JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

Geotechnical Engineering Stream

The potential use of the cinder (scoria) as a base course material when blended with fine crushed rock (The case of Adama Area)

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Geotechnical Engineering**)**

By

Hawi Abdissa

Dec, 2022

Jimma, Ethiopia

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APPROVAL SHEET

As member of the Bored of Examiner of the MSc Thesis open defense examination, we certify that we have read and evaluated the thesis prepared by Hawi Abdissa and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the degree of Master of Science in Geotechnical Engineering.

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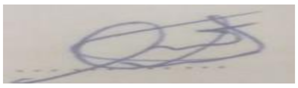
Habte Tamirat (MSc)		20/04/2023
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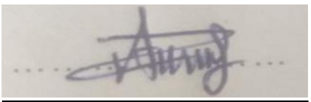
Alemineh Sorsa (PhD)		20/04/2023
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DECLARATION

I, hereby declare that this thesis entitled: **"The Potential use of the Cinder (Scoria) as a Base Course material when blended with Fine Crushed Rock (The case of Adama Area)** is my original work; furthermore, this study has not been presented in any other university or institution for the award of degree or diploma. All sources of materials used for this thesis have been duly acknowledged.

Hawi Abdissa  16/04/2023

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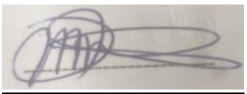
As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc thesis prepared under my guidance by Hawi entitled**: "The Potential use of the Cinder as a Base Course material when blended with Fine Crushed Rock (The case of Adama Area)**

Damtew Tsige (PhD)  18/04/2023

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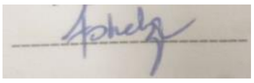
Shelema Amena (MSc)  17/04/2023

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ACKNOWLEDGMENTS

First, I would like to thank the almighty God for giving me strength and helping in all aspects of my life.

I would like to thank my main advisor Dr Damtew Tsige and co-advisor Mr. Shelema Amena for their valuable advice and limitless efforts in guiding me through my work when I am preparing this thesis.

I would also like to express my deepest appreciation goes to Jimma University, School of Graduate Studies, Jimma Institute of Technology, Civil and Environmental Engineering Department, Geotechnical Engineering chair holder and staff for facilitating this program which helps me for upgrading my profession and municipality of Adama town administration.

Finally, but not least, my heartfelt gratitude goes to my families and friends who supported and encouraged me to reach the destination of this journey.

Abstract

In recent years, the highway and construction industries have consumed an enormous amount of conventional aggregate every year. The increasing demand for conventional aggregate causes an increase in the cost of construction. In such instances, using of locally available materials plays a significant role in the cost and time saving of road construction projects. *Hence, this research was initiated with the motivation of upgrading and utilizing the cinder gravel, which is one of the abundantly available low-cost materials in the main rift valley of Ethiopia. Besides, in some regional parts of Ethiopia, there is a scarcity of good base course materials. Using these materials everywhere incurs transportation cost and is time-consuming. Therefore, this study has been carried out in order to investigate the performance of mechanically blended natural cinder gravels to be used as a road base course material and to provide an alternative material for road construction.* An attempt has been made in this study to evaluate the potential use of cinder gravel as a base course material when blended with fine crushed rock aggregate. *To achieve the objectives of the research, mechanical stabilization and laboratory tests have been carried out at different percentages of cinder gravel by (0%, 15%, 20%, 25%, and 30%) of fine crushed rock weights. The laboratory test results for cinder gravel indicated* Los Angeles abrasion value *(LAA),* specific gravity (*SG),* aggregate crushing value *(ACV), and aggregate impact* value *(AIV). Plastic Index, Water Absorption, and California Bearing Ratio (CBR) of 42.7, 2.4, 45.7%, 32.4%, non-plastic, 8.83%, and 65.54%, respectively. These test results failed the ERA standard specification for some tests, and they showed marginal quality values for the standard specification for GB2 and GB3 base course materials. Thus, mechanical stabilization was done to improve the mechanical and physical properties of cinder gravel. Blending of 75% cinder gravel with 25% CFA results in LAA, SG, ACV, AIV, Plastic Index, Water Absorption, and CBR of 35.7%, 2.7, 28.1%, 27.98%, non-plastic, 1.16%, and 125%, respectively. At this proportion, the gradation is also observed to fit with the required ERA standard specification of GB2 and GB3 materials. Therefore, it can be concluded that the use of cinder gravel up to 75% by weight is recommended for the road base course layer in places where the materials are abundantly available.*

Keywords: *Base Course, Cinder Gravel, Optimum Fine Crushed Rock content, stabilization*

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LIST OF ACRONYMS

AASHTO	American Association of States Highway and Transportation Officials
AC	Asphalt Concrete
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California Bearing Ratio
CA	Conventional Aggregate
FCR	Fine Crushed Rock
ERA	Ethiopian Road Authority
HMA	Hot Mix Asphalt
IS	Indian Standard
KN	Kilo Newton
LAA	Los Angles Abrasion
LL	Liquid Limit
NCG	Natural Cinder Gravel
NMA	Nominal Maximum Aggregate
PL	Plastic Limit
PSD	Particle Size Distribution
RAP	Reclaimed Asphalt Pavement
RCA	Recycled Concrete Aggregate
SG	Specific Gravity
TFV	Ten Percent Fines value
USCS	Unified Soil Classification System

1. INTRODUCTION

1.1 Background

Transportation is an important part of a country's infrastructure. The growth rate of a country's economy is inextricably tied to the growth rate of its transportation sector(1)

To satisfy the demands of industrialization and urbanization, a large volume of road network is required, and construction procedures should be done in such a way that decent roads are achieved with the least amount of money spent. The structural components of the roadways, such as the subgrade, subbase, base, and surface courses. In recent years, coarse aggregate has become the most valuable material in civil engineering projects, and as a result, it is becoming quite expensive due to rising costs and declining supplies, along with fine aggregates, especially suitable base course materials essential for road construction, they are currently in short supply in many areas. Using these conventional materials, road construction ends up with uneconomical pavement construction. Hence, it is necessary to find alternative materials for economical road construction (1)

A wide range of materials can be used in Ethiopia as unbound base course including crushed quarried rock, crushed, and screened, mechanically stabilized, modified, or naturally occurring „as dug‟ or „pit run‟ gravels. Their suitability for use depends primarily on the design traffic level of the pavement and climate. However, all base course materials must have a particle size distribution and particle shape which provide high mechanical stability and should contain enough fines to produce a dense material when compacted. In circumstances where several suitable types of base course materials are available. However, availability of good quality aggregate may be a problem in some locations, and then very high prices must be paid in road construction process which causes future risk of getting this scares material which can support fast growing road infrastructure construction. This gives rise to the need for use of locally available marginal materials by improving physical and engineering properties with suitable mechanical stabilization[1].

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, had only occasionally been used for road construction, even though their use would substantially reduce road construction costs in many instances. However, the variability in its engineering parameters, particularly its grading, density, porosity, and strength, have meant that the material often fails to meet standard specifications for road construction. In addition, they were reportedly difficult to compact [2].

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. The process may include blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil. Stabilizing material in the construction industry is essential if there are no locally available materials meet the required quality[3].

1.2 Statements of the Problem

Currently, researchers are working around the world to find road construction materials that are both cost-effective and environmentally friendly. The use of in-situ and non-industrial material in road construction was observed to be the best solution especially when using various stabilization techniques and chemicals. These stabilization methods have proven to be useful and cost-effective in increasing the quality of material that was previously considered mediocre, despite the high costs associated with cement and other chemical stabilizer[5].

In road projects, the quality of the base course depends on factors like gradation, angularity of the particles, shape of particles, soundness of the aggregate particles and resistance to weathering.

In our country materials to be utilised for base course construction have been specified which mainly include crushed stone and natural river gravels. If the required base course material is not available within a reasonable distance of the construction site, then high prices must be paid during the road construction process, causing major delays or cost increases. In such cases, working with locally accessible low-quality materials affects the road quality and durability over time and results in very significant losses. Improving the quality of materials is very important for road construction works, in order to ensure that projects satisfy the necessary cost and quality criteria[4].

Cinder gravel is abundantly distributed in our country. However, this material has a compaction problem due to its light weight, its rough circular surface, and its high porosity. Besides, in some regional part of Ethiopia, there is scarcity of a good base course material such as natural gravel, crushed rock, or recycled pavement material. Since the distribution of these base course materials are limited only in some parts of the country, using these materials everywhere incurs transportation cost and is time consuming. In some areas where cinder gravels are available, they are mixed with fine-grained soils without consideration to any research-based output or proportioning guidelines[6].

Therefore, it is important to see an alternative mineral aggregate material for cost-effective road construction. Thus, this paper attempts at the application of cinder gravel as a conventional aggregate for base coarse materials in flexible pavement and provide proper mixing proportion of cinder gravel with fine crushed rock at study area.

1.3 Research Questions

- What are the different engineering properties of the cinder gravel and stabilized material for base course preparation?
- How to improve the compaction property of cinder gravel?
- Is it possible to use cinder gravel for road base (base course) construction with blending material?

1.3The Objective of the Study

1.4.1 General Objective

The general objective of this study is to determine a good blending proportion of the cinder gravel with fine crushed rock in order to use it as a road base course material. This is achieved through the following specific objectives.

1.4.2 Specific Objectives

- To investigate different engineering properties of the cinder gravel for base course.
- To improve the compaction property of the cinder gravel.
- To assess suitability of cinder gravel for base course with blending material.

1.5 Scope of the Study

The scope of the study is to investigate the performance of cinder gravel when blended with crushed fine for road construction, specifically for base course, and propose the optimum blending proportion by conducting laboratory tests. The laboratory tests that were used to determine the usability of cinder gravel and crushed fine mix are gradation tests, aggregate crushing value (ACV) tests, aggregate impact value (AIV) tests, Los Angeles abrasion tests, compaction tests, and California Bearing Ratio (CBR) tests according to standard specifications for base course construction. The sample was collected from an available area, namely the Adama Area. Therefore, this paper would be taken as an indicative and alternative way of improving soils in the study area to be used as a road base course material.

1.6 Significance of the Study

In recent years road construction has become very expensive, one of the main reasons is a shortage of natural aggregate production. The essence of this study has provided an alternative material for road base course construction, the materials used for construction of base course layers shall be either natural gravel, cinder gravel, weathered rock, crushed gravel or crushed boulders, recycled pavement material. In this study try to explore the potential use of cinder gravel as a base course when it is mechanically stabilized. The importance of this study to overcome problems regarding shortage of standard materials near to project site by making use of locally available materials, encourage use of locally available material by improving the pertinent engineering properties. So that owners, contractors and consultants benefit from using abundantly available resources rather than scarce standard materials, implying conservation of natural resources, and reducing costs and environmental benefit gained from using locally available cinder gravel for projects to be built in study area will assist the government in building more networks by eliminating extra costs of hauling from far distance and time delay, which is one of the issues that prevent the road construction from being completed on time. As a result, this paper aims to assist civil engineers in Ethiopia in increasing their use of these materials where they are available, with the government of Ethiopia benefiting by lowering construction costs in areas where abundant cinder is available and alternative ways of improving soils in the research area to be used as road base course material.

1.7 Justification of the Study

The reasoning for conducting this research was to improve the performance of cinder gravel by mechanical stabilization. This research was conducted in order to produce the locally available cinder gravel safe, durable, comfortable, convenient, and low-cost road construction materials.

1.8 Limitation of the Study

The research was conducted only on the available cinder gravel of Adama area which is part of main rift valley. As a result, this study is not applicable to Jimma town and requires additional hauling costs due to the material location.

1.9 Research Gap of the Study

According to previous studies, only a few experimental researches have been conducted using this material for base course in road construction, and there is also a lack of further study and standard specifications for blending cinder gravel with fine crushed rock for base course, so the researcher must develop the use of cinder gravel for base course construction by only modifying them using mechanical stabilization with crushed fine and modifying the ratio of cinder gravel when blending with fine crushed rock to determine an acceptable blending proportion based on the required standard specification of road base construction.

2. LITERATURE REVIEW

2.1 Introduction

A highway pavement is a structure consisting of superimposed layers of processed materials above natural sub-grade soil, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure built up of several layers, consisting of sub-grade, sub-base, base course, and surface layer; these layers together constitute the pavement structure for both flexible and rigid pavement. Each pavement layer has different functions to perform which must be accordingly considered during the design process. Inflexible pavements, dense-graded unbound aggregate base and subbase layers serve as major structural components of the pavement system, distributing load (i.e., dissipating high wheel load stresses with depth) and providing enough support and stability for the asphalt surfacing[7].

2.2 The Function of Base Course

The base course is important layer of pavement structure and it distributes the loads from top layers to underneath sub base and subgrade layers. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials. The base course is the basic structural layer of a flexible pavement whose function is to support the wheel load applied on it which is coming from traffic and distribute the load in such a manner that materials beneath it will not become overloaded[8]. Other base course functions should be built with hard and durable aggregates that are either stabilized or granular, or both.

2.3 Base Course Materials for Pavement Construction

Various materials are used in the construction of roads but it is an intelligence of a highway engineer to select an appropriate material suitable for a particular road project which is also be locally available and should be cheap. Prominent engineers and researchers made a no research work to explore the construction materials for roads situated at different locations. By studying the works carried by the intelligent researchers will be beneficial to study and make understanding about the highway construction materials. A wide range of materials can be used as a base course is generally composed of granular materials such as crushed aggregate, gravel, selected soil, or a mixture of selected soil and aggregate. Their suitability for use depends primarily on the design traffic level of the pavement and climate. Using locally available materials is encouraged, particularly at low traffic volumes. Their use should be based on the findings of performance studies and should incorporate any special design features which insure their satisfactory performance[1].

2.4 Aggregates

Aggregates comprise the major portion of stabilized base. Normally, between 80 to 95 percent by weight of a stabilized base or subbase mix may consist of aggregates. A wide range of different types and gradations of aggregates have been used in stabilized base and subbase mixtures. These include conventional aggregate sources, such as crushed stone or natural crushed rock, sand and gravel, and other aggregate materials, such as blast furnace slag, recycled paving materials, and bottom ash or boiler slag from coal-fired power plants. Reclaimed pavement materials have also been successfully recycled into stabilized base and subbase mixtures, as have some marginal aggregates. Aggregates used should have the proper particle size, shape, gradation, and particle strength to belong to a mechanically stable mixture[9].

2.4.1 Coarse Aggregate

Coarse-grained aggregates will not pass through a sieve with 4.75 mm openings (No. 4). Those particles that are predominantly retained on the 4.75 mm (No. 4) sieve and will pass through a 3-inch screen, are called coarse aggregate. The course the aggregate, the more cost-effective the mixture. Larger pieces have less surface area of the particles than smaller pieces of the same volume. The use of coarse aggregate with the biggest allowable maximum size allows for a reduction in cement and water usage. When coarse aggregates are used in excess of the maximum size allowed, they can interlock and form arches or obstacles within the concrete form. As a result, the area below becomes a void, or at most, only fills with finer gravel and cement particles, resulting in a weakened area[10].

2.4.2 Fine Aggregate

Fine aggregate are those particles passing the 9.5mm(3/8in) sieve, almost totally pass through the 4.75 (No.4) sieve, and are mostly retained on the 75 µm (No. 200) sieve. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent[10].

2.5 Conventional Aggregates

Natural crushed rock materials, gravels and sands, or slag aggregates are the most common materials used in road pavements under their own or in combination with a cementitious material. Despite the low value of basic products, conventional aggregates are a large contribution to the construction sector and an indicator of the economic well-being of the nation[11]. Conventional Aggregate usually accounts for 92 to 96 percent of HMA and about 70 to 80 percent of Portland cement concrete by volume. This Aggregate is also used for base and subbase courses for both flexible and rigid pavements. Generally, they are extracted from larger rock formations through an open excavation. Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often the by product of other manufacturing industries[12].

2.5.1 Conventional Aggregate Material Sources

Aggregates can be obtained from both natural and man-made sources Aggregates are commonly found in hard rocks. There are various sorts of rocks, all of which are made up of crystalline mineral grains bound together in various ways. The Property of a rock are determined by the attributes of its constituent minerals and nature of the bond between them (i.e., composition, grain size and texture of the rock), which are determined by the mode of origin. According to the mode of formation, geologists divide rocks into three categories. These are Igneous, Sedimentary, and Metamorphic rocks[1].

Igneous rock: -These rocks are primarily crystalline and are formed by the cooling of molten rock material beneath the earth's crust (magma[(1].

Sedimentary rocks: - These rocks are made up of insoluble material that has been deposited (e.g., the remains of existing rock deposited on the bottom of an ocean or lake). This material is transformed into rock by heat and pressure. Sedimentary rocks are layered in appearance and are further classified based on their predominant mineral as calcareous (limestone, chalk, etc.), siliceous (chert, sandstone, etc.) or argillaceous (shale, etc.)[1].

Metamorphic rock: -These are igneous or sedimentary rocks that have been exposed to high enough heat and/or pressure great enough to change their mineral structure to be different from the original rock. A manufactured rock typically consists of industrial by-products such as slag (a by-product of the metallurgical processing – typically produced from processing steel, tin, and copper) or specialty rock that is produced to have a physical property not found in natural rock (such as the low density of lightweight aggregate)[1].

2.6 The Location and Engineering Properties of Volcanic Cinder Gravels in Ethiopia

2.6.1 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 (mostly water) dissolved in molten rock (magma), generating a froth that cools and hardens 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. Cinder gravels have a lower density and higher porosity than most other rock types due to their vesicular nature. Sharp cutting edges are constantly formed as the vesicle walls are broken. These properties are the basis for their commercial value as lightweight aggregates, insulators, absorbents, and abrasives[13]. They occur in characteristically straight sided cone-shaped hills which frequently have enormous concave depressions in their tops or sides where mixtures of solids and gases were released during the formation of the cone. Cinders can be red, brown, grey, or black, and can vary in color even inside the same cone. The cinder particles range in size from big irregularly shaped lumps up to 50 cm in diameter, as well as sand and silt. Particles may be more homogeneous in some cones, with the greatest size not exceeding 3 cm in diameter. Other distinguishing characteristics of cinders include their light weight, rough vesicular surface, and high porosity. They are usually weak enough to be crushed beneath the heel[2].

2.6.2 General Location of Cinder Gravel in Ethiopia

The survey's field visits took place within a 150-kilometer radius around Addis Ababa. They were primarily found in the areas surrounding DebreZeit, Adama (Nazreth), Ziway, Butajira, and Giyon. Samples were taken from either existing borrow pits where material had been extracted previously or from digging pits where the cinder cones had not been disturbed. Borrow pits already in place allowed for the collection of deeper profile samples that were more representative of the cone[2].

2.6.3 Engineering Geology of Cinder Gravel (Scoria) In Ethiopia

Ethiopia's geological outcrop pattern is as diverse as any other country, with igneous, metamorphic, and sedimentary rocks. In several sections of the country, a humid, subtropical environment has resulted in the development of deep residual soils, with enormous areas holding very limited naturally available gravels for road construction. The transportation of suitable naturally occurring gravels over long distances, as well as the usage of crushed rock as road construction material, are both costly procedures that limit the efficacy of resource-constrained road construction and restoration projects. The Rift Valley is home to the world's most active divergent transcontinental plate boundary. During the Plio-Pleistocene, felsic and mafic lavas as well as pyroclastic materials were extruded and ejected from fissures and vents surrounding the Rift Valley and the Afar Depression, with Holocene activity reaching the Rift Valley floor in conjunction with the active Wonji Fault Belt. Pyroclastic material ejected during these events has typically formed cones comprising ash, lapilli, bombs, and blocks of varying vascularity[2].

2.6.4 Formation of Scoria (Cinder Gravel)

Scoria forms when magma containing abundant dissolved gas flows from a volcano or is blown out during an eruption The pressure on the molten rock decreases as it emerges from the Earth, and the dissolved gas begins to escape in the form of bubbles. The bubbles become little spherical or elongated cavities in the rock if the molten rock solidifies before the gas has escaped. This dark-colored igneous rock with the trapped bubbles is known as scoria[14] [15]. When some volcanoes erupt, a rush of gas blows out of the vent. this gas had previously been dissolved in the magma underneath it. Small bodies of magma are frequently blown out by the gas, which harden as they travel through the air. This activity can result in a scoria ground cover all around the volcanic vent, with the densest deposits on the downwind side[15] Small particles of scoria that litter the landscape around the volcano are known as "lapilli" if they are between 2 millimeters and 64 millimeters in size. Larger particles are known as "blocks."[15].

2.7 Engineering Properties of Cinder Gravel

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. The black color is mostly due to its high iron content while the red color is causes from oxidation of iron in the scoria, which may have occurred because of rainfall during the eruption. The Color of cinder doesn’t have significance effect on their properties. The difference in their properties is attributed to:

a. Initial deposition of the cone and,

b. The way they have been modified since their depositions.

Cinder gravels have weak particles that are easily broken down, and they are coarser materials in their natural state. Although Compaction produces finer particles, it may also minimize the number of coarser particles required. This property makes them difficult to be compacted to a stable layer. The material has moderate durability, has a high porosity and CBR value well less than that is required to be used as base course material for heavily trafficked roads. An advantage of cinders as a road construction material is the relative ease with which they can be dug from the quarry; a mechanical shovel or hand tools are usually sufficient for their extraction although occasionally a bulldozer may be required to open a working[4] [15] [14].

2.8 Physical and Mechanical Properties of Aggregate

The most essential physical and mechanical properties of aggregates are the most readily apparent aggregate properties, and they also have the greatest direct impact on how an aggregate function as a pavement material constituent or as a base or subbase material on its own. The aggregates' physical and mechanical properties have a considerable impact on the performance of asphalt pavements. It is, however, difficult to separate the effects of different aggregate characteristics on asphalt performance. The following are some of the most measured physical and mechanical properties aggregates:[16].

- Gradation
- Toughness and Abrasion Resistance
- Durability and Soundness
- Particle Shape and Surface Texture
- Cleanliness and deleterious material
- Moisture content
- Absorption and Particle density
- Hardness and Resistance to polishing

The purpose of an unbound layer in a pavement is to provide a stable platform on which the pavement's upper layers can be compacted and constructed. The unbound layers should be permeable and frost resistant, and they should act as a frost protection layer, protecting the subgrade from frost. Finally, an unbound layer, like the bound layers, should distribute traffic loads to lessen stress on the underlying pavement layer and subgrade, preventing overstress and rutting[17].

2.9 Specifications and Quality Requirements of Aggregates as Base course

The performance of any constructed pavement system mainly depends on the quality of materials used in different layers. To confirm the adequate performance of pavements under stress, transportation agencies have developed specifications that address certain minimum properties or qualities of construction material[7].

The amount by which an unbound aggregate material is deformed when loaded depends on its stiffness and stability. Stiffness, or the ability to spread the load, is a measure indicating resilient deformation resistance. It is expressed in terms of a modulus of elasticity or resilience that is used in designing the pavement ability to resist permanent deformation is measured by stability. Another term is load-bearing capacity, which can be defined as the load a layer of material can bear without deforming beyond its allowable limits. As a result, determining the bearing capacity necessitates the use of a limiting factor[17].

Aggregates have a variety of qualities that are examined separately using several sorts of tests before being used in pavement construction. To achieve better results after construction, Aggregate should qualify all tests performed. The properties of aggregate and tests are given below[18].

Table 2. 1: Properties and Tests of Aggregates for Pavement Works

Aggregate Property	**Tests to be Conducted**
Strength	Crushing strength test, CBR test
Hardness Abrasion test	Abrasion test
Impact value	Impact test
Shape of aggregate	Shape test
Bitumen adhesion Bitumen Adhesion test	Bitumen Adhesion test
Specific gravity	Specific gravity test
Water absorption	Water absorption test
Particle size	Graduation test

The performance of a material depends on where it exists in the pavement structure. Traffic induced stress is highest on the road surface and decreases with depth according to the load-spreading capacity of the various materials. Unbound materials are less able to spread load than bitumen-bound materials[17]. The materials used in the construction of the base course layer must be hard, durable, tough, and strong particles or fragments of stone that must be resistant to carry the load imposed on them during construction and design life. They must be mechanically interlocking, resistant to mineralogical change, and physically break down due to cyclic environmental change[1].

As shown in Table 2.2 materials acquiring Suitable for base course construction have been labeled by ERA as standard materials designated as GB1, GB2, GB3, and GB2A with a certain specification of grading, shape, and minimum strength. A wide range of materials are included in these categories, and the selection among them depend upon traffic level and local climate[1].

2.10 Material requirements for naturally occurring granular materials, boulders, weathered rock (GB2 and GB3).

A. General

A wide range of materials including lateritic, calcareous and quartzite gravels, river gravels, boulders, and other transported gravels, as well as granular materials formed by the weathering of rocks, can all be utilized successfully as base course materials. The material must be able to be easily transported, spread, and compacted without becoming segregated[19].

B. Grading

The particle size distribution should be nearly parallel with the grading envelope, to ensure that the material has maximum mechanical stability, in the grading limits shown in Table 2-3 when determined in accordance with the standards of AASHTO T-27. The mass of material passing the 0.075mm sieve must be determined according to AASHTO T-11 specifications. Table 2-3 shows two particle size distributions for suitable materials with maximum nominal sizes of 37.5 mm and 20 mm, respectively.

Table 2. 2: Properties of unbound materials[1].

Code	Description	Summary of Specification
GB1	Fresh, crushed rock	Dense-graded, un weathered crushed stone, non-plastic parent fines
GB2	Crushed weathered rock, gravel, or boulders	Dense grading, PI<6, soil, or parent fines; PP<60
GB2A	Dry-bound and water-bound Macadam	Aggregate properties as for GB2 PI<6; PP<60
GB3	Natural coarsely graded granular material, including processed and modified gravels	Dense grading, PI<6, CBR after soaking>80%
GS	Natural Gravel	CBR after soaking >30%
GC	Gravel or gravel-soil	Dense-graded; CBR after soaking>15%

1. These specifications are sometimes modified according to site conditions, material type, and principal use.
2. PP= Plastic product= PI*(percent passing 0.075mm sieve).
3. GB=Granular base course, GS= Granular sub-base, GC =Granular capping layer.

Table 2. 3: Recommended Particle Size Distributions for Mechanically Stable Natural Gravels and Weathered Rocks for Use as Base Course Material (GB2, GB3)[3].

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

C. Plasticity Index

The fine fraction of a GB1 material shall be non-plastic or shall have a maximum Plasticity Index of 6 when determined in accordance with AASHTO T-90.

D. Californian Bearing Ratio (CBR)

When used as a base course, the material should be compacted to a density equal to or greater than 98 percent of the maximum dry density achieved in the ASTM Test Method D 1557 (Heavy Compaction). After four days of immersion in water, the material should have a minimum CBR of 80% when compacted to this density in the laboratory (ASTM D 1883).

E. Aggregate Crushing Value (ACV)

Minimum soaked Ten percent Fines Value (TFV) Value (BS 812, Part 111) shall be 50 KN.

F. Abrasion

The Los Angeles Abrasion value, determined by testing in accordance with AASHTO T96 shall not exceed 45 at 500 revolutions unless otherwise specified in the Project Specifications.

G. Water Absorption

The water absorption shall not exceed 2% when determined in accordance with the requirements of AASHTO T-85.

2.11 Stabilization method of aggregate materials

The term 'Stabilization' may be defined as the alteration of the properties of an existing aggregate by blending (mixing) two or more materials and improving particle size distribution or, by using stabilizing additives to meet the specified engineering properties. Quite often soils and aggregates are stabilized for road construction in most parts of the world for the following one or more objectives[3].

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

In general, two techniques of aggregate stabilizations are commonly practiced in pavement construction[20].These are: -

I. Mechanical stabilization

Mechanical stabilization is the process of improving the particle size distribution and plasticity of an existing material by blending it with one or more other materials. Typical materials used for mechanical stabilization include river deposited sand, natural gravel, silty sands, sandy clays, silty clays, crushed run quarry products, and waste quarry products, volcanic cinders and scoria, poorly graded laterites, and beach sands, etc. Materials produced by blending have properties like conventional unbounded materials and can be examined using standard methods[20].

II. Chemical stabilization

Chemical stabilization is performed by mixing chemicals with soils and aggregates to make a stronger composite material, such as cement, lime, fly ash, or bitumen, or combinations of these elements. The type and percentage of additive to use is determined by the soil classification and the level of improvement required[20].

2.12 Blending Aggregates

To achieve the graduation requirements of aggregates for uses in pavement construction, it is often necessary to blend two or more aggregates together. To achieve this mixing, charts and diagrams are available, but the trial-and-error method is simpler than and almost as fast as more complex ways. The blending of two or more aggregates is to obtain different aggregate properties. It is the ability to mix aggregates in order meet a specified target. Asphalt concrete requires the combining of two or more aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix. Blending involves the mixing of materials that have different properties (typically particle size distribution) to form a material with characteristics that improve upon the limitations of the source materials. In most instances, blending often entails adding coarse aggregates to the finer in situ material[8].

2.13 Previous Works on Cinder Gravels in Road Construction

There is very little documented work on the use of cinder gravels in road construction in Ethiopia, or anywhere else for that matter, although a few specimens are listed below.

2.13.1 Stabilizing Cinder Gravels for Heavily Trafficked Base Course.

As documented in this study, samples acquired from quarry sites around Alemgena and Lake Chamo were used to investigate the enhancement of natural gravel utilizing stabilizing techniques. In two later phases, mechanical and cement stabilization were examined. In the first phase, optimum number of fine soils that makes up the deficiency of the fine particles of natural cinder gravels was found to be 12%. In the second phase, natural cinder gravel sample without, and with 12% fine soils were stabilized with 3, 5, 7, and 10% of cement by mass. The result of investigation indicated that the optimum amount of cement required to achieve the minimum UCS of 3.0 MPa as specified in ERA and AACRA pavement design standard for heavily trafficked base course without adding fine soil is found to be 7% cement. However, this high cement requirement was lowered to 5% cement which is a feasible value by mechanically stabilizing cinder gravel with 12% of fine soils before cement stabilization. Nevertheless, it was suggested 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[14].

2.13.2 The Use of Natural Pozzolana (Volcanic Ash) to Stabilize Cinder Gravel for a road Base

Two varieties of natural pozzolanas were collected from the Ziway Area for this investigation. One was pumice, (coarser) and the other was volcanic ash (Pumicite). The cinder gravel is blended with 0,4,8,12,16,20, and 24 percent by mass of volcanic ash (Pumiced). 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 percent by mass proportion at a density of 1.76g/cc. The air curing technique was used for the soaked and unsoaked conditions where the stabilized samples were covered with a polyethylene sheet and kept at a normal air temperature and out of water intrusion for a curing time of zero, three, seven, fourteen, and twenty-eight days. The range of soaked CBR increases from 98 percent to 245 percent for the optimal blending proportion, whereas the unsoaked condition increases from 118 percent to 307 percent for 0 to 28 days of curing[13].

2.13.3 Blending of Cinder Gravels with Fine Grained Soil to be used as Sub Base Material

The performance of mechanically stabilized natural cinder gravel from the Butajira area for usage as a road sub-base material was investigated in this study. To meet Ethiopia Road Authority manual specifications, cinder gravel was blended with a trail proportion of 0, 5, 10, 15, 20, and 25% fine-grained soil by mass, and various laboratory tests were performed, including grain size distribution, Atterberg Limit, compaction, CBR, LAA, absorption, and linear shrinkage. According to the laboratory test results, the optimum amount of fine-grained soil required to improve its properties is 19 percent by mass proportion from both the MDD-percent of fine-grained soil curve and the CBR-percent of fine-grained soil curve[6].

2.13.4 Potential Use of Cinder Gravel as an Alternative Base Course Material through Blending with Crushed Stone Aggregate and Cement Treatment.

An experiment was conducted by blending cinder gravel with conventional crushed stone base course material, Crushed Stone Aggregate (CSA), in various proportions of cinder/CSA (10%, 20%, 30%, 40%, 50%), and treating it with 6.8% and 10% cement. According to results of sieve analysis, aggregate crushing value (ACV), flakiness index, and California Bearing Ratio (CBR), 30% of crushed stone aggregate (CSA) can be replaced by cinder gravel for use as fresh, crushed rock (GB1) material and for cement treated cinder gravel, adding 6% and 8% cement makes them suitable for use as stabilized base course (CB2) and (CB1) base course materials respectively, referring to their 14 day compressive strength as determined by Unified compressive strength test(UCS) test[21].

2.13.5 The Potential use of Cinder Gravel as a Base Course Material when Stabilized by Volcanic Ash (Pumicite) and Lime.

In this study, an investigation into the improvement of natural cinder gravel by stabilization technique was conducted using samples collected from the Metehara area. In the first phase of investigation, mechanical stabilization was carried out at various proportions of volcanic ash blended with cinder gravel. The compaction method was used to determine the optimum amount of volcanic ash that makes up for the deficiency of fine particles. In this method, the optimum amount of volcanic ash has been found to be 22% by weight. CBR values of soaked and unsoaked conditions were determined for cinder gravel stabilized mechanically with the indicated optimum amount of volcanic ash at 3,7,14 and 28 days after wrapping the sample in the mold with a polyethylene sheet. The test results showed that the CBR values for all these days of wrapping the sample in the mold were more than 80%, as required by the ERA specification for road base, whereas the cinder gravel alone was found to be 72%. However, the CBR values were not affected by the duration of wrapping the sample in the mold. In this phase, the CBR value for the soaked conditions has been found to be less than that of the un soaked condition as expected.

The second phase of investigation, mechanical as well as lime stabilization were carried out simultaneously in which 20% of volcanic ash and 2% of lime were blended with cinder gravel in order to find out how the CBR would be changed. Soaked and unsoaked conditions at 3,7,14 and 28 days of wrapping and keeping the sample in the mold indicated that the CBR values in this phase were higher than the similar values obtained by blending cinder with volcanic ash solely. The CBR value in this scenario was observed to increase with the duration of wrapping and keeping the sample in the mold, unlike in the first phase. Furthermore, the CBR value after four days of soaking was found to be greater than that of the unsoaked condition for a given duration of time. Although the current study's laboratory findings show that stabilized cinder gravel can be used as a base course material, the field performance of this stabilized material should be tested on a trial stretch[22].

In Ethiopia and around the world, there is very little research on the usage of cinder gravel in road construction. This study intends to help Ethiopian engineers make better use of these materials for base courses where they are available, lowering costs and increasing the possibility for road construction in such locations. A few numbers of experimental investigations have been conducted out employing this material for base course in road construction, as reported in prior publications. And, there is no further study and standard specification for blending cinder gravel with fine crushed rock for base course, researchers must develop the usage of cinder gravel for base course construction by mechanically stabilizing it with fine crushed rock material. However, few studies have used two or more stabilization methods to stabilize cinder gravel for base course.

2.13.6 Replacing Cinder Gravel as Alternative Base Course material

Costs relating to haulage and processing of materials have considerable impact upon economics of road construction. Hence material search is generally restricted to about 10km corridor centering on the road but materials found at this distance may not satisfy the required quality. Cinder gravels are most abundant materials found in tropical countries like Ethiopia especially in rift valley zones where there are active volcanoes. The main objective of the study was to investigating use of cinder gravels as base course material through blending with conventional base course material, CSA, and stabilization with cement. According to results of sieve analysis, ACV, flakiness index and CBR, 30% of CSA can be replaced by cinder gravels for use as GB1 material and for cement treated cinder gravels adding 6% and 8% cement make them suitable for use as CB2 and CB1 base course materials respectively, referring to their 14 day compressive strength as determined by UCS test while the mix with 10% cement satisfies US Army specification. Based on the results of the research, it is recommended that utilization of the locally available cinder gravels shall be given due consideration for upcoming road construction projects in the study area or in other locations with similar characteristics[23] .

2.13.7 Engineering geology of cinder gravel in Ethiopia: prospecting, testing and application to low-volume roads

Expansion of the rural road network in Ethiopia requires the availability of low-cost materials for road construction, including capping layer and subgrade improvement, sub-base, base course, gravel wearing course and bituminised surface treatment. A reluctance to use cinder gravels for these purposes in the past has stemmed from the view that their properties, in terms of grading and CBR strength, are marginal and highly variable when compared to international specifications for road works. The geographical variability in Ethiopian cinder gravel geochemistry and engineering properties is described and comparisons are made with engineering geological field descriptions and cinder cone morphology, leading to the conclusion that maars and steep-sided, well-defined cones tend to yield the better-quality materials. The performance of trial sections of road constructed using cinder gravel is assessed and combined with the results of laboratory testing to develop a guideline for the wider use of the material in roadworks, either directly or through processes of blending, alternative compaction methods and cement stabilisation to yield a product that can be considered Bfit for purpose^ for a range of uses in low-volume road construction[24] .

3. METHODS AND MATERIALS

3.1 Introduction

The overall goal of this research was to find an acceptable blending mix of cinder gravel and crushed rock for usage as a road base course material. These constituent materials were subjected to various laboratory tests in order to determine their physical and mechanical properties whether they can meet the required specification limits or not. These quality tests that have been performed on the aggregates are sieve analysis, specific gravity and water absorption test, Los Angeles abrasion, impact value, aggregate crushing value, Modified compaction, and CBR.

3.2 Study Area

The laboratory experiment was conducted out at the Jimma University Institute of Technology.The study area was adama city, it is in eastern Showa in the Oromia Region. It is one of the largest and most populated towns in Oromia National Regional State. It is located at $8^{\circ}33'35''$N - $8^{\circ}3'46''$ N latitude and $39^{\circ}11'57''$ E – $39^{\circ}21'15''$ E longitude. It is about 100 kilometers away from Addis Ababa in southeast direction. Adama has a total area of about 13,000 hectares, which has been subdivided into 14 urban kebele (least administrative structure) administrations. The altitude of Adama varies from about 1500m to 1670 above mean sea level. Generally, regions between 1500-2500 meters a.m.s.l. (categorized as woin adega or subtropical climate). Adama is found within the Wonji fault belt, which is one of the main structural systems in the Ethiopian rift valley. Its physiographic condition is, therefore, mainly the result of volcano-tectonic activities that occurred in the past and partly the result of deposition of sediments[23].

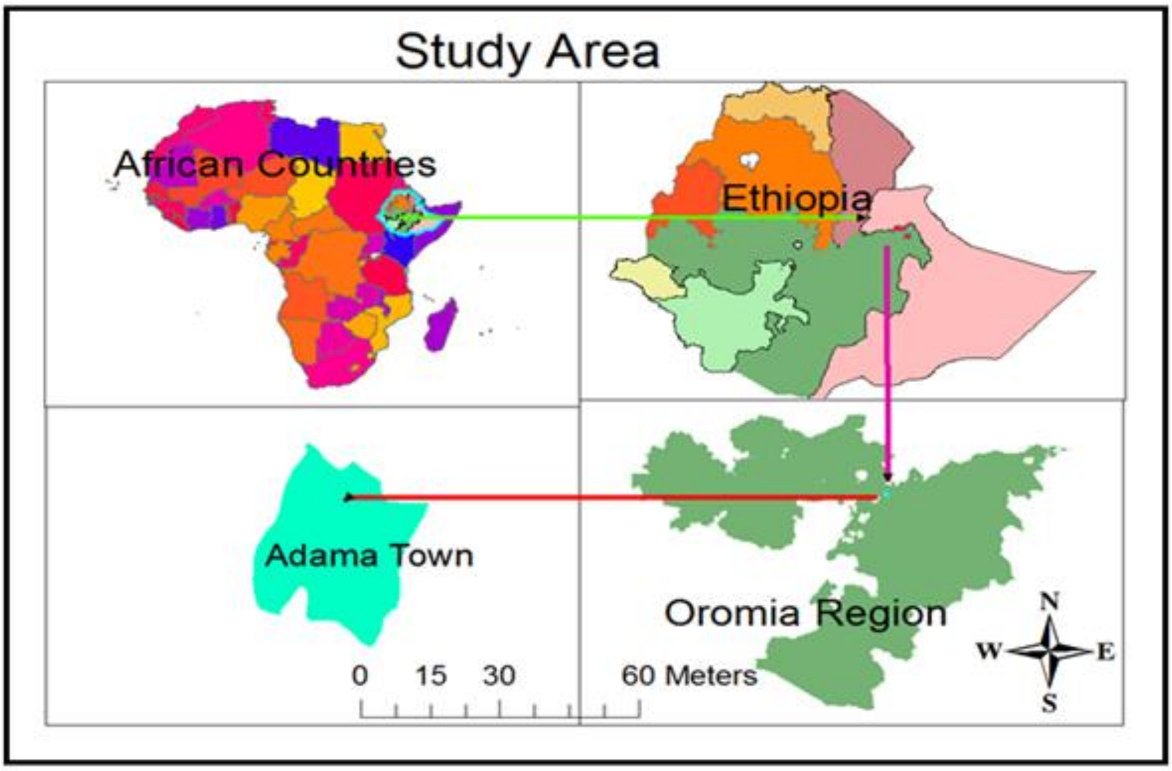

Figure 3. 1: Location of the research area on the map of Ethiopia

3.3 Study Period

This research was carried out within the prescribed period as per the attached work schedule/plan from Oct 2020 to April 2022.

3.4 Research Design

The study has followed the experimental type of study which was beginning with collecting samples and procedures including: Taking samples from the site, preparing samples for each laboratory test, laboratory tests on the physical and mechanical properties of fine crushed rock and cinder gravel materials, determining the effect of cinder gravel on the quality requirements of base course material, and blending cinder gravel with fine crushed rock to find out a possible replacement amount that satisfies the ERA manual standard specification and gradation requirement for base course material. The overall research design is as the chart below.

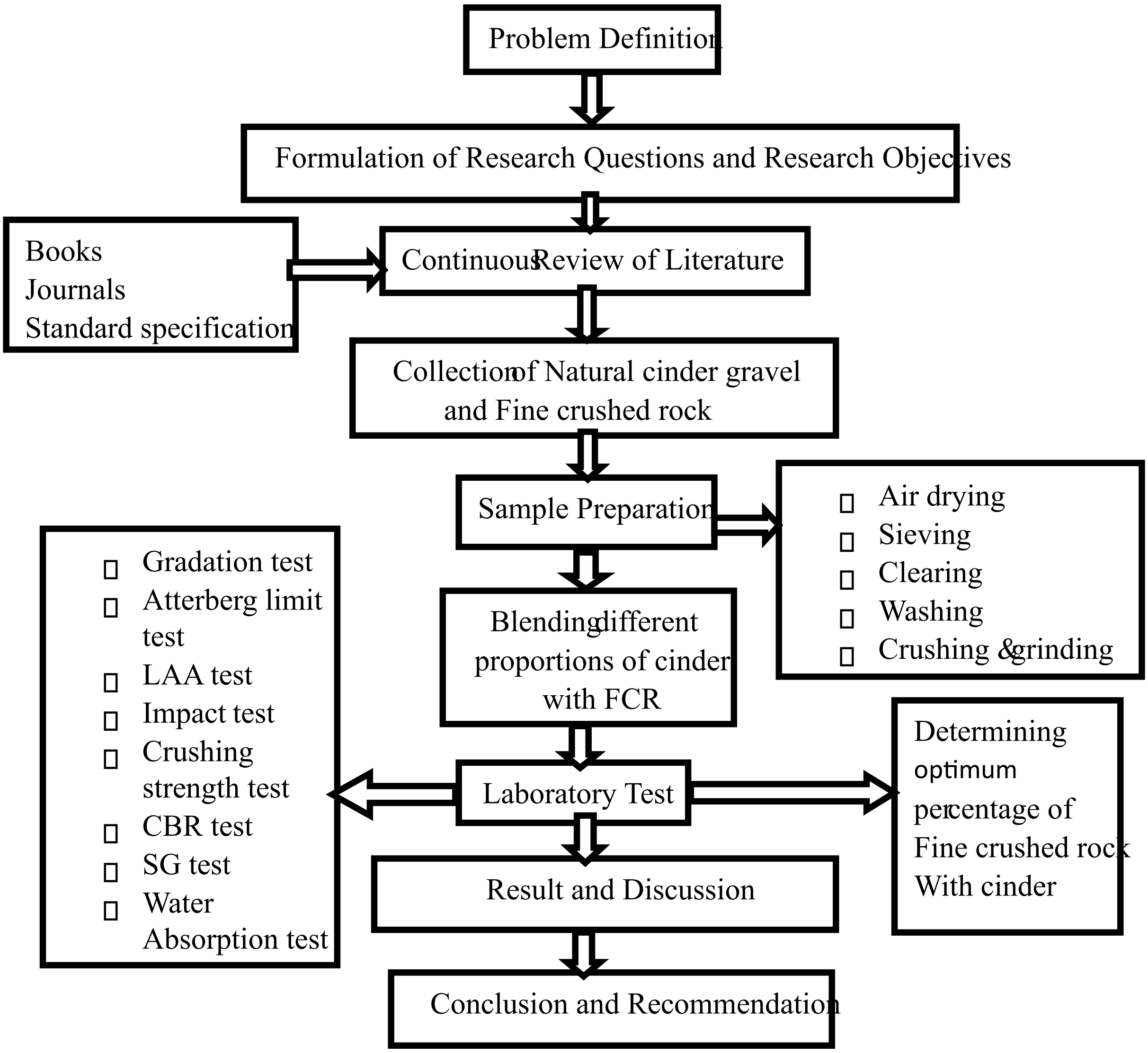

Figure 3. 2: Flow Chart for Research Design

3.5 Population

The study focused on two types of aggregate: cinder gravel aggregate and fine crushed rock aggregate, which were taken from two distinct places and combined to make a hard and stable base course. This population was used by the researcher to obtain the essential data for the study.

3.5.1 Sample Size and Selection

This study followed a purposive sampling selection process. The representative sample size required for each test has been collected in accordance with the standard specification of the AASHTO T-2 Methodology for sampling from existing place. Based on this method samples of cinder gravel from adama city have been collected. This area was selected due to its accessibility and availability of proposed material.

3.5.2 Sampling Techniques and Procedures

Purposive sampling techniques were used in this research, which is a non-probability method that involves the selection of a group from the population purposefully to achieve the studies goal. For aggregate laboratory tests, the sample preparation procedures are depending on the types of test requirements and standards. The samples were collected according to the procedure AASHTO T-2 Methodology for sampling from adama town.

3.6 The Study Variables

3.6.1 Dependent Variable

The dependent variables are more closely related to the general objective of the study that is the engineering performance of the mix of natural cinder gravel and fine crushed rock.

3.6.2 Independent Variable

Independent variables of this study are the results of laboratory tests that describe the engineering property of fine crushed rock and natural cinder gravel. This includes: - Grain size/Gradation, nature of parent rock (mineralogical composition of cinder gravel), moisture content, Atterberg limit, Specific gravity and water absorption, Aggregate crushing value Aggregate, Impact value, Los Angeles abrasion value Moisture-Density relation (Compaction) Test, and California Bearing Ratio.

3.7 Data Processing and Analysis

The cinder gravel material and the stabilized fine crushed rock were collected from Adama town. After data was collected it has been organized and evaluated in accordance with the objectives. Quantitative and qualitative data were utilized based on the necessary input parameters for the analysis by comparing them with ERA manuals The laboratory test results were show the optimum amount of fine crushed rock required to achieve the ERA manual standard specification requirement. Physical and all the tests were carried out on cinder gravel with various percentages of fine crushed rock, in accordance with ASTM and AASHTO testing procedures to identify the engineering qualities of the cinder gravel with fine crushed rock and to determine the workability of the cinder gravel for basecourse. Processing and analysis of data were presented and explained by using different formulas, graphs, tables, and charts as required. The analysis was based on the outstanding and present standard specifications of the ERA pavement design manual. Laboratory tests are conducted, the results are taken and analysis is done in accordance with the standard procedure used for the laboratory data analysis of each test.

3.8 Laboratory Tests

The Data collection was mainly based on the tests to be conducted on the prepared samples in the laboratory and reviewing related literature. First, the ingredients have been collected from their respective locations to the research center. Following that, sample preparation for each laboratory test. Finally, laboratory tests are performed, and the data was collected from all experiments according to relevant standard specifications and formats. The data becomes input for the analytical analysis and for drawing conclusions and recommendations. The laboratory tests were examined: Gradation, Atterberg limit, Compaction, California Bearing Ratio (CBR), Los Angeles Abrasion (LAA) test, Specific Gravity, and absorption, Ten Percent Fine (TFV) value and Aggregate Crushing Value, then after the comparison of ERA standard specification and the actual result of the identified material.

3.8.1 Particle Size Analysis

The test was performed to determine the percentage of different grain sizes contained within aggregates, grain size analysis for each material was conducted as per AASHTO T 27-93 manual. Blending of cinder gravel and crushed aggregates was done by trial and error to reach the required specification limit, grading was analyzed according to the ERA flexible pavement design manual for base course and for hot mix asphalt requirements[24].

Sieve analysis is the process of weighing an aggregate sample and then passing it through a nest of sieves. The nest of sieves is made up of a stack of wire-cloth screens with progressively smaller openings from top to bottom. The material retained on each sieve is weighed and compared to the total sample mass. Particle size distribution is expressed as a percent retained or percent passing by weight on each sieve size[25].

The test can be conducted on either dry or washed aggregate. The washed sieve analysis takes a long time but, produces a more accurate gradation result, mainly for the percent passing the No. 200 (0.075 mm) sieve since these washing helps to remove the smallest particles from the larger particles. The dry sieve analysis procedures are repeatedly used wherever rapid results are required[8].

Table 3. 1: Recommended particle size distributions according to ERA for 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

3.8.2 Atterberg's Limits

The Liquid Limit and Plastic Limits of Soil indicate the water content of the soil at specific changes in its physical behavior. The liquid limit test is conducted as per AASHTO T 89 whereas the plastic limit test is conducted as per AASHTO T 90. 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 into a thread of 3.2mm diameter without crumbling. The "Plasticity index" (PI) of a soil is defined as the numerical difference between the liquid and plastic limits. For the following reasons, plasticity is a crucial aspect in the performance of a gravel wearing course. Material with plasticity that is too low tends to loosen quickly as a result of diminished binding and the rate of gravel loses is generally very high. Loose material is pushed off into the drains or washed away by run-off or blown away by the wind when dry. High plasticity causes the wearing course to be slippery when wet and the material may soften to an extent where the gravel layer deforms and fails instantaneously under traffic[6].

As per ERA 2013, standard specification all base coarse materials shall have a maximum plasticity index of 6 when determined in accordance with AASHTO T-90[3].

3.8.3 Specific Gravity and Water Absorption

Specific gravity is a measure of a material's density (mass per unit volume) as compared to the density of water at 73.4°F (23°C). Therefore, by definition, water at a temperature of 73.4°F (23°C) has a specific gravity of 1. The coarse aggregate specific gravity test determines the specific gravity of a coarse aggregate sample by calculating the weight of a given volume of aggregate divided by the weight of an equal volume of water. Absorption can be used as an indicator of aggregate durability as well as the volume of asphalt binder it is likely to absorb[26].

Absorption, which is also determined by the same test procedure, is a measure of the amount of water that an aggregate can absorb into its pore structure. Water absorption gives an idea of the internal structure of aggregate. Aggregates with higher absorption are porous in nature and are generally deemed undesirable unless strength, impact, and hardness testing show that they are acceptable[26].

Bulk Specific Gravity: - According to AASHTO T-85, bulk specific gravity (SSD) 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 a specified temperature, to the weight in air of an equal volume of gas free distilled water at the same temperature.

According to the ERA manual 2013, the minimum recommended value of specific gravity for base course and subbase is 2.5-3.0[1].

3.8.4 Aggregate crushing value and Ten Percent Fines Value

Aggregate crushing value test on coarse aggregates provides a relative measure of the aggregates resistance to crushing under 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 coarse aggregate crushing value is the percentage by weight of the crushed material obtained when test aggregates are subjected to a specified load under standardized conditions. Aggregate crushing value is a numerical index of the strength of the aggregate and it is used in the construction of roads and pavements[27].

Ten Percent Fines Value (TPF): is a measure of the resistance of aggregate crushing subjected to loading and it is applicable to both weak and strong aggregate. Fine aggregates are defined as those passing 2.36mm sieve. The test aims at looking for the forces required to produce 10% of fine values (i.e., the weight of fine aggregates/weight of all aggregates = 10%). This test is very similar to the Aggregate Crushing Test, in which a standard force 400kN is applied and fines material expressed as a percentage of the original mass is the aggregate crushing value[28].

TPF was determined by measuring the load required to crush samples prepared in the same way as for ACV test described above, with the exception that two sets of samples are required, one set for testing in a dry condition and the other for testing in soaked condition to understand the change in strength when moist[8].

In the ERA pavement design manual, there are specific requirements of both ACV & TFV that should be fulfilled by materials to approve their use of a flexible pavement base course material (GB1). The maximum value set under this manual for ACV is 29, while TFV is a minimum of 50KN in dry condition test and 75% and 60% ratios of wet-dry test for places with a typical annual rainfall of >500mm and <500mm respectively[29]. For materials whose stability decreases with a breakdown, an aggregate hardness based on a minimum-soaked ten percent fines value of 50 KN may be specified for materials to be used as a GB2 and GB3 materials[8].

3.8.5 Aggregate impact value

The aggregate impact test is carried out to evaluate the resistance to the impact of aggregates. 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. It was measured as a percentage of aggregates passing 2.36mm sieve to the total weight of the sample[14].

3.8.6 Los Angeles Abrasion test

Aggregates undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities including manufacturing, stockpiling, production, placing and compaction. Furthermore, they must be able to adequately transmit loads from the pavement surface to the underlying layers and eventually the subgrade. Aggregates not adequately resistant to abrasion and polishing may cause premature structural failure and loss of skid resistance.

In Ethiopia Road Authority standard technical specifications manual recommends that the Los Angeles Abrasion value shall not exceed 45% when determined in accordance with the requirements of AASHTO T-96[3].

The Los Angeles abrasion test is used to determine the percentage wear caused by relative rubbing between the aggregate and the steel balls used as an abrasive charge. The number of the abrasive spheres changes according to the grading of the sample. The amount of aggregate to be utilized is determined by the gradation and typically ranges from 5 to 10 kilograms. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500 -1000 revolutions depending upon the gradation of aggregates. After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called the Los Angeles abrasion value[8].

3.8.7 Moisture- Density relationship

The objective of this test is to obtain relationships between compacted dry density and aggregate moisture content. The test is used to provide a guide for specifications on-field compaction. The dry density which can be achieved for an aggregate depends on the degree of compaction applied and the moisture content. The moisture content which gives the highest dry density is called the optimum moisture content for that type of compaction[8]. Compaction means pressing the soil particles close to each other by mechanical methods. Air during compaction is expelled from the void space in the soil mass and, therefore, the mass density is increased. Compaction of a soil mass is done to improve its engineering properties. Compaction generally increases the soils shear strength, and hence its stability and bearing capacity. It also useful in reducing the soils compressibility and permeability[30].

In this research, a heavily trafficked asphalt road was considered hence the modified proctor test is used. The Ethiopia Road Authority recommends using AASHTO T-180 method D. In this test, a specimen is prepared by compacting soil in 152.4 mm mold in 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.

3.8.8 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test is one of the most often used testing methods to evaluate the strength (stiffness) of subgrade, subbase, and base materials for pavement design. The resilient modulus can also be estimated using CBR test results. CBR is a measurement of a material's resistance to penetration of a plunger under controlled density and moisture conditions. The CBR test is one of the most used methods to evaluate the strength of subgrade soil, sub-base, and base course material. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement. The CBR value for a soil depends upon its density, molding moisture content and moisture content after soaking. The CBR test is a long-established, very extensively applied test yielding an empirical evaluation of the quality of granular road materials. The CBR-test was developed initially for the evaluation of the laboratory and in situ subgrade strength. the laboratory CBR test is now widely used across the world as a rapid way of characterizing qualitatively the bearing capacity of soils and unbound base and subbase materials. The CBR value is determined by force needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimen's[8].

As per AASHTO T-193, the method uses material passing 19 mm size and provides the CBR value of the material at optimum water content. Before penetration, the specimen should be soaked. A surcharge is placed on the surface to represent the mass of pavement material above the base course. The expansion of the sample is measured during soaking to check for potential swelling. To determine the strength and swelling potential of the samples, a test has been carried out by 4-days soaking-3-point CBR and loaded Swell testing procedure. The material strength has been used for design purposes by interpolating the CBR values at different compaction levels, with 10, 30 and 65 blows and compacting in 5 layers by heavy compaction. This procedure is necessary to obtain 98% of dry density as determined by the laboratory compaction test. The amount of Water to be added was calculated from the compaction test result which is the OMC obtained at MDD and by considering the natural moisture content of the material at the test[8] [31].

Table 3. 2: Summary of Standard tests conducted on Aggregate Quality Evaluation.

Type of Test	**Standard Code Used**	**ERA, IS, and BS Governing Specification**
Gradation Test	AASHTO T27	-
Specific Gravity Water Absorption	AASHTO T84, T85	>2.5% <2%
Atterberg's Limit Tests	AASHTO T89, T90	Non-plastic/PI<6
ACV and TFV Tests	BS-812-Part-111	<29% and >50KN
Aggregate Impact Value	BS-812-part-111	<30%
Los Angles Abrasion Test	AASHTO T96	<45%
Moisture-Density Relation	AASHTO T180	Not Specified
CBR Test	AASHTO T-193	>80%

4. RESULTS AND DISCUSSION

4.1 Introduction

The 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 towards more savings in the construction industry. In this research, locally available cinder gravel material was blended with crushed rock to fill in the scarcity of cinder gravel with the objective of using it as a road base material. Descriptive test results are shown below for the cinder gravel material and crushed rock used in this study.

4.2 Characterization of the Cinder Gravel

4.2.1 Particle Size Distribution and Gradation

The result from the gradation tests is used to determine the particle size distribution with appropriate specification requirement.

Detailed procedures for performing a grain size analysis of coarse aggregate and fine aggregate are given in AASHTO Method T-27[32]. The particle size distribution requirement depends on the nominal maximum particle size as shown in Table 3.1. When we refer to Table 3.1, two grain size distribution choices are presented depending on the nominal maximum particle size. In this study, a grain size distribution test for the nominal maximum particle size of 37.5mm was carried out on the cinder gravel and the results are as shown in Fig 4.1. (The details are indicated in Appendix A).

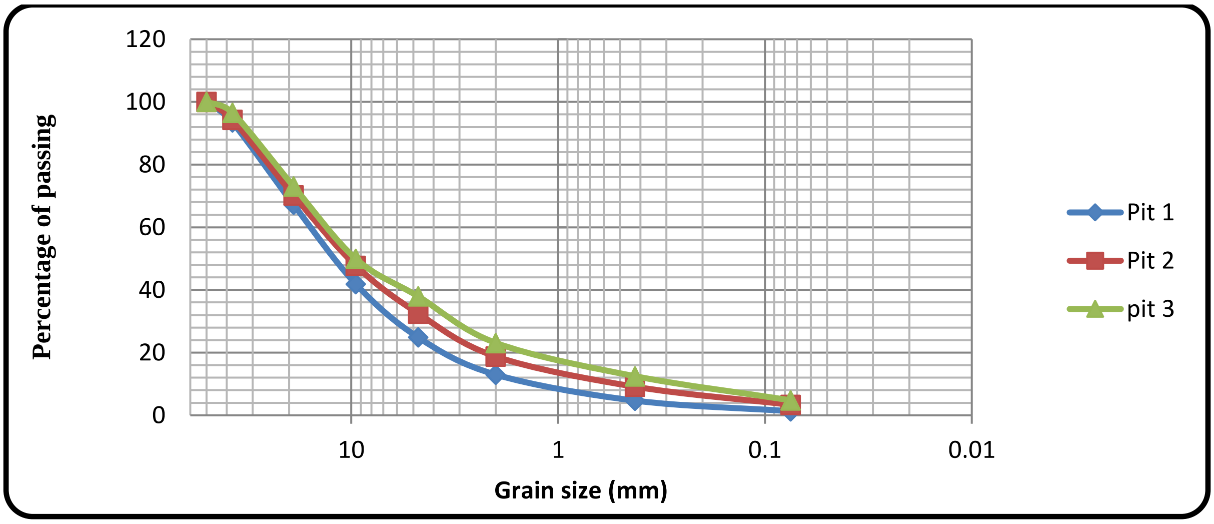

Figure 4. 1: Grain size distribution curve of pit 1, pit 2 and pit 3 for natural cinder gravel

The result of particle size analysis from sieve analysis for natural cinder gravel only is shown in figure 4.1 above. The grading curve of natural cinder gravel in fig 4.1 shows the deficiency in fine particles. Therefore, it does not meet the requirements of the ERA specification. The gradation is improved by blending aggregates with a trial percentage of fine-grained aggregate, and the optimum proportioning was determined to fulfill the ERA standard specification manual requirement.

4.2.2 Atterberg Limits

Atterberg limit tests were subsequently carried out on the samples of natural cinder gravel and fine crushed rock to characterize the plasticity of the fines in accordance with AASHTO T89, T90. There are two methods of liquid limit tests: Casagrande's method and cone penetrometer method. In this study due to the unsuitability of both aggregates for Casagrande's apparatus, cone penetrometer was used and more accurate data will be found with a penetrometer test. fines were obtained from the material passing the 0.425mm sieve size.

Following T-90 standards, laboratory test results showed that the cinder gravel and fine crushed rock is a non-plastic (NP) material. This result satisfies the requirement of ERA technical specification for base course (GB1).

Table 4. 1 Plastic index for natural cinder material

Natural cinder gravel	Plasticity index
Pit 1	NP
Pit 2	NP
Pit 3	NP

4.2.3 Absorption and specific gravity

In order to know some of the special characteristics of cinder gravel, it is important to determine the of absorption potential and specific gravity of natural cinder gravel[6].

Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including Portland cement concrete and other mixtures that are proportioned or analyzed on an absolute volume basis. The bulk specific gravity determined on the saturated surface-dry basis is used if the aggregates is wet, that is, if its absorption has been satisfied[6] [32].

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

Therefore, AASHTO T-84 method which is used for the determination of absorption and specific gravity of grain size less than 4.75mm was followed instead of AASHTO T-85[6] [32].

Accordingly, laboratory test results revealed that the absorption & specific gravity of the cinder gravels that pass sieve 4.75 mm are 8.83% and 2.4 for sample1, 8.71% and 2.4 for sample2 and 8.87% and 2.4 for sample3 respectively as indicated in Table B-1, B-2, and B-3 of Appendix B. Therefore, the cinder gavel has high water absorption capacity because of its high porosity.

4.2.4 Moisture- Density relations by Modified Proctor Test

In this research, a heavily trafficked asphalt road was considered hence the modified proctor test is used. The Ethiopia Road Authority recommends using AASHTO T-180 method D.

Accordingly, the test was carried out which produced that the maximum dry density (MDD) of cinder gravel for sample 1 has a maximum dry density and optimum moisture content of 1.49 g/cc and 5.2% respectively. Similarly, sample 2 has a maximum dry density and optimum moisture content of 1.57 g/cc and 6.1%, and the sample 3 of natural cinder gravel has a maximum dry density and optimum moisture content of 1.65 g/cc and 7.25%. Detailed laboratory data was attached as Appendix G.

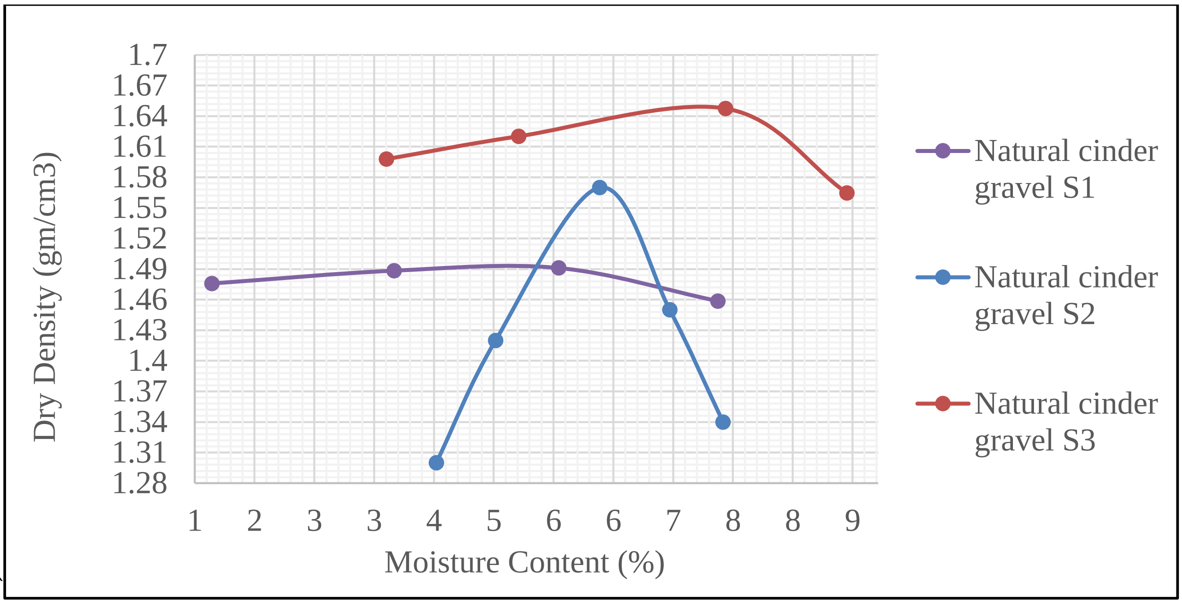

Figure 4. 1: Dry density- moisture content relationship for Natural Cinder Gravel of sample 1, sample2 and sample 3 respectively.

4.2.5 California Bearing Ratio (CBR) Tests

According to ERA manual, the minimum soaked California Bearing Ratio (CBR) for the base course material shall be 80% when determined in accordance with the requirements of AASHTO T-193. The Californian Bearing Ratio (CBR) shall be determined at a density of 98% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D[3].

Laboratory Test Result for Un-stabilized Cinder Gravel

The CBR value of sample 1, sample 2 and sample 3 un stabilized cinder gravel were shown in figure 4.6.

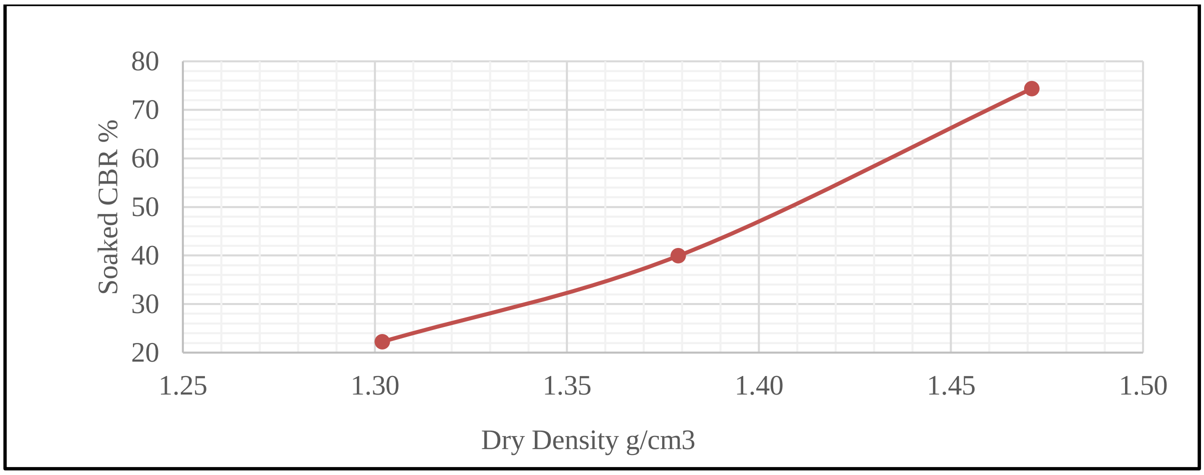

Figure 4. 2: CBR test result of natural cinder gravel for sample 1

Sample 1 had 65.54% CBR value at maximum dry density with 0.02% CBR swell, sample 2 had 65.73% CBR value with 0.02% CBR swell and for sample 3 had 66.09% CBR value with 0.09% CBR swell. Due to the results, unstabilized cinder gravel has a low CBR value and does not meet the ERA manual's minimal requirements for base course material.

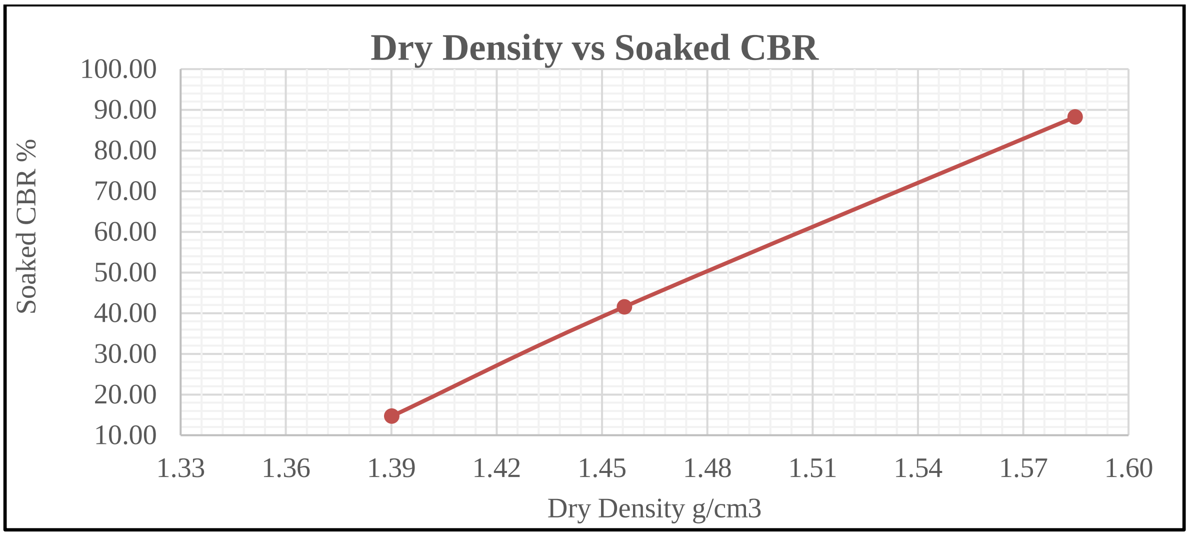

Figure 4. 3: CBR test result of natural cinder gravel for sample 2

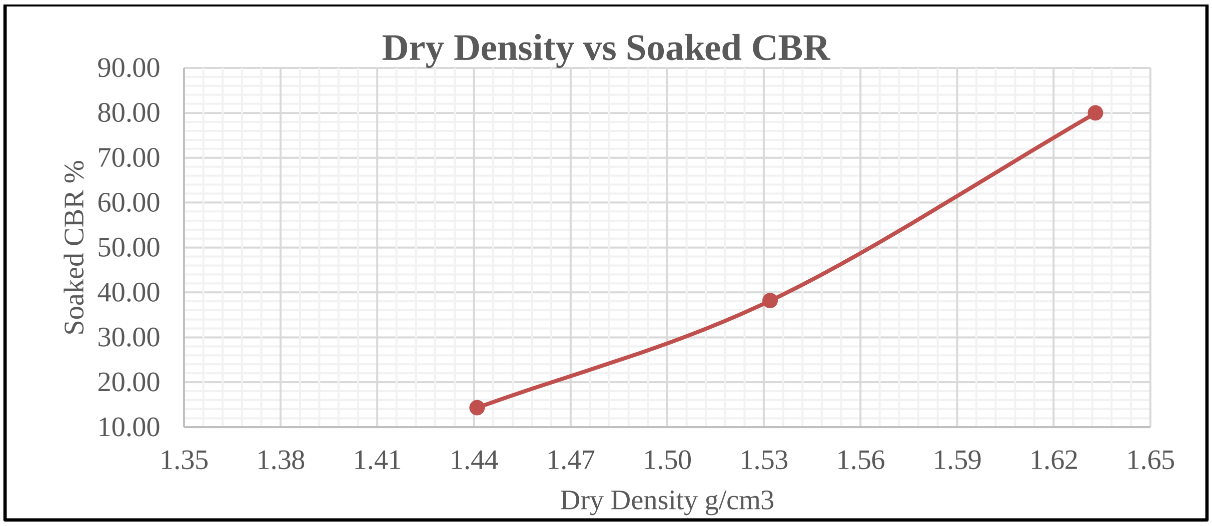

Figure 4. 4: CBR test result of natural cinder gravel for sample 3

4.2.6 Los Angeles Abrasion (LAA) Results for Natural Cinder Gravel

In order to evaluate the resistance of aggregate against abrasion and impact, Los Angeles abrasion test was conducted according to AASHTO T96.

Table 4. 2: Los Angeles Abrasion (LAA) result for natural cinder gravel.

Aggregate Type	Average LAA, (%)	ERA2013, Standard Specification
Natural Cinder Gravel Sample 1	42.7	LAA<45%
Natural Cinder Gravel Sample 2	42.9	
Natural Cinder Gravel Sample 3	42.4	

The test was carried out accordingly and Los Angeles Abrasion value (LAAV) of Natural Cinder Gravel has been found to be 43%, 43% and 42% for sample1,2 and sample3 respectively. The specification of ERA sets the maximum value of LAA 45% for the unbounded base course (GB2 and GB3). Here the result shows that cinder gravel satisfy the requirement in terms of LAA for base course materials. The details of this test are indicated in Table F-1to F-3 of appendix F.

4.2.7 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 percent fines value described in BS 812-111 is applicable. For the Natural Cinder Gravel, the aggregate crushing value is found to be for sample1 is 45.7%, for sample2 is 44.0% and for sample3 is 44.1% which is greater than 30kN.The results are presented in Table C1 to C3, Appendix-C. Therefore, the ten percent fines value is applicable as described in BS 812[13].

4.2.8 Ten Percent Fines Value (TFV)

To ensure that the materials are sufficiently durable, the minimum-soaked Ten percent Fines Value (TFV) according to BS 812, Part 111 shall be 50 KN(3). However, the Ten Percent Fines Value (TFV) of the cinder gravel was found to be 32.5kN for sample1, 31.8 for sample2 and 32.3 for sample3 respectively. as shown in Table D-1 to D-3 of Appendix D. As a result, it has failed to meet the requirements of the ERA technical standard specification.

4.2.9 Aggregate Impact value (AIV)

The test method that is followed in this regard is BS812 part112.This method provides a relative measure of an aggregate's resistance to sudden shock or impact.

Accordingly, the test was carried out. The aggregate impact value of the natural cinder gravel for sample1 is 32.4%, for sample2 is 33.6% and for sample3 is 32.6% respectively revealing that the cinder gravel has failed to meet the requirement[14]. The details of the test are presented in Table E-1 to E-3of Appendix E.

4.2.10 Additional Tests

Table 4. 3 Physical and Mechanical Properties of Fine Crushed Rock

Properties	Crushed Fine Rock
Particle size distribution	Meet ERA specification
Specific gravity	2.9
CBR	171.4
Atterberg limit	NP
ACV	9.3
AIV	4.67
LAA	11.4

4.3 Laboratory Test Results of Cinder Blended with Fine Crushed Rock

4.3.1 Absorption and Specific gravity of the Optimum Amount of Fine Crushed Rock

The limit as per ERA standard specification for maximum absorption for using aggregate material in pavement construction was 2%. Therefore, the results of the blending of natural cinder gravel and the optimum amount of fine crushed rock are satisfies the ERA manual. The sample1 is 1.2, for sample2 is 1.12 and for sample3 is 1.16 respectively.

The Specific Gravity is the measure of the density of soil or aggregate relative to that of water. According to ERA 2013, standard specification materials used for base course and sub base construction have a minimum specific gravity of 2.5. hence based on the test result the

Natural Cinder Gravel blended with Optimum Amount of Fine Crushed Rock for sample1 is 2.7, for sample2 is 2.68 and for sample3 is 2.71. the value obtained from test results was greater than the minimum ERA recommended value, then the aggregates are suitable to use as a base course material based on their specific gravity and water absorption value.

Table 4. 4: Specific gravity of all mixtures used in this Research

Mixture Name	Average Specific Gravity			Average Absorption
	The bulk (Dry)	The bulk (SSD)	Apparent	
15% FCR-85%CG	2.3	2.4	2.51	3.79
20% FCR-80%CG	2.44	2.5	2.6	2.46
25% FCR-75%CG	2.71	2.62	2.71	1.16
30% FCR-70%CG	2.7	2.7	2.78	1.05

4.3.2 Determination of Moisture- Density relation of the Optimum Amount of Fine Crushed Rock

The proportion of fine crushed rock that produces maximum density is the optimum amount fine crushed rock that was needed to be determined. To this end, compaction was carried out by blending cinder gravels with fine crushed rock in varied quantities of 15%, 20%, 25%, and 30% by weight of the cinder gravel. The method of compaction that was followed in this regard was AASHTO-T180 method D (Modified Proctor Test). The moisture density relations for various blending proportions of fine crushed rock are shows in Appendix- J.

The summary of test results of compaction of cinder gravel blended with fine crushed rock at various amounts are indicated below by a graph.

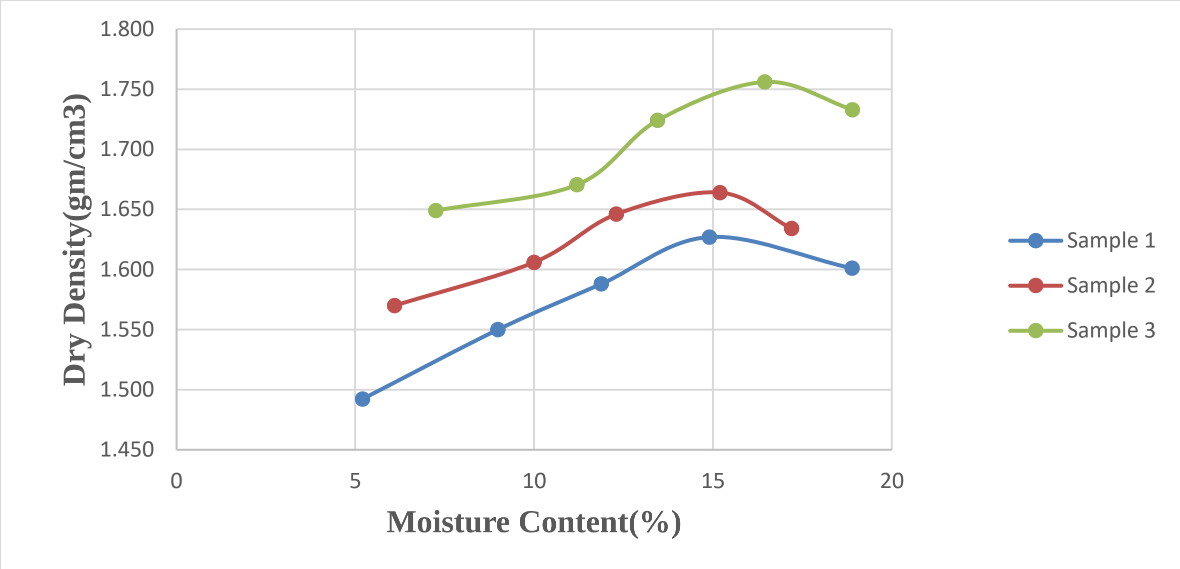

Figure 4. 5: Summary of MDD versus OMC of stabilized cinder gravel in various amount of fine crushed rock.

Figure 4.3,4.4 and 4.5 shows that the maximum dry density increases from zero up to 25 % of fine crushed rock proportion by mass and a further increase in the percentage of fine crushed rock bring a decrement in the maximum dry density for sample1, sample2 and sample3 respectively. By adding 25% of fine crushed rock, the maximum dry density of the natural cinder gravel for sample1 has improved from 1.49g/cm3 to 1.63g/cm3 at OMC of 14.9%, for sample2 has from 1.57g/cm3 to 1.66g/cm3 at OMC of 15.2% and for sample3 has improved from 1.65g/cm3 to 1.76g/cm3 at OMC of 16.5%. This shows that the arithmetic method can be used as a good indicator, which result 25% of fine crushed rock.

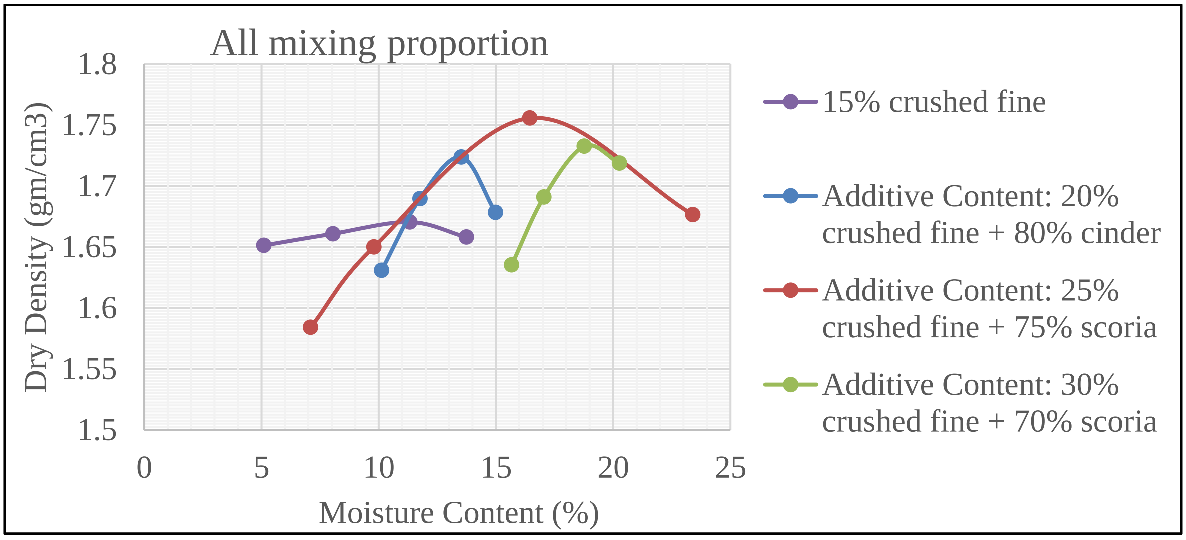

Figure 4. 6: OMC and MDD of cinder gravel and fine crushed rock mixtures test results.

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 crushed rock to the cinder gravel still gains its strength due to 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 crushed rock fills all the voids. This resulted in a relatively higher density. Beyond this optimum fine crushed rock grain-to-grain contact gradually decreases leading to the decrement of density.

4.3.3 California Bearing Ratio Test for Natural Cinder Gravel Blended with Fine Crushed Rock

This test method covers the determination of the CBR of pavement sub-grade, sub-base, and base course materials from laboratory compacted specimens. The method uses soil particles that pass 19 mm size and provides CBR value of a material at optimum water content. 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.

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[31].

The natural cinder gravel stabilized by fine crushed rock showed an improvement in strength. CBR is one of the parameters used to measure strength. The addition of fine crushed rock increased the socked CBR of all the samples. The CBR test was carried out on cinder with different percentages of fine crushed rock of 0%, 15%, 20%, 25% and 30% of the dry weight of the fine crushed rock. The test result of stabilized natural cinder gravel at different mix-ratio for sample1, sample2 and sample3 is presented in figure below and the detail result is shown in appendix.

All the results shown in the graph above for 0, 15, 20, 25 and 30% of fine crushed rock satisfies the ERA manual requirements. The variations of California Bearing Ratio (CBR) with different percentage of fine crushed rock are shown in figure 4.7 for soaked condition.

The maximum California Bearing Ratio (CBR) value of sample1 is 125%, sample2 is 126% and sample3 is 128% is found to occur with the combination of 25% of fine crushed rock contents under soaked condition.

Figure 4. 7: summary of CBR value VS % of fine crushed rock with stabilized cinder gravel.

From the CBR vs. percent of fine crushed rock shown in Figure one can see that the CBR value increased as the percentage of fine crushed rock increase up to 25 % and decrease beyond that this implies the optimum amount of fine crushed rock is 25 % by dry weight.

The results shows that the minimum soaked CBR meets the minimum requirements of the specification. Overall, the results confirms that the blended material is best option when used as a road- base material.

4.3.4 Grain Size Distribution of Natural Cinder Gravel Blended with the Optimum Amount of Fine Crushed Rock

The gradation of the blended material is checked whether it falls in ERA upper and lower limit boundary. The 75% Cinder Gravel mixed with 25%Fine Crushed were completely fitted with ERA Standard specification for GB2 and GB3 base course material which is usually used for a heavy trafficked road in Ethiopia. As it was observed from fig. 4-8, mix proportion of 75% Cinder Gravel 25% Fine Crushed has a particle size distribution curve within the acceptable value of ERA for GB2 and GB3 as a base coarse material. These mix proportions gradation curve was parallel to the lower and upper limit value and the value of percent passing was close to the target value of the governing specification.

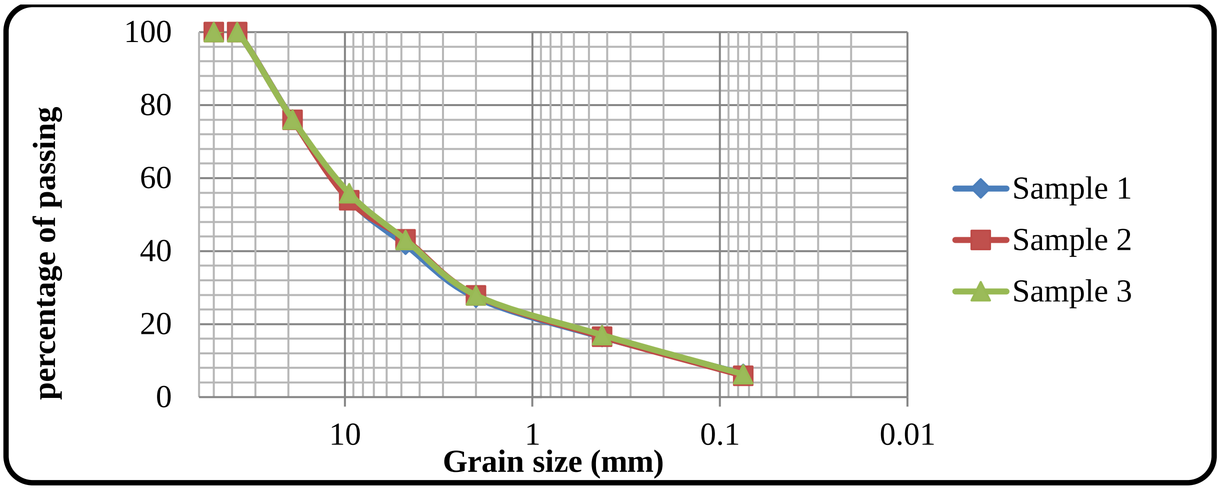

Figure 4. 8: Gradation of natural cinder gravel for sample1, sample2 and sample3 blended with the optimum amount of fine crushed rock.

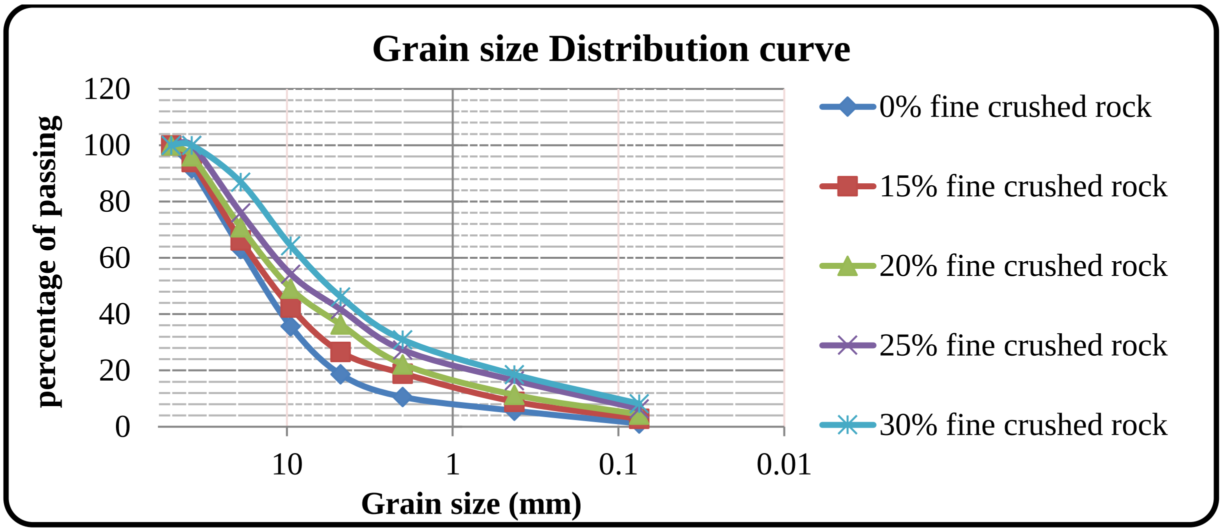

Figure 4. 9: Particle Size Distribution of all Mixtures used in this Research

4.3.5 Aggregate Crushing Value and Ten Percent Fines Value Blended Samples of Cinder Gravel & FCR

The laboratory tests are conducted and the results of the test were presented in table 4-6. The tests are conducted on the specimens prepared by combining FCR with a Cinder Gravel of 70%, 75%, 80%, and 85% for a base course material. The aggregate crushing value and ten percent fines value test result clearly shows that replacing FCR with optimum amount of Cinder Gravel was not out of ERA standard specification requirement for GB2 and GB3 base course material which requires a maximum value of 28.1ACV and 52.6TFV respectively.

Table 4. 5: ACV and TFV test results for blended Cinder Gravel and Fine Crushed Rock

Mixtures Name	**ACV, (%)**	**TFV, (%)**	**ERA 2013 standard specification for base course**	
85% CG-15%FCR	39.05	38.6	ACV<30%	TFV>50KN
80% CG-20%FCR	34.7	44.4		
75% CG-25%FCR	28.1	52.6		
70% CG-30%FCR	25.71	55.5		

4.3.6 Aggregate Impact Value for Blended Samples of Cinder Gravel & FCR

Table 4. 6: AIV test results for blended Cinder Gravel and Fine Crushed Rock

Mixtures Name	**AIV, (%)**	**ERA 2013 standard specification for base course**
85% CG-15%FCR	31.34	AIV<30%
80% CG-20%FCR	29.2	
75% CG-25%FCR	28.0	
70% CG-30%FCR	26.92	

Table 4-6 shows that the summary of all test results for different percentage replacement of FCR by weight of Cinder Gravel (70%, 75%, 80%, and 85%). As is clearly seen from the table AIV were increased 32.5% of neat Cinder Gravel to 28% at 25%FCR replacement. Hence, the higher AIV of the material the lower resisting capacity of the material under sudden impact load.

4.3.7 Los Angeles Abrasion (LAA) Value for Blended Samples of Cinder Gravel & FCR

According to the requirements of ERA specifications, the maximum abrasion value of the base course is limited to 45%, as can be seen from table 4.8 the result of this test indicates that the optimum percentage of FCR fulfill ERA standard specification and would not cause any abrasion problems.

Table 4. 7: LAA Value test results for blended Cinder Gravel and Fine Crushed Rock

Mixtures Name	Average (LAA), %	ERA 2013 standard specification for base course
85% CG-15%FCR	39.97	LAA<45%
80% CG-20%FCR	37.5	
75% CG-25%FCR	35.7	
70% CG-30%FCR	34.50	

4.4 Discussion

The properties of cinder gravel are altered as a result of the addition of fine crushed rock, The laboratory test results were show the optimum amount of fine crushed rock required to achieve the ERA manual standard specification requirement. Blending fine crushed rock to cinder gravel leads to make radical change in laboratory test of compaction characteristic, CBR value and Gradation test. In compaction characteristic, when the fine crushed rock blending with cinder gravel makes to increase the maximum density at optimum amount of fine crushed rock, these shows that 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 crushed rock to the cinder gravel still gains its strength due to grain-to-grain contact and leads to the increment of density up to an optimum point. In addition, the blending of fine crushed rock on the CBR can increase the result of CBR value. This indicate that the natural cinder gravel stabilized by fine crushed rock showed an improvement in strength. CBR is one of the parameters used to measure strength. The value of CBR is increased from 65.54 to 125 at 25% fine crushed rock which results used for base course. From the CBR vs. percent of fine crushed rock shown that the CBR value increased as the percentage of fine crushed rock increase up to 25 % and decrease beyond that this implies the optimum amount of fine crushed rock is 25 % by dry weight. Additionally mix proportion of 75% Cinder Gravel 25% Fine Crushed has a particle size distribution curve within the acceptable value of ERA for GB2 and GB3 as a base coarse material. Therefore, fine crushed rock is a good stabilized material when blending with cinder gravel and shows a good improvement at required optimum percentage.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This thesis attempted to investigate the mechanical stabilization of cinder gravel of Adama area would be used as a base course material when stabilized by fine crushed rock. The under listed conclusions are made from the thesis work.

1. The gradation of cinder gravel samples lacking in fine particles and 25% of fine crushed rock by weight was found to be optimum for making up this deficiency. And fall within the envelope of ERA specification.
2. The plastic limit and liquid limit of the Cinder gravel and fine crushed rock samples could not be obtained. Hence it can be taken as non-plastic (NP).
3. Based on moisture density relationship or compaction test, the optimum amount of fine crushed rock to be blended with cinder gravel was found to be 25% by mass.
4. The California bearing ratio (CBR) of natural cinder gravel samples do not satisfy the required ERA manual standard specification for base course material in pavement construction. Hence, The CBR value of cinder gravel has been significantly improved to the extent of being more than double when blended with the optimum amount fine crushed rock.
5. The property of cinder gravel is improved when blended with optimum amount of fine crushed rock percentage. Therefore 75% of cinder gravel with 25% of fine crushed rock could be used as a base course material.

Based on the findings, one can conclude that fine crushed rock improves the strength characteristics of the given cinder gravel.

5.2 Recommendations

Based on the results of this study, it is recommended that improvement and application of fine crushed rock improves the strength characteristics of cinder gravel. However, this research it was conducted to obtain the optimum blending proportion of cinder with fine crushed rock only in the case of Adama area. Due to financial restrictions and time limitations the present research work did not cover the whole cinder gravel is available in Ethiopia.

The following recommendations could be drawn from the study:

- According to laboratory testing, cinder gravel blended by fine crushed rock has achieved the needed strength as a base course material. However, a pilot section should be conducted for field performance evaluation.
- The findings in this study can be used as a basis for further research in the field of cinder gravel found in different parts of the country.
- Further research should be conducted in order to evaluate the long-term effects and performance of Cinder Gravel at the base course layer on durability.
- Standard should be developed to make use of natural cinder gravel and fine crushed rock as a road construction material across Ethiopia.
- In some areas of Ethiopia, cinder gravel is not available. Therefore, it is recommended to use this material only in areas where it is accessible to save money.

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APPENDIX

Appendix A: Particle Size Distribution Tests

Table A-1: Pit 1 Result of Sieve Analysis for cinder gravel only

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50.000	0.000	0.00	0.00	100.00	100	100
37.500	494.000	8.23	8.23	91.77	80	100
19.000	1711.500	28.53	36.76	63.24	60	80
9.500	1652.000	27.53	64.29	35.71	45	65
4.750	1024.500	17.08	81.37	18.63	30	50
2.000	483.500	8.06	89.43	10.58	20	40
0.425	293.500	4.89	94.32	5.68	10	25
0.075	270.000	4.50	98.82	1.18	5	15
Pan	71.000	1.18	100.00	0.00		
Sum	6000.00					

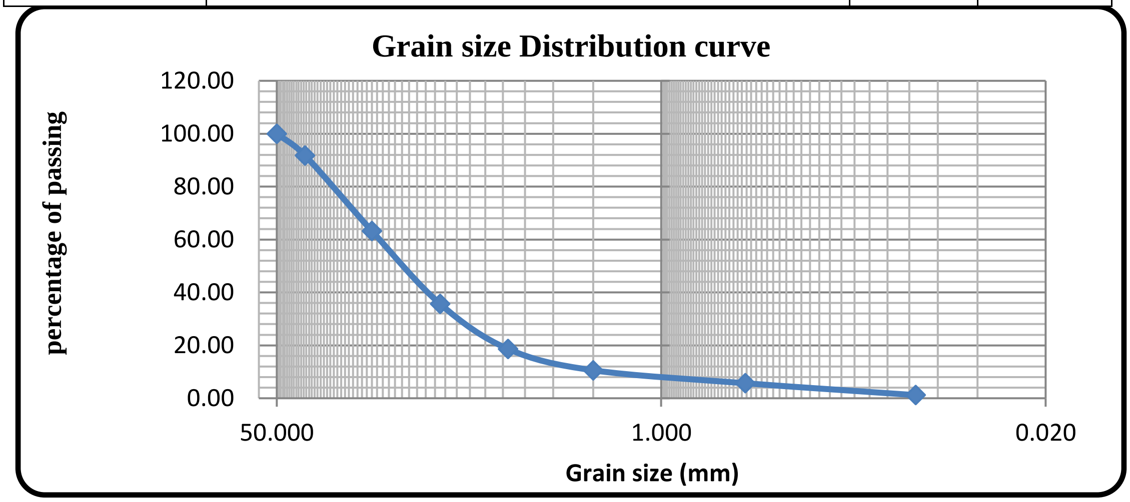


Fig A-1: Sieve analysis for Pit 1 cinder gravel only

Table A-2: Pit 2 Result of Sieve Analysis for cinder gravel only

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50.000	0.000	0.00	0.00	100.00	100	100
37.500	545.100	9.09	9.09	90.92	80	100
19.000	1328.000	22.13	31.22	68.78	60	80
9.500	1389.400	23.16	54.38	45.63	45	65
4.750	1108.000	18.47	72.84	27.16	30	50
2.000	745.500	12.43	85.27	14.73	20	40
0.425	574.000	9.57	94.83	5.17	10	25
0.075	215.000	3.58	98.42	1.58	5	15
Pan	95.000	1.58	100.00	0.00		
Sum	6000.000					

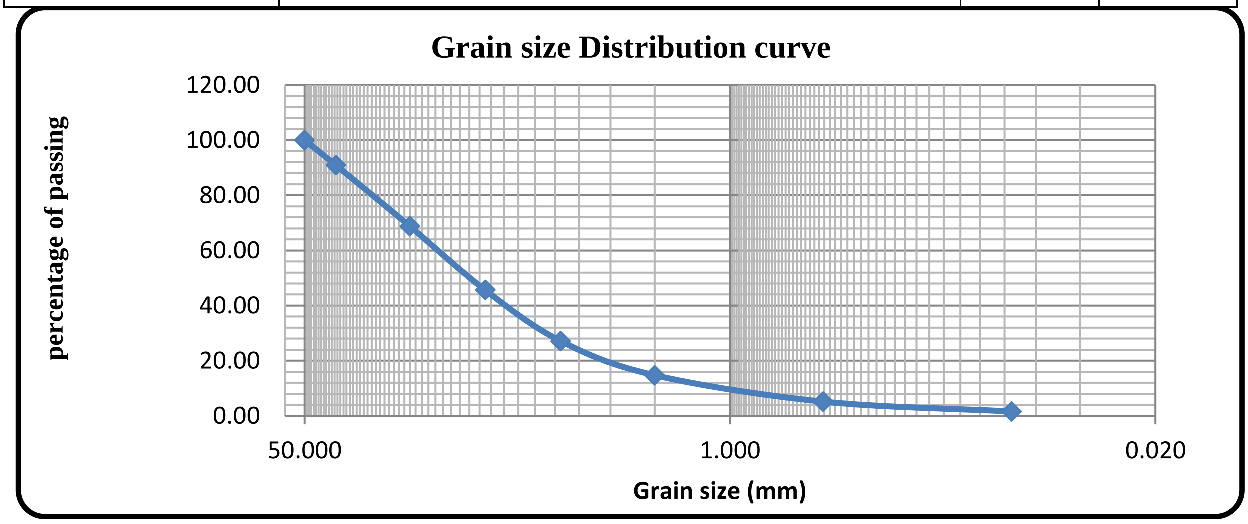


Fig A-2: Sieve analysis for Pit 2 cinder gravel only

Table A-3: Pit 3 Result of Sieve Analysis for cinder gravel only

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50.000	0.000	0.00	0.00	100.00	100	100
37.500	393.000	6.55	6.55	93.45	80	100
19.000	1573.500	26.23	32.78	67.23	60	80
9.500	1522.000	25.37	58.14	41.86	45	65
4.750	1018.500	16.98	75.12	24.88	30	50
2.000	715.000	11.92	87.03	12.97	20	40
0.425	497.000	8.28	95.32	4.68	10	25
0.075	203.000	3.38	98.70	1.30	5	15
pan	78.000	1.30	100.00	0.00		
Sum	6000.000					

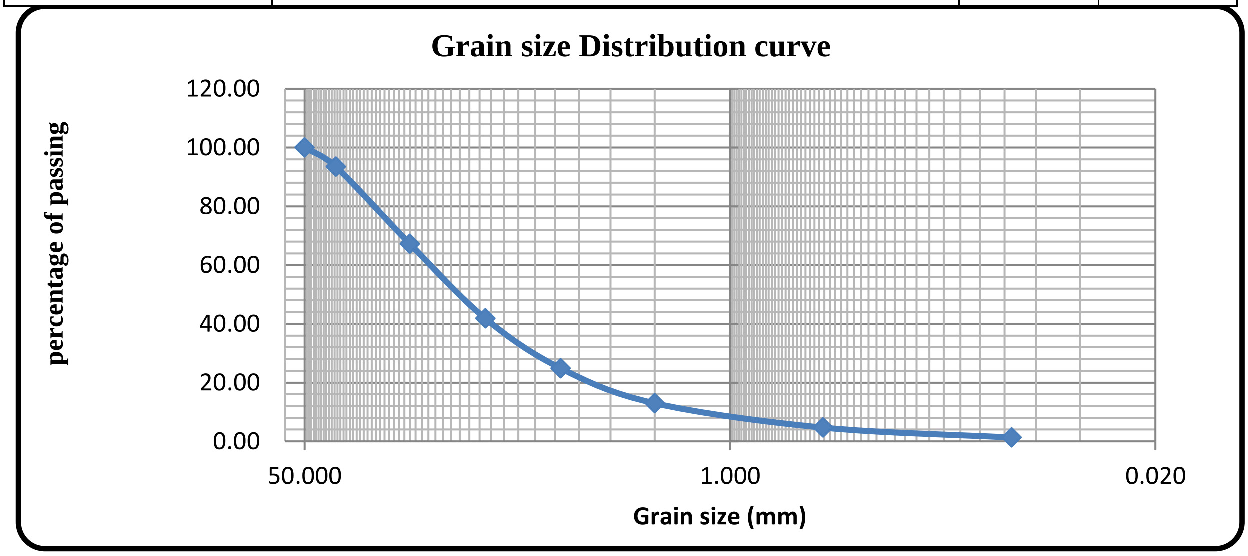


Fig A-3: Sieve analysis for Pit 3 cinder gravel only

Appendix B: Specific Gravity and Water Absorption Test Results

Table B-1: Pit 1 result of Specific Gravity and Water Absorption for cinder gravel only

Trial number		**A**	**B**
Dry Weigt(g)	A	1864.85	1869.4
Saturated Surface Dry Weight (g)	B	2035.5	2028.3
Weight in Water(g)	C	1071.4	1088.6
(A-C) (g)	D	793.45	780.8
(B-C) (g)	E	964.1	939.7
Apparent Specific Gravity (g/cm3)	A/D	2.35	2.39
	Average	2.4	
Bulk Specific Gravity (SSD) Saturated surface Dry(g/cm3)	B/E	2.1	2.16
	Average	2.13	
Bulk Specific Gravity (g/cm3))	A/E	1.93	1.99
	Average	1.96	
Water Absorption*100%	(B-A)/A	9.15	8.50
	Average	8.83	

Table B-2: Pit 2 result of Specific Gravity and Water Absorption for cinder gravel only

Trial number		**A**	**B**
Dry Weigt(g)	A	1848.4	1854.8
Saturated Surface Dry Weight (g)	B	2014.6	2011.2
Weight in Water(g)	C	1060.2	1086.1
(A-C) (g)	D	788.2	768.7

(B-C) (g)	E	954.4	925.1
Apparent Specific Gravity (g/cm3)	A/D	2.35	2.41
	Average	2.4	
Bulk Specific Gravity (SSD) Saturated surface Dry(g/cm3)	B/E	2.1	2.17
	Average	2.14	
Bulk Specific Gravity (g/cm3))	A/E	1.94	2.00
	Average	1.97	
Water Absorption*100%	(B-A)/A	8.99	8.43
	Average	8.71	

Table B-3: Pit 3 result of Specific Gravity and Water Absorption for cinder gravel only

Trial number		A	B
Dry Weigt(g)	A	1837.23	1845.76
Saturated Surface Dry Weight (g)	B	2007.3	2002.4
Weight in Water(g)	C	1058.37	1075.2
(A-C) (g)	D	778.86	770.56
(B-C) (g)	E	948.93	927.2
Apparent Specific Gravity (g/cm3)	A/D	2.36	2.40
	Average	2.4	
Bulk Specific Gravity (SSD) Saturated surface Dry(g/cm3)	B/E	2.1	2.16
	Average	2.14	
Bulk Specific Gravity (g/cm3))	A/E	1.94	1.99

	Average	1.96	
Water Absorption*100%	(B-A)/A	9.26	8.49
	Average	8.87	

Appendix C: Aggregate Crushing Value Test Results

Table C-1: Pit 1 Aggregate Crushing Value test result for cinder gravel only

S No	Details	Trial NO	
1	Total weight of oven- dried aggregate sample=(A)gm	1807.7	1796.4
2	Weight of aggregate passing B.S 2.36mm sieve after crushing=(B)gm	822.1	824.3
3	Aggregate Crushing Value, ACV%= (B/A) *100	45.48	45.89
4	Average Aggregate Crushing value, (%)	45.68	

Table C-2: Pit 2 Aggregate Crushing Value test result for cinder gravel only

S No	Details	Trial NO	
1	Total weight of oven- dried aggregate sample=(A)gm	1760.1	1744.3
2	Weight of aggregate passing B.S 2.36mm sieve after crushing=(B)gm	776.5	765.3
3	Aggregate Crushing Value, ACV%= (B/A) *100	44.12	43.87
4	Average Aggregate Crushing value, (%)	44.00	

Table C-3: Pit 3 Aggregate Crushing Value test result for cinder gravel only

S No	Details	Trial NO	
1	Total weight of oven- dried aggregate sample=(A)gm	1759.42	1767.3

2	Weight of aggregate passing B.S 2.36mm sieve after crushing=(B)gm	771.6	783.5
3	Aggregate Crushing Value, ACV%= (B/A) *100	43.86	44.33
4	Average Aggregate Crushing value, (%)	44.09	

Appendix D: Ten Percent Fines Value Test Results

Table D-1: Pit 1 Ten Percent Fines Value test result for cinder gravel only

Test No	1	2
Mass of aggregate passing 14mm and retained on 10mm, gm. Before compression	1423.7	1403.5
Mass of aggregate, retained on 2.36mm sieve size, gm. After compression	1312.3	1290.6
% Of material passing 2.36 mm(m)	7.82	8.04
Duration of testing, min.	10.3	10.2
Maximum load, f(KN)	28.9	26.5
Force required to produce 10% fines in (KN)= 14*f/(m+4)	34.23	30.81
Average Force TFV in KN,	32.5	

Table D-2: Pit 2 Ten Percent Fines Value test result for cinder gravel only

Test No	1	2
Mass of aggregate passing 14mm and retained on 10mm, gm. Before compression	1409.2	1402.3
Mass of aggregate, retained on 2.36mm sieve size, gm. After compression	1295.4	1286.6
% Of material passing 2.36 mm(m)	8.1	8.2
Duration of testing, min.	10.3	10.2

Maximum load, f(KN)	28.4	26.8
Force required to produce 10% fines in (KN)= 14*f/(m+4)	32.86	30.75
Average Force TFV in KN,	31.8	

Table D-3: Pit 3 Ten Percent Fines Value test result for cinder gravel only

Test No	1	2
Mass of aggregate passing 14mm and retained on 10mm, gm. Before compression	1407.5	1415.1
Mass of aggregate, retained on 2.36mm sieve size, gm. After compression	1293.03	1298.4
% Of material passing 2.36 mm(m)	8.13	8.25
Duration of testing, min.	10.3	10.4
Maximum load, f(KN)	28.8	27.5
Force required to produce 10% fines in (KN)= 14*f/(m+4)	33.24	31.43
Average Force TFV in KN,	32.3	

Appendix E: Aggregate Impact Value Test Results

Table E-1: Pit 1 Aggregate Impact Value test result for cinder gravel only

S NO	Details	Trial NO	
		1	2
1	Total weight of aggregate sample filling the cylindrical measure=W1	404.35	411
2	Weight of aggregate passing 2.36mm sieve after the test=W2	130.55	133.5
3	Weight of aggregate retained 2.36mm sieve after the test=W3	273.8	277.5
4	W2=W1-W3	130.55	133.5

5	Aggregate Impact Value=W2/W1*100	32.29	32.48
	Average	32.38	

Table E-2: Pit 2 Aggregate Impact Value test result for cinder gravel only

S NO	Details	Trial NO	
		1	2
1	Total weight of aggregate sample filling the cylindrical measure=W1	381.9	388.6
2	Weight of aggregate passing 2.36mm sieve after the test=W2	127.8	130.9
3	Weight of aggregate retained 2.36mm sieve after the test=W3	254.1	257.7
4	W2=W1-W3	127.8	130.9
5	Aggregate Impact Value=W2/W1*100	33.46	33.69
	Average	33.57	

Table E-3: Pit 3 Aggregate Impact Value test result for cinder gravel only

S NO	Details	Trial NO	
		1	2
1	Total weight of aggregate sample filling the cylindrical measure=W1	398.3	386.2
2	Weight of aggregate passing 2.36mm sieve after the test=W2	129.2	126
3	Weight of aggregate retained 2.36mm sieve after the test=W3	269.1	260.2
4	W2=W1-W3	129.2	126

Appendix F: Los Angeles Abrasion Test Results

Table F-1: Pit 1 Los Angeles Abrasion test result for cinder gravel only

Trial	1	2
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000
Wt. of Tested Sample Retained on No 1.7 Sieve (g)	2860.6	2868.4
Percent Loss (%)	42.79	42.63
Average	42.71	

Table F-2: Pit 2 Los Angeles Abrasion test result for cinder gravel only

Trial	1	2
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000
Wt. of Tested Sample Retained on No 1.7 Sieve (g)	2853.2	2857.5
Percent Loss (%)	42.94	42.85
Average	42.9	

Table F-3: Pit 3 Los Angeles Abrasion test result for cinder gravel only

Trial	1	2
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000

Wt. of Tested Sample Retained on No 1.7 Sieve (g)	2881.6	2874.3
Percent Loss (%)	42.37	42.51
Average	42.44	

Appendix G: Moisture- Density Relation Test Results

Table G-1: Pit 1 Moisture- Density relation test result for cinder gravel only

Sample Location: Adama 1				**Natural soil of Adama 1**				
Density Determination								
Test No.	1		2		3		4	
Mass of Mold +Wet soil(gm)(A)	10100.10		10201.90		10273.80		10257.70	
Mass of Mold(gm)(B)	6677.30		6677.30		6677.30		6677.30	
Mass of Wet Soil(gm)A-B=C	3422.80		3524.60		3596.50		3580.40	
Volume of Mold cm^3(D)	2285.00		2285.00		2285.00		2285.00	
Bulk Density gm/cm^3 C/D=(E)	1.50		1.54		1.57		1.57	
Moisture Content Determination								
Container Code.	NC	G63	C3	190	F	D	T1	5
Mass of Wet soil+ Container(gm)	113.50	157.00	87.92	207.80	82.22	105.20	134.70	124.59
Mass of dry soil+ container(gm)	112.10	154.92	85.65	201.60	78.80	100.60	126.50	117.30
Mass of container(gm)	17.50	17.70	25.10	25.20	17.70	17.30	17.30	17.90
Mass of moisture(gm)	1.40	2.08	2.27	6.20	3.42	4.60	8.20	7.29
Mass of Dry soil(gm)	94.60	137.22	60.55	176.40	61.10	83.30	109.20	99.40
Moisture content %	1.48	1.52	3.75	3.51	5.60	5.52	7.51	7.33

Avg. Moisture content %	**1.50**	**3.63**	**5.56**	**7.42**
Dry Density gm/cm3	**1.48**	**1.49**	**1.49**	**1.46**

OMC (%)	**5.2**	**MDD (gm/cm^3)**	**1.49**

Table G-2: Pit 2 Moisture- Density relation test result for cinder gravel only

Sample Location: Adama 2					**Natural soil of Adama 2**					
Density Determination										
Test No.	1		2		3		4		5	
Mass of Mold+ Wet soil(gm)(A)	9770.41		10078.44		10481.47		10217.85		9968.36	
Mass of Mold(gm)(B)	6677.30		6677.30		6677.30		6677.30		6677.30	
Mass of Wet Soil(gm)A-B=C	3093.11		3401.14		3804.17		3540.55		3291.06	
Volume of Mold cm^3(D)	2285.00		2285.00		2285.00		2285.00		2285.00	
Bulk Density gm/cm^3 C/D=(E)	1.35		1.49		1.66		1.55		1.44	
Moisture Content Determination										
Container Code.	G63	5	190	P3	C3	P6	D	NC		
Mass of Wet soil+ Container(gm)	91.70	101.89	90.31	101.03	122.12	112.83	97.15	100.80	87.84	83.20
Mass of dry soil+ container(gm)	89.36	98.72	87.16	97.97	117.27	107.60	92.66	96.14	83.61	79.37
Mass of container(gm)	27.50	28.00	27.70	27.70	29.70	27.70	27.70	27.60	27.70	27.70
Mass of moisture(gm)	2.34	3.17	3.15	3.06	4.85	5.23	4.49	4.66	4.23	3.83
Mass of Dry soil(gm)	61.86	70.72	59.46	70.27	87.57	79.90	64.96	68.54	55.91	51.67
Moisture content %	3.7	4.48	5.2	4.35	5.54	6.54	6.9	6.80	7.5	7.4

	8		9				2		6	1
Avg. Moisture content %	**4.13**		**4.82**		**6.04**		**6.86**		**7.48**	
Dry Density gm/cm3	**1.30**		**1.42**		**1.57**		**1.45**		**1.34**	
	OMC (%)		**6.1**		**MDD (gm/cm^3)**		**1.57**			

Table G-3: Pit 3 Moisture- Density relation test result for cinder gravel only

Sample Location: Adama 3					**Natural soil of Adama 3**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold +Wet soil(gm)(A)	10457.80		10568.00		10724.60		10572.10	
Mass of Mold(gm)(B)	6677.30		6677.30		6677.30		6677.30	
Mass of Wet Soil(gm)A-B=C	3780.50		3890.70		4047.30		3894.80	
Volume of Mold cm^3(D)	2285.00		2285.00		2285.00		2285.00	
Bulk Density gm/cm^3 C/D=(E)	1.65		1.70		1.77		1.70	
Moisture Content Determination								
Container Code.	P65	A2	A1	P2	A3	C2	A4	J41
Mass of Wet soil+ Container(gm)	117	118	132.3	123.7	214	197.6	108.6	107
Mass of dry soil+ container(gm)	114	115	126.7	118.6	201.8	185.6	101.2	99.8
Mass of container(gm)	17.1	16.7	17.3	17.9	36.5	28.7	17.9	17.4
Mass of moisture(gm)	3.50	3.40	5.60	5.10	12.20	12.00	7.40	7.40
Mass of Dry soil(gm)	96.80	97.90	109.40	100.70	165.30	156.90	83.30	82.40
Moisture content %	3.62	3.47	5.12	5.06	7.38	7.65	8.88	8.98

Avg. Moisture content %	**3.54**	**5.09**	**7.51**	**8.93**
Dry Density gm/cm3	**1.60**	**1.62**	**1.65**	**1.56**

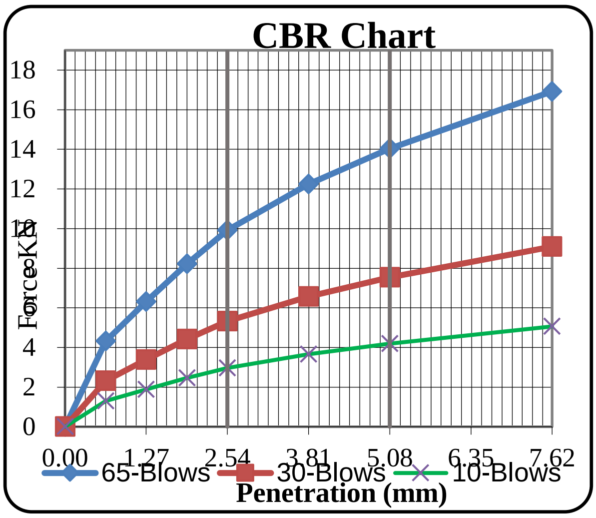
OMC (%)	**7.25**	**MDD (gm/cm^3)**		**1.65**

Appendix H: CBR Test Results

Table H-1: Pit 1 CBR test result for cinder gravel only

PENETRATION AND LOAD DETERMINATION									
NATURAL SOIL OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	4.321	6.313	8.216	9.921	12.24	14.043	16.924
	CBR (%)					**74.37**		**70.22**	
30-Blows	**Load (KN)**	0	2.321	3.390	4.412	5.328	6.575	7.542	9.089
	CBR (%)					**39.94**		**37.71**	
10-Blows	**Load (KN)**	0	1.292	1.888	2.457	2.967	3.662	4.200	5.062
	CBR (%)					**22.24**		**21.00**	

CBR RESULT SUMMARY			
OMC (%)	5.20		
MMDD	1.492		
Dry Density at 97% of MDD	1.447		
No of Blows	65	30	10
CBR Values (%)	74.37	39.94	22.24
DDBS g/cc	1.471	1.379	1.302
CBR at 97% MDD	**65.54**		



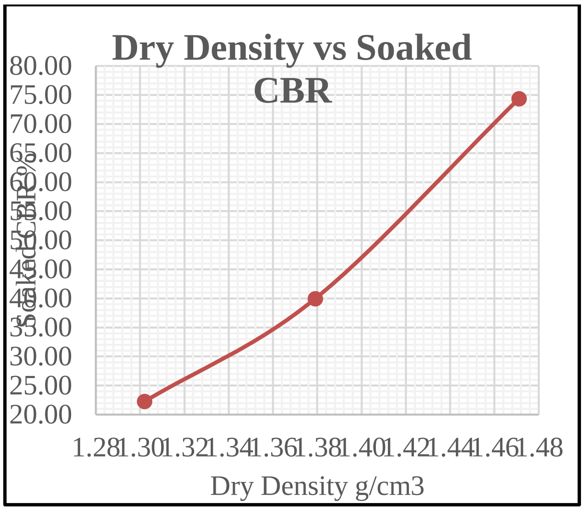
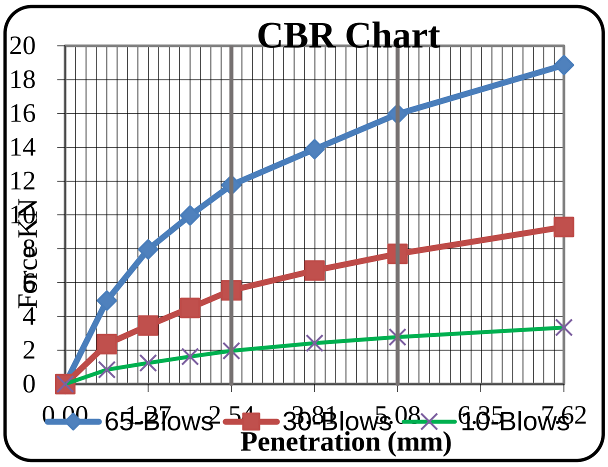


Fig- H-1: Load vs. Penetration and Dry Density vs. CBR value of cinder gravel only

Table H-2: Pit 2 CBR test result for cinder gravel only

PENETRATION AND LOAD DETERMINATION									
NATURAL SOIL OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	4.944	7.964	9.962	11.770	13.890	15.970	18.860
	CBR (%)					**88.23**		**79.85**	
30-Blows	**Load (KN)**	0	2.372	3.465	4.510	5.545	6.720	7.708	9.289
	CBR (%)					**41.57**		**38.54**	
10-Blows	**Load (KN)**	0	0.853	1.246	1.622	1.958	2.417	2.772	3.341
	CBR (%)					**14.68**		**13.86**	

CBR RESULT SUMMARY			
OMC (%)	6.10		
MMDD	1.570		
Dry Density at 97% of MDD	1.523		
No of Blows	65	30	10
CBR Values (%)	88.23	41.57	14.68
DDBS g/cc	1.585	1.456	1.390
CBR at 97% MDD	**65.73**		



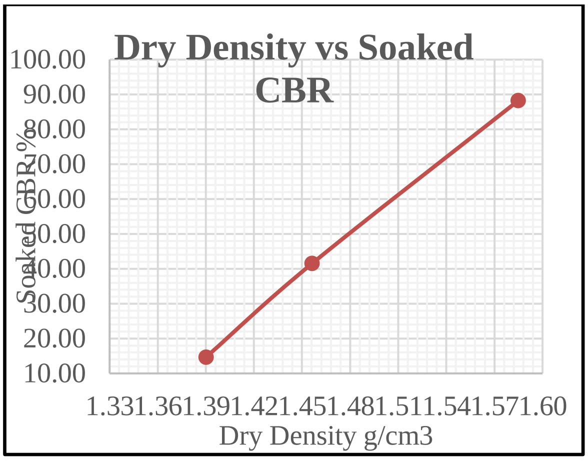
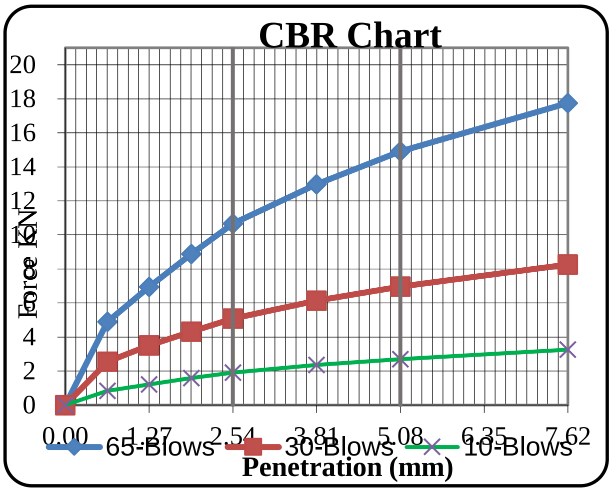


Fig- H-2: Load vs. Penetration and Dry Density vs. CBR value of cinder gravel only

Table H-3: Pit 3 CBR test result for cinder gravel only

PENETRATION AND LOAD DETERMINATION									
NATURAL SOIL OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	4.905	6.935	8.875	10.663	12.980	14.916	17.752
	CBR (%)					**79.93**		**74.58**	
30-Blows	**Load (KN)**	0	2.556	3.507	4.319	5.090	6.141	6.956	8.260
	CBR (%)					**38.16**		**34.78**	
10-Blows	**Load (KN)**	0	0.831	1.214	1.580	1.908	2.355	2.701	3.255
	CBR (%)					**14.31**		**13.51**	

CBR RESULT SUMMARY			
OMC(%)	7.25		
MMDD	1.649		
Dry Density at 97% of MDD	1.600		
No of Blows	65	30	10
CBR Values (%)	79.93	38.16	14.31
DDBS g/cc	1.633	1.532	1.441
CBR at 97% MDD	**66.09**		



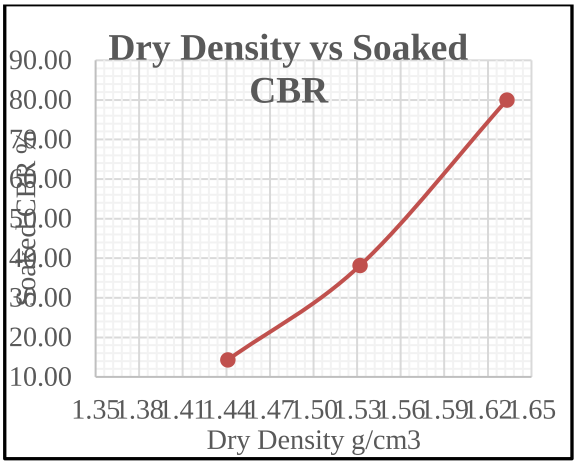


Fig- H-3: Load vs. Penetration and Dry Density vs. CBR value of cinder gravel only

Test Results of Cinder Gravel Blended with Fine Crushed rock

Appendix I: Particle Size Distribution Tests Results of cinder gravel Blended with Fine Crushed Rock

Table I-1: Pit 1 Particle Size Distributions for the blending of cinder gravel with 25% by weight of fine crushed rock

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle	Lower Limit ERA Spec.	Upper Limit ERA Spec.
50.000	0.000	0.00	0.00	100.00	100	100
37.500	0.000	0.00	0.00	100.00	80	100
19.000	1437.500	23.96	23.96	76.04	60	80
9.500	1307.000	21.78	45.74	54.26	45	65
4.750	753.000	12.55	58.29	41.71	30	50
2.000	865.500	14.43	72.72	27.28	20	40
0.425	651.000	10.85	83.57	16.43	10	25
0.075	602.000	10.03	93.60	6.40	5	15

pan	384.000	6.40	100.00	0.00		
Sum	6000.000					

Table I-2: Pit 2 Particle Size Distributions for the blending of cinder gravel with 25% by weight of fine crushed rock

Sieve size (mm)	**Mass of Retain on Each Sieve (g)**	**Percentage of Retained Soil**	**Percentage of cumulative Retained Soil**	**Percentage of Passing Soil Particle**	**Lower Limit ERA Spec.**	**Upper Limit ERA Spec.**
50.000	0.000	0.00	0.00	100.00	100	100
37.500	0.000	0.00	0.00	100.00	80	100
19.000	1443.000	24.05	24.05	75.95	60	80
9.500	1319.200	21.99	46.04	53.96	45	65
4.750	642.500	10.71	56.75	43.26	30	50
2.000	924.500	15.41	72.15	27.85	20	40
0.425	678.500	11.31	83.46	16.54	10	25
0.075	640.000	10.67	94.13	5.87	5	15
pan	352.300	5.87	100.00	0.00		
Sum	6000.000					

Table I-3: Pit 3 Particle Size Distributions for the blending of cinder gravel with 25% by weight of fine crushed rock

Sieve size (mm)	**Mass of Retain on Each Sieve (g)**	**Percentage of Retained Soil**	**Percentage of cumulative Retained Soil**	**Percentage of Passing Soil Particle**	**Lower Limit ERA Spec.**	**Upper Limit ERA Spec.**
50.000	0.000	0.00	0.00	100.00	100	100

37.500	0.000	0.00	0.00	100.00	80	100
19.000	1436.000	23.93	23.93	76.07	60	80
9.500	1212.000	20.20	44.13	55.87	45	65
4.750	767.500	12.79	56.93	43.08	30	50
2.000	910.500	15.18	72.10	27.90	20	40
0.425	653.000	10.88	82.98	17.02	10	25
0.075	645.500	10.76	93.74	6.26	5	15
pan	375.500	6.26	100.00	0.00		
Sum	6000.000					

Table I-4: Pit 1 Particle Size Distributions for the blending of cinder gravel with all mixture by weight of fine crushed rock

Sieve Size, mm pit 1	0% fine crushed rock	15% fine crushed rock	20% fine crushed rock	25% fine crushed rock	30% fine crushed rock	ERA Governing specification for GB2 and GB3
50	100	100	100	100	100	100 to 100
37.5	91.77	94.02	96.12	100	100	80 to 100
19	63.24	66.3	70.88	76.04	86.92	60 to 80
9.5	35.71	42.43	49.10	54.26	64.35	45 to 65
4.75	18.63	26.59	36.36	41.71	46.21	30 to 50
2	10.58	18.94	22.20	27.28	30.93	20 to 40
0.425	5.68	8.93	11.35	16.43	18.56	10 to 25
0.075	1.18	2.84	4.4	6.4	8.22	5 to 15

Appendix J: Moisture – Density Relation Tests Results of cinder gravel Blended with Fine Crushed Rock

Table J-1: Pit Relationship b/n Moisture and Density for the blending of cinder gravel with 15% by weight of fine crushed rock

Sample Location: Adama 1			**Additive Content: 15% crushed fine + 85%cinder**		
Density Determination					
Test No.	1	2	3	4	5
Mass of Mold+ Wet soil(gm)(A)	10142.16	10333.18	10434.11	10367.72	10250.55
Mass of Mold(gm)(B)	6574.00	6574.00	6574.00	6574.00	6574.00
Mass of Wet Soil(gm)A-B=C	3568.16	3759.18	3860.11	3793.72	3676.55
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00	2285.00
Bulk Density gm/cm^3 C/D=(E)	1.56	1.65	1.69	1.66	1.61

Moisture Content Determination										
Container Code.	P3	T1	G63	5	D	C3	190	NC	F	P6
Mass of Wet soil+ Container(gm)	144.92	163.28	142.45	145.54	155.27	155.47	165.53	168.57	150.81	148.75
Mass of dry soil +container(gm)	136.67	155.86	134.73	136.86	143.90	146.60	153.50	157.32	138.88	138.16
Mass of container(gm)	35.50	32.50	35.50	32.50	31.00	35.50	40.50	32.50	36.50	28.50
Mass of moisture(gm)	8.24	7.43	7.72	8.68	11.37	8.86	12.03	11.25	11.93	10.60
Mass of Dry soil(gm)	101.17	123.36	99.23	104.36	112.90	111.10	113.00	124.82	102.38	109.66
Moisture content %	8.15	6.02	7.78	8.32	10.0	7.98	10.6	9.01	11.6	9.66

			7	4	5
Avg. Moisture content %	**7.08466**	**8.04873**	**9.02261**	**9.82722**	**10.65630**
Dry Density gm/cm3	**1.46**	**1.52**	**1.55**	**1.51**	**1.45**
			OMC (%) **8.99**	**MDD (gm/cm^3)**	**1.55**

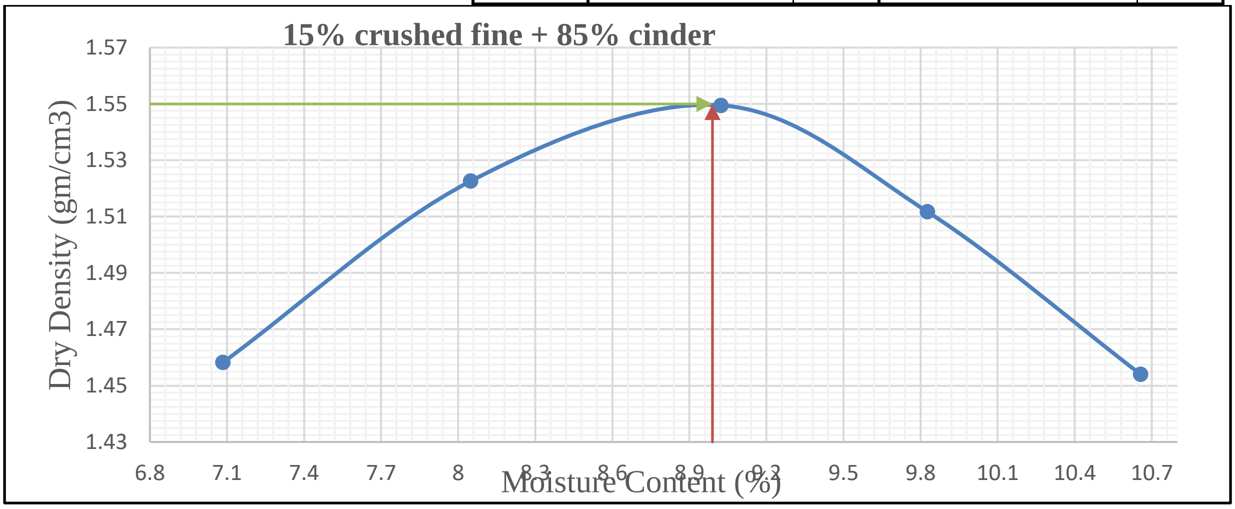


Fig-J-1: Pit1 Relationship between moisture and density for cinder gravel blended with 15%by weight of fine crushed rock.

Table J-2: Pit1 Relationship b/n Moisture and Density for the blending of cinder gravel with 20% by weight of fine crushed rock

Sample Location: Adama 1			**Additive Content: 15% crushed fine + 85%cinder**		
Density Determination					
Test No.	1	2	3	4	5
Mass of Mold+ Wet soil(gm)(A)	10142.16	10333.18	10434.11	10367.72	10250.55
Mass of Mold(gm)(B)	6574.00	6574.00	6574.00	6574.00	6574.00
Mass of Wet Soil(gm)A-B=C	3568.16	3759.18	3860.11	3793.72	3676.55
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00	2285.00

Bulk Density gm/cm^3 C/D=(E)	1.56		1.65		1.69		1.66		1.61	
Moisture Content Determination										
Container Code.	P3	T1	G63	5	D	C3	190	NC	F	P6
Mass of Wet soil+ Container(gm)	144.92	163.28	142.45	145.54	155.27	155.47	165.53	168.57	150.81	148.75
Mass of dry soil +container(gm)	136.67	155.86	134.73	136.86	143.90	146.60	153.50	157.32	138.88	138.16
Mass of container(gm)	35.50	32.50	35.50	32.50	31.00	35.50	40.50	32.50	36.50	28.50
Mass of moisture(gm)	8.24	7.43	7.72	8.68	11.37	8.86	12.03	11.25	11.93	10.60
Mass of Dry soil(gm)	101.17	123.36	99.23	104.36	112.90	111.10	113.00	124.82	102.38	109.66
Moisture content %	8.15	6.02	7.78	8.32	10.07	7.98	10.64	9.01	11.65	9.66
Avg. Moisture content %	**7.08466**		**8.04873**		**9.02261**		**9.82722**		**10.65630**	
Dry Density gm/cm3	**1.46**		**1.52**		**1.55**		**1.51**		**1.45**	
			OMC (%)			**8.99**	**MDD (gm/cm^3)**			**1.55**

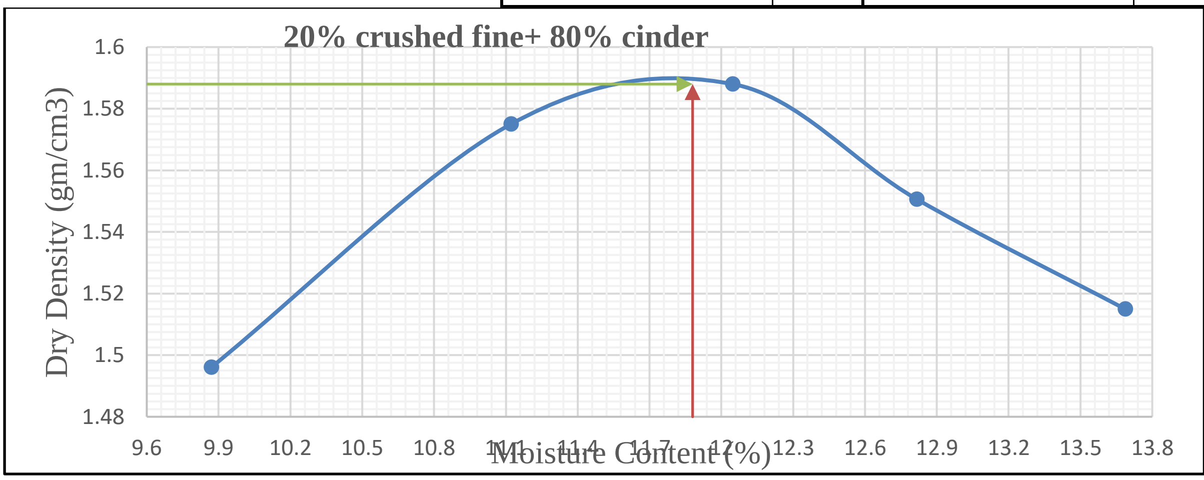


Fig-J-2: Pit1 Relationship between moisture and density for cinder gravel blended with 20%by weight of fine crushed rock.

Table J-3: Pit1 Relationship b/n Moisture and Density for the blending of cinder gravel with 25% by weight of fine crushed rock

Sample Location: Adama 1					**Additive Content: 25% crushed fine +75% cinder**					
Density Determination										
Test No.	1		2		3		4		5	
Mass of Mold +Wet soil(gm)(A)	10462.60		10603.61		10771.79		10873.35		10642.73	
Mass of Mold(gm)(B)	6596.00		6596.00		6596.00		6596.00		6596.00	
Mass of Wet Soil(gm)A-B=C	3866.598354		4007.605028		4175.787623		4277.349309		4046.728258	
Volume of Mold cm^3(D)	2285.00		2285.00		2285.00		2285.00		2285.00	
Bulk Density gm/cm3 C/D=(E)	1.69		1.75		1.83		1.87		1.77	
Moisture Content Determination										
Container Code.	A13	F	G-5	P6	ZE	G63	E	LHE	190	D
Mass of Wet soil+ Container(gm)	129.84	113.57	156.72	169.12	141.91	161.98	133.36	129.77	121.61	119.01
Mass of dry soil+ container(gm)	117.63	106.23	145.33	151.63	128.52	146.32	119.90	117.09	107.89	105.82
Mass of container(gm)	31.50	32.50	32.50	35.50	29.50	36.50	32.50	31.50	27.50	25.50
Mass of moisture(gm)	12.21	7.34	11.39	17.49	13.39	15.66	13.47	12.68	13.72	13.19
Mass of Dry soil(gm)	86.13	73.73	112.83	116.13	99.02	109.82	87.40	85.59	80.39	80.32
Moisture content % (I/J)	14.18	9.95	10.10	15.06	13.52	14.26	15.41	14.81	17.07	16.43

Avg. Moisture content %	**12.07**	**12.58**	**13.89**	**15.11**	**16.75**
Dry Density gm/cm3	**1.51**	**1.56**	**1.60**	**1.63**	**1.52**
		OMC (%)	**14.9**	**MDD (gm/cm^3)**	**1.63**

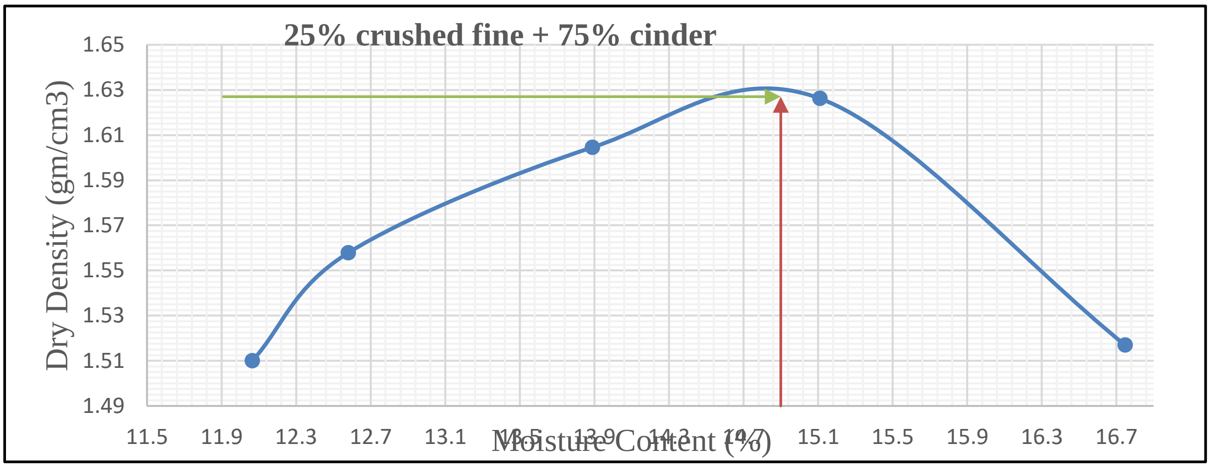


Fig-J-3: Pit1 Relationship between moisture and density for cinder gravel blended with 25%by weight of fine crushed rock.

Table J-4: Pit1 Relationship b/n Moisture and Density for the blending of cinder gravel with 30% by weight of fine crushed rock

Sample Location: Adama 1			**Additive Content: 30% crushed fine + 70% cinder**		
Density Determination					
Test No.	1	2	3	4	5
Mass of Mold+ Wet soil(gm)(A)	10569.05	10842.01	10950.59	10909.87	10802.99
Mass of Mold(gm)(B)	6596.00	6596.00	6596.00	6596.00	6596.00
Mass of Wet Soil(gm)A-B=C	3973.05	4246.01	4354.59	4313.87	4206.99
Volume of Mold cm^3(D)	2285.00	2285.00	2285.00	2285.00	2285.00

Bulk Density gm/cm^3 C/D=(E)	1.74		1.86		1.91		1.89		1.84	
Moisture Content Determination										
Container Code.	5	D	A3	P65	LHE	2	T1	P2	A13	P67
Mass of Wet soil+ Container(gm)(F)	182.28	203.00	196.60	171.96	199.69	183.08	212.59	218.14	201.76	196.23
Mass of dry soil+ container(gm)	162.94	178.88	170.23	152.63	172.90	159.71	183.21	186.96	173.45	166.39
Mass of container(gm)	28.50	34.50	32.50	31.60	32.50	36.50	35.50	35.50	36.50	34.50
Mass of moisture(gm)	19.34	24.12	26.37	19.32	26.80	23.37	29.38	31.18	28.31	29.84
Mass of Dry soil(gm)	134.44	144.38	137.73	121.03	140.40	123.21	147.71	151.46	136.95	131.89
Moisture content %	14.39	16.71	19.15	15.96	19.09	18.97	19.89	20.59	20.67	22.63
Avg. Moisture content %	**15.55**		**17.56**		**19.03**		**20.24**		**21.65**	
Dry Density gm/cm3	**1.50**		**1.58**		**1.60**		**1.57**		**1.51**	
			OMC (%)			**18.89**	**MDD (gm/cm^3)**			**1.60**

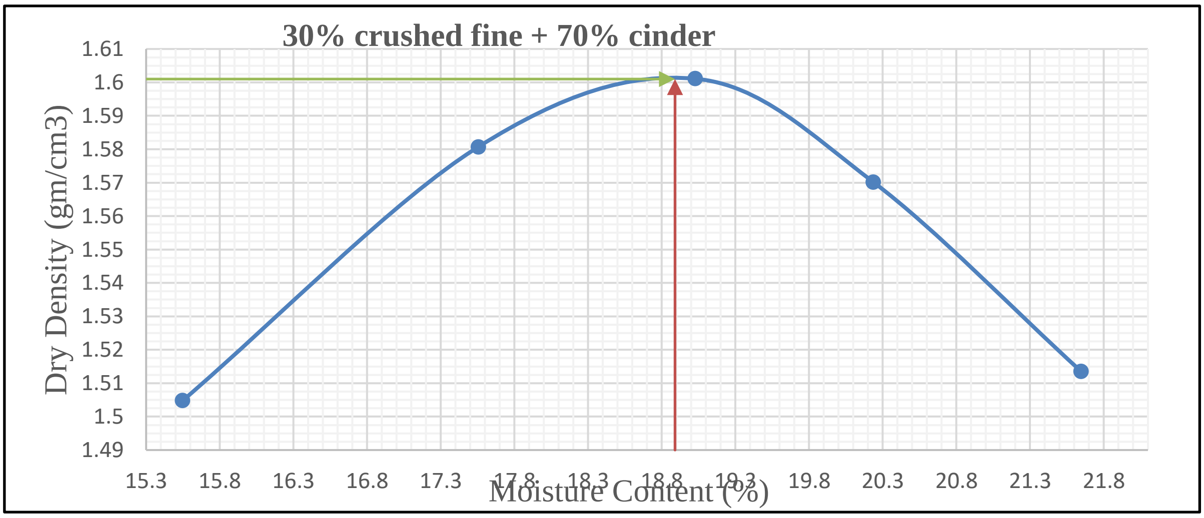


Fig-J-4: Pit1 Relationship between moisture and density for cinder gravel blended with 30%by weight of fine crushed rock.

Table J-5: Pit2 Relationship b/n Moisture and Density for the blending of cinder gravel with 15% by weight of fine crushed rock

Sample Location: Adama 2						Additive Content: 15% crushed fine + 85% cinder				
Density Determination										
Test No.	1		2		3		4		5	
Mass of Mold+ Wet soil(gm)(A)	9573.71		9698.60		9829.09		9906.19		9688.61	
Mass of Mold(gm)(B)	6157.60		6157.60		6157.60		6157.60		6157.60	
Mass of Wet Soil(gm)A-B=C	3416.11		3541.00		3671.49		3748.59		3531.01	
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.60		1.67		1.73		1.76		1.66	
Moisture Content Determination										
Container Code.	190	A3	LHE	T1	P2	P67	5	P65	2	A13
Mass of Wet soil+ Container(gm)(F)	222.27	217.68	196.23	192.00	237.21	209.12	179.85	204.76	233.23	186.54
Mass of dry soil+ container(gm)	208.04	204.54	184.07	179.00	220.08	194.52	165.22	189.13	213.22	170.57
Mass of container(gm)(H)	37.64	36.33	35.95	34.10	37.59	36.61	25.30	29.60	36.50	26.60
Mass of moisture(gm)	14.23	13.14	12.16	13.00	17.13	14.60	14.63	15.63	20.01	15.96
Mass of Dry soil(gm)	170.40	168.21	148.12	144.90	182.49	157.91	139.92	159.53	176.72	143.97
Moisture content %	8.35	7.81	8.21	8.97	9.38	9.24	10.46	9.80	11.32	11.09
Av. Moisture content %	**8.08**		**8.58**		**9.31**		**10.13**		**11.20**	

Dry Density gm/cm3	**1.49**	**1.54**	**1.58**	**1.60**	**1.49**

	OMC (%)	**10**	**MDD (gm/cm^3)**	**1.61**

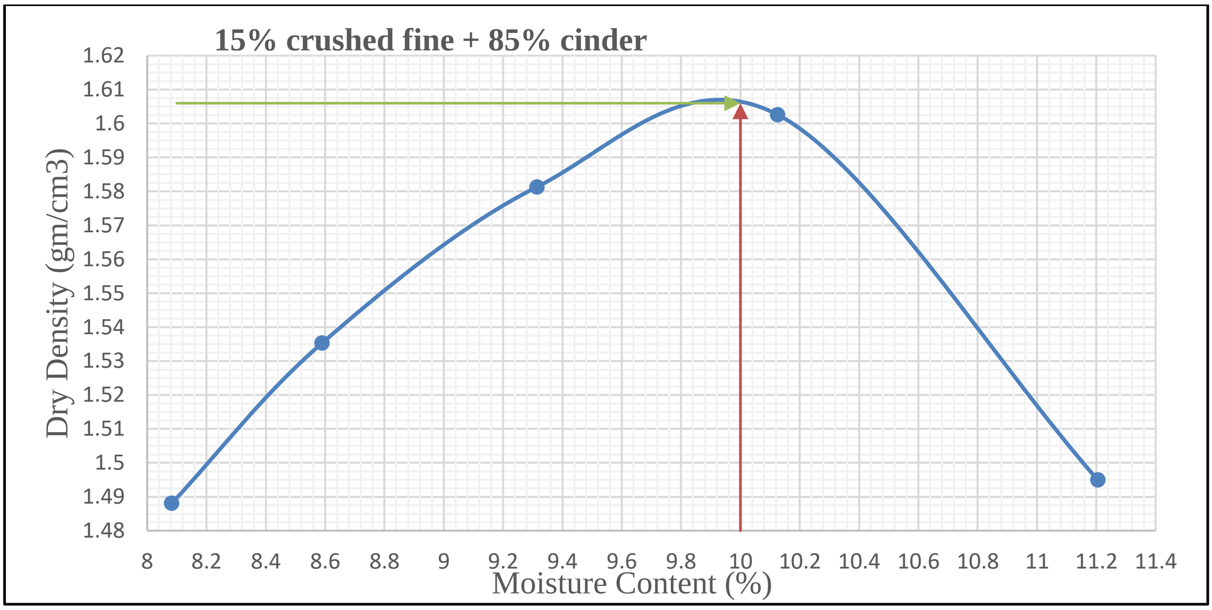


Fig-J-5: Pit2 Relationship between moisture and density for cinder gravel blended with 15%by weight of fine crushed rock.

Table J-6: Pit2 Relationship b/n Moisture and Density for the blending of cinder gravel with 20% by weight of fine crushed rock

Sample Location: Adama 2			**Additive Content: 20% crushed fine + 80% cinder**		
Density Determination					
Test No.	1	2	3	4	5
Mass of Mold+ Wet soil(gm)(A)	9738.26	9887.60	10038.37	10083.97	9947.37
Mass of Mold(gm)(B)	6157.60	6157.60	6157.60	6157.60	6157.60
Mass of Wet Soil(gm)A-B=C	3580.6567 49	3730.0035 51	3880.7715 14	3926.3702 98	3789.7720 81
Volume of Mold	2124.00	2124.00	2124.00	2124.00	2124.00

cm^3(D)										
Bulk Density gm/cm^3 C/D=(E)	1.69		1.76		1.83		1.85		1.78	
Moisture Content Determination										
Container Code.	A2	A4	P65	A1	J41	3	G-5	A3	5	1
Mass of Wet soil+ Container(gm)	226.96	242.20	211.73	193.61	233.71	214.21	229.13	244.81	208.59	224.94
Mass of dry soil+ container(gm)	212.90	220.50	194.14	178.43	212.46	196.45	208.86	219.89	186.55	199.81
Mass of container(gm)	33.54	37.95	34.58	34.10	37.78	36.60	32.90	36.45	21.23	25.22
Mass of moisture(gm)	14.05	21.70	17.59	15.17	21.25	17.76	20.27	24.93	22.04	25.13
Mass of Dry soil(gm)	179.36	182.55	159.56	144.33	174.68	159.85	175.96	183.44	165.32	174.59
Moisture content %	7.84	11.88	11.03	10.51	12.17	11.11	11.52	13.59	13.33	14.39
Avg. Moisture content %	**9.86**		**10.77**		**11.64**		**12.55**		**13.86**	
Dry Density gm/cm3	**1.53**		**1.59**		**1.64**		**1.64**		**1.57**	
			OMC (%)			**12.3**	**MDD (gm/cm^3)**			**1.65**

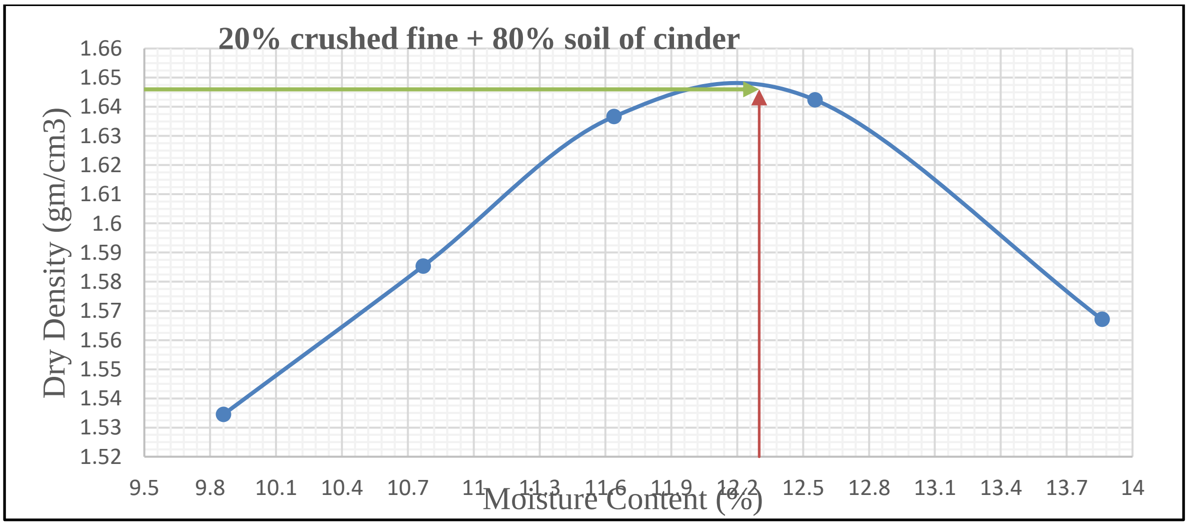


Fig-J-6: Pit2 Relationship between moisture and density for cinder gravel blended with 20%by weight of fine crushed rock.

Table J-7: Pit2 Relationship b/n Moisture and Density for the blending of cinder gravel with 25% by weight of fine crushed rock

Sample Location: Adama 2					**Additive Content: 25% crushed fine + 75% cinder**					
Density Determination										
Test No.	1		2		3		4		5	
Mass of Mold+ Wet soil(gm)(A)	9945.66		10145.42		10239.25		10172.38		10079.12	
Mass of Mold(gm)(B)	6157.60		6157.60		6157.60		6157.60		6157.60	
Mass of Wet Soil(gm)A-B=C	3788.061906		3987.82029		4081.65389		4014.779244		3921.517666	
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.78		1.88		1.92		1.89		1.85	
Moisture Content Determination										
Container Code.	E	A	2	ZE	A2	12	G-5	LHE	P2	P67
Mass of Wet soil+ Container(gm)	241.80	239.77	211.92	202.48	199.64	209.53	232.91	245.32	151.10	144.10
Mass of dry soil+ container(gm)	217.28	220.50	192.38	181.15	178.56	181.59	204.86	215.11	130.01	128.02
Mass of container(gm)	37.19	34.50	37.53	36.45	17.40	28.00	34.58	33.54	29.50	17.50
Mass of moisture(gm)	24.52	19.27	19.54	21.33	21.08	27.94	28.04	30.20	21.09	16.08
Mass of Dry soil(gm)	180.09	186.00	154.85	144.70	161.16	153.59	170.28	181.57	100.51	110.52
Moisture content %	13.62	10.36	12.62	14.74	13.08	18.19	16.47	16.63	20.98	14.55
Avg. Moisture content	**11.99**		**13.68**		**15.64**		**16.55**		**17.77**	
Dry Density gm/cm3	**1.59**		**1.65**		**1.66**		**1.62**		**1.57**	

OMC (%)	15.2	MDD (gm/cm^3)	1.66

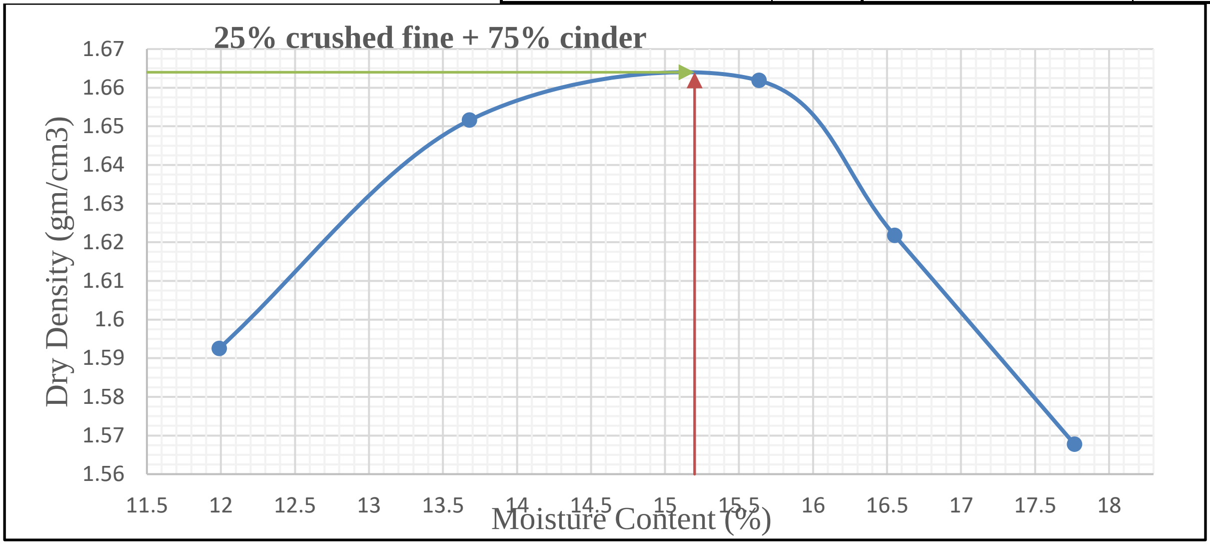


Fig-J-7: Pit2 Relationship between moisture and density for cinder gravel blended with 25%by weight of fine crushed rock.

Table J-8: Pit2 Relationship b/n Moisture and Density for the blending of cinder gravel with 30% by weight of fine crushed rock

Sample Location: Adama 2							**Additive Content: 30% crushed fine + 70% cinder**			
Density Determination										
Test No.	1		2		3		4		5	
Mass of Mold+ Wet soil(gm)(A)	9784.27		9946.27		10095.44		10227.66		10002.17	
Mass of Mold(gm)(B)	6157.60		6157.60		6157.60		6157.60		6157.60	
Mass of Wet Soil(gm)A-B=C	3626.67		3788.67		3937.84		4070.06		3844.57	
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.71		1.78		1.85		1.92		1.81	
Moisture Content Determination										
Container Code.	P2	P67	F	T1	P2	A13	5	1	190	J41
Mass of Wet soil+	229.	250.	210.	209.	227.	223.	241.	256.	174.	180.

Container(gm)	22	54	42	03	98	35	98	54	98	27
Mass of dry soil+ container(gm)	207.59	220.50	191.58	182.93	198.10	198.88	213.20	222.27	152.66	156.79
Mass of container(gm)	29.60	28.54	32.80	37.77	32.62	25.38	36.48	37.64	35.54	36.52
Mass of moisture(gm)	21.63	30.04	18.83	26.09	29.88	24.48	28.78	34.28	22.32	23.48
Mass of Dry soil(gm)	177.99	191.96	158.78	145.16	165.48	173.50	176.72	184.63	117.12	120.27
Moisture content % (	12.15	15.65	11.86	17.97	18.06	14.11	16.29	18.56	19.06	19.52
Avg. Moisture content %	**13.90**		**14.92**		**16.08**		**17.43**		**19.29**	
Dry Density gm/cm3	**1.50**		**1.55**		**1.60**		**1.63**		**1.52**	
			OMC (%)			**17.2**	**MDD (gm/cm^3)**			**1.63**

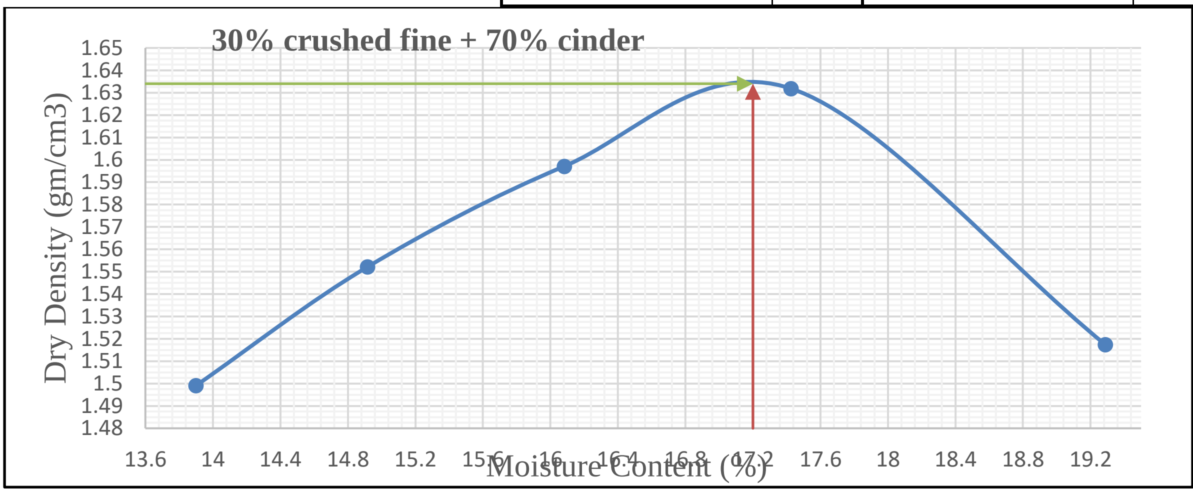


Fig-J-8: Pit2 Relationship between moisture and density for cinder gravel blended with 30%by weight of fine crushed rock.

Table J-9: Pit3 Relationship b/n Moisture and Density for the blending of cinder gravel with 15% by weight of fine crushed rock

Sample Location: Adama 3			**Additive Content: 15% crushed fine + 85% cinder**	
Density Determination				
Test No.	1	2	3	4

Mass of Mold+ Wet soil(gm)(A)	9208.518983		9333.872694		9472.084746		9527.781336	
Mass of Mold(gm)(B)	5522.5		5522.5		5522.5		5522.5	
Mass of Wet Soil(gm)A-B=C	3686.018983		3811.372694		3949.584746		4005.281336	
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.74		1.79		1.86		1.89	
Moisture Content Determination								
Container Code.	P3	T1	G63	5	D	C3	190	NC
Mass of Wet soil+ Container(gm)	216.50	210.74	128.94	122.85	219.70	201.35	112.87	154.43
Mass of dry soil+ container(gm)	207.66	201.96	120.67	114.99	201.75	183.91	101.14	138.33
Mass of container(gm)	31.39	32.78	17.84	17.47	35.49	36.61	18.19	17.49
Mass of moisture(gm)	8.83776	8.77462	8.26283	7.8577	17.9538	17.445	11.7329	16.10150161
Mass of Dry soil(gm)	176.268	169.182	102.836	97.5204	166.262	147.3	82.9493	120.83405
Moisture content %	5.01	5.19	8.03	8.06	10.80	11.84	14.14	13.33
Avg. Moisture content %	**5.1**		**8.05**		**11.32**		**13.73**	
Dry Density gm/cm3	**1.65**		**1.66**		**1.67**		**1.66**	
	OMC (%)			**11.2**	**MDD (gm/cm^3)**			**1.67**

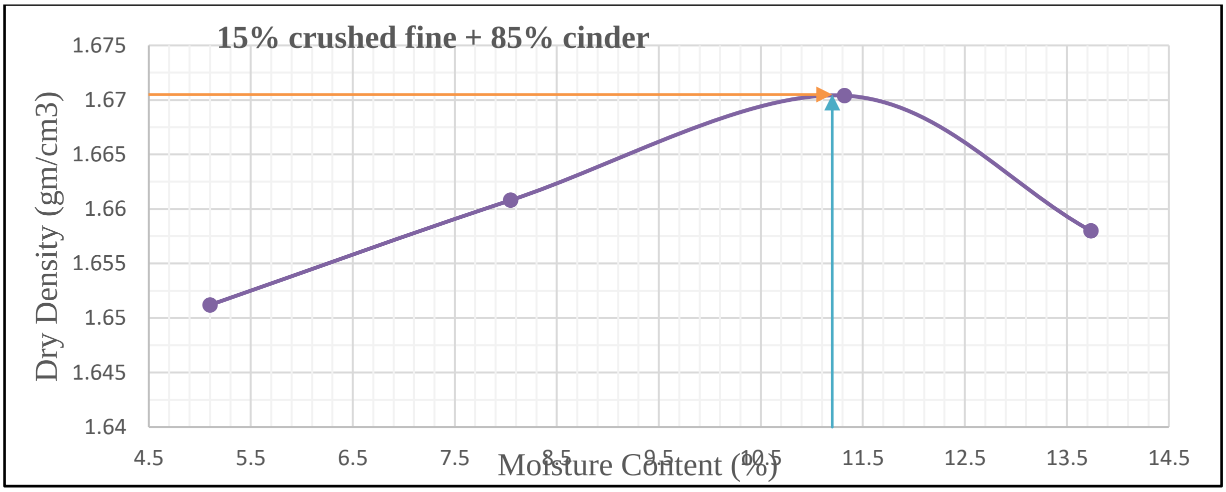


Fig-J-9: Pit3 Relationship between moisture and density for cinder gravel blended with 15%by weight of fine crushed rock.

Table J-10: Pit3 Relationship b/n Moisture and Density for the blending of cinder gravel with 20% by weight of fine crushed rock

Sample Location: Adama 3					**Additive Content: 20% crushed fine + 80% cinder**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold+ Wet soil(gm)(A)	9337.17		9533.37		9678.56		9621.24	
Mass of Mold(gm)(B)	5522.5		5522.5		5522.5		5522.5	
Mass of Wet Soil(gm)A-B=C	3814.667579		4010.869674		4156.064496		4098.73851	
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.80		1.89		1.96		1.93	
Moisture Content Determination								
Container Code.	P3	T1	G63	5	D	C3	190	NC
Mass of Wet soil+ Container(gm)	255.37	289.00	223.91	220.14	214.26	210.85	237.26	238.59
Mass of dry soil+ container(gm)	237.07	263.27	204.38	200.43	192.05	190.23	209.46	213.40

Mass of container(gm)	31.39	36.64	35.50	35.55	32.78	32.72	28.71	40.74
Mass of moisture(gm)	18.30 03	25.72 72	19.53 23	19.71 34	22.21 44	20.61 67	27.80 43	25.19558 114
Mass of Dry soil(gm)	205.6 84	226.6 3	168.8 8	164.8 73	159.2 7	157.5 08	180.7 45	172.6585 384
Moisture content %	8.90	11.35	11.57	11.96	13.95	13.09	15.38	14.59
Avg. Moisture content %	**10.12**		**11.76**		**13.52**		**14.99**	
Dry Density gm/cm3	**1.63**		**1.69**		**1.72**		**1.68**	
	OMC (%)		**13.45**		**MDD (gm/cm^3)**			**1.72**

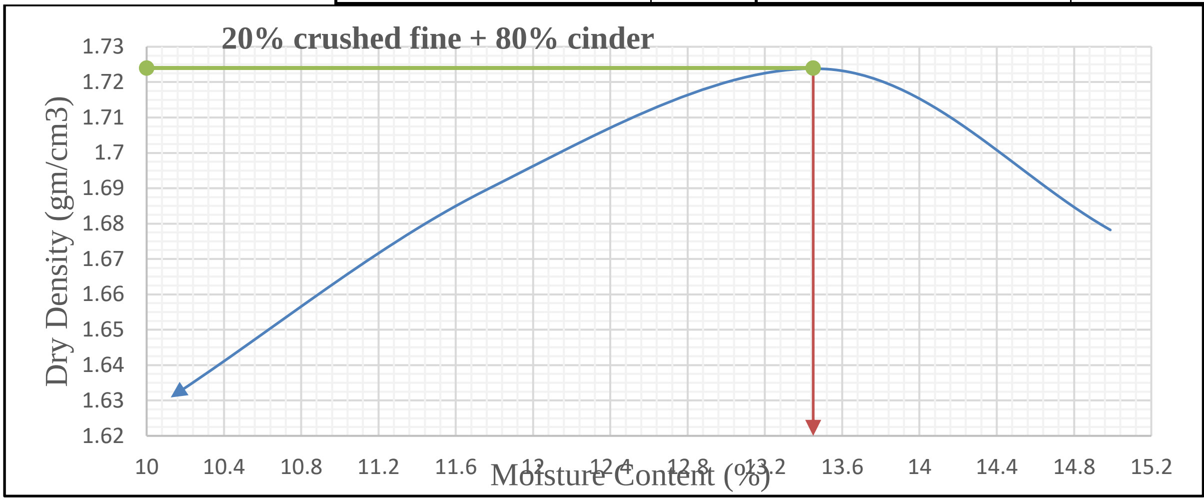


Fig-J-10: Pit3 Relationship between moisture and density for cinder gravel blended with 20%by weight of fine crushed rock.

Table J-11: Pit3 Relationship b/n Moisture and Density for the blending of cinder gravel with 25% by weight of fine crushed rock

Sample Location: Adama 3		**Additive Content: 25% crushed fine + 75cinder**		
Density Determination				
Test No.	1	2	3	4
Mass of Mold+ Wet soil(gm)(A)	10579.20	10824.02	11318.13	11369.89
Mass of Mold(gm)(B)	6976	6976	6976	6976
Mass of Wet Soil(gm)A-	3603.204176	3848.015298	4342.130807	4393.886464

B=C								
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.70		1.81		2.04		2.07	
Moisture Content Determination								
Container Code.	T1	F	1	P2	P67	A13	5	D
Mass of Wet soil+ Container(gm)	211.01	200.98	120.89	123.65	173.56	177.46	206.86	221.11
Mass of dry soil+ container(gm)	199.08	189.23	111.70	114.22	151.25	155.24	175.15	184.78
Mass of container(gm)	36.61	17.84	17.49	18.37	17.47	18.19	32.76	36.62
Mass of moisture(gm)	11.93	11.74	9.19	9.43	22.32	22.21	31.72	36.34
Mass of Dry soil(gm)	162.48	171.40	94.21	95.85	133.78	137.05	142.39	148.15
Moisture content %	7.34	6.85	9.76	9.84	16.68	16.21	22.27	24.53
Avg. Moisture content %	**7.10**		**9.80**		**16.45**		**23.40**	
Dry Density gm/cm3	**1.58**		**1.65**		**1.76**		**1.68**	
	OMC (%)			**16.45**	**MDD (gm/cm^3)**			**1.75**

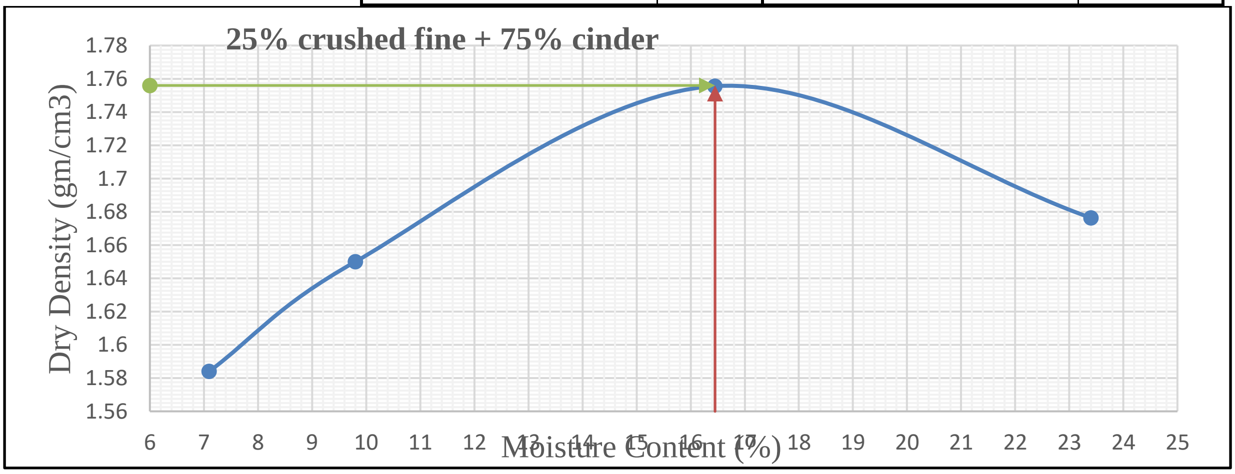


Fig-J-11: Pit3 Relationship between moisture and density for cinder gravel blended with 25%by weight of fine crushed rock.

Table J-12: Pit3 Relationship b/n Moisture and Density for the blending of cinder gravel with 30% by weight of fine crushed rock

Sample Location: Adama 3					**Additive Content: 30% crushed fine + 70% cinder**			
Density Determination								
Test No.	1		2		3		4	
Mass of Mold+ Wet soil(gm)(A)	10993.25		11179.44		11346.44		11366.42	
Mass of Mold(gm)(B)	6976		6976		6976		6976	
Mass of Wet Soil(gm)A-B=C	4017.25388		4203.443937		4370.442075		4390.421148	
Volume of Mold cm^3(D)	2124.00		2124.00		2124.00		2124.00	
Bulk Density gm/cm^3 C/D=(E)	1.89		1.98		2.06		2.07	
Moisture Content Determination								
Container Code.	LHE	2	T1	P65	P67	A3	P2	A13
Mass of Wet soil+ Container(gm)	196.39	221.96	144.68	132.98	166.77	167.47	178.05	181.35
Mass of dry soil+ container(gm)	175.72	196.41	128.74	118.76	144.48	142.41	153.41	156.46
Mass of container(gm)	36.65	41.34	40.75	29.76	17.73	16.77	28.71	36.62
Mass of moisture(gm)	20.67	25.55	15.94	14.22	22.29	25.06	24.64	24.89
Mass of Dry soil(gm)	139.07	155.07	87.99	89.01	126.76	125.64	124.69	119.84
Moisture content %	14.87	16.47	18.12	15.97	17.59	19.94	19.76	20.77
Avg. Moisture content %	**15.67**		**17.05**		**18.77**		**20.27**	
Dry Density gm/cm3	**1.64**		**1.69**		**1.733**		**1.72**	
	OMC (%)			**18.9**	**MDD (gm/cm^3)**			**1.73**

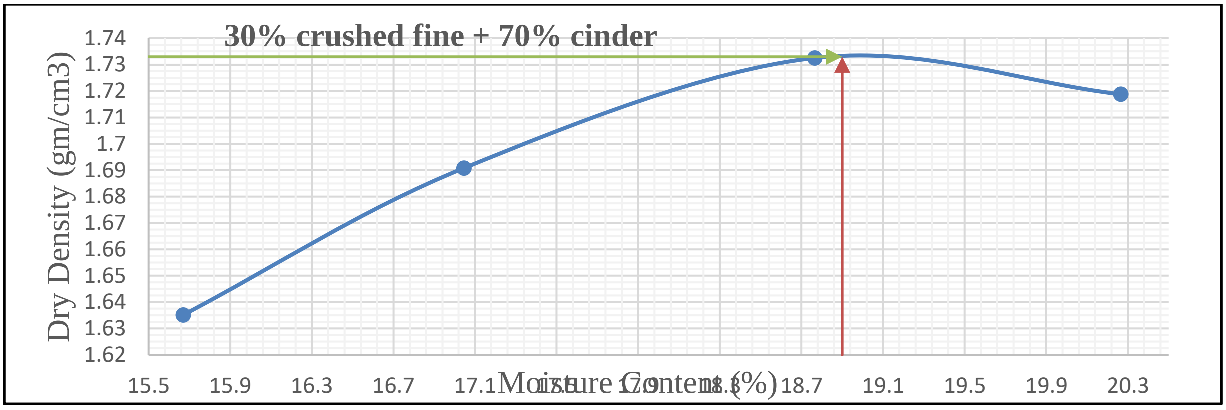


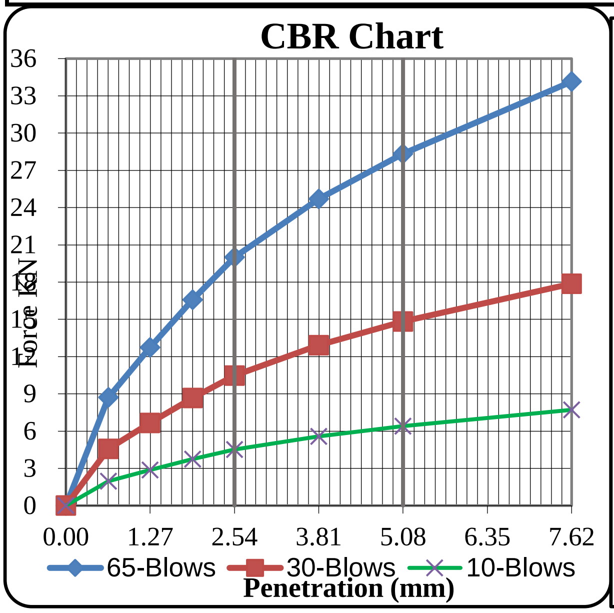
Fig-J-12: Pit3 Relationship between moisture and density for cinder gravel blended with 30%by weight of fine crushed rock.

Appendix K: CBR Tests Results of cinder gravel Blended with Fine Crushed Rock

Table K-1: Pit1 CBR test results for the blending of cinder gravel with 15% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0.000	8.719	12.737	16.578	20.018	24.703	28.336	34.149
	CBR (%)					**150.06**		**141.68**	
30-Blows	**Load (KN)**	0	4.564	6.667	8.677	10.478	12.93	14.832	17.874
	CBR (%)					**78.54**		**74.16**	
10-Blows	**Load (KN)**	0	1.9695	2.877	3.745	4.522	5.580	6.401	7.714
	CBR (%)					**33.90**		**32.00**	
CBR RESULT SUMMARY									
OMC (%)				8.99					

MMDD	1.55		
Dry Density at 97% of MDD	1.504		
No of Blows	65	30	10
CBR Values (%)	150.06	78.54	33.90
DDBS g/cc	1.593	1.483	1.378
CBR at 97% MDD	**91.68**		



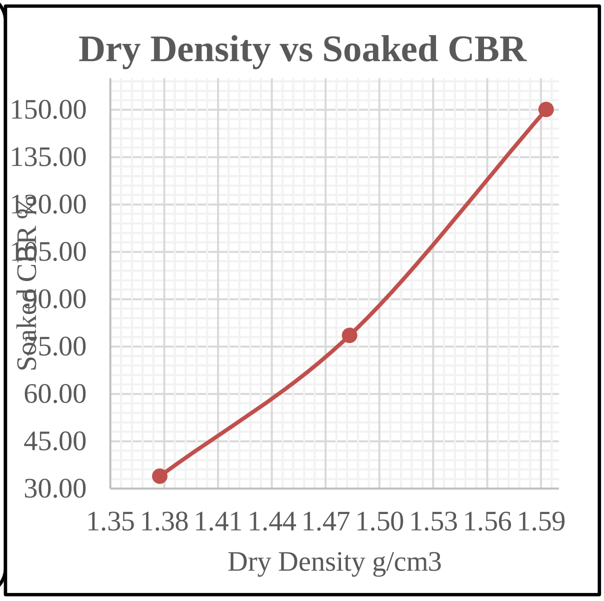


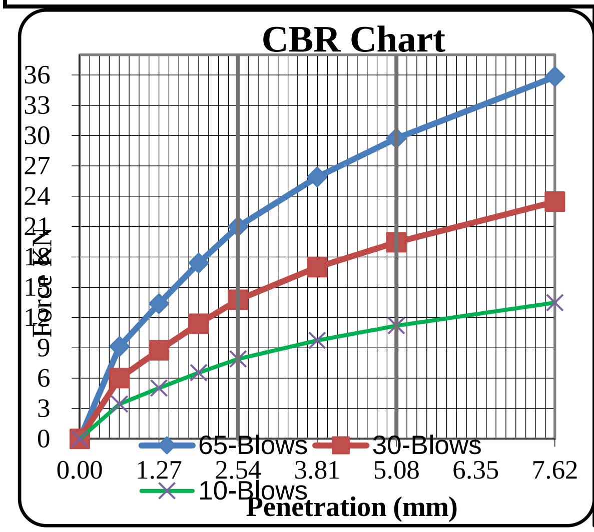
Fig-K-1: Pit1 CBR test results for cinder gravel blended with 15%by weight of fine crushed rock.

Table K-2: Pit1 CBR test results for the blending of cinder gravel with 20% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	9.145	13.360	17.388	20.996	25.910	29.721	35.817
	CBR (%)					**157.39**		**148.60**	

30-Blows	**Load (KN)**	0	5.988	8.747	11.385	13.747	16.965	19.46	23.452
	CBR (%)					**103.05**		**97.30**	
10-Blows	**Load (KN)**	0	3.440	5.026	6.541	7.898	9.747	11.181	13.474
	CBR (%)					**59.21**		**55.90**	

CBR RESULT SUMMARY			
OMC (%)	11.88		
MMDD	1.588		
Dry Density at 97% of MDD	1.540		
No of Blows	65	30	10
CBR Values (%)	157.39	103.05	59.21
DDBS g/cc	1.649	1.501	1.412
CBR at 97% MDD	**117.38**		



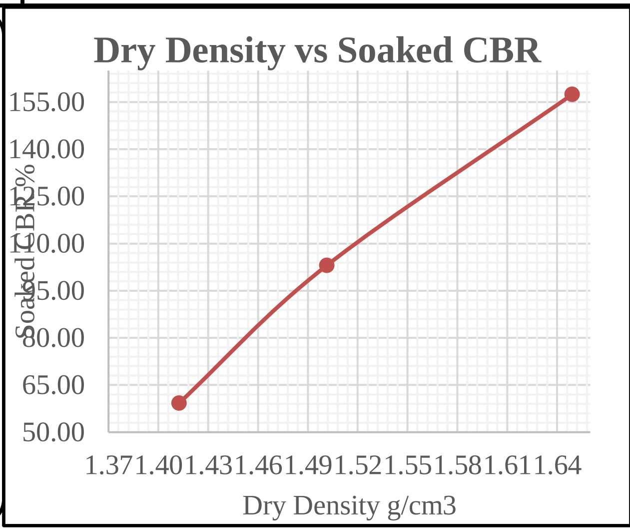


Fig-K-2: Pit1 CBR test results for cinder gravel blended with 20%by weight of fine crushed rock.

Table K-3: Pit1 CBR test results for the blending of cinder gravel with 25% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	10.21	14.909	19.405	23.431	28.92	33.168	39.972
	CBR (%)					**175.65**		**165.84**	
30-Blows	**Load (KN)**	0	5.930	8.662	11.274	13.614	16.800	19.271	23.224
	CBR (%)					**102.05**		**96.36**	
10-Blows	**Load (KN)**	0	3.312	4.839	6.297	7.604	9.384	10.764	12.972
	CBR (%)					**57.00**		**53.82**	

CBR RESULT SUMMARY			
OMC (%)	14.90		
MMDD	1.627		
Dry Density at 97% of MDD	1.578		
No of Blows	65	30	10
CBR Values (%)	175.65	102.05	57.00
DDBS g/cc	1.643	1.549	1.449
CBR at 97% MDD	**124.93**		

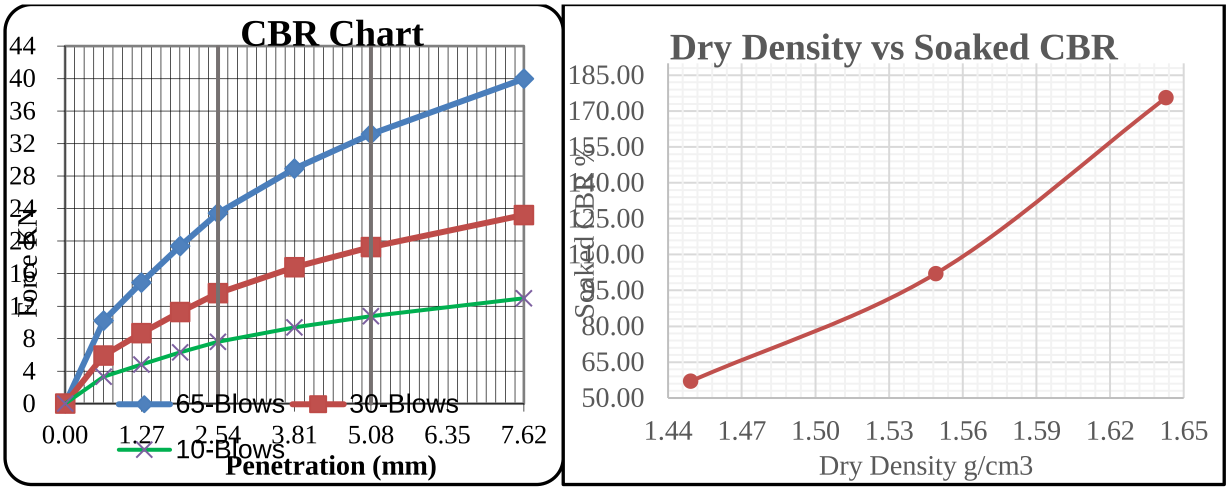


Fig-K-3: Pit1 CBR test results for cinder gravel blended with 25%by weight of fine crushed rock.

Table K-4: Pit1 CBR test results for the blending of cinder gravel with 30% by weight of fine crushed rock

PENETRATION AND+AT3:BC17 LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	5.927	8.843	11.730	14.127	17.527	20.163	24.281
	CBR (%)					**105.90**		**100.82**	
30-Blows	**Load (KN)**	0	4.276	6.431	8.490	10.024	12.848	14.796	17.914
	CBR (%)					**75.14**		**73.98**	
10-Blows	**Load (KN)**	0	2.086	3.047	3.966	4.789	5.910	6.779	8.170
	CBR (%)					**35.90**		**33.90**	
CBR RESULT SUMMARY									
OMC(%)	18.89								
MMDD	1.601								
Dry Density at 97% of MDD	1.553								
No of Blows	65	30	10						
CBR Values (%)	105.90	75.14	35.90						

DDBS g/cc	1.588	1.525	1.471
CBR at 97% MDD	**88.72**		

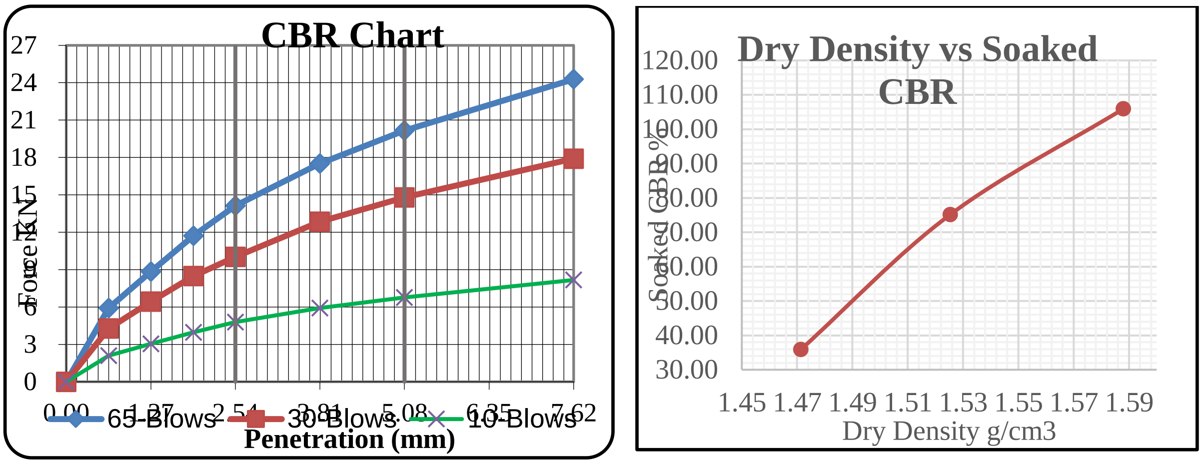


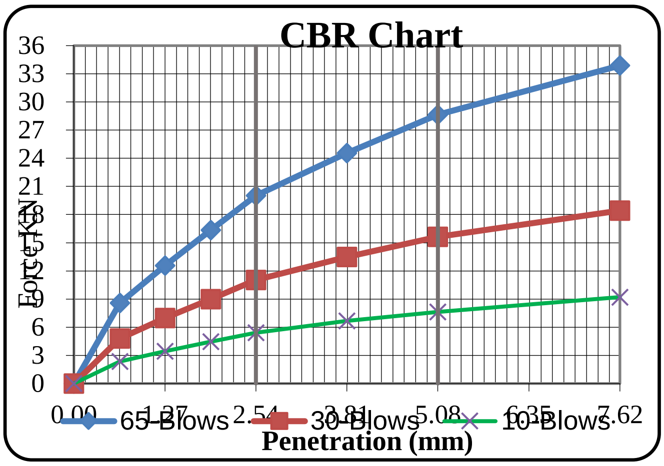
Fig-K-4: Pit1 CBR test results for cinder gravel blended with 30%by weight of fine crushed rock.

Table K-5: Pit2 CBR test results for the blending of cinder gravel with 15% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL SOIL OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	8.598	12.560	16.347	20.040	24.560	28.643	33.874
	CBR (%)					**150.22**		**143.22**	
30-Blows	**Load (KN)**	0	4.792	6.993	8.981	11.045	13.486	15.621	18.428
	CBR (%)					**82.80**		**78.11**	
10-Blows	**Load (KN)**	0	2.352	3.435	4.471	5.399	6.663	7.642	9.210
	CBR (%)					**40.47**		**38.21**	

CBR RESULT SUMMARY			
OMC(%)	10.00		
MMDD	1.604		
Dry Density at 97% of MDD	1.556		
No of Blows	65	30	10
CBR Values (%)	150.22	82.80	40.47
DDBS g/cc	1.612	1.547	1.478

CBR at 97% MDD	**92.19**



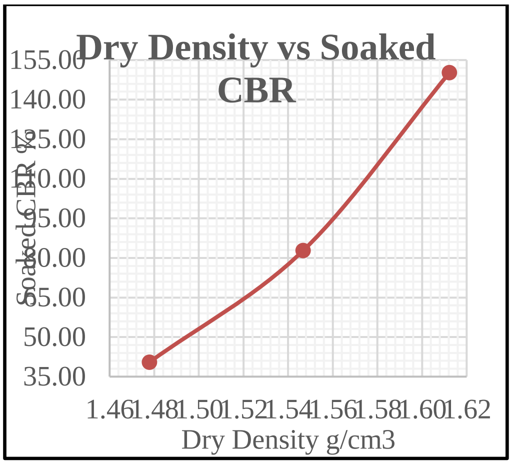
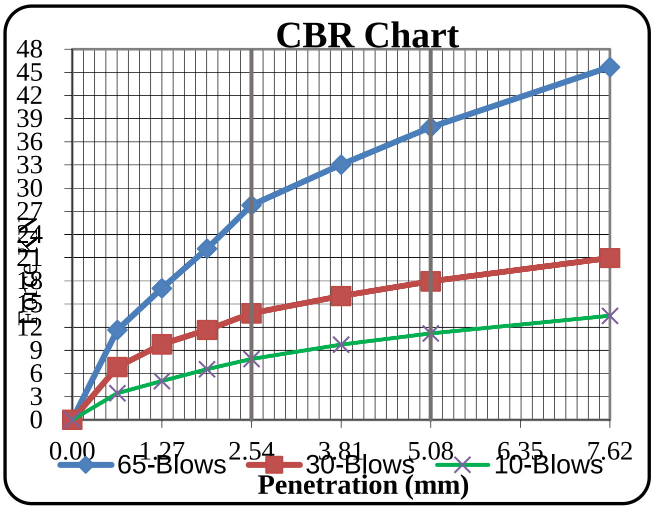


Fig-K-5: Pit1 CBR test results for cinder gravel blended with 15%by weight of fine crushed rock.

Table K-6: Pit2 CBR test results for the blending of cinder gravel with 20% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL SOIL OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	11.668	17.045	22.184	27.800	33.06	37.920	45.698
	CBR (%)					**208.40**		**189.60**	
30-Blows	**Load (KN)**	0	6.840	9.788	11.634	13.786	16.046	17.926	20.968
	CBR (%)					**103.34**		**89.63**	
10-Blows	**Load (KN)**	0	3.443	5.030	6.546	7.904	9.755	11.189	13.484
	CBR (%)					**59.25**		**55.95**	
CBR RESULT SUMMARY									
OMC(%)	12.30								
MMDD	1.645								
Dry Density at 97% of MDD	1.596								
No of Blows	65	30	10						
CBR Values (%)	208.40	103.34	59.25						
DDBS g/cc	1.651	1.587	1.552						

CBR at 97% MDD	**117.53**



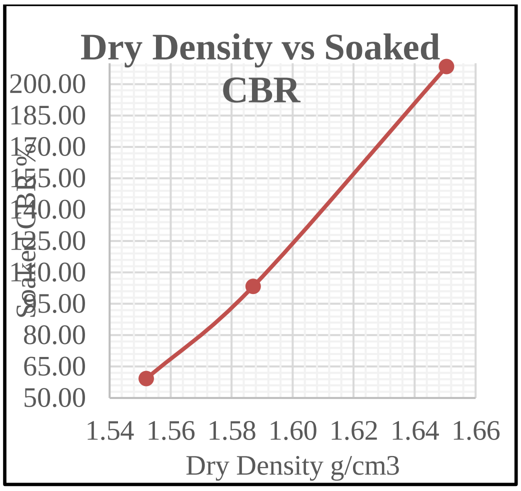
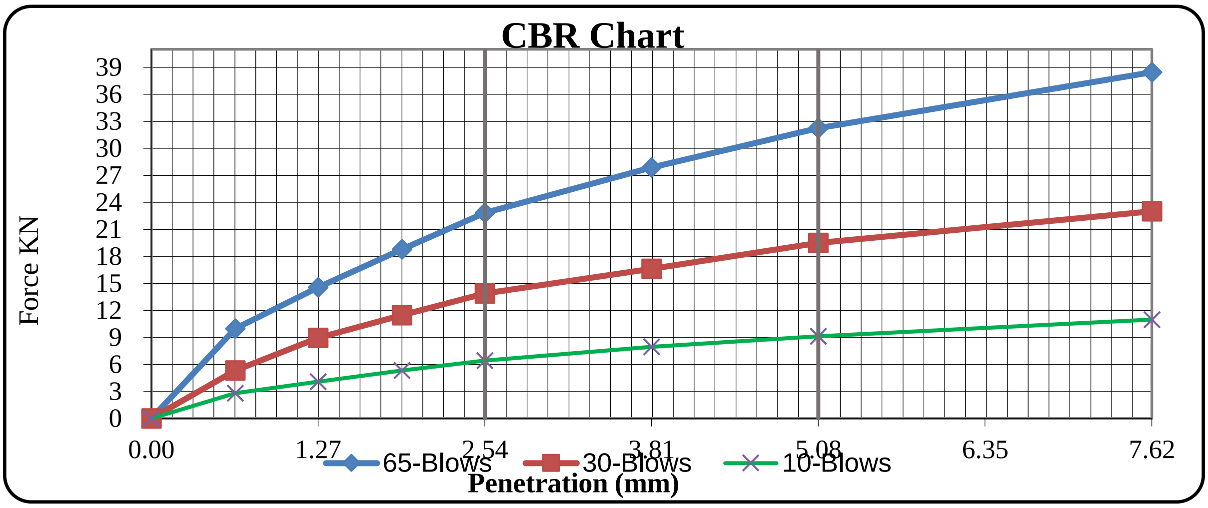


Fig-K-6: Pit2 CBR test results for cinder gravel blended with 20%by weight of fine crushed rock.

Table K-7: Pit2 CBR test results for the blending of cinder gravel with 25% by weight of fine



crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL SOIL OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	9.967	14.568	18.770	22.824	27.873	32.23	38.453
	CBR (%)					**171.09**		**161.15**	
30-Blows	**Load (KN)**	0	5.319	8.955	11.474	13.88	16.605	19.489	23.010
	CBR					**104.04**		**97.45**	

	(%)								
10-Blows	Load (KN)	0	2.805	4.097	5.333	6.439	7.946	9.115	10.985
	CBR (%)					**48.27**		**45.58**	

CBR RESULT SUMMARY			
OMC(%)	15.20		
MMDD	1.664		
Dry Density at 97% of MDD	1.6141		
No of Blows	65	30	10
CBR Values (%)	171.09	104.04	48.27
DDBS g/cc	1.653	1.595	1.565
CBR at 97% MDD	**125.94**		

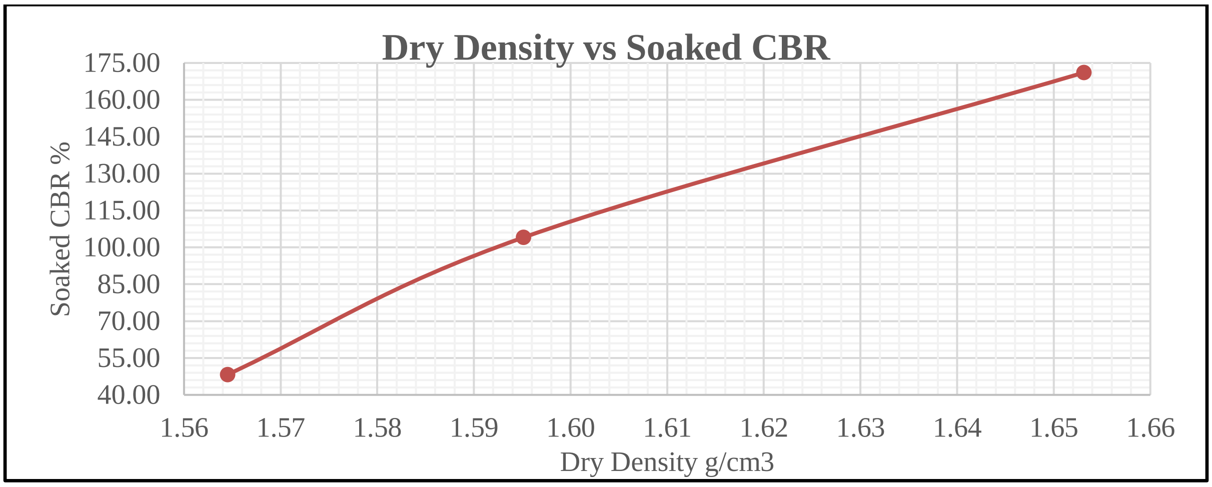


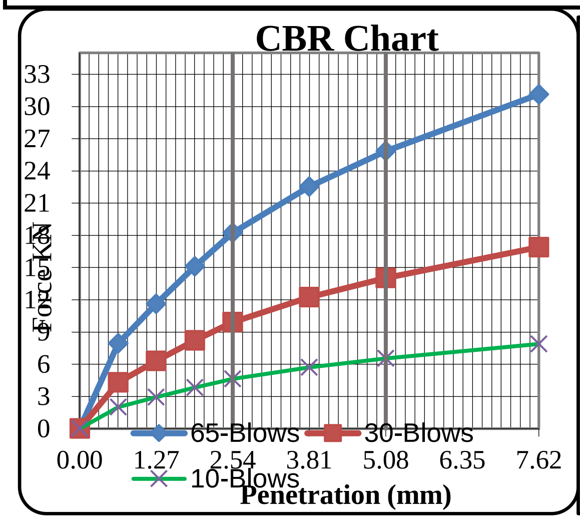
Fig-K-7: Pit2 CBR test results for cinder gravel blended with 25%by weight of fine crushed rock.

Table K-8: Pit2 CBR test results for the blending of cinder gravel with 30% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	7.948	11.611	15.112	18.248	22.520	25.831	31.130
	CBR (%)					**136.79**		**129.16**	

30-Blows	**Load (KN)**	0	4.316	6.305	8.206	9.909	12.228	14.026	16.903
	CBR (%)					**74.28**		**70.13**	
10-Blows	**Load (KN)**	0	2.014	2.942	3.829	4.624	5.706	6.546	7.888
	CBR (%)					**34.66**		**32.73**	

CBR RESULT SUMMARY			
OMC (%)	17.20		
MMDD	1.634		
Dry Density at 97% of MDD	1.585		
No of Blows	65	30	10
CBR Values (%)	136.79	74.28	34.66
DDBS g/cc	1.635	1.570	1.538
CBR at 97% MDD	**88.96**		



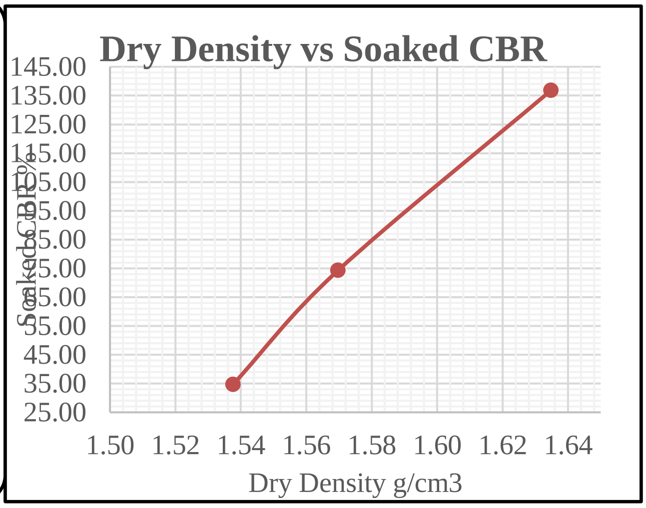


Fig-K-8: Pit2 CBR test results for cinder gravel blended with 30%by weight of fine crushed rock.

Table K-9: Pit3 CBR test results for the blending of cinder gravel with 15% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	7.357	10.747	13.988	16.890	20.844	23.909	28.814
	CBR (%)					**126.62**		**119.55**	
30-Blows	**Load (KN)**	0	4.459	6.514	8.477	10.237	12.633	14.491	17.46
	CBR (%)					**76.74**		**72.45**	
10-Blows	**Load (KN)**	0	1.980	2.893	3.765	4.547	5.611	6.436	7.756
	CBR (%)					**34.08**		**32.18**	

CBR RESULT SUMMARY			
OMC (%)	11.20		
MMDD	1.671		
Dry Density at 97% of MDD	1.620		
No of Blows	65	30	10
CBR Values (%)	126.62	76.74	34.08
DDBS g/cc	1.681	1.588	1.530
CBR at 97% MDD	**94.18**		

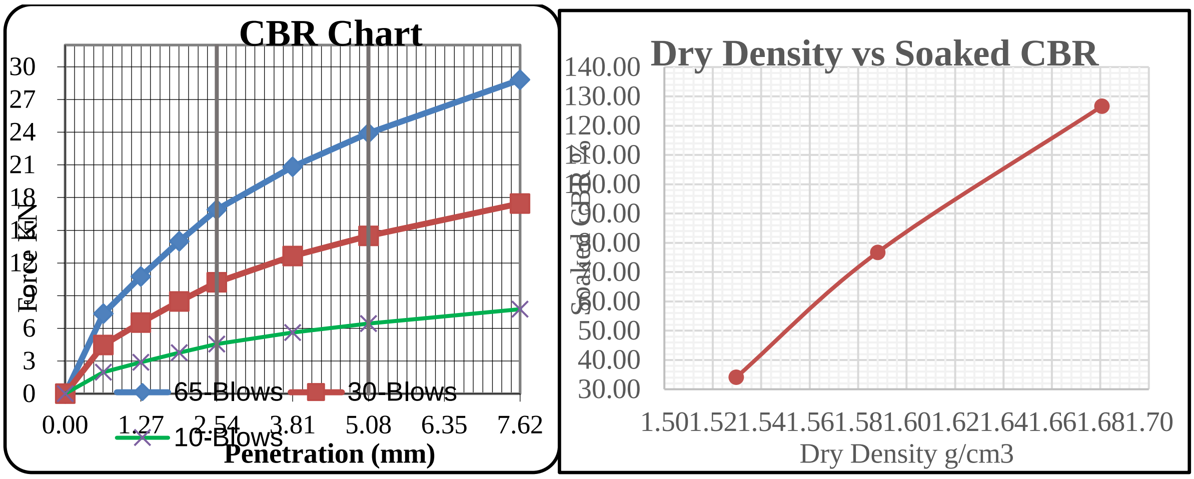
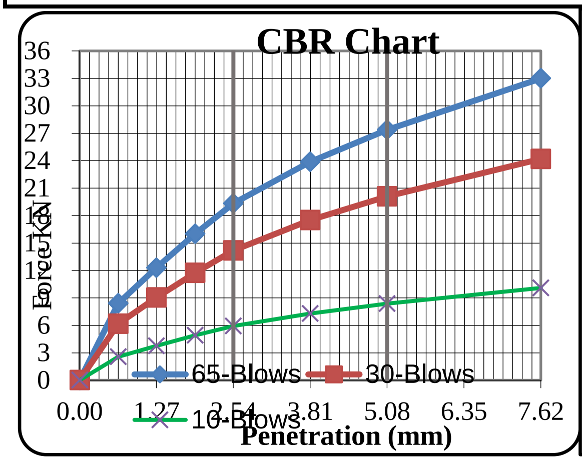


Fig-K-9: Pit3 CBR test results for cinder gravel blended with 15%by weight of fine crushed rock.

Table K-10: Pit3 CBR test results for the blending of cinder gravel with 20% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	8.422	12.303	16.012	19.335	23.86	27.37	32.984
	CBR (%)					**144.94**		**136.85**	
30-Blows	**Load (KN)**	0	6.178	9.025	11.746	14.183	17.503	20.077	24.195
	CBR (%)					**106.32**		**100.39**	
10-Blows	**Load (KN)**	0	2.576	3.763	4.898	5.914	7.299	8.372	10.090
	CBR (%)					**44.34**		**41.86**	
CBR RESULT SUMMARY									
OMC (%)				13.45					

MMDD	1.724		
Dry Density at 97% of MDD	1.672		
No of Blows	65	30	10
CBR Values (%)	144.94	106.32	44.34
DDBS g/cc	1.727	1.648	1.584
CBR at 97% MDD	**118.21**		



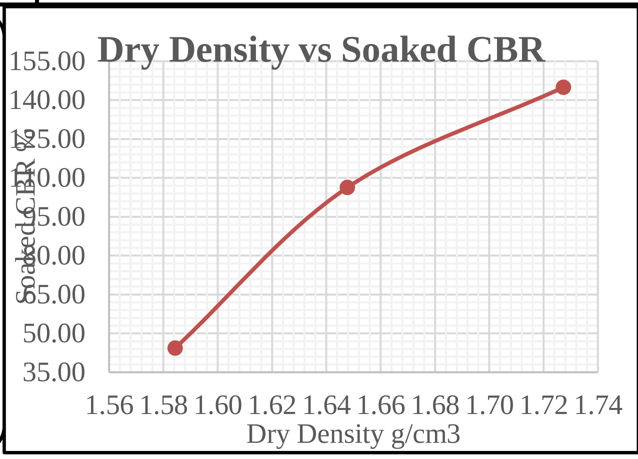


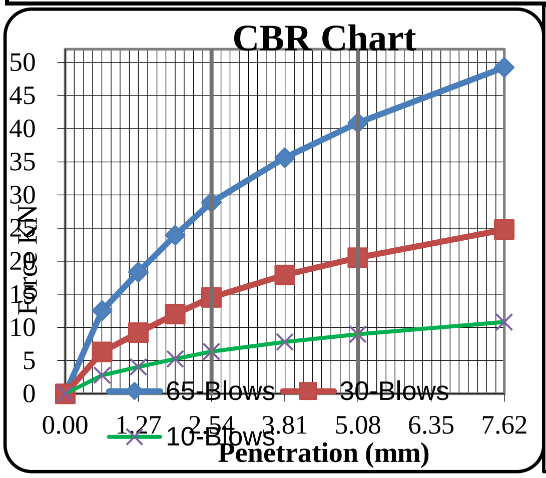
Fig-K-10: Pit3 CBR test results for cinder gravel blended with 20%by weight of fine crushed rock.

Table K-11: Pit3 CBR test results for the blending of cinder gravel with 25% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	12.576	18.372	23.912	28.874	35.632	40.872	49.256
	CBR (%)					**216.44**		**204.36**	

30-Blows	**Load (KN)**	0	6.324	9.239	12.025	14.520	17.919	20.554	24.770
	CBR (%)					**108.84**		**102.77**	
10-Blows	**Load (KN)**	0	2.765	4.039	5.256	6.347	7.833	8.985	10.828
	CBR (%)					**47.58**		**44.92**	

CBR RESULT SUMMARY			
OMC (%)	16.45		
MMDD	1.756		
Dry Density at 97% of MDD	1.703		
No of Blows	65	30	10
CBR Values (%)	216.44	108.84	47.58
DDBS g/cc	1.761	1.691	1.632
CBR at 97% MDD	**127.71**		



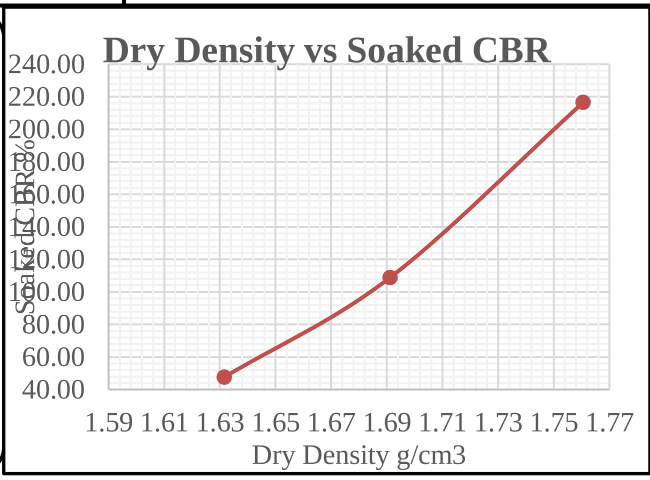
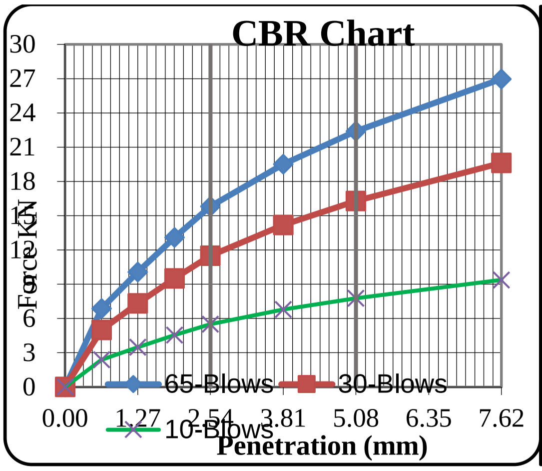


Fig-K-11: Pit3 CBR test results for cinder gravel blended with 25%by weight of fine crushed rock.

Table K-12: Pit3 CBR test results for the blending of cinder gravel with 30% by weight of fine crushed rock

PENETRATION AND LOAD DETERMINATION									
NATURAL CINDER OF ADAMA									
Penetration	**mm**	0	0.64	1.27	1.91	**2.54**	3.81	**5.08**	7.62
65-Blows	**Load (KN)**	0	6.887	10.061	13.09	15.811	19.512	22.382	26.973
	CBR (%)					**118.52**		**111.91**	
30-Blows	**Load (KN)**	0	5.008	7.317	9.523	11.499	14.191	16.278	19.617
	CBR (%)					**86.20**		**81.39**	
10-Blows	**Load (KN)**	0	2.396	3.500	4.555	5.500	6.788	7.786	9.383
	CBR (%)					**41.23**		**38.93**	

CBR RESULT SUMMARY			
OMC (%)	18.90		
MMDD	1.733		
Dry Density at 97% of MDD	1.681		
No of Blows	65	30	10
CBR Values (%)	118.52	86.20	41.23
DDBS g/cc	1.739	1.669	1.632
CBR at 97% MDD	**91.83**		



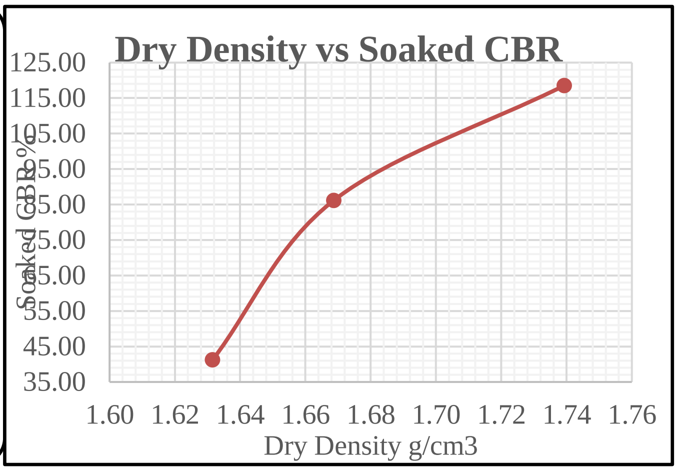


Fig-K-12: Pit3 CBR test results for cinder gravel blended with 30%by weight of fine crushed rock.

Appendix L: Specific Gravity and Water Absorption Test Results of cinder gravel blended with fine crushed rock

Table L-1: Pit 1 Specific Gravity and Water Absorption of the blending of cinder gravel with 15% by weight of fine crushed rock

Trial number:15%		A	B
Weight of Saturated & Surface dry Aggregate(gm)	(A)	500	500

Weight of Pycnometer + Water(gm)	(B)	1530.6	1532.3
Weight of Pycnometer + Sample + Water(gm)	(C)	1820.1	1823
Weight of oven Dry Sample (gm)	(D)	482	481.5
Bulk specific gravity (SSD basis)	A/(B+A-C)	2.38	2.39
	Average	2.4	
Bulk specific gravity (OD basis)	D/(B+A-C)	2.29	2.30
	Average	2.30	
Apparent specific gravity	D/(B+D-C)	2.50	2.52
	Average	2.51	
Absorption (%)	[(A-D)/D] *100	3.73	3.84
	Average	3.79	

Table L-2: Pit 1 Specific Gravity and Water Absorption of the blending of cinder gravel with 20% by weight of fine crushed rock

Trial Number:20%		**A**	**B**
Weight of Saturated & Surface dry Aggregate(gm)	(A)	500	500
Weight of Pycnometer + Water(gm)	(B)	1522	1524.1
Weight of Pycnometer + Sample + Water(gm)	(C)	1822	1824.4
Weight of oven Dry Sample (gm)	(D)	487.6	488.4
Bulk specific gravity (SSD basis)	A/(B+A-C)	2.50	2.50
	Average	2.5	
Bulk specific gravity(OD basis)	D/(B+A-C)	2.44	2.45
	Average	2.44	
Apparent specific gravity	D/(B+D-C)	2.60	2.60
	Average	2.60	

Absorption (%)	[(A-D)/D]*100	2.54	2.38
	Average	2.46	

Table L-3: Pit 1 Specific Gravity and Water Absorption of the blending of cinder gravel with 25% by weight of fine crushed rock

Trial number		**A**	**B**
Weight of Saturated & Surface dry Aggregate(gm)	(A)	500	500
Weight of Pycnometer + Water(gm)	(B)	1513.94	1513.1
Weight of Pycnometer + Sample + Water(gm)	(C)	1825.51	1824.2
Weight of oven Dry Sample (gm)	(D)	494.26	493.8
Bulk specific gravity (SSD basis)	A/(B+A-C)	2.65	2.65
	Average	2.7	
Bulk specific gravity (OD basis)	D/(B+A-C)	2.62	2.61
	Average	2.62	
Apparent specific gravity	D/(B+D-C)	2.71	2.70
	Average	2.70	
Absorption (%)	[(A-D)/D] *100	1.16	1.25
	Average	1.2	

Table L-4: Pit 1 Specific Gravity and Water Absorption of the blending of cinder gravel with 30% by weight of fine crushed rock

Trial number:30%		**A**	**B**
Weight of Saturated & Surface dry Aggregate(gm)	(A)	500	500
Weight of Pycnometer + Water(gm)	(B)	1516.7	1515

Weight of Pycnometer + Sample + Water(gm)	(C)	1833	1832
Weight of oven Dry Sample (gm)	(D)	494.6	495
Bulk specific gravity (SSD basis)	A/(B+A-C)	2.72	2.73
	Average	2.7	
Bulk specific gravity (OD basis)	D/(B+A-C)	2.69	2.70
	Average	2.70	
Apparent specific gravity	D/(B+D-C)	2.77	2.78
	Average	2.78	
Absorption (%)	[(A-D)/D] *100	1.09	1.01
	Average	1.05	

Appendix M: ACV and TFV Test Results of cinder gravel blended with fine crushed rock

Table M-1: Pit 1 ACV and TFV of the blending of cinder gravel with 15% by weight of fine crushed rock

Trial No:15%	1	2

Mass of aggregate passing 14mm and retained on 10mm, gm. Before compression	1412.5	1409.6
Mass of aggregate, retained on 2.36mm sieve sizing. After compression	1326	1327
% of material passing 2.36 mm(m)	8.2	8.3
Duration of testing, min.	10.2	10.2
Maximum load, f(KN)	33.5	34
Force required to produce 10% fines in (KN)= 14*f/(m+4)	38.44	38.70
Average Force TFV in KN,	38.6	

Table M-2: Pit 1 ACV and TFV of the blending of cinder gravel with 20% by weight of fine crushed rock

Test No:20%	**1**	**2**
Mass of aggregate passing 14mm and retained on 10mm,gm. Before compression	1420.5	1416
Mass of aggregate, retained on 2.36mm sieve size,gm. After compression	1345.5	1334.5
% of material passing 2.36 mm(m)	8	7.8
Duration of testing, min.	10.1	10.2
Maximum load, f(KN)	37	38.4
Force required to produce 10% fines in (KN)= 14*f/(m+4)	43.17	45.56
Average Force TFV in KN,	44.4	

Table M-3: Pit 1 ACV and TFV of the blending of cinder gravel with 25% by weight of fine crushed rock

Test No:25%	**1**	**2**

Mass of aggregate passing 14mm and retained on 10mm, gm. Before compression	1417	1415.3
Mass of aggregate, retained on 2.36mm sieve size,gm. After compression	1347	1342
% of material passing 2.36 mm(m)	7.8	8.02
Duration of testing, min.	10.1	10.2
Maximum load, f(KN)	44	45.5
Force required to produce 10% fines in (KN)= 14*f/(m+4)	52.20	53.00
Average Force TFV in KN,	52.6	

Table M-4: Pit 1 ACV and TFV of the blending of cinder gravel with 30% by weight of fine crushed rock

Test No:30%	1	2
Mass of aggregate passing 14mm and retained on 10mm, gm. Before compression	1415.4	1415
Mass of aggregate, retained on 2.36mm sieve size,gm. After compression	1355.4	1358
% of material passing 2.36 mm(m)	7.7	7.9
Duration of testing, min.	10.1	10.2
Maximum load, f(KN)	46	47.5
Force required to produce 10% fines in (KN)= 14*f/(m+4)	55.04	55.88
Average Force TFV in KN,	55.5	

Appendix N: AIV Test Results of cinder gravel blended with fine crushed rock

Table N-1 Pit 1 AIV of the blending of cinder gravel with 15% by weight of fine crushed rock

S NO	Trials:15%	Trial NO	
		1	2

1	Total weight of aggregate sample filling the cylindrical measure=W1	400.5	406.5
2	Weight of aggregate passing 2.36mm sieve after the test=W2	125.1	127.8
3	Weight of aggregate retained 2.36mm sieve after the test=W3	275.4	278.7
4	W2=W1-W3	125.1	127.8
5	Aggregate Impact Value=W2/W1*100	31.24	31.44
	Average	31.34	

Table N-2: Pit 1 AIV of the blending of cinder gravel with 15% by weight of fine crushed rock

S NO	Trials:20%	Trial NO	
		1	2
1	Total weight of aggregate sample filling the cylindrical measure=W1	410.5	408
2	Weight of aggregate passing 2.36mm sieve after the test=W2	120.3	118.8
3	Weight of aggregate retained 2.36mm sieve after the test=W3	290.2	289.2
4	W2=W1-W3	120.3	118.8
5	Aggregate Impact Value=W2/W1*100	29.31	29.12
	Average	29.21	

Table N-3: Pit 1 AIV of the blending of cinder gravel with 25% by weight of fine crushed rock

S NO	Trials:25%	Trial NO	
		1	2
1	Total weight of aggregate sample filling the cylindrical	407.8	402

	measure=W1		
2	Weight of aggregate passing 2.36mm sieve after the test=W2	115.3	111.3
3	Weight of aggregate retained 2.36mm sieve after the test=W3	292.5	290.7
4	W2=W1-W3	115.3	111.3
5	Aggregate Impact Value=W2/W1*100	28.27	27.69
	Average	27.98	

Table N-4: Pit 1 AIV of the blending of cinder gravel with 30% by weight of fine crushed rock

S NO	Trials:30%	Trial NO	
		1	2
1	Total weight of aggregate sample filling the cylindrical measure=W1	416.5	411.5
2	Weight of aggregate passing 2.36mm sieve after the test=W2	115.3	111.3
3	Weight of aggregate retained 2.36mm sieve after the test=W3	303.6	301.5
4	W2=W1-W3	112.9	110
5	Aggregate Impact Value=W2/W1*100	27.11	26.73
	Average	26.92	

Appendix O: LAA Test Results of cinder gravel blended with fine crushed rock

Table O-1: Pit 1 LAA of the blending of cinder gravel with 15% by weight of fine crushed rock

Trial:15%	1	2
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000
Wt. of Tested Sample Retained on No 1.7 Sieve (g)	3000	3003.7
Percent Loss (%)	40	39.9
Average	39.97	

Table O-2-: Pit 1 LAA of the blending of cinder gravel with 20% by weight of fine crushed rock

Trial:20%	1	2
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000
Wt. of Tested Sample Retained on No 1.7 Sieve (g)	3127.5	3131.7
Percent Loss (%)	37.5	37.4
Average	37.45	

Table O-3-: Pit 1 LAA of the blending of cinder gravel with 25% by weight of fine crushed rock

Trial:25%	1	2
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000
Wt. of Tested Sample Retained on No 1.7 Sieve (g)	3214.6	3217.5
Percent Loss (%)	35.71	35.65
Average	35.7	

Table O-4-: Pit 1 LAA of the blending of cinder gravel with 30% by weight of fine crushed rock

Trial:30%	**1**	**2**
No of Revolution	500	500
Total Wt. of Sample Tested (g)	5000	5000
Wt. of Tested Sample Retained on No 1.7 Sieve (g)	3276.8	3270.3
Percent Loss (%)	34.5	34.6
Average	34.5	