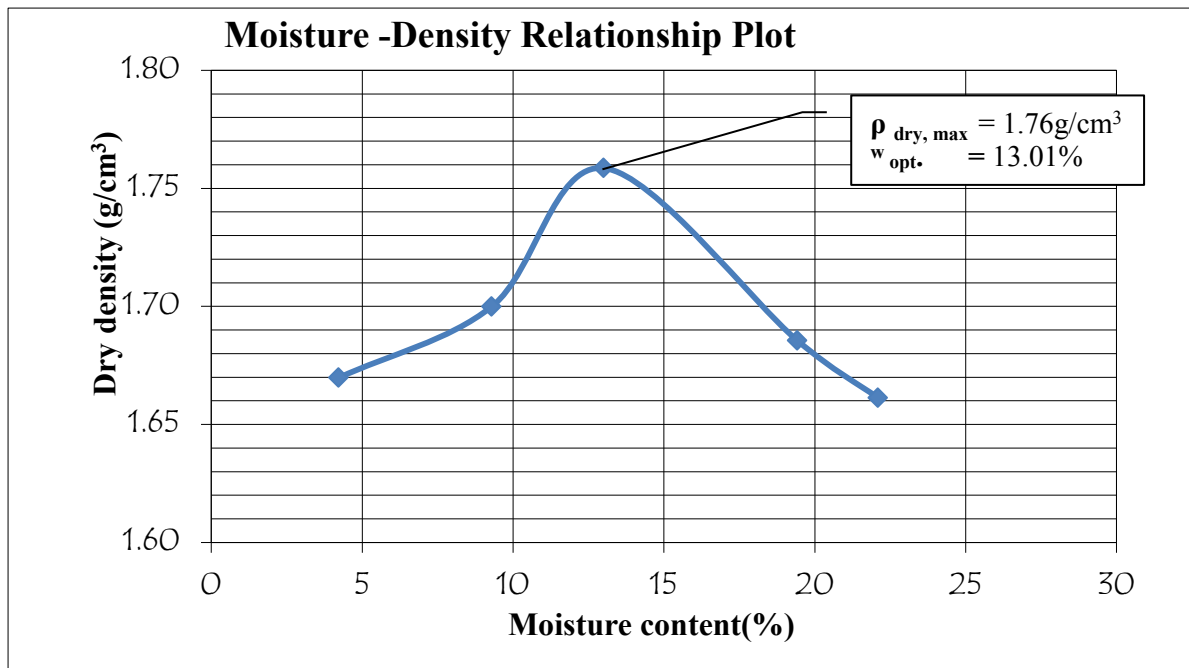


Table C - 6 Moisture Content Vs. Density Relation of Cinder (76%)
blended With Volcanic Ash/Pumicite (24%)

| | | | | |
|----------------------------------|---------|---------|---------|---------|
| Determination No. | 2.0 | 3.0 | 4.0 | 5.0 |
| Mass of Mold, g | 4728.8 | 4728.8 | 4728.8 | 4728.8 |
| Mass of mold + Compacted Soil, g | 8444.5 | 8690.7 | 8854.2 | 8833.4 |
| Mass of Compacted soil, g | 3715.7 | 3961.9 | 4125.4 | 4104.6 |
| Volume of Mold, cm ³ | 2050.71 | 2050.71 | 2050.71 | 2050.71 |
| Bulk density, g/cm ³ | 1.81 | 1.93 | 2.01 | 2.00 |
| Water Content, % | 10.07 | 14.06 | 18.10 | 21.74 |
| Dry density, g/cm ³ | 1.65 | 1.69 | 1.70 | 1.64 |
| Water Content Determination | | | | |
| Container No | 2.0 | 3.0 | 4.0 | 5.0 |
| Mass of container, g | 227.8 | 224.9 | 229.1 | 237.2 |
| Mass of container + wet soil, g | 768.0 | 731.1 | 792.2 | 956.8 |
| Mass of container + Dry soil, g | 718.6 | 668.7 | 705.9 | 828.3 |
| Mass of Water, g | 49.40 | 62.40 | 86.30 | 128.50 |
| Mass of Dry soil, g | 490.80 | 443.80 | 476.80 | 591.10 |
| Water content, % | 10.07 | 14.06 | 18.10 | 21.74 |

| | |
|---|-------|
| Opt. moisture content, (%)= | 18.10 |
| Max.dry density, (g/cm ³) = | 1.70 |

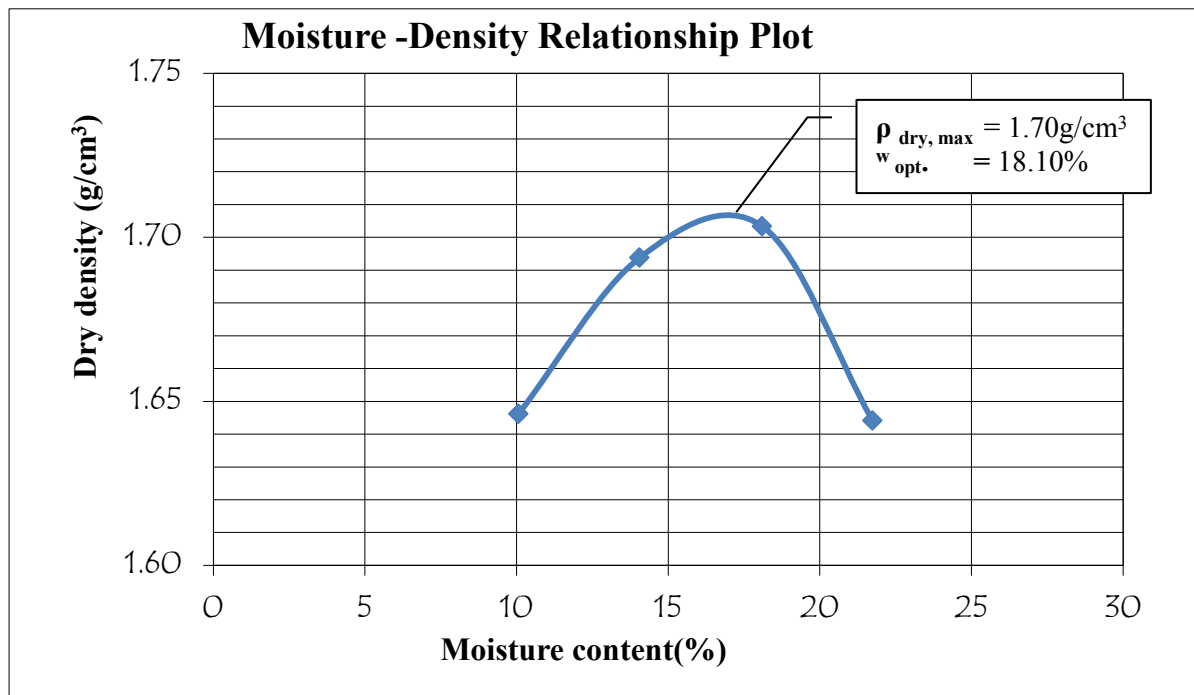


Table C - 7 Maximum Dry Density vs. % Volcanic Ash/Pumicite for Different Blending proportions

| % Volcanic Ash | MDD |
|----------------|------|
| 4 | 1.58 |
| 8 | 1.60 |
| 12 | 1.65 |
| 16 | 1.72 |
| 20 | 1.76 |
| 24 | 1.70 |

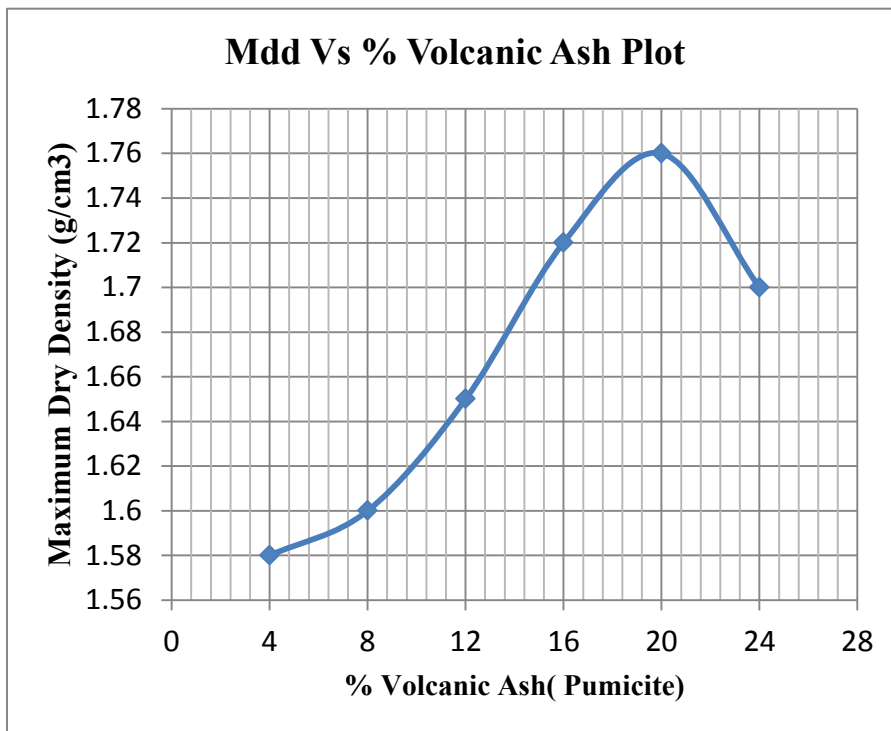


Table C - 8 0-Days Soaked CBR for the Optimum Blending proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | | |
|--|----------------------------|---------------|---|------------------------|---------------|--------|--------|-------|
| TEST METHOD AASHTO T-193 | | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | | |
| Test Description | 0 Days - Soaked | | | Date tested | July 13, 2015 | | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | | |
| Density Determination | | | | Moisture Determination | | | | |
| | Before Soaking | After Soaking | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before Soaking | After Soaking | | | |
| Mold No. | 6 | | | B-4 | C-1 | B-12 | K | |
| Weight of soil + mould g | 10397 | 10558 | Container number | 432.51 | 433.31 | 455.36 | 447.17 | |
| Weight of mould g | 6317 | 6317 | Wet soil + container (g) | 392.51 | 390.78 | 402.96 | 395.58 | |
| Weight of soil g | 4080 | 4241 | Dry soil + container (g) | 67.39 | 69.79 | 78.52 | 77.53 | |
| Volume of mould g | 2077.31 | 2077.31 | Weight of container (g) | 325.12 | 320.99 | 324.44 | 318.05 | |
| Wet density of soil g/cc | 1.96 | 2.04 | Weight of dry soil (g) | 12.30 | 13.25 | 16.15 | 16.22 | |
| Dry density of soil g/cc | 1.75 | 1.77 | Moisture content % | | | | | 15.21 |
| Load - Penetration Data | | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | | |
| 0 | 0 | 0.00 | | | | | | |
| 0.635 | 25 | 0.56 | | | | | | |
| 1.27 | 74 | 1.65 | | | | | | |
| 1.905 | 130 | 2.89 | | | | | | |
| 2.54 | 194 | 4.31 | 62 | | | | | |
| 5.08 | 453 | 10.07 | 98 | | | | | |
| 7.62 | 651 | 14.48 | | | | | | |
| Ring factor (N/div)= 43.04 | | | | | | | | |
| Swelling Data | | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | | |
| No. of blows | 56 | | | | | | | |
| Before soaking | 1308 | | | | | | | |
| After soaking | 1308 | | | | | | | |
| % swell | 0 | | | | | | | |
| Remark: The sample is Cured for 0 days and soaked for 4 days .The CBR value is 98% @ 5.08mm Penetration. | | | | | | | | |

Table C - 9 0-Days Unsoaked CBR for the Optimum Blending proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | |
|--|----------------------------|--|--------------------|
| TEST METHOD AASHTO T-193 | | | |
| Sampled From | Quarry | | |
| Test Description | 0 Days - Unsoaked | Date Sample | |
| Material Description | (80%)Cinder+(20%)Pozzolana | Date tested | July 13,2015 |
| Density Determination | | Moisture Determination | |
| | Before Penetration | Soaked <input type="checkbox"/> Unsoaked <input checked="" type="checkbox"/> | Before Penetration |
| Mold No. | 54 | Container number | R-F |
| Weight of soil + mould g | 10605 | Wet soil + container (g) | 442.35 |
| Weight of mould g | 6475 | Dry soil + container (g) | 401.35 |
| Weight of soil g | 4130 | Weight of container (g) | 67.92 |
| Volume of mould g | 2108.55 | Weight of dry soil (g) | 333.43 |
| Wet density of soil g/cc | 1.96 | Moisture content % | 12.30 |
| Dry density of soil g/cc | 1.74 | | |
| Load - Penetration Data | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % |
| 0 | 0 | 0.000 | |
| 0.635 | 36 | 0.801 | |
| 1.27 | 100 | 2.224 | |
| 1.905 | 180 | 4.003 | |
| 2.54 | 269 | 5.982 | 86 |
| 5.08 | 552 | 12.275 | 118 |
| 7.62 | 714 | 15.877 | |
| Ring factor (N/div)= 43.04 | | | |
| Swelling Data | | | |
| Height of specimen(mm) | 125 | | |
| No. of blows | 56 | | |
| Before soaking | 356 | | |
| After soaking | 356 | | |
| % swell | 0 | | |
| Remark: | | | |
| The sample is Cured for 0 days and penetrated .The CBR value is 118% @ 5.08mm Penetration. | | | |

Table C - 10 3-Days Soaked CBR for the Optimum Blending proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | |
|---|----------------------------|---------------|---|------------------------|---------------|--------|--------|
| TEST METHOD AASHTO T-193 | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | |
| Test Description | 3 Days - Soaked | | | Date tested | April 02,2015 | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | |
| Density Determination | | | | Moisture Determination | | | |
| | Before soaking | After soaking | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before soaking | After soaking | | |
| | | | | | Top | Middle | Bottom |
| Mold No. | 54 | | Container number | B-14 | B-8 | B-5 | B-6 |
| Weight of soil + mould g | 10594 | 10855 | Wet soil + container (g) | 470.07 | 502.36 | 452.09 | 400.95 |
| Weight of mould g | 6475 | 6475 | Dry soil + container (g) | 426.89 | 428.61 | 395.88 | 349.98 |
| Weight of soil g | 4119 | 4380 | Weight of container (g) | 75.94 | 69.45 | 78.99 | 69.95 |
| Volume of mould g | 2108.55 | 2108.55 | Weight of dry soil (g) | 350.95 | 359.16 | 316.89 | 280.03 |
| Wet density of soil g/cc | 1.95 | 2.08 | Moisture content % | 12.30 | 20.53 | 17.74 | 18.20 |
| Dry density of soil g/cc | 1.74 | 1.76 | | | | 18.82 | |
| Load - Penetration Data | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | |
| 0 | 0 | 0.0 | | | | | |
| 0.635 | 85 | 0.948 | | | | | |
| 1.27 | 425 | 4.739 | | | | | |
| 1.905 | 695 | 7.749 | | | | | |
| 2.54 | 979 | 10.916 | 171 | | | | |
| 5.08 | 1300 | 14.495 | 145 | | | | |
| 7.62 | 1453 | 16.200 | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | |
| Swelling Data | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | |
| No. of blows | 56 | | | | | | |
| Before soaking | 200 | | | | | | |
| After soaking | 200 | | | | | | |
| % swell | | | | | | | |
| Remark: The sample is Cured for 3 days and Soaked for 4 days. The corrected CBR value is 171% @ 2.54mm Penetration. | | | | | | | |

Table C - 11 3-Days Unsoaked CBR for the Optimum Blending Proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | | |
|--|----------------------------|--------------|--------------------------|---|---------------|--------------|--------|--------|
| TEST METHOD AASHTO T-193 | | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | | |
| Test Description | 3 Days - Unsoaked | | | Date tested | April 02,2015 | | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | | |
| Density Determination | | | | Moisture Determination | | | | |
| | Before Curing | After Curing | | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before Curing | After Curing | | |
| | | | | | | Top | Middle | Bottom |
| Mold No. | 61 | | Container number | | B-14 | B-3 | B-5 | B-6 |
| Weight of soil + mould g | 9884 | 9840 | Wet soil + container (g) | | 470.58 | 404.68 | 438.41 | 431.09 |
| Weight of mould g | 5770 | 5770 | Dry soil + container (g) | | 427.36 | 370.12 | 401.23 | 391.49 |
| Weight of soil g | 4114 | 4070 | Weight of container (g) | | 75.94 | 81.64 | 79.04 | 68.99 |
| Volume of mould g | 2077.31 | 2077.31 | Weight of dry soil (g) | | 351.42 | 288.48 | 322.19 | 322.5 |
| Wet density of soil g/cc | 1.98 | 1.96 | Moisture content % | | 12.30 | 11.98 | 11.54 | 12.28 |
| Dry density of soil g/cc | 1.76 | 1.75 | | | | 11.93 | | |
| Load - Penetration Data | | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | | |
| 0 | 0 | 0.0 | | | | | | |
| 0.635 | 275 | 3.066 | | | | | | |
| 1.27 | 410 | 4.571 | | | | | | |
| 1.905 | 545 | 6.077 | | | | | | |
| 2.54 | 666 | 7.426 | 107 | | | | | |
| 5.08 | 847 | 9.444 | 92 | | | | | |
| 7.62 | 1006 | 11.217 | | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | | |
| Swelling Data | | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | | |
| No.of blows | 56 | | | | | | | |
| Before soaking | 200 | | | | | | | |
| After soaking | 200 | | | | | | | |
| % swell | | | | | | | | |
| Remark: The sample is Cured for 3 days and penetrated .The corrected CBR value is 107% @ 2.54mm Penetration. | | | | | | | | |

Table C - 12 7-Days Soaked CBR for the Optimum Blending proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | | |
|--|----------------------------|--------------|--------------------------|---|---------------|---------------|--------|--------|
| TEST METHOD AASHTO T-193 | | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | | |
| Test Description | 7 Days - Soaked | | | Date tested | June 20,2015 | | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | | |
| Density Determination | | | | Moisture Determination | | | | |
| | Before soaking | After soakin | | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before soakin | After soaking | | |
| | | | | | | Top | Middle | Bottom |
| Mold No. | 63 | | Container number | | B-6 | B-12 | B-N | C-1 |
| Weight of soil + mould g | 10347 | 10609 | Wet soil + container (g) | | 444.29 | 468.85 | 468.91 | 467.77 |
| Weight of mould g | 6220 | 6220 | Dry soil + container (g) | | 403.17 | 399.24 | 409.78 | 413.41 |
| Weight of soil g | 4127 | 4389 | Weight of container (g) | | 68.98 | 78.75 | 68.31 | 69.97 |
| Volume of mould g | 2091.09 | 2091.1 | Weight of dry soil (g) | | 334.19 | 320.49 | 341.47 | 343.44 |
| Wet density of soil g/cc | 1.97 | 2.10 | Moisture content % | | 12.30 | 21.72 | 17.32 | 15.83 |
| Dry density of soil g/cc | 1.76 | 1.81 | | | | | | 18.29 |
| Load - Penetration Data | | | | | | | | |
| Penetratio | Dial | Load | CBR % | | | | | |
| n (mm) | reading | (Mpa) | | | | | | |
| 0 | 0 | 0.0 | | | | | | |
| 0.635 | 14 | 0.156 | | | | | | |
| 1.27 | 123 | 1.371 | | | | | | |
| 1.905 | 458 | 5.107 | | | | | | |
| 2.54 | 746 | 8.318 | 178 | | | | | |
| 5.08 | 1465 | 16.334 | 176 | | | | | |
| 7.62 | 1785 | 19.902 | | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | | |
| Swelling Data | | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | | |
| No.of blows | 56 | | | | | | | |
| Before soaking | 710 | | | | | | | |
| After soaking | 710 | | | | | | | |
| % swell | 0 | | | | | | | |
| Remark: The sample is Cured for 7 days and Soaked for 4 days.The corrected CBR value is 178% @ 2.54mm Penetration. | | | | | | | | |

Table C - 13 7-Days Unsoaked CBR for the Optimum Blending Proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | |
|--|----------------------------|--------------|--------------------------|---|---------------|--------------|--------|
| TEST METHOD AASHTO T-193 | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | |
| Test Description | 7 Days - Unsoaked | | | Date tested | June 16,2015 | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | Date tested | June 16,2015 | | |
| Density Determination | | | | Moisture Determination | | | |
| | Before Curing | After Curing | | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before Curing | After Curing | |
| | | | | | | Top | Middle |
| | | | | | | Top | Top |
| Mold No. | 56 | 56 | Container number | B-8 | B-12 | C-1 | B-11 |
| Weight of soil + mould g | 10295 | 10221 | Wet soil + container (g) | 450.95 | 408.22 | 406.57 | 404.07 |
| Weight of mould g | 6135 | 6135 | Dry soil + container (g) | 409.16 | 372.48 | 373.01 | 369.43 |
| Weight of soil g | 4160 | 4086 | Weight of container (g) | 69.46 | 78.75 | 69.97 | 67.75 |
| Volume of mould g | 2110.46 | 2110.5 | Weight of dry soil (g) | 339.7 | 293.73 | 303.04 | 301.68 |
| Wet density of soil g/cc | 1.97 | 1.94 | Moisture content % | 12.30 | 12.17 | 11.07 | 11.48 |
| Dry density of soil g/cc | 1.76 | 1.74 | | | | 11.57 | |
| Load - Penetration Data | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | |
| 0 | 0 | 0.0 | | | | | |
| 0.635 | 3 | 0.033 | | | | | |
| 1.27 | 14 | 0.156 | | | | | |
| 1.905 | 60 | 0.669 | | | | | |
| 2.54 | 175 | 1.951 | 210 | | | | |
| 5.08 | 1349 | 15.041 | 191 | | | | |
| 7.62 | 1842 | 20.538 | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | |
| Swelling Data | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | |
| No. of blows | 56 | | | | | | |
| Before soaking | 514 | | | | | | |
| After soaking | 514 | | | | | | |
| % swell | 0 | | | | | | |
| Remark: The sample is Cured for 7 days and penetrated .The corrected CBR value is 210% @ 2.54mm Penetration. | | | | | | | |

Table C - 14 14-Days Soaked CBR for the Optimum Blending Proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | | |
|--|----------------------------|--------------|--------------------------|---|----------------|--------------|--------|--------|
| TEST METHOD AASHTO T-193 | | | | | | | | |
| Sampled From | Quarry | | | | | | | |
| Test Description | 14 Days - Soaked | | | Date Sampled | | | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | Date tested | April 10,2015 | | | |
| Density Determination | | | | Moisture Determination | | | | |
| | Before soaking | After Curing | | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before soaking | After Curing | | |
| | | | | | | Top | Middle | Top |
| Mold No. | 63 | | Container number | | B-14 | B4 | B15 | B10 |
| Weight of soil + mould g | 10290 | 10615 | Wet soil + container (g) | | 460.8 | 485 | 484.68 | 475.35 |
| Weight of mould g | 6200 | 6200 | Dry soil + container (g) | | 419.71 | 408.7 | 416.25 | 405.96 |
| Weight of soil g | 4090 | 4415 | Weight of container (g) | | 75.92 | 67.39 | 71.54 | 74.56 |
| Volume of mould g | 2091.09 | 2091.09 | Weight of dry soil (g) | | 343.79 | 341.3 | 344.71 | 331.4 |
| Wet density of soil g/cc | 1.96 | 2.11 | Moisture content % | | 11.95 | 22.35 | 19.85 | 20.94 |
| Dry density of soil g/cc | 1.75 | 1.74 | | | | | | 21.05 |
| Load - Penetration Data | | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | | |
| 0 | 0 | 0.0 | | | | | | |
| 0.635 | 50 | 0.557 | | | | | | |
| 1.27 | 194 | 2.163 | | | | | | |
| 1.905 | 720 | 8.028 | | | | | | |
| 2.54 | 843 | 9.399 | 181 | | | | | |
| 5.08 | 1440 | 16.056 | 171 | | | | | |
| 7.62 | 1726 | 19.244 | | | | | | |
| Ring factor (N/div)=21.58 | | | | | | | | |
| Swelling Data | | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | | |
| No. of blows | 56 | | | | | | | |
| Before soaking | 315 | | | | | | | |
| After soaking | 315 | | | | | | | |
| % swell | 0 | | | | | | | |
| Remark: The sample is Cured for 14 days and Soaked for 4 days. The corrected CBR value is 181% @ 2.54mm Penetration. | | | | | | | | |

Table C - 15 14-Days Unsoaked CBR for the Optimum Blending Proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | |
|---|----------------------------|------------|---|--------------|---------------|--------|---------|
| TEST METHOD AASHTO T-193 | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | |
| Test Description | 14 Days - Unsoaked | | | Date tested | April 06,2015 | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | |
| Density Determination | | | Moisture Determination | | | | |
| | Before | After | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before | After Curing | | |
| | e | Curing | | soaking | Top | Middle | Bottom |
| Mold No. | 60 | | Container number | B-P | B-Q | B-R | B-S |
| Weight of soil + mould g | 10315 | 10241 | Wet soil + container (g) | 498.02 | 413.54 | 410.51 | 412.24 |
| Weight of mould g | 6199 | 6198.5 | Dry soil + container (g) | 451.56 | 377.76 | 377.26 | 379.295 |
| Weight of soil g | 4117 | 4042 | Weight of container (g) | 73.845 | 67.86 | 70.165 | 74.605 |
| Volume of mould g | 2093 | 2092.93 | Weight of dry soil (g) | 377.715 | 309.9 | 307.1 | 304.69 |
| Wet density of soil g/cc | 1.97 | 1.93 | Moisture content % | 12.30 | 11.55 | 10.83 | 10.81 |
| Dry density of soil g/cc | 1.75 | 1.74 | | | 11.06 | | |
| Load - Penetration Data | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | |
| 0 | 0 | 0.0 | | | | | |
| 0.635 | 74.5 | 0.831 | | | | | |
| 1.27 | 585 | 6.523 | | | | | |
| 1.905 | 929 | 10.358 | | | | | |
| 2.54 | 1216 | 13.558 | 221 | | | | |
| 5.08 | 1716.5 | 19.138 | 196 | | | | |
| 7.62 | 1963 | 21.887 | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | |
| Swelling Data | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | |
| No. of blows | 56 | | | | | | |
| Before soaking | 276 | | | | | | |
| After soaking | 276 | | | | | | |
| % swell | 0 | | | | | | |
| Remark: The sample is Cured for 14 days and penetrated .The corrected CBR value is 221% @ 2.54mm Penetration. | | | | | | | |

Table C - 16 28-Days Soaked CBR for the Optimum Blending Proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | | |
|--|----------------------------|--------------|---|------------------------|----------------|---------|---------|-------|
| TEST METHOD AASHTO T-193 | | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | | |
| Test Description | 28 Days - Soaked | | | Date tested | April 28, 2015 | | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | | |
| Density Determination | | | | Moisture Determination | | | | |
| | Before soaking | After Soakin | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before soaking | After Soaking | | | |
| | | | | | Top | Middle | Bottom | |
| Mold No. | 54 | | Container number | B-14 | B10 | B4 | B15 | |
| Weight of soil + mould g | 10503.5 | 10737 | Wet soil + container (g) | 486.875 | 500.725 | 490.38 | 506.155 | |
| Weight of mould g | 6337.5 | 6337.5 | Dry soil + container (g) | 442.265 | 429.455 | 431.86 | 444.99 | |
| Weight of soil g | 4166 | 4399.5 | Weight of container (g) | 79.565 | 71.615 | 68.505 | 73.04 | |
| Volume of mould g | 2107.64 | 2107.64 | Weight of dry soil (g) | 362.7 | 357.84 | 363.355 | 371.95 | |
| Wet density of soil g/cc | 1.98 | 2.09 | Moisture content % | 12.30 | 19.92 | 16.11 | 16.44 | |
| Dry density of soil g/cc | 1.76 | 1.78 | | | | | | 17.49 |
| Load - Penetration Data | | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | | |
| 0 | 0 | 0.0 | | | | | | |
| 0.635 | 140 | 1.561 | | | | | | |
| 1.27 | 679.5 | 7.576 | | | | | | |
| 1.905 | 1174 | 13.090 | | | | | | |
| 2.54 | 1382.5 | 15.414 | 245 | | | | | |
| 5.08 | 1849.5 | 20.621 | 209 | | | | | |
| 7.62 | 2101 | 23.425 | | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | | |
| Swelling Data | | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | | |
| No. of blows | 56 | | | | | | | |
| Before soaking | 500 | | | | | | | |
| After soaking | 500 | | | | | | | |
| % swell | 0 | | | | | | | |
| Remark: The sample is Cured for 28 days and Soaked for 4 days. The corrected CBR value is 245% @ 2.54mm Penetration. | | | | | | | | |

Table C - 17 28-Days Unsoaked CBR for the Optimum Blending Proportion

| CALIFORNIA BEARING RATIO WORK SHEET | | | | | | | | |
|---|----------------------------|--------------|--------------------------|---|---------------|--------------|--------|--------|
| TEST METHOD AASHTO T-193 | | | | | | | | |
| Sampled From | Quarry | | | Date Sampled | | | | |
| Test Description | 28 Days - Unsoaked | | | Date tested | April 24,2015 | | | |
| Material Description | (80%)Cinder+(20%)Pozzolana | | | | | | | |
| Density Determination | | | | Moisture Determination | | | | |
| | Before curing | After Curing | | Soaked <input type="checkbox"/> Unsoaked <input type="checkbox"/> | Before curing | After Curing | | |
| | | | | | | Top | Middl | Bottom |
| Mold No. | 55 | | Container number | | B-7 | B-15 | B-11 | B-12 |
| Weight of soil + mould g | 10365 | 10275 | Wet soil + container (g) | | 560.24 | 514.96 | 491.84 | 508.03 |
| Weight of mould g | 6205 | 6205 | Dry soil + container (g) | | 507.38 | 471.42 | 453.63 | 467.79 |
| Weight of soil g | 4160 | 4070 | Weight of container (g) | | 77.5 | 71.52 | 67.59 | 78.53 |
| Volume of mould g | 2108.55 | 2108.55 | Weight of dry soil (g) | | 429.88 | 399.9 | 386.04 | 389.26 |
| Wet density of soil g/cc | 1.97 | 1.93 | Moisture content % | | 12.30 | 10.89 | 9.90 | 10.34 |
| Dry density of soil g/cc | 1.76 | 1.75 | | | | 10.37 | | |
| Load - Penetration Data | | | | | | | | |
| Penetration (mm) | Dial reading | Load (Mpa) | CBR % | | | | | |
| 0 | 0 | 0.0 | | | | | | |
| 0.635 | 110 | 1.226 | | | | | | |
| 1.27 | 787 | 8.775 | | | | | | |
| 1.905 | 1734 | 19.334 | | | | | | |
| 2.54 | 1840 | 20.515 | 307 | | | | | |
| 5.08 | 2106 | 23.481 | 234 | | | | | |
| 7.62 | 2367 | 26.391 | | | | | | |
| Ring factor (N/div)= 21.58 | | | | | | | | |
| Swelling Data | | | | | | | | |
| Height of specimen(mm) | 125 | | | | | | | |
| No.of blows | 56 | | | | | | | |
| Before soaking | 483 | | | | | | | |
| After soaking | 483 | | | | | | | |
| % swell | 0 | | | | | | | |
| Remark: The sample is Cured for 28 days and penetrated .The corrected CBR value is 307% @ 2.54mm Penetration. | | | | | | | | |

APPENDIX - D

Additional Test Results

Table D-1 Particle Size Distributions of 80%Cinder+20% Volcanic Ash/Pumicite Before
Compaction

| Washed gradation before Compaction | | | | | |
|------------------------------------|--------------|------------|-----------|-----------------|-----------------|
| Sieve | Wt. Retained | % Retained | % Passing | Lower Limit-ERA | Upper Limit-ERA |
| 50 | 0 | 0 | 100.00 | 100 | 100 |
| 37.5 | 0 | 0.00 | 100.00 | 80 | 100 |
| 20 | 798.6 | 22.11 | 77.89 | 60.00 | 80.00 |
| 10 | 690.5 | 19.12 | 58.77 | 45.00 | 65.00 |
| 5 | 857.5 | 23.74 | 35.02 | 30.00 | 50.00 |
| 2.36 | 460.5 | 12.75 | 22.27 | 20.00 | 40.00 |
| 0.425 | 338.5 | 9.37 | 12.90 | 10.00 | 25.00 |
| 0.075 | 224.5 | 6.22 | 6.68 | 5.00 | 15.00 |
| Wt. before washing | 3,611.5 | | | | |

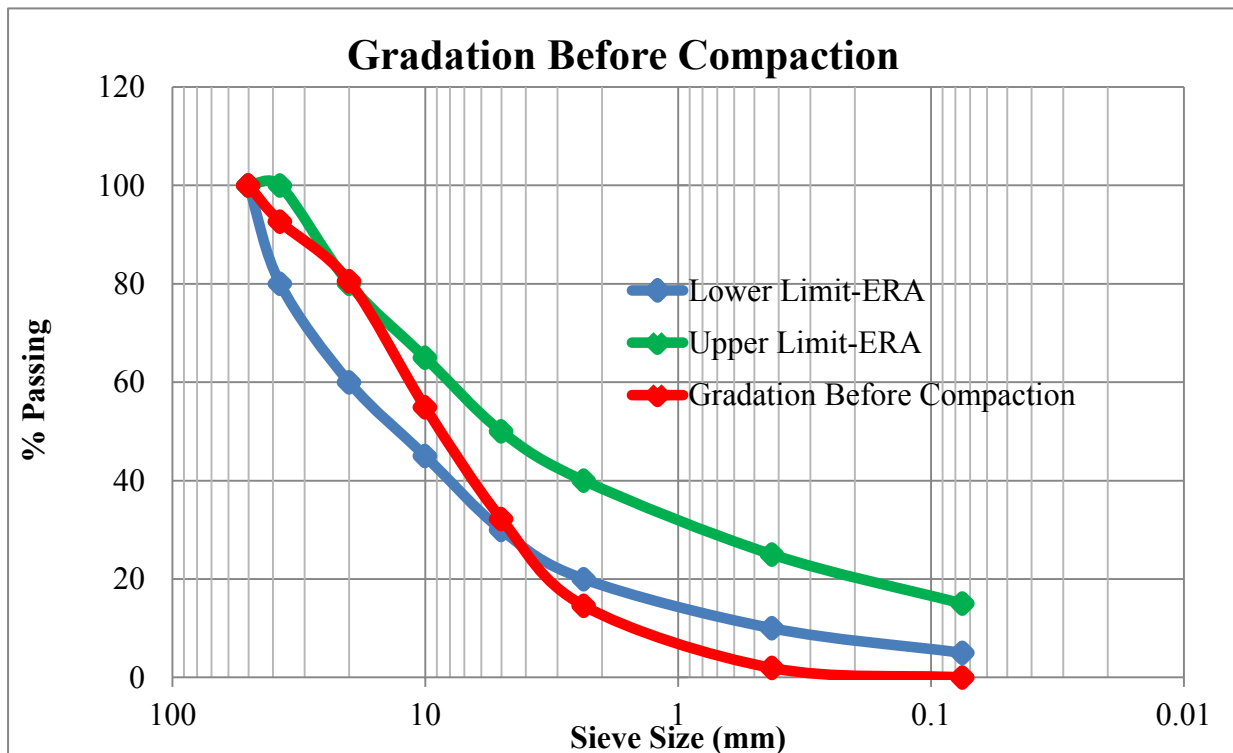


Figure D-1 Washed Gradation of 80%Cinder +20% volcanic ash/ Pumicite before
Compaction

Table D-2 Particle Size Distributions of 80%Cinder+20% Volcanic Ash/Pumicite after
Compaction

| Washed gradation after Compaction | | | | | |
|-----------------------------------|--------------|------------|-----------|-----------------|-----------------|
| Sieve | Wt. retained | % retained | % passing | Lower Limit-ERA | Upper Limit-ERA |
| 50 | 0 | 0 | 100.00 | 100 | 100 |
| 37.5 | 0 | 0 | 100.00 | 80 | 100 |
| 20 | 0 | 0 | 100.00 | 60.00 | 80.00 |
| 10 | 986.64 | 34.62 | 65.38 | 45.00 | 65.00 |
| 5 | 585.1 | 20.53 | 44.85 | 30.00 | 50.00 |
| 2.36 | 361 | 12.67 | 32.18 | 20.00 | 40.00 |
| 0.425 | 427 | 14.98 | 17.20 | 10.00 | 25.00 |
| 0.075 | 329 | 11.54 | 5.66 | 5.00 | 15.00 |
| Wt. before washing | 2,850.0 | | | | |

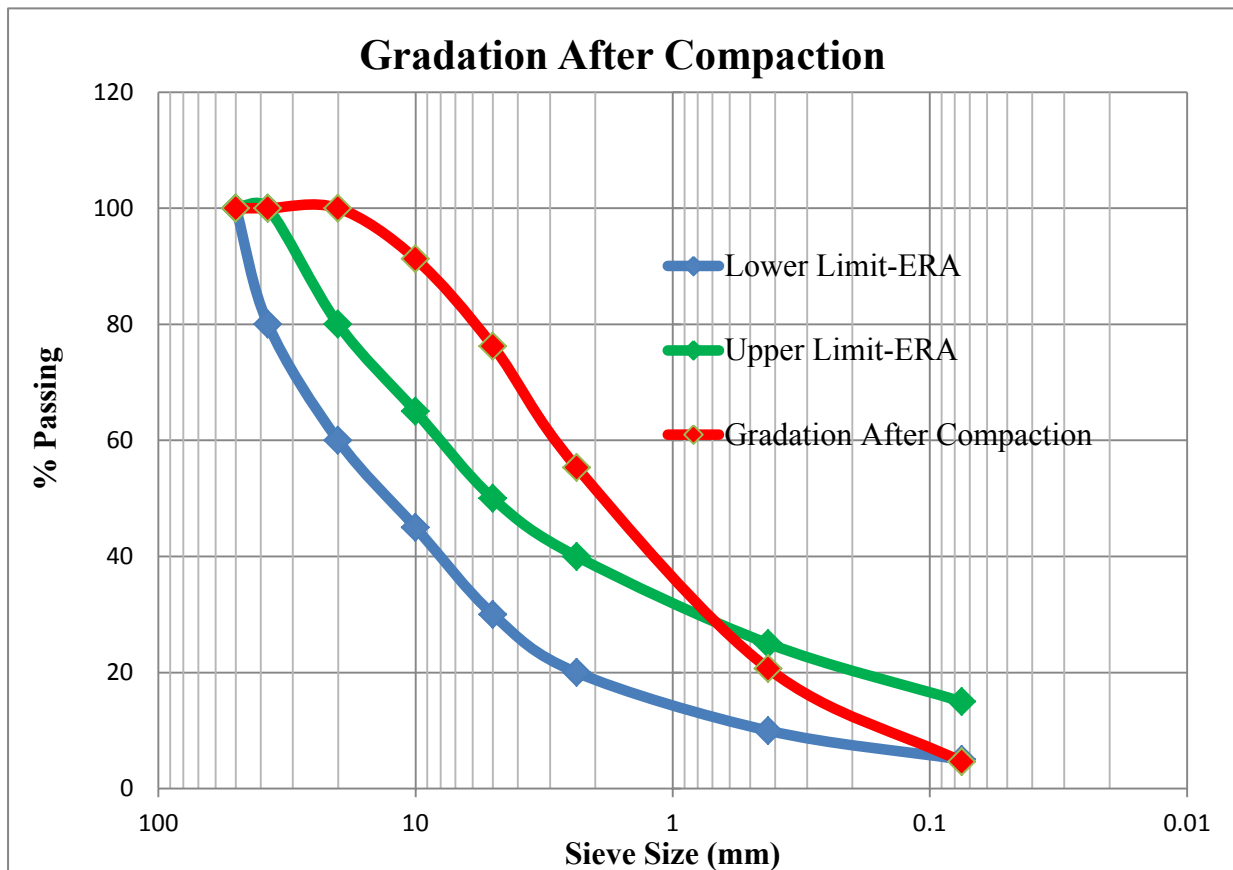


Figure D-2 Washed Gradation of 80%Cinder +20% volcanic ash/ Pumicite after Compaction

DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “THE USE OF NATURAL POZZOLANA(VOLCANIC ASH) TO STABILIZE CINDER GRAVEL FOR ROAD BASE (ALONG MODJO-ZIWAY ROUTE)” 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.

Thomas Teshome
(Candidate)

Date

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

Dr.Ing Samuel Tadesse
(Thesis Advisor)

Date