



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

“The Potential Use of Cinder as a Sub base Material When Blended with Fine Grained Soil (The Case of Durame Intercity Road Project)”

By:

Ermias Lulu

A Thesis Submitted to the Addis Ababa University School of Graduate Studies for the partial fulfillment of a Degree of Masters of Science in Civil Engineering (Geotechnical engineering)

Advisor:Dr. Im SooBeen

**Addis Ababa, Ethiopia
November, 2019**

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Road Project)

By:
Ermias Lulu
Addis Ababa Institute of Technology

Approved By the Board of Examiners

Approved By

Dr. Im SooBeen -

(Advisor)

Sign

Date

Dr.Ing.Samuel Taddese -

(External Examiner)

Sign

Date

Dr. Ing.Henok Fikre -

(Internal Examiner)

Sign

Date

(Chairman)

Sign

Date

DECLARATION

I hereby declare that this thesis is my original work that was carried out under the supervision of Dr.Im SooBeen. Furthermore, this thesis is not 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.

Name: Ermias Lulu

Signature: _____

Place: Addis Ababa University

AAiT

Addis Ababa

Date: October, 2019

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ABSTRACT

Soil stabilization is the process of improving the engineering properties of the soil and thus making it more stable. In the process of soil stabilization and modification or soil strengthening, emphasis is given for maximum utilization of local materials. In this study, cinder and fine grained soil were blended to be used as sub base material.

The research is basically conducted based on the available cinder gravel and fine grained soil found in Durame area. The significance of the study is to provide alternative material for road construction, specifically for road sub base construction. The objective of this study is to investigate the strength characteristics of mechanically stabilized cinder to be used as sub base material. An attempt has been made in this study to evaluate the potential use of cinder gravel as sub base material when blended with fine grained soil.

Accordingly, to achieve the Ethiopia Road Authority manual specification, the cinder gravel was blended with some trail proportion of 0, 10, 20 and 33 % of fine-grained soil by dry weight. In this study the conducted tests includes gradation, compaction test, atterberg limits, free swell, specific gravity, and California Bearing Ratio test.

Laboratory test results showed that the optimum amount of fine grained soil required to achieve the ERA manual standard specification requirement was found to be 20 %. Laboratory tests conducted on specimen prepared using the optimum amount of fine grained soils revealed that cinder gravel responded very well to the fine grained soil treatment, as exhibited in improvement of its gradation and plasticity. From the laboratory test results of moisture content vs. density relationship, it has been observed that the optimum amount of fine grained soil is 20 % by weight proportion at a density of 1.87 g/cc, the range of soaked CBR of the blended mix increases from 64 % to 97 % and PI value from zero to 0 % to 6.1 %.

KEY WORDS: CBR, Cinder Gravel, Compaction, Gradation, Sub base, Optimum fine- grained soil Content

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LIST OF ABBREVIATIONS

AACRA	Addis Ababa City Road Authority
AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
E	Easting
ERA	Ethiopian Roads Authority
GPS	Global Position System
GSB	Granular Sub-Base
ITCZ	Inter Tropical Convergence Zone
LAA	Los Angeles Abrasion
LL	Liquid Limit
MDD	Maximum Dry Density
ML	Inorganic Silts with low plasticity
N	Northing
NP	Non plastic
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
TRRL	Transport and Road Research Laboratory
UCS	Unconfined compressive strength
UK	United kingdom
USA	United States of America

Units

Gm	Gram
kg	Kilogram
km	Kilometer
kN	Kilo Newton
mm	millimeter
g/cm ³	Gram per centimeter cube
kN/m ²	Kilo Newton per meter square
kPa	Kilo Pascal
Mm	millimeter
°C	Degree Centigrade
cc	Centimeter cube
In	inch
cm ³	Centimeter cube

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Transport is a key infrastructure of a country. The rate at which a country's economy grows is very closely linked to the rate at which the transport sector grows. To meet the demands of industrialization and urbanization high quality of road network is required and construction methods should be done in a manner so as to achieve good roads with minimum expenditure. Performance of the roads depends on the structural components of the road pavement such as subgrade, sub base, base and surface courses. Presently suitable sub base materials required for construction of roads are insufficient at many locations. Hence it is necessary to find the alternative materials for economical road construction [12].

Cinder is a highly porous pyroclastic material and is vitric in nature and does meet the conventional sub base specification when stabilized with fine grained soil. The suitability of a cinder for a particular use should be determined based on its engineering characteristics and not on visual inspection. In this study try to explore the potential use of cinder as sub base material when stabilized with fine grained soil. They occur in characteristically straight sided cone-shaped hills which frequently have large concave depressions in their tops or sides where mixtures of solids and gases were released during the formation of the cone. Cinders vary in color, often within the same cone and may be red, brown, grey or black [6].

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 is no locally available material meet the required quality [9].

During construction the selection of material for pavement layer is very critical. Among the layers of the pavement special attention should be given to sub base course because it serves as a

separating layer preventing contamination of the road base by the sub-grade material and, under wet conditions; it has an important role to play in protecting the sub-grade from damage by construction traffic. The component parts of a road consist of individual layers of specified materials laid and compacted to form a stable composite [8].

A road foundation consisting of sub-base and capping layers is designed to achieve a satisfactory working platform for constructing the pavement. On thinner pavements, it also contributes to the overall load spreading capability of the pavement structure [6]. A capping layer is a layer of selected fill material placed on the top of the topmost embankment layer or the bottom of excavation. These materials are often required to provide sufficient cover on weak sub-grades. They are used in the lower pavement layers as a substitute for a thick sub-base to reduce costs, and a cost comparison should be conducted to assess their cost effectiveness [14].

Sub-base is the secondary load-spreading layer underlying the road base. It enables traffic stresses to be reduced to acceptable levels in the sub-grade, acts as a working platform for the construction of the upper pavement layers and serves as a separation layer between sub-grade and base course. It also consist of a material of lower quality than that used in the road base such as unprocessed natural gravel, gravel-sand, or gravel-sand-clay. This layer also serves as a separating layer preventing contamination of the road base by the sub-grade material and, under wet conditions; it has an important role to play in protecting the sub-grade from damage by construction traffic [8].

Material selection is an important component of pavement design. In wet climatic conditions, the most stringent requirements are dictated by the need to support construction traffic and paving equipment. In these circumstances, the sub-base material needs to be more tightly specified. In dry climatic conditions, in areas of good drainage, and where the road surface remains well sealed, unsaturated moisture conditions prevail and sub-base specifications may be relaxed. The selection of sub-base materials will therefore depend on the design function of the layer and the anticipated moisture regime, both in service and during construction [3].

Material selection is therefore an important component of pavement design. The selection of appropriate quality of materials for selected sub-grade, sub-base and road-base determines the whole life costs of the road. The use of locally available materials is very much encouraged in most road construction especially in rural road engineering [3]. The materials used for the construction

of sub-base layers shall be either natural gravel, cinder gravel, weathered rock, crushed gravel, crushed rock or crushed boulders, recycled pavement material [8]. This research was tried to show the use of cinder gravel for the construction of sub base.

In general, from the various ground improvement techniques, the technique of soil stabilization is being widely used now-a-days and replacing the conventional ground improvement techniques [2].

This research was conducted taking the case of Durame Intercity Road Project which was 6.56 km length. In most of the area along the side of road, good type of sub-base material is not available. But in this area there is abundant cinder gravel material and is used as a sub-base material by mixing it with fine-grained soil but without any specified proportion. The objective of this thesis is to investigate the performance of cinder gravel blended with fine-grained soil as sub-base material and propose the optimum blending proportion. For this purpose, cinder samples and locally available fine-grained soil were collected from the Project site which is under construction and blended with different percentage in order to use as sub base material.

1.2. Statement of the problem

In road projects, the quality and quantity of the sub-base material is very important. If appropriate sub-base material cannot be found in areas close to the construction site, then very high prices have to be paid in road construction process, which causes significant delays or cost increases. In such cases, sometimes work with low-quality materials affects the road quality and durability over time and results in very significant losses. Improving the quality of materials is very important for road construction works, in order to ensure that projects meet the necessary cost and quality criteria. If the material found close to the construction site does not meet the specifications, the materials may be improved with suitable chemicals such as lime, cement and fly ash, etc. Unfortunately, the costs of these stabilizers are on the other side making them economically unattractive as stabilizing agents. Recent trend in research works in the field of geotechnical engineering and construction materials focuses more on the search of cheap and locally available material like fine grained soil as stabilizing agents for the purpose of full or partial replacement of traditional stabilizers.

In our country, there is widely distributed cinder gravel. However, this material has the problem of compaction due to its light weight, its rough circular surface and its high porosity. Beside, in some regional part of Ethiopia, there is a scarcity of a good sub-base material such as natural gravel and

crushed rock. Since the distribution of these sub base materials is limited only in some parts of the country, using these materials everywhere increase transportation cost and is time consuming. In those areas where cinder gravel is available, they are used by mixing with fine-grained soils without having any research based output and guideline about their proportion.

The project standard technical specification states that, “sub base material shall be natural screened or crushed or an approved blended combination of such material providing a smooth continuous grading within the limits for grading “A” given in Table 5104/1 of the standard technical specification or as directed by the Engineer. If the natural material available at the project can’t meet the specified grading requirements, it shall be screened, crushed and screened or blended as required to meet the grading requirement.” [9].

Based on the project initial investigation made by the design consultant for identification of sub base sources, it actually found that most of the sources pertained to the required tests; fail to satisfy the requirement of the project technical specification or ERAS 2002 Standard Technical Specification. Especially to the required indices or properties of the material especially to its gradation, and plasticity index.

Accordingly, blending of the locally available cinder material with fine grained soil is taken to solve the problem in the project area. In this project area cinder gravel is mixed with fine-grained soils without having any research based output and guideline about their proportion. Therefore, determining a good blending proportion of the cinder gravel with fine-grained soil is required.

1.3. Objective of the study

1.3.1 General objective

The general objective of this study is to evaluate the potential use of cinder gravel as sub base material when blended with fine grained soil. This is achieved through the following specific objectives:

1.3.2 Specific Objective

- ❖ To evaluate the effect of fine grained soil on the properties of cinder by conducting atterberg limits, gradation, free swell, compaction and CBR tests.
- ❖ To compare the changes in properties of cinder with respect to fine grained soil.

- ❖ To determine a good blending proportion of the cinder gravel with fine-grained soil used as sub-base materials.

1.4. Methodology

To achieve the objectives mentioned, different data collection procedures and analysis techniques were adopted.

- I. Sampling and testing: material sampling and testing methods that have been employed are critical, since they are required to characterize material and physical properties of the soil that can potentially affect the performance of the road.
- II. Sampling procedures: The procedures used in order to perform the laboratory tests are AASHTO and ASTM standard tests. The program include various laboratory tests on the samples such as; grain size analysis, atterberg Limit Test, Determination of Specific Gravity, California Bearing Ratio, LAA, Modified Compaction Tests and Free Swell tests
- III. Sample preparation of the experimental work involved air drying, pulverization and sieving of the natural soil sample and also cinder gravel sample to the required particle sizes. Classification of soil was made by running grain size distribution and Atterberg limit tests. Then Atterberg limit, free swell, gradation, compaction and California Bearing Ratio tests are carried out on cinder as well as on cinder mix to study the effect of the stabilizer (fine grained soil)
- IV. Analysis and discussion of test results: based on the theories and laboratory tests performed, the results obtained have been analyzed and discussed thoroughly.
- V. Formulation of conclusions and recommendations based on the results obtained is done.

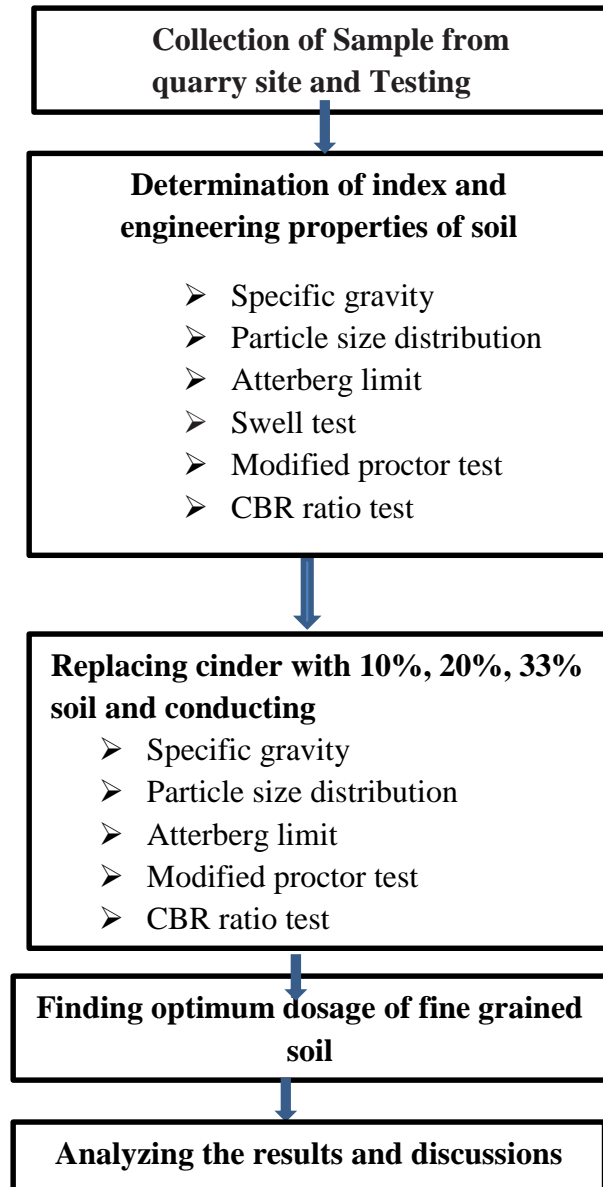


Figure 1-1 Methodology

1.5. Scope of the Study

This study is supported by different types of literatures and a series of laboratory experiments. However, the findings of the research are limited to sample considered in this research. The results are also specific to the type of material in the project site and test procedures that will be adopted in the experimental work. Therefore, this research work can also be taken as an indicative and alternative way of improvement of soils in the research area to be used as road sub base material.

1.6. Materials used

To achieve the objectives of this research work, fine grained soil samples are collected from Durame Intercity Road Project quarry site and Cinder gravel which obtained around the Road Project crusher site.

1.7. Limitation of the Study

The study is conducted on selected road project of a particular area and samples were taken from project quarry source for laboratory studies. Limited numbers of tests are conducted only to achieve the objectives of the present study.

1.8. Organization of the Thesis

The presentation of this thesis work is organized in five Chapters. The first Chapter gives a brief description of the thesis background, objectives, scope, materials, limitation and methodology employed. Chapter two; related works on cinder gravel in road construction and economical advantage of blending material and In the third Chapter, the general description of the study area and the proposed material source are discussed. The fourth Chapter briefly describes the laboratory test results and their analysis. Finally, conclusions and recommendations drawn from the research are will be presented in Chapter five. Reference materials and sources used in the research work are appropriately sited and listed. The thesis ends with appendices which contain detail experimental results of laboratory investigation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Review of Previous Research

KASSAYE & NEWILL (1980) studied the location and engineering properties of volcanic cinder gravels in Ethiopia. The main conclusions from this preliminary investigation of cinder gravels which covered a field survey, a laboratory study and an examination of a cinder gravel road, are given below [12]:-

- i. Cinder gravels are more widespread in Ethiopia than was originally believed; this showed the value of using aerial photographs in survey work and enabled a preliminary map to be prepared giving the distribution of cinder cones.
- ii. In order to obtain representative material from a cinder cone, it is important that samples are taken from below the weathered zone, which can extend to a depth of two meters.
- iii. Although 'as dug' cinder gravels do not meet the recommended grading requirements for road base materials, the laboratory investigation revealed that, because of the weak nature of the aggregate particles, breakdown under compaction occurred with an improvement in both grading and strength properties.
- iv. In the laboratory investigation, the cinder gravels were not affected by changes in moisture and even complete immersion in water only reduced their strength slightly.
- v. The addition of locally available plastic volcanic ash soil, to make up for the deficiency of fine material in the grading, improved the mechanical stability of cinder gravels and indicated that this could be a valuable construction practice. However, unlike the natural cinders the mixed materials lost some of their strength when they were saturated with water.
- vi. The gravel road study confirmed that an improvement in the grading and the strength of cinder gravels occurred under normal road conditions even when trafficking was used as the means of compaction.

The results from the preliminary investigations indicated that cinders could provide useful road construction materials especially for gravel roads. However, it was necessary to carry out further work under known conditions of traffic and climate in bituminous surfaced roads, as well as in

gravel roads, before limits could be recommended for their various uses. It was therefore decided to construct pilot scale compaction trials and then a full-scale road experiment to examine these aspects further.

Kassaye A., D.Newill and R .Robinson (1987) Studied Experimental Use of Cinder Gravel in Ethiopia. Based on this study [6], it showed that they typically have weak particles, deficient in fine material and upon compaction breakdown of large particles occurs producing a better grading and a higher strength. It was also found that the addition of fines improves the strength and density of the compacted cinder gravels. The Road examination confirmed that the action of traffic produces the same breakdown effect in gravel roads as was observed in the laboratory compaction tests [6]. A full scale experiment has been carried out in Ethiopia to examine the performance of volcanic cinder gravels as the surfacing material for unpaved roads and as the road base under bituminous surfaced roads as a joint road research project by the Ethiopian Transport Construction Authority and the Transport and Road Research Laboratory (UK) Compaction trials were carried out to determine the type of plant to be used and an experimental road comprising 20 different sections was then constructed. Six sections were left unsurfaced and were monitored for 28 months during which they carried approximately 140,000 vehicles. A bitumen surface was provided for the remaining 14 sections and these carried 150-200 vpd (Vehicles per day) for 7.5 years giving a total of 440,000 esa in one direction. Monitoring was carried out by taking quantitative measurements of the performance of the road pavement throughout this period. As a result of the study, recommendations are made for the use of cinders in both paved and unpaved roads [6].

For unpaved roads, recommendations are made for a particle size distribution which provides a road surface that is resistant to corrugations. Improved performance can be obtained by mechanically stabilizing cinders with plastic fines. For paved roads, it is concluded that the types of materials used in this experiment are all capable of carrying in excess of 400,000 ESA when sealed with a surface dressing and designed according to Road Note 31. Road mixed asphalt is not a suitable surfacing for cinder gravels. In addition to the cinders, other materials also performed satisfactorily including dry bound macadam, agglomerate and a tuff. Cinders are easier to compact when they are mechanically stabilized with 10 percent of volcanic ash soil [6].

Teshome, T. (2015), Studied The Use of Natural Pozzolana (Volcanic Ash) to Stabilize Cinder Gravel for a Road Base (Along Modjo-Ziway Route). Based on the study the cinder gravel is blended with 0, 4, 8, 12, 16, 20, and 24% by mass of volcanic ash (Pumicite). Compaction, CBR, Gradation, Atterberg limit, Los Angeles Abrasion, Aggregate Crushing Value, Ten Percent Fines Value, Absorption and Specific gravity tests were conducted in the laboratory. From the laboratory test results of moisture content vs. density relationship, it has been observed that the optimum amount of natural pozzolana (volcanic ash) is 20% by mass proportion at a density of 1.76g/cc. Air curing technique was used for the soaked and unsoaked condition where the stabilized samples were covered with a polyethylene sheet and kept in a normal air temperature and out of water intrusion during the a curing period of zero, three, seven, fourteen and twenty eight days. For the optimum blending proportion; the range of soaked CBR increases from 98% to 245% whereas for the unsoaked condition the CBR increases from 118% to 307%, for 0 to 28 days curing [15].

Girma, B. (2009) studied stabilizing cinder gravel for heavily trafficked base course. Based on this study Mechanical and cement stabilization were investigated in two subsequent phases. In the first phase, optimum amount of fine soils that makes up the deficiency of the fine particles of natural cinder gravels was found to be 12%. In the second phase, natural cinder gravel sample without, and with 12% fine soils were stabilized with 3, 5, 7, and 10% of cement by weight. The result of investigation indicated that the optimum amount of cement required to achieve the minimum UCS of 3.0 MPa as specified in ERA and AACRA pavement design standard for heavily trafficked base course without adding fine soil is found to be 7% cement. However, this high cement requirement was reduced to 5% cement which is practical value by mechanically stabilizing cinder gravel with 12% of fine soils before cement stabilization. Nevertheless, it was recommends that the performance of cement stabilized cinder gravel should be investigated in a full-scale road experiment against cracking due to stresses induced by thermal, shrinkage and traffic [11].

Aiswarya P, (2017) an Experimental Investigation on stabilization of fine grained soil using cinder and coir pith. Based on this study The CBR ratio at 15% replacement of cinder was found to be 13.31%. The CBR increased 1.8 times than untreated soil sample. The CBR at 1% replacement of coir pith was obtained as 12.06%. The CBR value increased 1.7 times than the pure soil. At 15% replacement of cinder, compressive strength was obtained as 0.14kg/cm² for 0 days curing. The strength increased 1.19 times compared to pure soil specimen. At 1% replacement of coir pith, the

compressive strength was obtained as 0.132kg/cm² for 0 days curing. The strength increased 1.12 times compared to pure soil specimen. The optimum amount of cinder is obtained as 15% and that of coir pith is obtained as 1%. The CBR value is obtained as 15% which is 2.12 times the untreated soil sample. From these observations it can be concluded as cinder and coir pith can be used as the stabilizers for the improvement of strength properties of the soil [2].

Yitayou E. (2011) studied blending of cinder gravels with fine grained soil to be used as sub base material. In road construction, the use of locally available materials should be made as much as possible. However, when appropriate material cannot be found in areas close to the construction site, very high prices have to be paid with significant time delays and cost increases. In many parts of Ethiopia, there is widely distributed cinder gravel. However, this material has the problem of compaction due to its light weight, its rough circular surface and its high porosity. An investigation has been made on the performance of mechanically stabilized natural cinder gravels of Butajira area to be used as road sub-base material. To achieve the Ethiopia Road Authority manual specification, the cinder gravel was blended with some trail proportion of 0, 5, 10, 15, 20, and 25 % of fine-grained soil by weight and different tests including grain size distribution, Atterberg Limit, compaction, CBR, LAA, absorption and linear shrinkage are conducted in the laboratory. Based on the laboratory test results it is shown that, from both MDD and CBR percent of fine grained soil curve, the optimum amount of fine-grained soil required in order to improve its properties is 19 % by weight proportion [16].

2.2. Sub Base Materials in General

Sub base is layer of aggregate materials laid on sub grade on which the base coarse layer is located and it is often the main load bearing layer of the pavement. It protects the subgrade against significant deformation due to traffic loading and provides an adequate drainage for the infiltration of rain water through the cracks and joints. In addition it is also serve to protect sub grade against frost and environmental damage. The major requirements of for sub base material usually are given in terms of gradation, plastic characteristics, and strength of materials [8].

Sub base course with thickness typically between 100 and 405 mm is a layer of selected material between the subgrade and the base course. Sub base course provides uniform support and adds to the required structural capacity of the pavement section. The material can be gravel, crushed stone or subgrade soil stabilized with cement, fly ash or lime [9].The use of permeable sub base course is

becoming more common to accommodate drainage of water infiltrating from the surface or to keep subsurface water from reaching the surface. In certain regions, the course is also used to impede frost penetration into the subgrade and thereby minimizing frost heave damage to the pavement surface. Compaction and moisture control is generally achieved with specialized equipment as opposed to solely by construction traffic [8].

2.3. Location of volcanic cinder in Ethiopia

2.3.1. Definition of Volcanic cinder

Volcanic cinders are pyroclastic materials associated with recent volcanic activity. They occur in characteristically straight sided cone-shaped hills which frequently have large concave depressions in their tops or sides where mixtures of solids and gases were released during the formation of the cone. Cinders vary in color often within the same cone and may be red, brown, grey or black. The cinder particles also vary in size from large irregularly shaped lumps 50 cm in size, to sand and silt sizes. In some cones, however, particles may be more uniform with the largest size not exceeding 3 cm in diameter. Other characteristic features of cinders are their light weight, their rough vesicular surface and their high porosity. An advantage of cinders as a road construction material is the relative ease with which they can be dug from the quarry; a mechanical shovel or hand tools are usually adequate for their extraction although occasionally a bulldozer may be required to open up a working face [13].

2.3.2. Location of Cinder Gravel in Ethiopia

Field visits in connection with the survey were all carried out within a distance 150 km from Addis Ababa. They were concentrated in areas near to Debrezeit, Nazaret, Zwai, Butajira and Giyon. More than 90 samples were collected for laboratory examination. Samples were obtained either from existing borrow pits from which material had previously been extracted or by digging pits where cinder cones had not been disturbed [13].

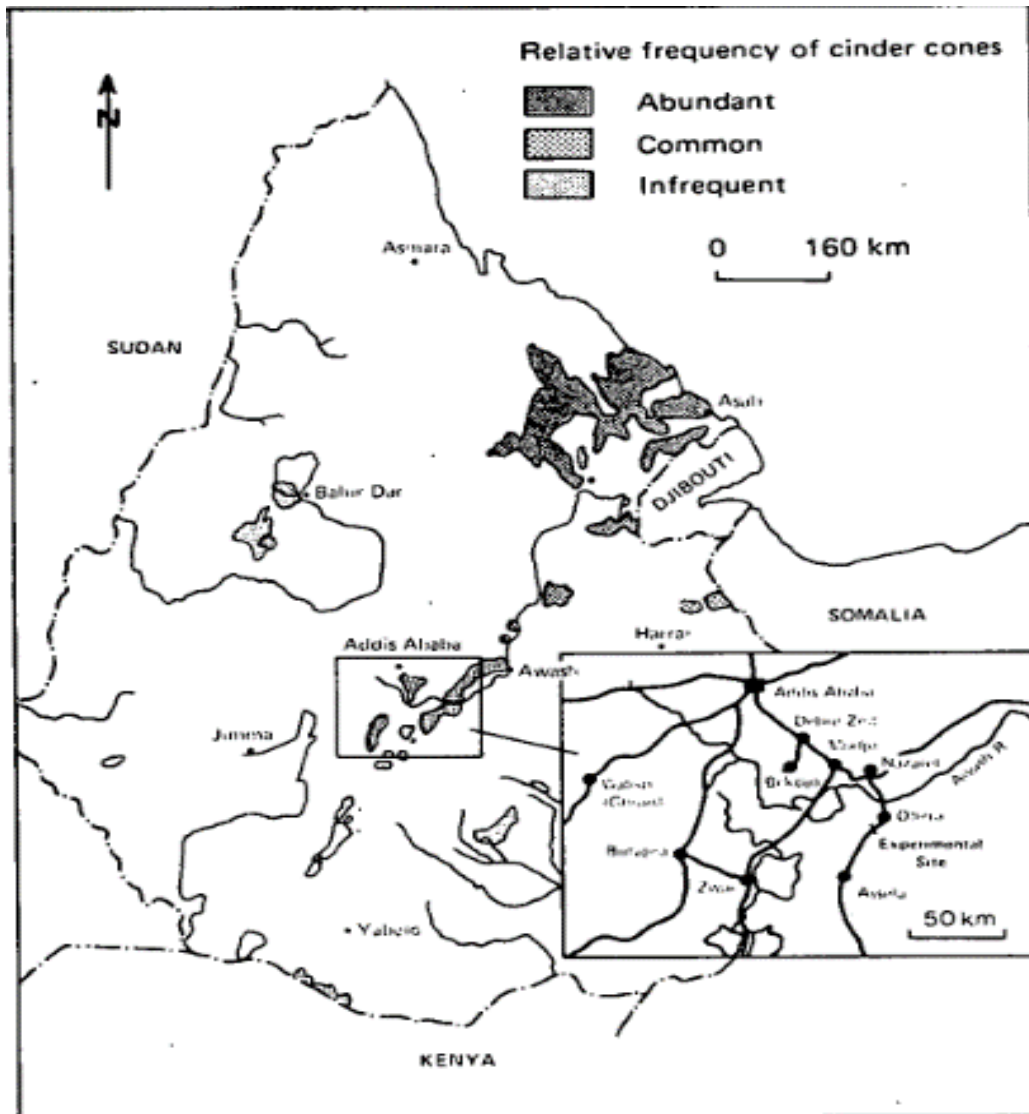


Figure 2-1 Cinder Cone Distribution in Ethiopia, Survey area enlarged [13].

Recent (Quaternary) volcanics on the geological map, a preliminary map was compiled showing the occurrence of cones throughout the country (see Fig 2-1). They were mostly concentrated in the Rift Valley which extends from Tanzania and Kenya and bisects the country in a SSW-NNE direction; an indication of~ their frequency for each of the areas that were identified has been given [13].

2.3.3. Engineering Geology of Cinder Gravel(scoria) in Ethiopia

The geological outcrop pattern of Ethiopia is as complex as any country, with a wide range of igneous, metamorphic and sedimentary rocks. A humid, sub-tropical climate has led to the development of deep residual soils in many parts of the country, with large areas containing very

limited naturally occurring gravels for use in road construction. The haulage of suitable naturally occurring gravels over long distances, and the use of crushed rock as road construction aggregate, are expensive operations that limit the effectiveness of resource constrained road construction and rehabilitation programs. The Rift Valley is the most active divergent intercontinental plate boundary in the world. During the Plio-Pleistocene, felsic and mafic lavas and pyroclastic materials have been extruded and ejected from fissures and vents bordering the Rift Valley and the Afar Depression, with Holocene activity continuing on the Rift Valley floor in association with the active Wonji Fault Belt (Fig. 2-1). Pyroclastic material ejected during these events has typically formed cones comprising ash, lapilli, bombs and blocks of varying vascularity [13].

Basaltic scoriaceous (cinder) gravel, cobbles and boulders are common constituents of these cones and, in some areas, have been extensively quarried for use in the manufacture of hollow blocks. Selected materials have also been used as subgrade replacement, capping layer and sub-base in trial sections of road construction and as surfacing gravel in the rehabilitation of some town roads [13].

2.3.3.1. Formation of scoria (cinder gravel)

Scoria forms when magma containing abundant dissolved gas flows from a volcano or is blown out during an eruption. As the molten rock emerges from the Earth, the pressure upon it is reduced and the dissolved gas starts to escape in the form of bubbles. If the molten rock solidifies before the gas has escaped, the bubbles become small rounded or elongated cavities in the rock. This dark-colored igneous rock with the trapped bubbles is known as scoria [6].

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

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." [6].

2.4. Engineering Properties of Cinder Gravel

Natural cinders gravels are pyroclastic natural materials associated with recent volcanic activity. They vary in color, often within the same quarry and may be red, brown, grey, or black. The particle

sizes also vary from irregularly shaped lumps of 0.5 m in diameter to sand and silt sizes. Other characteristics features of cinder are their light weight, their rough vesicular surface, and their high porosity [6].

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

2.5. Modification of properties of existing materials

Existing materials may require modifications so as to improve their engineering properties. Also, locally available materials, which are otherwise not satisfying general specification requirement, can be suitably modified to become acceptable. This also serves the purpose of economy in terms of saving of haulage of costly materials from elsewhere. Sometimes, design may require special purpose material having specific properties which can be achieved through material modification [9].

2.6. Soil Stabilization

Soil stabilization is the process of altering the properties of a soil by applying some modifiers to meet specified Engineering requirements of road pavement layers. Soil stabilization can be taken as alternate to borrow selected materials and it has advantage that the effect to the environment is reduced and in areas where selected/granular materials are scarce, stabilization have comparative economic advantage. The presence of organic matters and sulphate affects the effectiveness of stabilizers [9].

In road projects with weak subgrades, it is common practice to provide capping layers between the subgrade and the sub-base. The capping layer is of granular material of less quality of the specification requirement for sub-base material. As alternative to provision of capping layer of imported granular material, subgrade soil stabilization using different stabilizers such as lime, cement and fly ash has comparative advantage with respect to environmental protection and economic advantage in areas where the granular materials are scarce [9].

In road construction, all the naturally available material cannot be utilized as construction material as there exists some problematic soils (such as expansive soils) and soils with limitations to meet

specifications and design standards. The problematic nature and limitations of such soils can be improved by application of stabilizing agents.

The application of stabilizing agents can improve: [9].

- ❖ Strength (stability and bearing capacity) of the soil
- ❖ Durability and resistance to the effect of water
- ❖ Volume stability
- ❖ Permeability
- ❖ Wet soils can be dry out
- ❖ The workability of clay soils
- ❖ Load spreading capacity of pavement layers

2.6.1 Techniques of Stabilization

2.6.1.1 Mechanical Stabilization

Mechanical stabilization by compaction produces an interlocking of soil-aggregate particles. The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted. Mechanical stabilization can be accomplished by uniformly mixing the material and then compact the mixture. As an alternative, additional fines or aggregates may be blended before compaction to form a uniform, well graded, dense soil-aggregate mixture after compaction. The choice of methods should be based on the gradation of the material. In some instances, geotextiles can be used to improve a soil's engineering characteristics [3].

The three essentials for obtaining a properly stabilized soil mixture are:

- ❖ Proper gradation.
- ❖ A satisfactory binder soil.
- ❖ Proper control of the mixture content.

The mixture will normally be compacted at or near OMC to obtain satisfactory densities. The objective of mechanical stabilization is to blend available soils so that, when properly compacted, they give the desired stability. In certain areas, for example, the natural soil at a selected location may have low load-bearing strength because of an excess of clay, silt, or fine sand. Within a reasonable distance, suitable granular materials may occur that may be blended with the existing soils to markedly improve the soil at a much lower cost in manpower and materials than is involved in applying imported surfacing [3].

2.6.1.2 Cement Stabilization

Cement Stabilization is done by mixing pulverized soil and Portland cement with water and compacting the mix to attain strong material. The material obtained by mixing soil and cement is known as soil –cement. The soil cement becomes strong and hard material as the cement hydrates and develops strength [3].

2.6.1.3 Lime Stabilization

Lime stabilization is done by adding lime to soil.it is useful for stabilization of clayey soil. When lime reacts with soil, there is exchange of cations in the adsorbed water layer and decrease the plasticity of the soil occurs [3].

2.6.1.4 Bitumen stabilization

Bitumen stabilization generally done with asphalt as binder. Any inorganic soil which can be mixed with asphalt is suitable for bituminous stabilization. In cohesion less soil, asphalt binds the soil particle together and thus as a bonding or cementing agent. In cohesive soils, asphalt protects the soil by plugging its voids and water proofing it.it helps the cohesive soil to maintain low moisture content and to increase the bearing capacity [3].

2.6.1.5 Chemical stabilization

Chemical stabilization of soil is mixing of soil with one or a combination of admixtures of powder, slurry, or liquid for the general objective of improving or controlling its volume stability, strength and stress-strain behavior. Soil improvement by means of chemical stabilization can be grouped into three chemical reactions; cation exchange, flocculation – agglomeration, pozzolanic reactions [3].

2.7. Economical Advantage of Blending

Economic adaptation of a road to special needs and its technical adaptation to local conditions are two complementary aspects which greatly influence planning decisions. The excavation, haulage, and laying of satisfactory pavement materials must be accomplished as economical as possible for all highway projects. However, in developing countries, where a high percentage of the roads to be built and maintained are primarily unsurfaced and involve a gravel placement, investment in materials is normally higher. Therefore, in order to obtain the most cost-effective construction, it is necessary for haulage distances, which form the major item of expense, to be minimized by making the best use of locally available materials [6].

2.8. Properties of Material for Sub Base

Material to be used for sub-base shall be obtained from approved sources in borrow areas, cuts or existing pavement layers. The complete sub-base shall contain no material having a maximum dimension exceeding two-thirds of the completed layer thickness. Sub-base material shall, unless otherwise fulfill the requirements stated in the standard [6]. The following tests were conducted in this research:-

2.8.1. Particle-size distribution

Grain size analysis is used to determine the effective diameter of the soil particles that constitute and strongly affect the uniformity characteristics of the soil mass. Mechanical analysis is used for the coarse sized soils by using a set of sieve sizes and hydrometer analysis is used for fine grained soils. For a soil-containing fine to coarse sized particles the combined analysis is employed.

2.8.2. Atterberg Limits

Atterberg Limits tests are used to confirm visual descriptions. They are performed on fine grained soils (clays, silts) to determine the amount of water necessary to achieve a range of behavioral states. These test results have been correlated with other soil properties. The liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) are Atterberg limits. However, for classification purposes, the term Atterberg limit generally refers to the more common liquid and plastic limits only. The shrinkage limit test is less often included in common laboratory programs. The shrinkage limit test is performed when swelling behavior in soils are suspected that could influence design and construction [3].

i) Liquid Limit: The liquid limit is determined by ascertaining the moisture content at which two halves of a soil cake will flow together for a distance of 0.5 inch (13 mm) along the bottom of the groove separating the halves, when the bowl they are in is dropped 25 times for a distance of 0.4 inches (10 mm) at the rate of 2 drops/second. Tests shall be performed in accordance with ASTM D 4318.

ii) Plastic Limit: The plastic limit is determined by ascertaining the lowest moisture content at which the material can be rolled into threads 0.125 inches (3.2 mm) in diameter without crumbling. Tests shall be performed in accordance with ASTM D 4318.

iii) Plasticity Index: is simply the numerical difference between the liquid limit and the plastic limit and indicates the magnitude of the range of moisture content over which the soil remains plastic. It is the measure of the cohesion qualities of the binder resulting from the clay content. Also it gives some indication of the amount of swelling and shrinkage that will result in the wetting and drying of that fraction tested. The plasticity index is nothing but a measure that gives the amount of water which must be added to change a soil from its plastic limit to its liquid limit. Generally the behavior of all soils and specifically clays considerably differs with the presence of water so one needs a reference index to clarify the effects [3].

The Atterberg limits and related indices have proved to be very useful for soil identification and classification. The limits are often used directly in specifications for controlling soil quality for use in fill and in semi empirical methods of design. Soils are classified by AASHTO and USCS based on their Atterberg limits and on particle size as determined by sieving [3].

2.8.3. Free swell

The amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several physico-chemical aspects of the soil. Among clay minerals Montmorillonite influences the magnitude of swelling as compared to Illites and kaolinites. The simplest test conducted is free swell test. The test is performed by slowly pouring 10cm³ of dry soil which has passed the No. 40 (0.425mm) sieve in to 100 cm³ graduated cylinder filled with distilled water. After 24 hours, final volume of the suspension is read. Hence, free swell is defined as: [4].

$$\text{free swell} = \frac{\text{final volume} - \text{initial volume}}{\text{initial volume}} * 100\%$$

- Free swell < 50% , Not Expansive
- Free swell between 50- 100%, Marginal
- Free swell > 100, Expansive

2.8.4 Californian Bearing Ratio (CBR)

The strength of sub base materials are expressed in terms of their California bearing ratio (CBR) value. This test is used to evaluate the potential strength of sub grade, sub base and base coarse material including recycled materials for use in road and air field pavement. It is conducted to determine the load that the material can carry in kilo newton per square meter (kN/m²). The test

method is primarily intended for but not limited to evaluating the strength of cohesive materials having maximum particle size less than 19mm. the determination of the CBR of a material is at optimum moisture water content or range of water content from specified compaction test and specified dry unit weight. The dry unit weight is usually given as a percentage of maximum dry unit weight from the compaction test. This method covers the laboratory determination of the California Bearing Ratio of a compacted or undisturbed sample of soil. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio [1].

2.8.5 Moisture – Density relations by modified proctor test

The test is conducted for determining the relationship between the moisture content and density of soil when compacted in a given mold of a given size with 4.54kg or 10lb rammer dropped from a height of 457mm (18in)[1]. Four alternative procedures are provided according to AASHTO T 180-95 as follows.

Method A – A 101.60mm (4 in) mold: soil material passing a 4.75mm sieve size.

Method B – A 152.40mm (6 in) mold: soil material passing a 4.75mm sieve size.

Method C – A 101.60mm (4 in) mold: soil material passing a 19mm sieve size.

Method D – A 152.40mm (6 in) mold: soil material passing a 19mm sieve size.

The minimum in- situ dry density of sub-base material shall be as specified hereinafter for the layers in terms of a percentage of modified AASHTO density.

✦ 95% or 97% as required for material not chemically stabilized.

✦ 95% or 96 % as required for chemically stabilized material.

2.8.6 Specific Gravity

The specific gravity (G) of soil is defined as the ratio in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at standard temperature. The specific gravity is given by:

$$G = \frac{\gamma_s}{\gamma_w}, \quad \text{Where:} \quad G = \text{specific gravity of soil solids}$$

γ_s =unit weight of soil particles.

γ_w =unit weight of water.

The specific gravity of a soil is used in calculating the phase relationships of soils water, and solids in a given volume of the soil. Also specific gravity of soils is an important engineering index. Which is frequently used in determination of different properties of soils in laboratory as well as in real practice. In the present tests, it will be used to calculate the percentage finer in hydrometer analysis. Procedures for performing the specific gravity are provided in ASTM D854-00 [4]

CHAPTER THREE

3. OVERVIEW OF THE STUDY AREA

3.1. General

Durame is a town in South Ethiopia, located in Kembata Tembaro zone of the South Region, about 345 kilometers from Addis Ababa. It has a latitude of 7° 14'N 37°53'E and elevation of 2101 meter above sea level. Durame prosperity was due to its location on the Durgi-Addis Ababa road route. Two roads connect the town from Addis Ababa through Shashamene and from Addis Ababa through Hosanna. The road when completed will enhance all round development in the town in particular and in the country in general.

3.2. Description of the Project

The research was conducted as a case study on the Durame Intercity Road Project which is a part of the project road Mazonia – Durame – Durgi contract 1 Km 0+000 – 37+500 located in the Southern Nations, Nationalities and Peoples Regional States (SNNPRS) and it connects two major link roads, namely Alemgena – Hosanna – Sodo and Alaba – Sodo – Arbaminch. The project starts at Mazonia Town, 335km South West of Addis Ababa, and passes through Durame and Shinshicho towns. The work comprises upgrading of an existing road to a DS4 standard road as per ERA's manual 2002 Classification. The detailed engineering design and tender documents for the proposed works have been carried out by METAFERIA consulting engineers PLC.

The road when completed will enhance all round development in the vicinity of the project in particular and in the country in general. Moreover, in addition to accelerating the economic development, the road will reduce the operation cost of vehicles and increase the administrative and social coverage in the region.

3.3. Climate

The major factors influencing the rainfall in Ethiopia are the Inter Tropical Convergence Zone (ITCZ) and winds blowing from the Atlantic and Indian Ocean. The traditional classification of

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

climatic zones in Ethiopia is based on altitude and temperature. It divides the country into five climatic zones as shown in the table [9]:

Table 3-1: Ethiopian climatic zones [9]

Climatic Zone	Elevation (m)	Average Temperature (°C)	Average Annual Rainfall (mm)
Wurch (cold)	> 3 200	< 10	< 800
Dega (cool-cold)	2 300 – 3 200	10 - 16	1 000 - 2000
Weina Dega (warm-cool)	1 500 – 2 300	16 - 20	1 200
Kolla (hot-warm)	500 – 1 500	20 - 28	600 (1 000 in places)
Berha (hot)	< 500	28 - 34	< 400

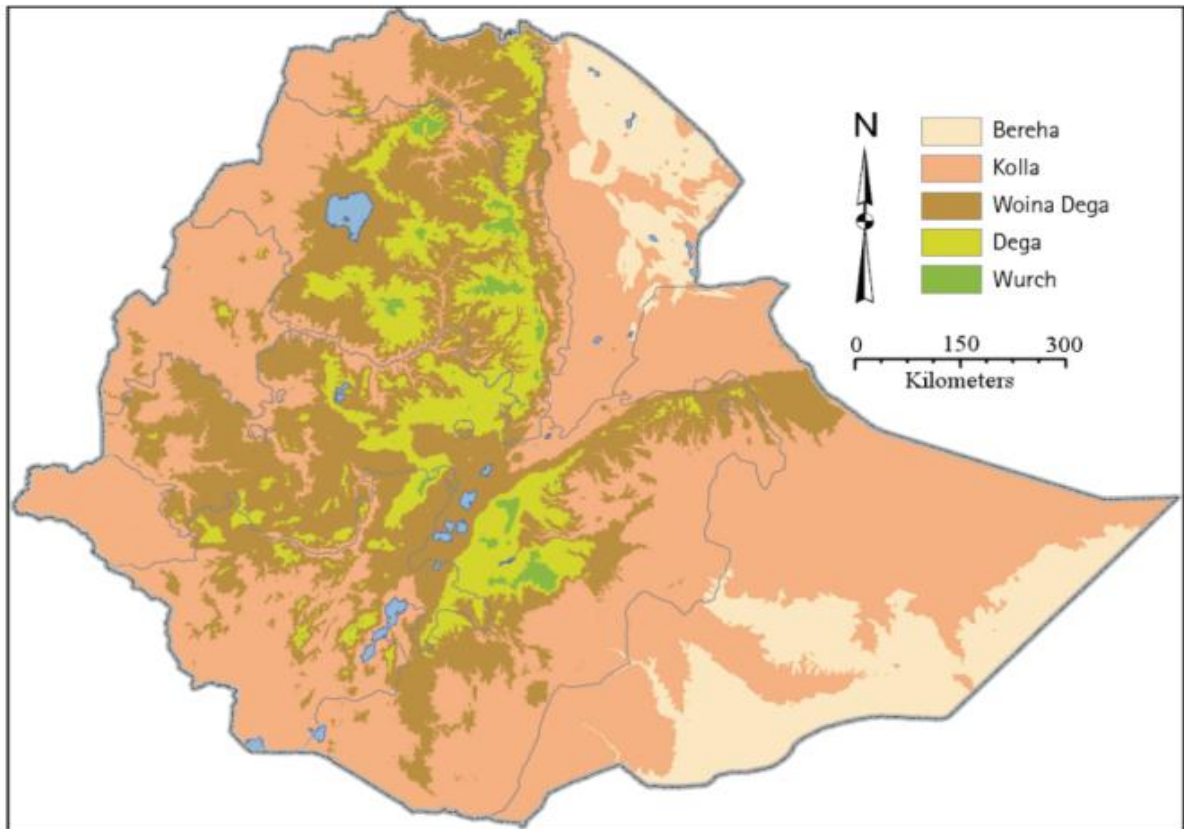


Figure 3-1 Traditional climatic zones in Ethiopia [9]

The project area is located in the Southern part of Ethiopia with elevation of 2101 meters above sea level and fall in temperate/ Woinadega climatic zones. The mean monthly temperature of the area varies between 10°C and 30°C and the project area receives mean annual rainfall ranging from 1200mm to 1600mm. The monthly distribution of the rainfall indicates that the minimum rainfall is

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

received from the month November to February which amounts from 10mm to 50mm, while the maximum rainfall is received from June to August ranging from 100mm to 300mm. The mean period of onset of summer rains is from 6th to 10th of April and the mean period of cessation of summer rain is from September 28 to October 20.

Table 3-2: Monthly Rainfall and Average Temperature at project corridor

Item	September - October	November - February	March - May	June - August
Rainfall (mm)	10-50			100-300
Average Temperature (°c)	10-30			

Source: National Meteorological Services Agency (NMSA)

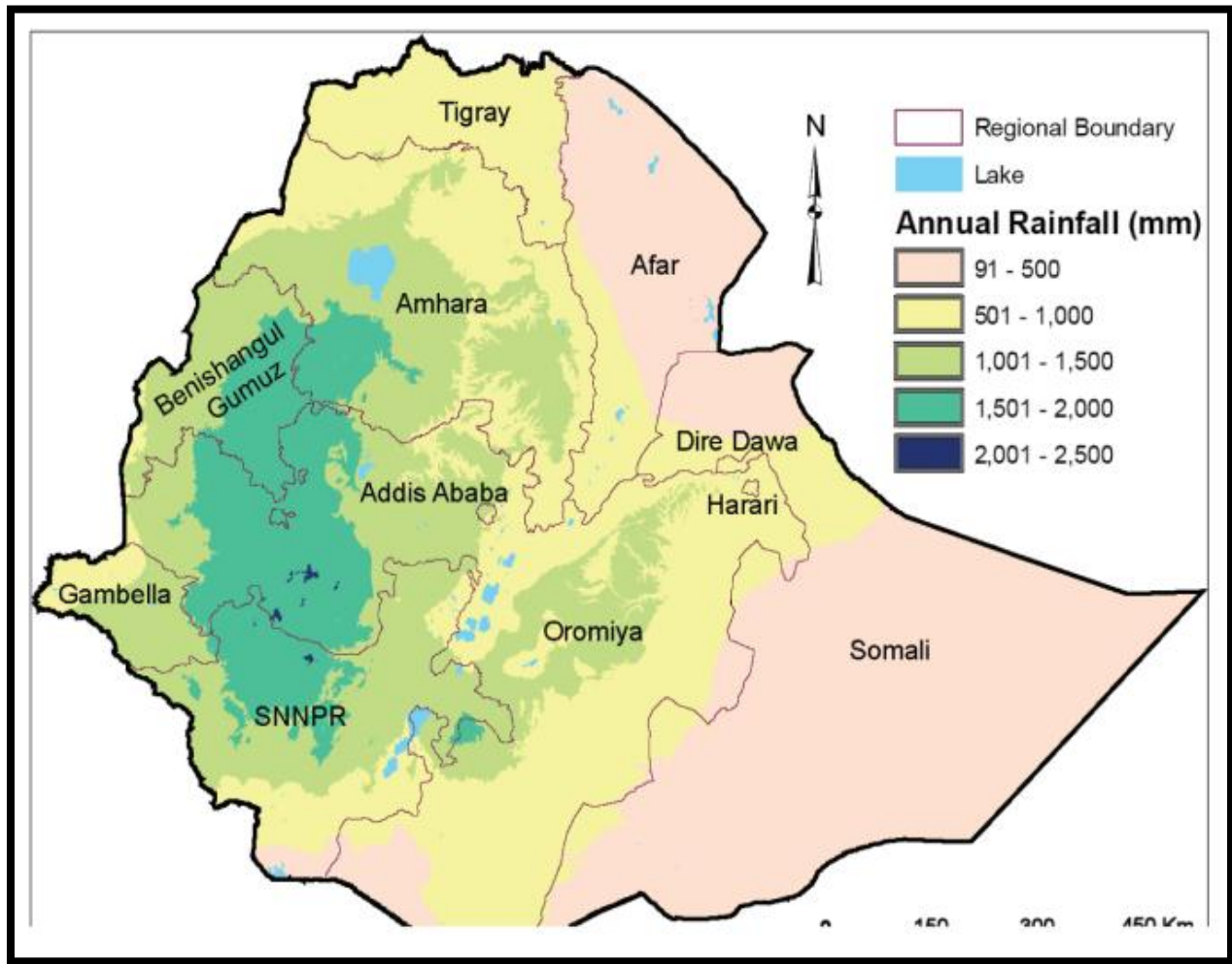


Figure 3-2 Traditional climatic zones in Ethiopia [9]

3.4. Soil and Material

The project technical specification for the quality of the material or sub base states that, “sub base material shall be natural screened or crushed or an approved blended combination of such material providing a homogeneous sub base material meeting the requirements of grading A of table 5104/1 of the standard technical specification or as directed by the Engineer. If the natural material available at the project can't meet the specified grading requirements, it shall be screened, crushed and screened or blended as required to meet the grading requirement.”

Based on the project initial investigation made by the design consultant for identification of sub base sources, it actually found that most of the sources pertained to the required tests; fail to satisfy the requirement of the project technical specification or ERA 2002 Manual Standard Technical Specification. Especially to the required indices or properties of the material especially to its liquid limit, plasticity index and gradation problem. In order to solve this problem, the contractor use by blending the fine grained soil with locally available cinder.

The samples in this study were collected around Durame area. The available cinder gravels are located 15 km (GPS indicated 07°04.5370'N, 037°58.8975'E) far from the project and the fine grained soil of the blending materials are located 5 km (GPS indicated 07°14.2191'N, 037°51.2904'E) far from Durame town. The fines borrow materials are also used in the sub-grade construction of the road. Cinder is collected from quarry. They vary in colour, often within the same quarry and may be red, brown, grey, or black. The particle sizes also vary from irregularly shaped lumps of 0.5 m diameter to sand and silt sizes. Other characteristics features of cinder are their light weight, their rough vesicular surface, and their high porosity. The surface of cinder aggregate is usually rough and highly porous due to its mineral structure. The specific gravity of cinder gravels is obtained as 2.44.

The status of the project, when this study was conducted, was under construction of the sub-base layer. The blended cinder gravels with fine-grained soils being used to construct the sub- base layer is without any specified proportion of the blended sub-base materials.



Figure 3-3 Location of the project (Source: Ethiopian Road Map)



Picture 3-1 Material site for fine grained soil



Picture 3-2 Quarry site for cinder gravel

CHAPTER FOUR

4. LABORATORY TEST RESULTS

4.1. General

In this chapter laboratory test results are presented and their analysis is briefly discussed. The relevant engineering property of the soil is evaluated both for natural and stabilized soil samples separately. The tests include Atterberg limits, free swell, compaction, grain size analysis and CBR. All the tests were conducted on Cinder gravel mixed with different percentage of fine grained soil according to standard testing procedure of ASTM and AASHTO.

4.2. Properties of Materials Used in the Study

4.2.1 Cinder Gravel

The cinder gravel is classified as A-1-a material since in gradation test of cinder gravel less than 15 % passes through No.200 sieve, less than 30 % passes through No.40 sieve and its PI value is less than 6%. The cinder gravel is a weak material and has a high water absorption capacity because of high porosity.

Table 4-1: Descriptive test results of natural cinder gravels used for the study

Type of test		Test Results
Gradation, % passing	63	100
	50	100
	25	69.2
	4.75	27.8
	0.075	2.1
Plasticity Index		NP
Moisture-Density Relation	MDD,g/cc	1.67
	OMC,%	2.3
Specific Gravity		2.44
CBR (%)		64

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

The descriptive test results in Table 4.1 show that cinder gravel is a weak material in general to be used as a Sub base material. The gradation test result has shown that the cinder gravel is deficient in fines. To improve the property of this material fine grained soils found near the quarry sites was blended with cinder gravel to make up for the deficiency of fine materials to use as Sub base material. Table 4.2 shows the descriptive test results carried out on fine grained soil samples that were collected from quarry sites of the road project for this purpose.

Other descriptive laboratory test results are attached in Appendices.

4.2.2 Fine grained Soil

A yellowish silt soil was used in this study. The following laboratory tests were conducted on the natural soil sample.

- ❖ Atterberg limits
- ❖ Grain size analysis
- ❖ Specific gravity
- ❖ Compaction
- ❖ CBR
- ❖ Free swell

From the summary of the test result shown in Table 4.1, the fine-grained soils obtained in the project area are visually classified as yellowish silt and based on the laboratory test results and AASHTO classification; it is classified as clay with medium plasticity (A-6) and ML based on USCS soil classification system. These materials were also used in the embankment and sub-grade road construction in the Matoria – Hadero upgrading road project. Test results have been summarized in table 4.2, and detailed test results are given in Appendices.

Table 4-2 : Test results of fine-grained soil used for mechanical stabilization

Type of test		Test Results
Gradation, % passing	63	100
	50	100
	25	98.73
	4.75	90.61
	0.075	53.32

Atterberg limits, %	Liquid Limit	37.8
	Plastic Limit	25.7
	Plasticity Index	12.1
Moisture- Density Relation	MDD,g/cc	1.55
	OMC,%	26
Specific Gravity		2.55
Free swell		37.5
CBR (%)		14
AASHTO Classification		A-6
USCS Classification		ML
Color		Yellowish/ashy

4.3. Laboratory Test Results of Cinder Blended with Fine grained soil

In this section, laboratory test results of blended materials was discussed for fine grained soil of various combinations.

4.3.1 Index property tests

Generally, the index tests are used to classify soils. Particle size distribution and gradation curve reveal the different proportion of particle sizes that comprise the soil. Therefore, it is a very important test in order to know and classify the soil type.

4.3.1.1 Particle size distribution & gradation

The test includes the determination of the size range of particles present in a soil, expressed as a percentage of the total dry weight. The results are used to determine particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various materials and mixtures containing aggregate used in road construction. Two methods are generally used to find the particle size distribution of soil:

- i) Sieve analysis:- for particle sizes larger than 0.075mm in diameter
- ii) Hydrometer analysis: - for particle sizes smaller than 0.075mm in diameter

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The property of aggregate used for road construction purpose is distribution of particles sizes in the aggregate mix. The gradation of cinder gravel improved by blending with the fine grained soil and the blend of the particle sizes in the mix, affects the density, strength, and economy of the pavement structure. A grain size analysis is used to determine the relative proportions of various particle sizes in a given soil. To do this analysis, a wet sieve analysis is performed which is given in AASHTO T-146 and selected sample of dried soil is shaken over a nest of sieves having selected sizes of square openings. The cinder sample is shaken, and the weight of material retained on each sieve is determined and expressed as a percentage of the original sample. Detailed procedures for performing a grain sieve analysis of coarse and fine aggregates are given in AASHTO Method T-27 [1].

In order to meet the requirements stipulated under ERA manual (2002), the sub-base material shall comply with one of the grading shown in Table 4.3. The material shall have a smooth continuous grading within the limits for grading A, B or C given below.

Table 4-3: Ethiopian Roads Authority grading limits for sub-base material [9]

Sieve Size (mm)	Mass Percent Passing			
	A	B	C	D
63.0	100	-		-
50.0	90 - 100	100	100	-
37.5			80-100	
25.0	51 - 80	55 - 85		100
20			60-100	
9.5	-	40 - 70		51 - 85
5			30-100	
4.75	35 - 70	30 - 60		35 - 65
2.0	-	20 - 51		25 - 51
1.18			17-75	
0.425	-	10 - 30		15 - 30
0.3			9-50	
0.075	5 - 15	5 - 15	5-25	5 - 15

The complete sub-base shall contain no material having a maximum dimension exceeding two-thirds of the compacted layer thickness.

Among the grading limits, grade A has a practical implementation as practiced in the Project. Taking these advantages this thesis work is made based on grading A specification.

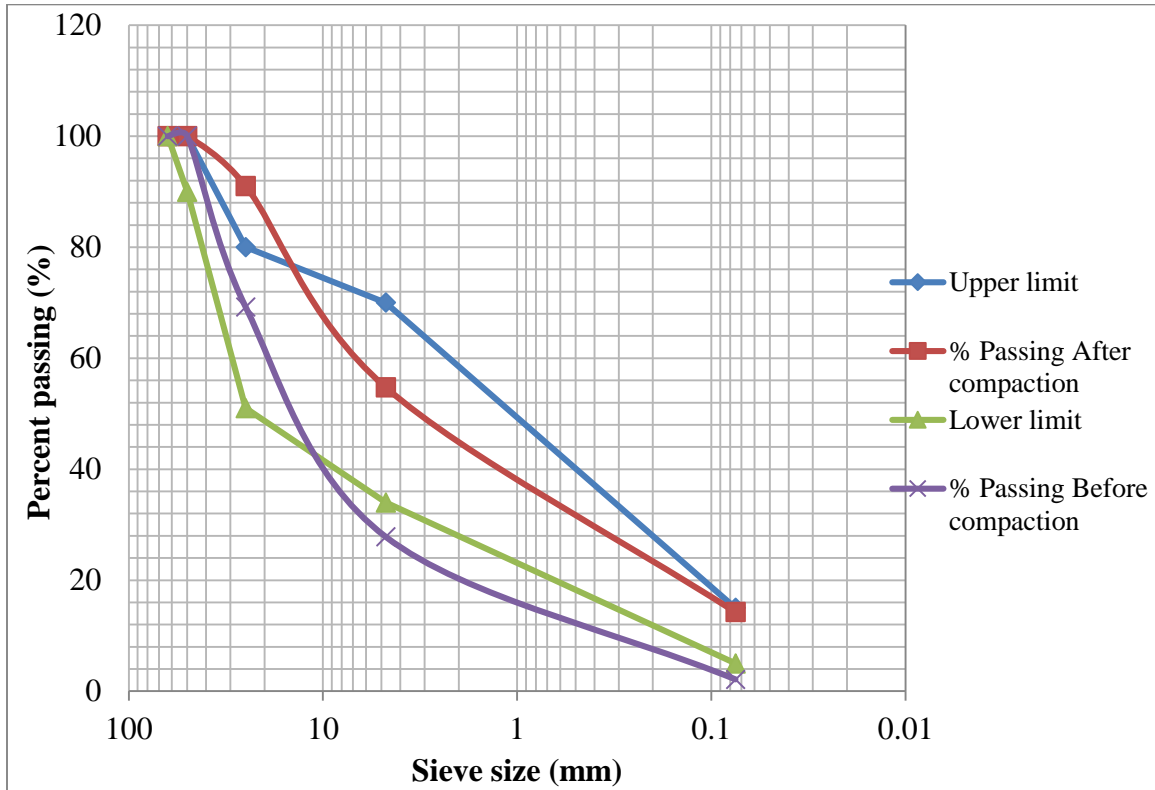


Figure 4-1 Gradation before and after compaction of natural cinder gravel only

The grading chart of natural cinder gravel in Figure 4.1 shows the deficiency in fine particle. Therefore, it is out of the specification. Blending of a trial proportion of fine-grained soil improves the gradation and the optimum proportioning is found to fulfill the ERA specification manual requirement for respective project. Among the trail proportioning of fine-grained soil 20 % and 10 % are good proportioning from gradation point of view. The next Figures summarize the above point.

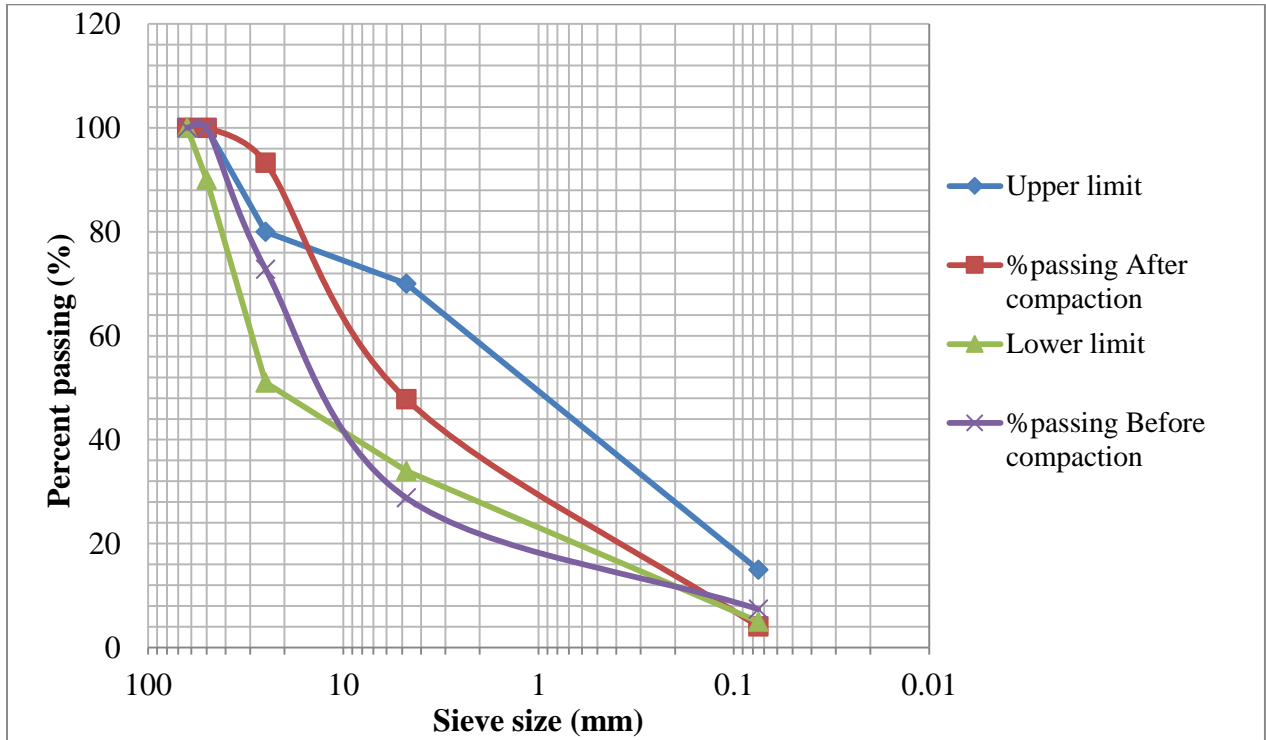


Figure 4-2 Gradation before and after compaction of cinder with 10 % fine-grained soil

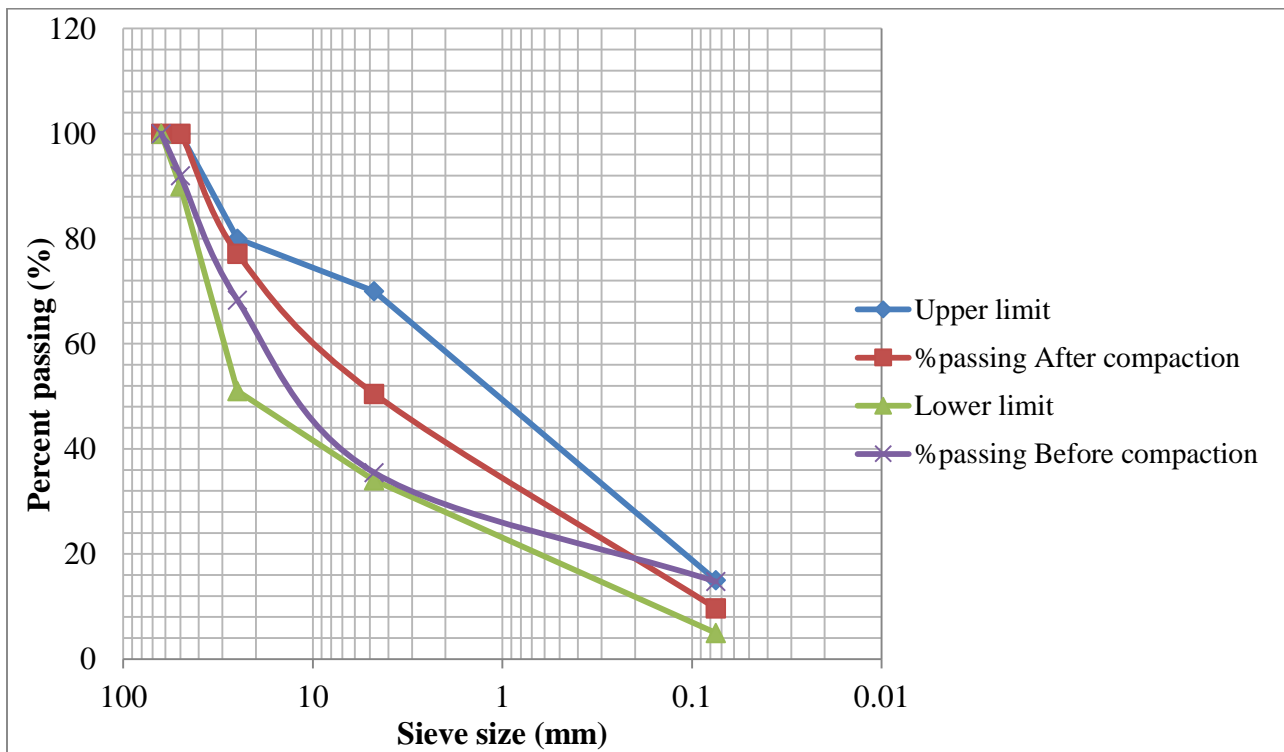


Figure 4-3 Gradation before and after compaction of cinder with 20 % fine-grained soil

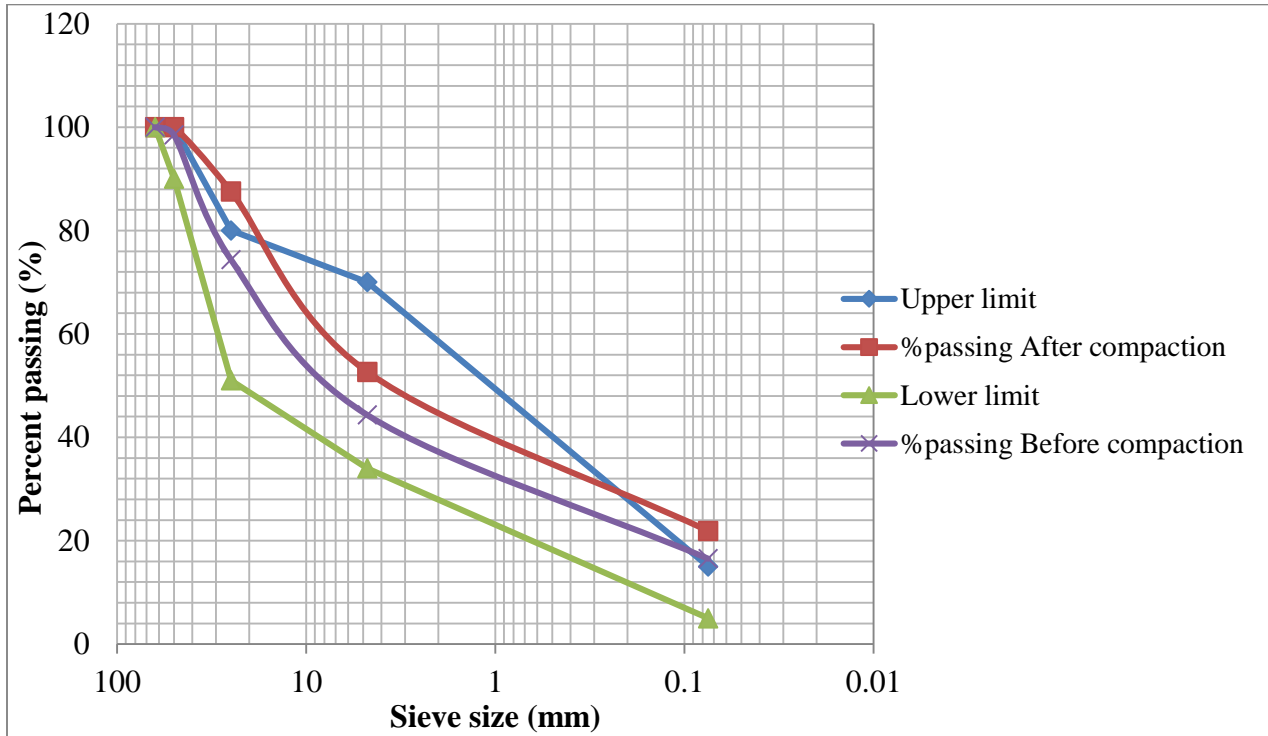


Figure 4-4 Gradation before and after compaction of cinder with 33 % fine-grained soil

Figures 4.1 to 4.4 clearly show that the modified AASHTO compaction method resulted in the largest amount of crushing. The laboratory test result shows that because of the weak nature of cinder gravels, break down under compaction occurred with an improvement of gradation but still needs an additional fine-grained soil to achieve the ERA specification. For construction purposes, optimum amount of fine-grained soils are required to ensure that the finished granular surface is stable enough to carry the paving equipment without disruption of the surface and some fines are required so that when the sub-base is compacted, the granular material will bind and the particles will inter lock. Otherwise they would shear when loaded [16].

If a material has a continuous grading following the full curve, then the voids between the larger particles are filled with fine material resulting in a dense packing. This immediately results in a larger number of contact points between the particles. The resistance to shear of the skeleton depends on the sum of the frictional forces that are generated between the particles. When the number of contact points increases, also the total friction in the skeleton increases which in turn results into a higher resistance to shear. Other descriptive results shown in the Appendices.

4.3.1.2 Moisture-Density Relationship by Modified Proctor Test

Compaction of a soil is a means of improving the engineering properties of soil by mechanical method. When a soil is compacted, air in the voids will be expelled and the density of the soil mass increases. Most soils exhibit a similar relationship between moisture content and density (dry unit weight) when subjected to dynamic compaction. Because, practically the cohesive soils have optimum moisture content at which the soil attains maximum density under a given compacting effort but the granular soils difficult to define. This fact, which was first stated by Proctor in a series of articles published in Engineering News-Record in 1933, forms the basis for modern construction process commonly used in the formation of highway sub-grades, bases, embankments, and earthen dams. In laboratory, dynamic compaction is achieved by use of a freely falling weight on confined soil mass; in the field, similar compaction is secured through the use of rollers or vibratory compactors applied to relatively thin layers of soil during construction process starting from road edge to the center of the road. 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 shear strength of the soil, and hence the stability and bearing capacity. It is also useful in reducing the compressibility and permeability of the soil [3].

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

In this thesis, 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. Table 4.4 summarize the variations of MDD and OMC with different proportion of fine grained soil. Figures 4.5 also show the variation of MDD and OMC for different proportion of cinder mixed with fine grained soil. The detailed test results are presented in appendix.

Table 4-4: Determination of MDD & OMC with different fine-grained soil proportions

% of fine grained soil replaced	MDD(g/cc)	OMC (%)
0	1.67	2.3
10	1.7	6.5
20	1.87	11.8
33	1.84	14

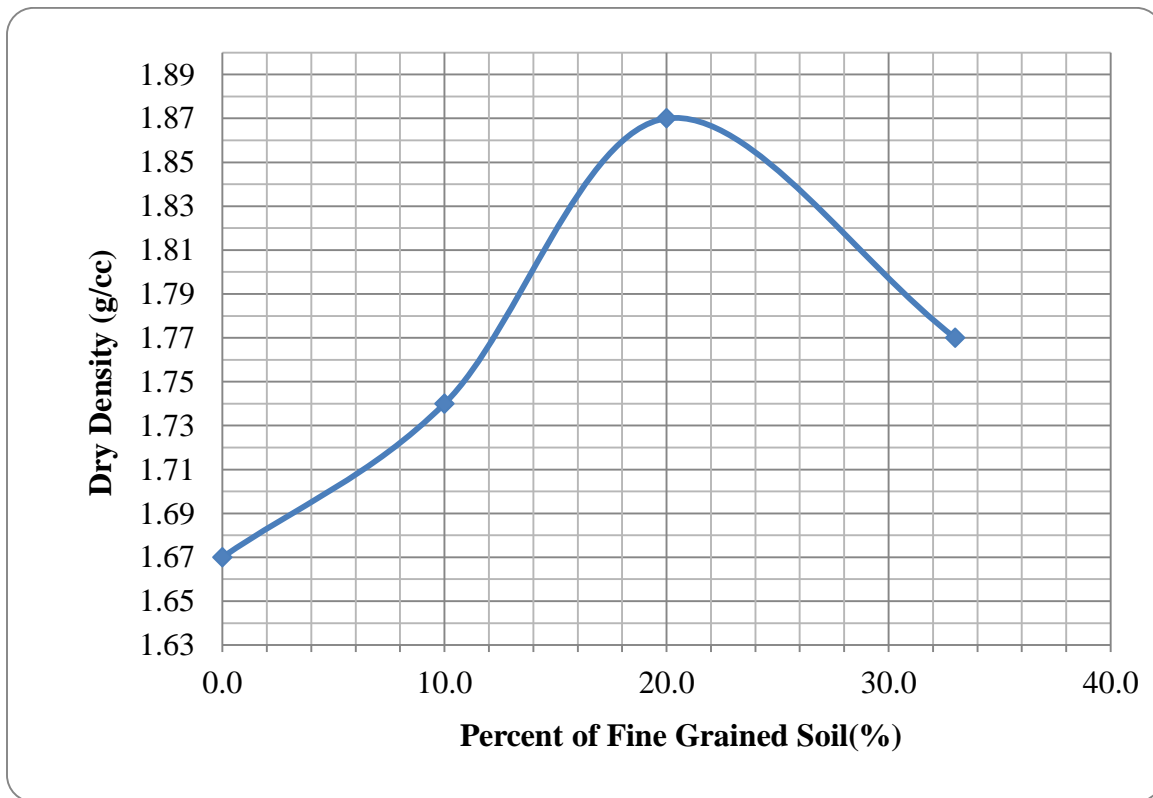


Figure 4-5 Variation of MDD with percentage of fine-grained soil mixed with cinder

From the compaction test result, it is found that, the max dry density increases by the addition of cinder up to 20 % and then the MDD decreases.

4.3.1.3 Atterberg limits

According to ERA specification, all sub-base materials shall have a maximum plasticity index of 12 when determined in accordance with AASHTO T-90. The plasticity product ($PP = PI \times$ percentage passing the 0.075mm sieve) shall not be greater than 75% [9]. Table 4.5 shows that 0 and 10 % of the blending proportion of material by weight with cinder has no plasticity characteristics and blending proportion 20 and 33 % has plasticity of 3.5 and 6.1 % respectively. Therefore, all the proportions except 33 % satisfy the ERA manual specification.

Table 4-5: Plastic index for blended material

% of fine grained soil replaced	Plasticity index
0	NP
10	NP
20	3.5
33	6.1

4.3.2 California Bearing Ratio (CBR) test

The test is conducted as per AASHTO T-180 method D. In CBR test mould of internal diameter 150 mm and height 175 mm and collar of 50 mm is used. From the maximum dry density obtained from modified proctor test, the mass of soil occupied in the mould is determined by multiplying the maximum dry density by volume of CBR mould. The soil is mixed with optimum amount of water and filled in the mould completely in 5 layers. Unsoaked samples were made for the determination of CBR ratio. Soil samples are placed on bottom plate of loading device. Annular surcharge weight equal intensity of base material and the pavement is placed. Load is applied at a strain rate of 1.27 mm/min. Penetration is measured by strain gauge. Load is recorded at the penetration of 0.0, 0.64,

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1.24, 1.96, 2.54, 3.18, 3.81, 4.48, 5.08, 7.62, and 10.16 mm. The CBR test has been performed on cinder with different percentage of fine grained soil of 0%, 10%, 20% and 33 % of dry weight of soil. This proportion was selected in order to comply with the actual site condition at the time of dumping.

According to ERA manual, for the sub-base material the minimum soaked California Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T-193. The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D [9]. The determination of the CBR and percent swell of cinder gravel only are presented in Appendix C.

Table 4-6: Values of CBR and Swell percent of different proportion of fine-grained soil

% of fine grained soil replaced	CBR (%)	(%)Swell
0	64	0.033
10	72	0.054
20	97	0.14
33	62	0.34

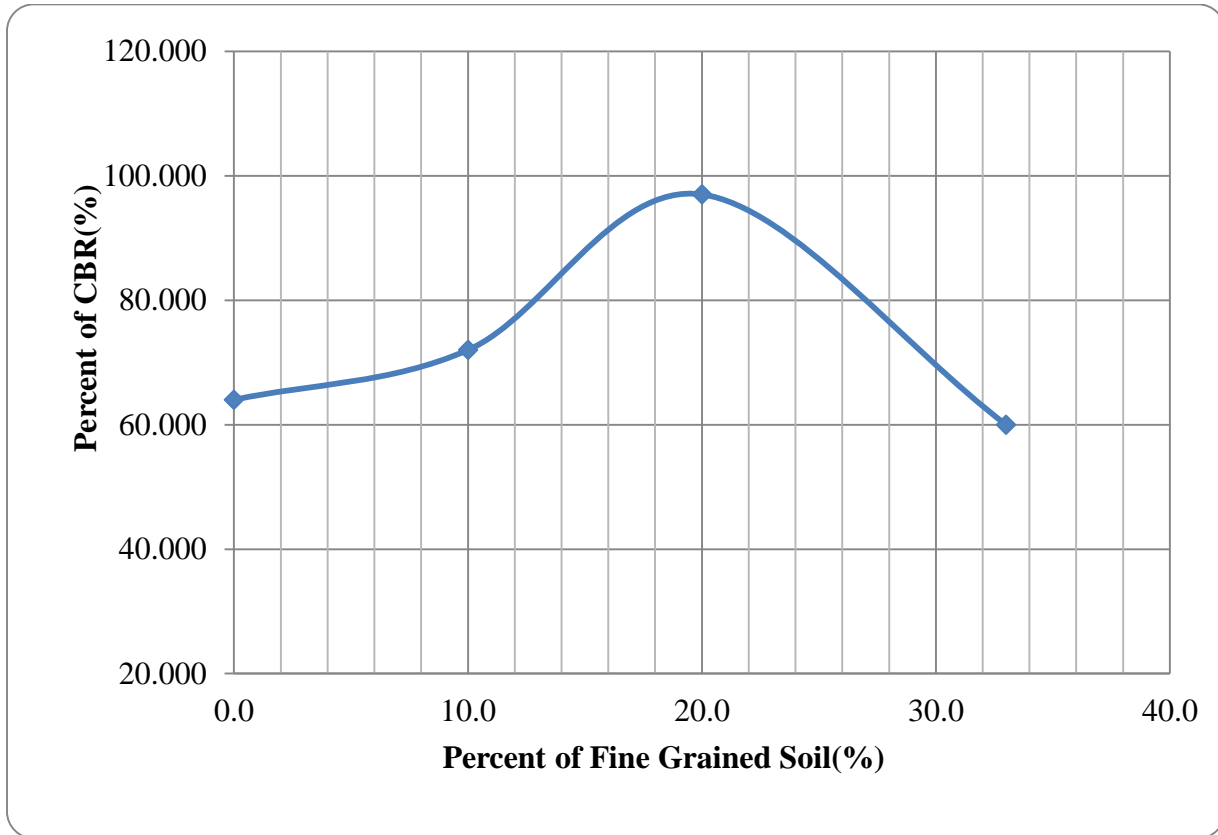


Figure 4-6: Percent of fine grained soil vs percent CBR

All the results shown on the above figure for 0, 10, 20 & 33 % of fine-grained soil by dry weight satisfies the ERA manual requirements. The variations of California Bearing Ratio (CBR) with different percentage of fine grained soil are shown in Figures 4.6 for soaked condition. The maximum California Bearing Ratio (CBR) value of 97% is found to occur with the combination of 20 % fine grained soil contents under soaked condition.

From the CBR vs. percent of fine grained soil shown in Figure 4-6 one can see that the CBR value increased as the percentage of fine grained soil increase up to 20 % and decrease beyond that this implies the optimum amount of fine-grained soil is 20 % by dry weight.

According to ERA specification, for the sub-base materials the minimum soaked California Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T-193. The result shows that the minimum soaked CBR meets the minimum requirements of the specification. The overall results confirms that the blended material is best material when used as a sub base material.

4.3.3 Free swell

This test helps to know the expansiveness of a soil by measuring the volume of soil sample that is soaked & settled down in water for 24 hrs. In this section, the free swell test was conducted for only fine grained soil.

The test is performed by slowly pouring 10cm³ of dry soil which has passed the No. 40 (0.425mm) sieve in to 100 cm³ graduated cylinder filled with distilled water. After 24 hours, final volume of the suspension is read. From the test results the value of the free swell was 37.5%, this shows that the soil was not expansive because the free swell < 50% .The details of the free swell test for fine grained soil is shown in Appendix A.

4.3.4 Abrasion resistance

This test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres, the number depending upon the grading of the test sample. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate picks up the sample and the steel spheres, and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss.

The Ethiopia Road Authority Manual Specification recommends that the Los Angeles Abrasion value shall not exceed 51% when determined in accordance with the requirements of AASHTO T-96. Abrasion resistance applies only to coarse aggregates. Aggregates vary in their resistance to fracturing under impact (toughness) and breaking down into smaller pieces from abrasive action (hardness). The acceptable limits are set by the Los Angeles Abrasion Test AASHTO T-96. The limits vary from 30.0 to 50.0 percent, depending on the classification of the aggregate. The percentage is a measure of the degradation or loss of material as a result of impact and abrasive actions [9].

To conduct this test the test sample place in the Los Angeles testing machine and rotate the machine at a speed of 30 to 33 r/min for 500 revolutions. After the prescribed number of revolutions,

discharge the material from the machine and make a preliminary separation of the sample on a sieve coarser than the 1.70-mm (No. 12).

$$LAA = \frac{(\text{Total weight of material tested} - \text{Material retained on 1.7mm sieve size after testing}) \times 100}{\text{Total weight of material tested}}$$

The average calculated values LAA for natural cinder by use of the Los Angeles Abrasion machine is 45.6 %. This value satisfies the ERA manual specification but shows that cinder gravel is weak in resistance to abrasion.

4.3.4 Specific Gravity

The specific gravity of a soil is used in calculating the phase relationships of soils water, and solids in a given volume of the soil. Also specific gravity of soils is an important engineering index. Which is frequently used in determination of different properties of soils in laboratory as well as in real practice. In the present tests, it will be used to calculate the percentage finer in hydrometer analysis. Procedures for performing the specific gravity are provided in ASTM D854-00 [4]

4.3.5 Absorption Test

To know some of the especial characteristics cinder gravel the determination of absorption potential is important. AASHTO T-85 defines absorption as the increase in the weight of aggregate because of water in the pores of the material, but not including water adhering to the outside surface of the particles. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by AASHTO T-255 drying [1].

Laboratory test results showed that the absorption of the cinder gravel that passes sieve 4.75 mm is 12.85 %. This high water absorption capacity of the cinder gravel is due to the fact that cinder is light weight aggregate and highly porous at its natural state.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

This chapter includes conclusions drawn from the laboratory test results discussed in the previous chapter and recommendations that are applicable in projects involving cinder gravel blended with fine grained soil to be used as a sub base material. It also provides recommendations research areas for the future.

5.1. Conclusion

The following conclusions can be drawn from the results of the study/investigation carried out within the scope of the study.

1. The sieve analysis, which was conducted after the compaction of natural cinder gravels, has shown that a significant breakdown of coarser cinder gravel particles.
2. The gradation of cinder gravel samples lacked fine particles and 20 % of fine soil by weight was found to be optimum for making up this deficiency.
3. The CBR ratio at 20% replacement of fine grained soil was found to be 97%. The CBR ratio increased 4 times than raw fine grained soil. This is the optimum percentage of fine grained soil from CBR-percent of fine-grained soil curve.
4. The property of cinder gravel is improved when blended with optimum fine grained soil percentage.

From the above results, one can conclude that fine grained soil improves the strength characteristics of the given cinder gravel.

5.2. Recommendation

From the results of the study, it is observed that the application of fine grained soil improves the strength characteristics of cinder gravel. However, this research was conducted to obtain the optimum blending proportion of cinder with fine-grained soil only in the case of Durame Intercity Road Project due to financial constraints and time limitations the present research work did not cover the whole cinder gravel in Ethiopia. As a result, the following recommendations for better use of cinder gravels in road construction.

1. Field performance evaluation of should be conducted at a pilot section.
2. Examining the performance of cinder gravel when blended with fine grained soil throughout the country was not the scope of this study. Therefore, further study should be done to assess the stabilizing potential of cinder gravel in Ethiopia to examine its use when blended with fine grained soil as sub base materials for different areas of cinders in Ethiopia.
3. The findings in this study can be used as a basis for further researches in the field of cinder gravels found in different parts of the country.
4. Standard should be developed to make use of natural cinder gravel as a road construction material across Ethiopia

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APPENDICES

Appendix A
Test results of Fine Grained Soil from quarry site

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Table A-1: Determination of specific gravity

Mass of empty ,clean pycnometer	gm.	M ₁	47.5	63.4
Mass of empty pycnometer +dry soil	gm.	M ₂	57.5	73.4
Mass of pycnometer + dry soil +water	gm.	M ₃	153.4	168.7
Mass of pycnometer + water	gm.	M ₄	147.35	162.6
Temperature	C ^o		22	21.5
G _T			0.9996	0.9997
Specific gravity	$G = \frac{GT \times (M2 - M1)}{(M2 - M1) + (M4 - M3)}$		2.53	2.56
			2.55	

Table A-2 : Sieve Analysis (wet preparation method)

Total weight before washing (gm)		949.1	
Total weight after washing (gm)		460	
Loss		489.1	
Sieve Sizes (mm)	Weight Retained (g)	Cumulative Pass	
		%retain	%pass
63	0.00	0.00	100.00
50	0.00	4.25	100
25	12	13.57	98.73
4.75	77	8.29	90.61
0.075	354	21.57	52.32
pan	506.1	55.31	

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table A-3 : Hydrometer analysis for fine grained soil

HYDROMETRE ANALYSIS									GS	2.55	
									sample weight	50	
time	Elapsed time (min)	T ⁰	Actual hydrometer reading	meniscus correction	L	k	D (mm)	Ct	Correct hydro.	%finer	%adjusted finer
1	1	21	1.032	1.033	7.8	0.014	0.04	0.0002	1.0322	96.31672	49.634923
2	2	21	1.0303	1.0313	8.1	0.014	0.029	0.0002	1.0305	91.23167	47.014446
4	4	21	1.028	1.029	8.1	0.014	0.02	0.0002	1.0282	84.35191	43.469094
8	8	21	1.025	1.026	8.3	0.014	0.015	0.0002	1.0252	75.3783	38.844722
16	16	21	1.022	1.023	8.5	0.014	0.01	0.0002	1.0222	66.40469	34.220351
30	30	21	1.019	1.02	8.9	0.014	0.008	0.0002	1.0192	57.43109	29.595979
60	60	21	1.015	1.016	9.3	0.014	0.006	0.0002	1.0152	45.46628	23.43015
120	120	22	1.0103	1.0113	9.8	0.014	0.004	0.0004	1.0107	32.00587	16.493592
240	240	23	1.009	1.01	10.	0.014	0.003	0.0007	1.0097	29.01466	14.952135
480	480	23	1.007	1.008	10.	0.014	0.002	0.0007	1.0077	23.03226	11.869221
960	960	22	1.0066	1.0076	10.	0.014	0.002	0.0007	1.0073	21.83578	11.252638
1440	1440	22	1.0056	1.0066	11	0.014	0.001	0.0007	1.0063	18.84457	9.7111806

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Dry Soil + Container (g)	38.20	41.20	36.9	23.50	23.00
Mass Container (g)	17.5	17.7	17.8	17.30	17.1
Mass Moisture (g)	7.7	8.9	7.3	1.50	1.60
Mass Dry Soil (g)	20.70	23.5	19.1	6.20	5.90
Moisture Content (%)	37.20	37.87	38.22	24.19	27.12
Average	37.76			25.66	

LL = 37.75%

PL = 25.66%

PI = 12.1%

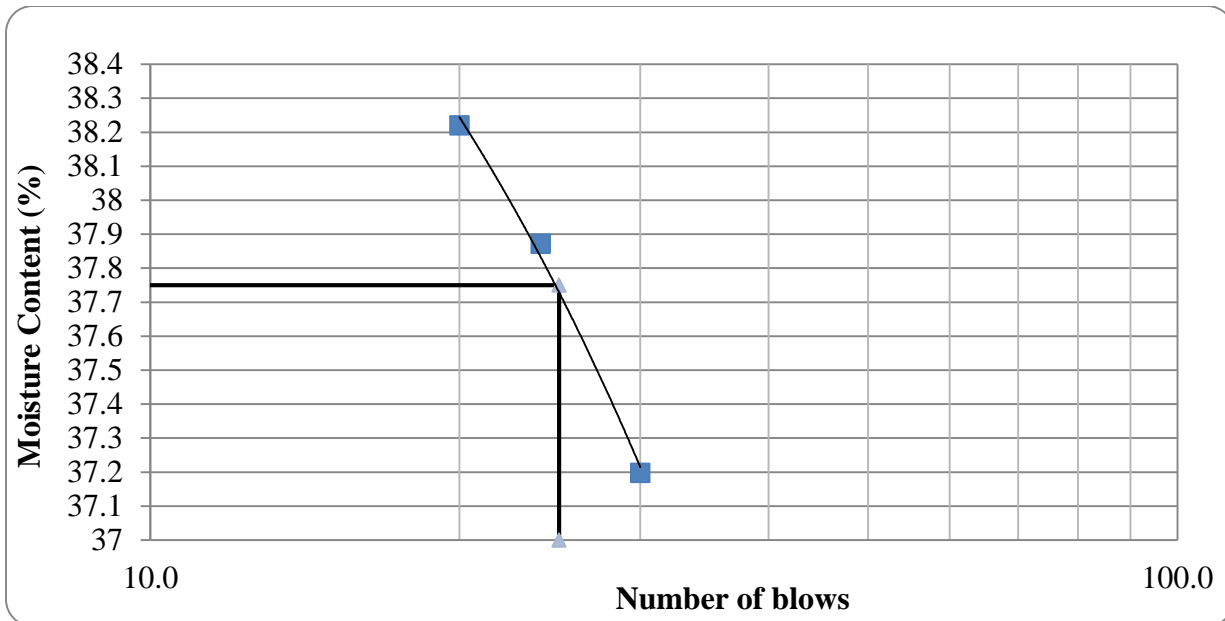


Figure A-2 : Flow curve for Fine Grained Soil

Modified Proctor test

(Test Method of AASHTO T-180)

Table A-6: Moisture-Density relations of Soils by Modified Proctor

DENSITY		TRIAL NUMBER	1	3	3	4
	1	WEIGHT OF SOIL + MOLD (g)	9539	9695	9815	9770
	2	WEIGHT OF MOLD (g)	5518	5518	5518	5518
	3	WEIGHT OF SOIL, (1-2) (g)	4021	4177	4297	4252
	4	VOLUME OF MOLD (cc)	2194	2194	2194	2194
	5	WET DENSITY OF SOIL, (3/4), (g/cc)	1.833	1.904	1.959	1.938
MOISTURE	6	CONTAINER NUMBER	N	E	Q	A1
	7	WET SOIL + CONTAINER (g)	205	214	221	227
	8	DRY SOIL + CONTAINER (g)	172	178	182	185
	9	WEIGHT OF CONTAINER (g)	30	31	32	33
	10	WEIGHT OF WATER, (7-8) (g)	33	36	39	42
	11	WEIGHT OF DRY SOIL, (8-9) (g)	142	147	150	152
	12	MOISTURE CONTENT, (10/11)*100, (%)	23.2	24.5	26.0	27.6
		DRY DENSITY OF SOIL, (5/(100+12))*100, (g/cc)	1.49	1.53	1.55	1.52

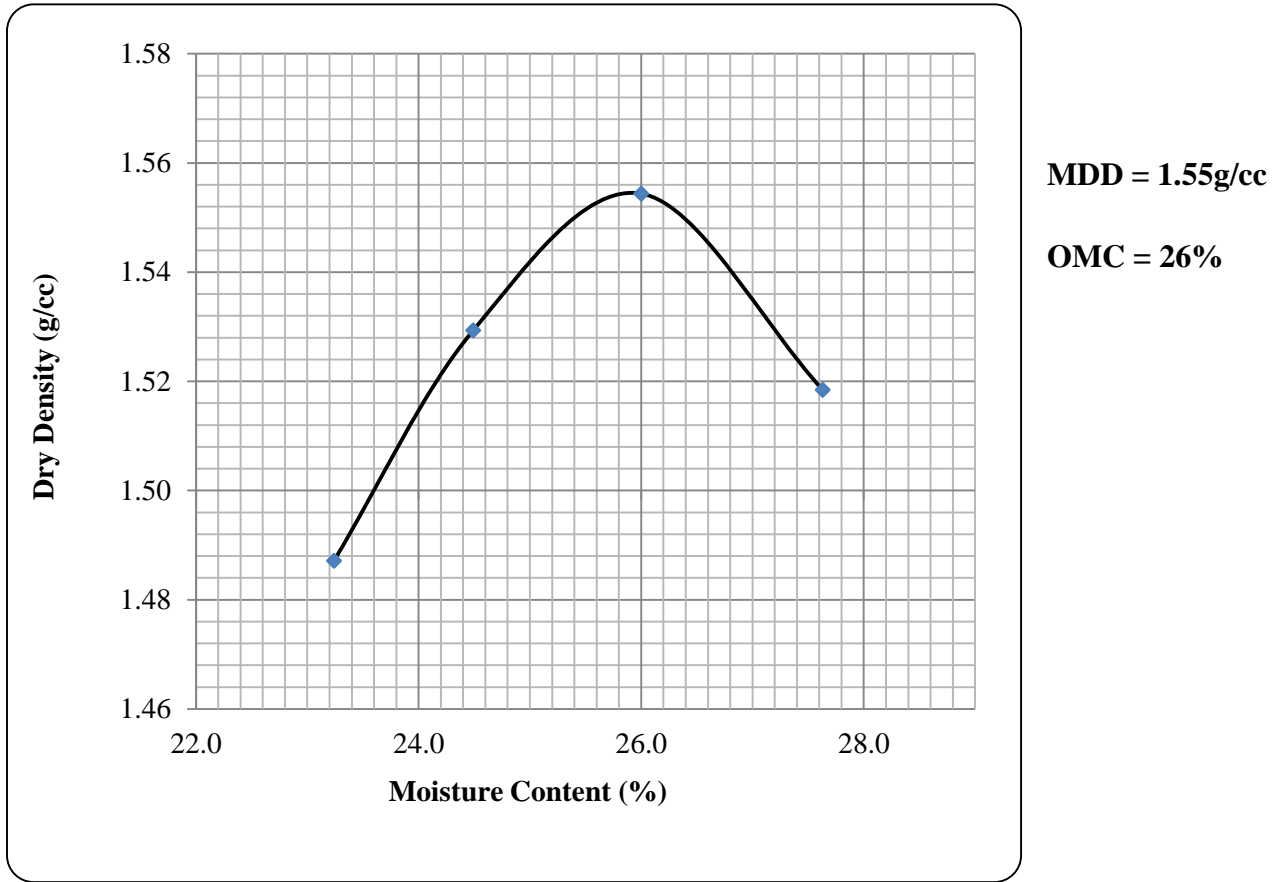


Figure A-3 : Moisture-Dry Density curve of fine grained soil

California Bearing Ratio (CBR) Test

(Test Method of AASHTO T-193)

Table A-7 : Dry density before & after soaking of fine-grained soil only

Blows	Before Soaking		After Soaking		SWELL
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)	
10	1.420	24.3	1.44	32.1	1.03
30	1.539	24.5	1.56	28.5	0.98
65	1.625	24.0	1.62	26.3	0.62

Table A-8: Penetration Test result of fine-grained soil

Penetration (mm)	10 Blows			30 Blows			65 Blows		CBR %
	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	
0	0	0.00		0	0.00		0	0.00	
0.64	8	0.35		12	0.52		24	1.04	
1.27	14	0.61		29	1.26		46	2.00	
1.96	17	0.74		46	2.00		74	3.21	
2.54	22	0.96	7.5	64	2.69	21.2	102	4.25	33
3.18	24	1.04		69	3.00		116	5.04	
3.81	26	1.13		78	3.39		126	5.47	
4.45	29	1.26		84	3.65		136	5.90	
5.08	31	1.35	6.5	88	3.82	19.1	141	6.12	30.6
7.62	45	1.95		115	4.99		169	7.34	
10.2	54	2.34		130	5.64		180	7.81	

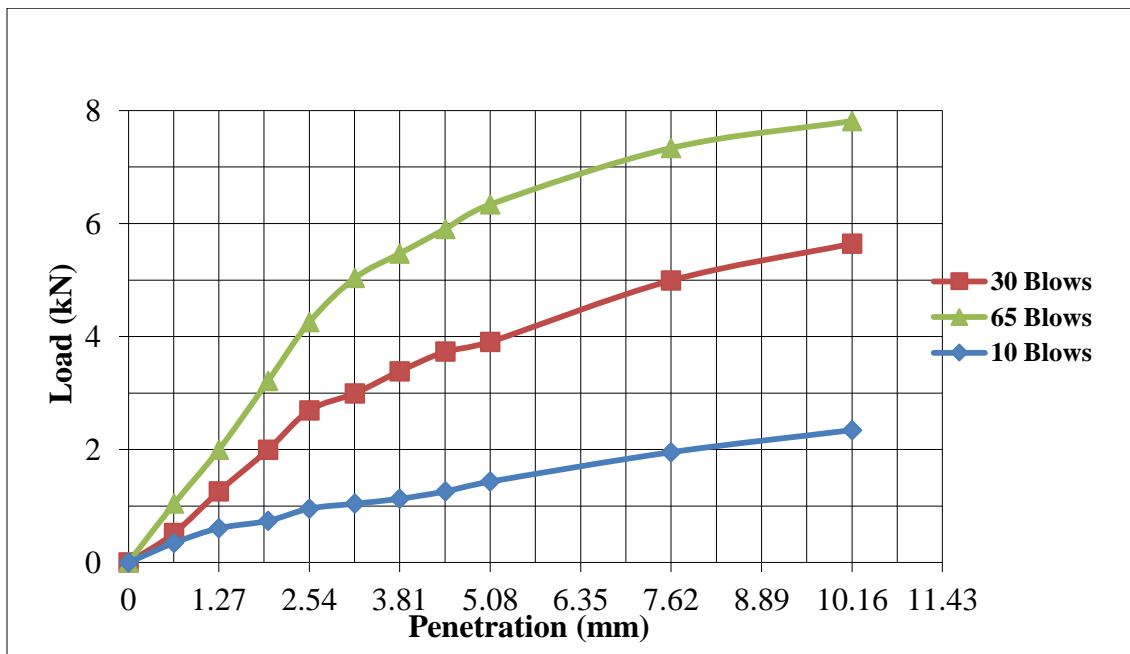


Figure A-4 : Load-penetration curves of fine-grained soil only

Table A-9: Determination of CBR & Swell (%) of fine-grained soil only

Blows	LOAD (kN)		CBR (%)		Swell (%)
	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.00	1.40	7.5	7.00	1.03
30	2.70	3.90	21.2	19.60	0.98
65	4.30	6.30	33.3	31.60	0.62

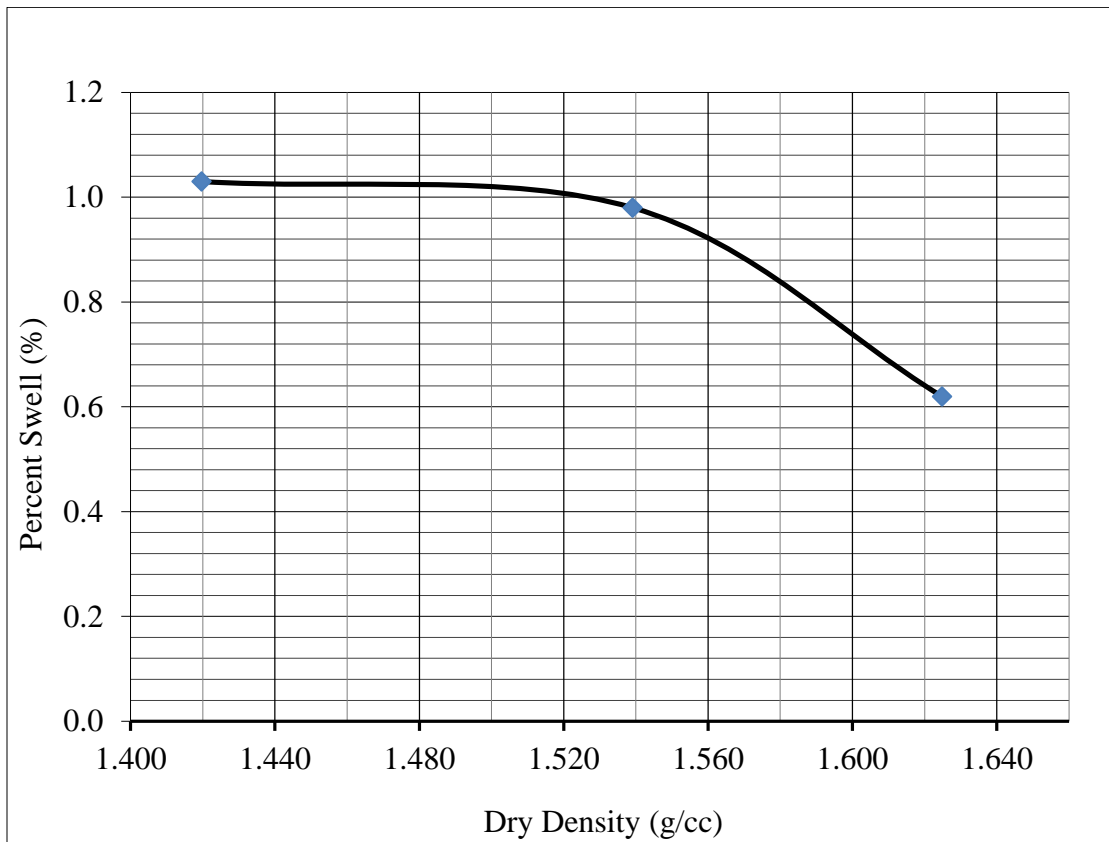


Figure A-5 : Dry Density Vs Percent Swell of fine-grained soil only

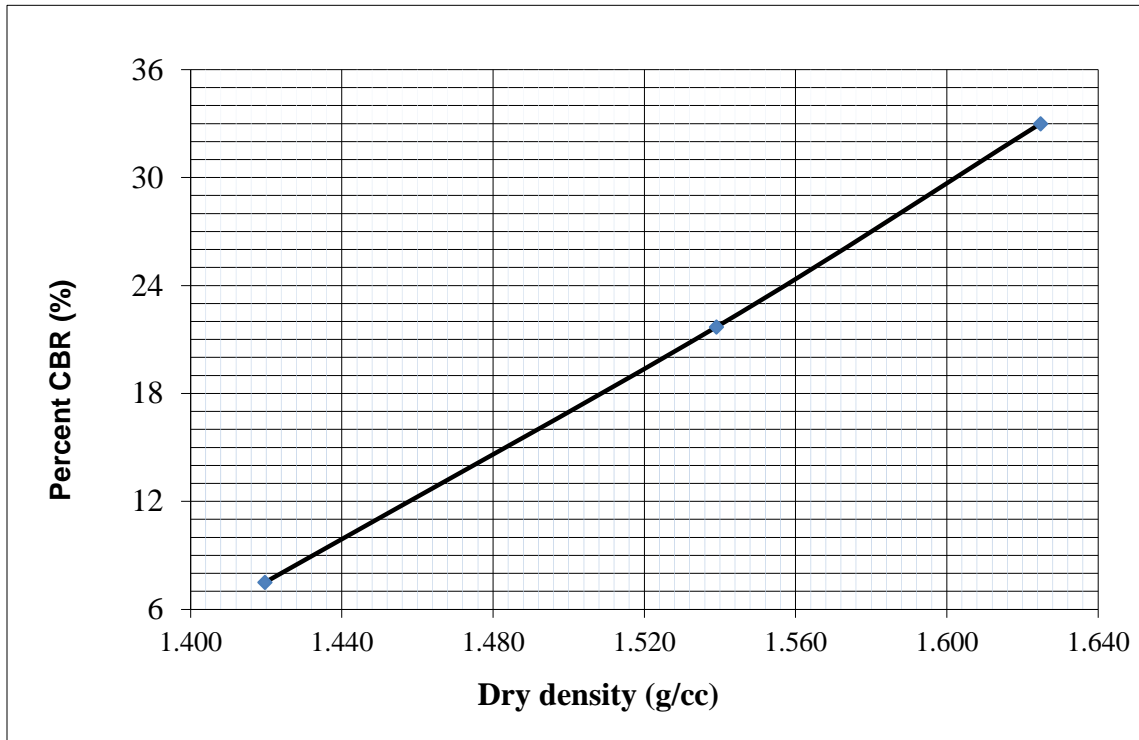


Figure A-6 : Dry Density Vs Percent CBR of fine-grained soil only

Table A-10: Determination of CBR & Swell at 95 % of MDD of fine-grained soil only

Blow	Dry Density (g/cc)	CBR (%)	Swell (%)
10	1.420	7.50	1.03
30	1.539	20.20	0.98
65	1.625	32.20	0.62
OMC (%)			24
MDD (g/cc)			1.55
95 % of MDD (%)			1.47
CBR at 95 % of MDD (%):			14
Percent Swell (%):			0.88

Appendix B
Moisture-Density relation by modified proctor test

Table B -1: Moisture-Density relations for cinder gravel only

DENSITY		TRIAL NUMBER	1	2	3	4
	1	WEIGHT OF SOIL + MOLD (g)	9089	9163	9250	9153
	2	WEIGHT OF MOLD (g)	5422	5422	5422	5422
	3	WEIGHT OF SOIL, (1-2) (g)	3667	3741	3828	3731
	4	VOLUME OF MOLD (cc)	2194	2194	2194	2194
	5	WET DENSITY OF SOIL, (3/4), (g/cc)	1.671	1.705	1.745	1.701
MOISTURE	6	CONTAINER NUMBER	P	C	A	M1
	7	WET SOIL + CONTAINER (g)	384.0	380.0	382.0	385.0
	8	DRY SOIL + CONTAINER (g)	379.0	372.0	363.0	361.0
	9	WEIGHT OF WATER, (7-8) (g)	5.0	8.0	19.0	24.0
	10	WEIGHT OF CONTAINER (g)	31.0	27.0	30.0	33.0
	11	WEIGHT OF DRY SOIL, (8-10) (g)	348.0	345.0	333.0	328.0
	12	MOISTURE CONTENT, (9/11)*100, (%)	1.4	2.3	5.7	7.3
		DRY DENSITY OF SOIL, (5/(100+12))*100, (g/cc)	1.65	1.67	1.65	1.58

MDD = 1.67 g/cc

OMC = 2.3 %

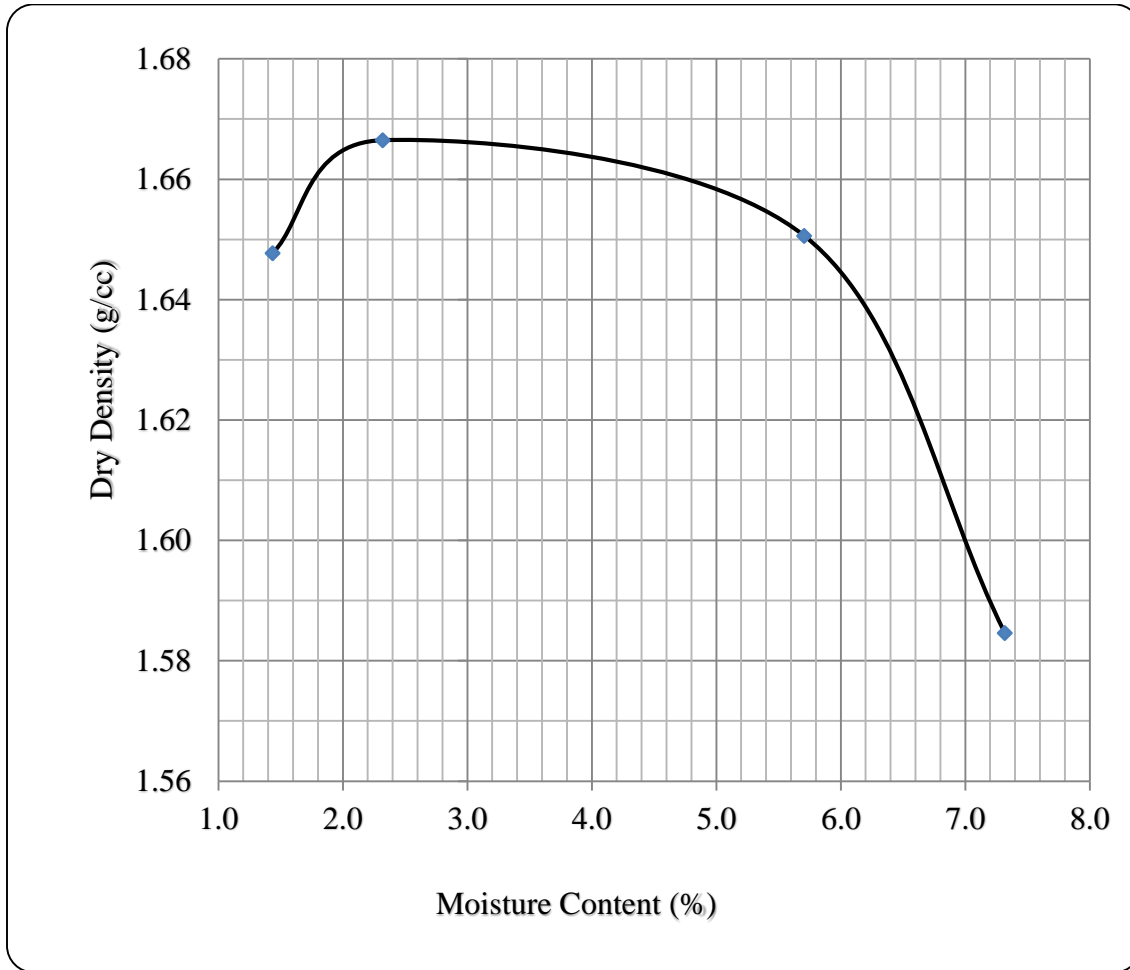


Figure B- 1: Moisture-Dry density curve for cinder gravel only

Table B-2: Moisture-Density relations for cinder gravel with 10 % fine-grained Soil

DENSITY	TRIAL NUMBER	1	2	3	4	
	1	WEIGHT OF SOIL + MOLD (g)	9100	9214	9488	9422
	2	WEIGHT OF MOLD (g)	5422	5422	5422	5422
	3	WEIGHT OF SOIL, (1-2) (g)	3678	3792	4066	4000
	4	VOLUME OF MOLD (cc)	2194	2194	2194	2194
	5	WET DENSITY OF SOIL, (3/4), (g/cc)	1.676	1.728	1.853	1.823

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MOISTURE	6	CONTAINER NUMBER	P	C	A	M1
	7	WET SOIL + CONTAINER (g)	394.0	390.0	392.0	395.0
	8	DRY SOIL + CONTAINER (g)	380.0	372.0	370.0	361.0
	9	WEIGHT OF WATER, (7-8) (g)	14.0	18.0	22.0	34.0
	10	WEIGHT OF CONTAINER g	31.0	27.0	30.0	33.0
	11	WEIGHT OF DRY SOIL, (8-10) g	349.0	345.0	340.0	328.0
	12	MOISTURE CONTENT, (9/11)*100, %	4.0	5.2	6.5	10.4
DRY DENSITY OF SOIL, (5/(100+12))*100, g/cc			1.61	1.64	1.74	1.65

MDD = 1.74 g/cc

OMC = 6.5 %

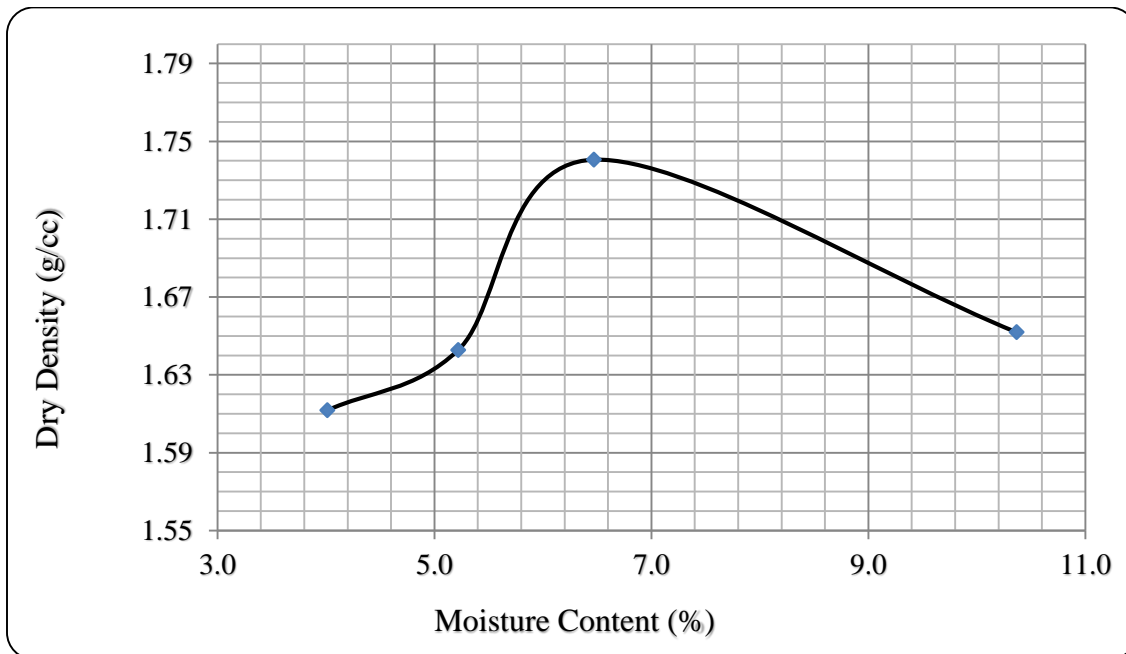


Figure B-2: Moisture-Dry density curve for cinder gravel with 10 % fine-grained soil

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Table B-3: Moisture-Density relations for cinder gravel with 20 % fine-grained Soil

DENSITY	TRIAL NUMBER	1	2	3	4	
	1	WEIGHT OF SOIL + MOLD (g)	9663	9862	10098	9850
	2	WEIGHT OF MOLD (g)	5517	5517	5517	5517
	3	WEIGHT OF SOIL, (1-2) (g)	4146	4345	4579	4333
	4	VOLUME OF MOLD (cc)	2194	2194	2194	2194
	5	WET DENSITY OF SOIL, (3/4), (g/cc)	1.89 0	1.980	2.087	1.975
MOISTURE	6	CONTAINER NUMBER	T	K	I	F
	7	WET SOIL + CONTAINER (g)	225. 0	216.0	222.0	229.0
	8	DRY SOIL + CONTAINER (g)	208. 0	198.8	202.0	210.3
	9	WEIGHT OF WATER, (7-8) (g)	17.0	17.2	20.0	33.0
	10	WEIGHT OF CONTAINER (g)	31.0	30.0	32.0	34.0
	11	WEIGHT OF DRY SOIL, (8-10) (g)	177. 0	168.8	170.0	176.3
	12	MOISTURE CONTENT, (9/11)*100, (%)	9.6	10.2	11.8	18.7
	DRY DENSITY OF SOIL, (5/(100+12))*100, (g/cc)	1.72	1.80	1.87	1.66	

MDD = 1.87 g/cc

OMC = 11.8 %

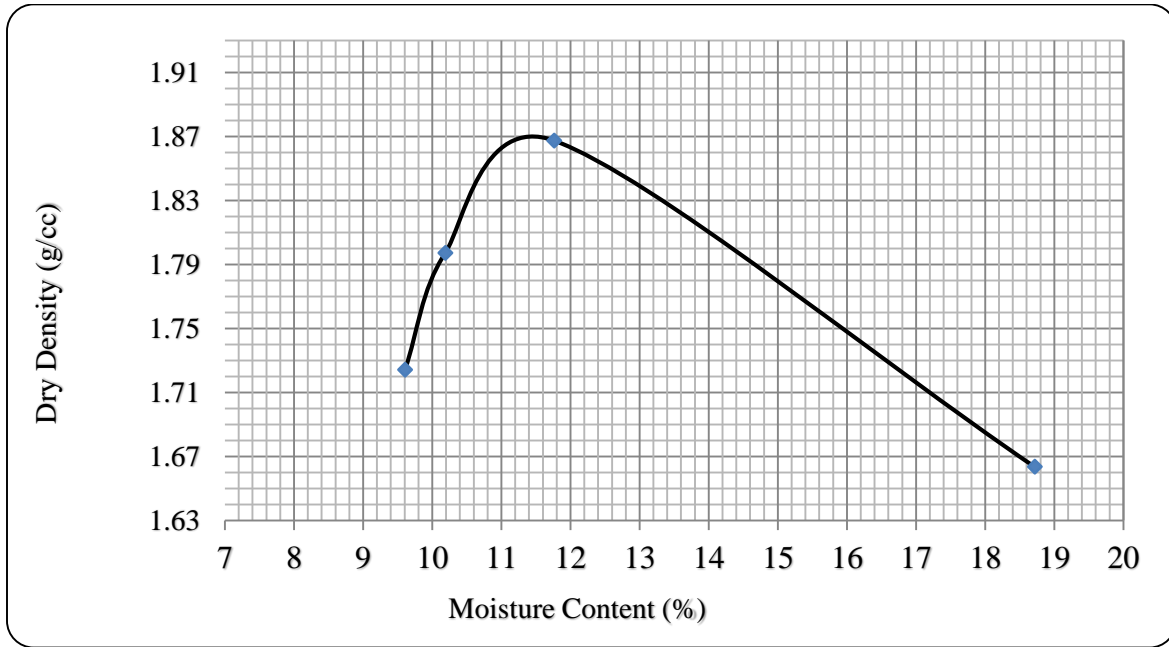


Figure B- 3: Moisture-Dry density curve for cinder gravel with 20 % fine-grained Soil

Table B-4: Moisture-Density relations for cinder gravel with 33 % fine-grained Soil

		TRIAL NUMBER	1	2	3	4
DENSITY	1	WEIGHT OF SOIL + MOLD (g)	9415	9627	9879	9879
	2	WEIGHT OF MOLD (g)	5454	5454	5454	5454
	3	WEIGHT OF SOIL, (1-2) (g)	3961	4173	4425	4425
	4	VOLUME OF MOLD (cc)	2194	2194	2194	2194
	5	WET DENSITY OF SOIL, (3/4), (g/cc)	1.805	1.902	2.017	2.017
MOISTURE	6	CONTAINER NUMBER	L	I	D	K
	7	WET SOIL + CONTAINER (g)	200.0	209.0	212.0	217.0

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8	DRY SOIL + CONTAINER (g)	192.0	194.0	190.0	192.0
9	WEIGHT OF WATER, (7-8) (g)	8.0	15.0	22.0	25.0
10	WEIGHT OF CONTAINER (g)	30.0	31.0	32.0	34.0
11	WEIGHT OF DRY SOIL, (8-10) (g)	162.0	163.0	158.0	158.0
12	MOISTURE CONTENT, (9/11)*100, (%)	4.9	9.2	13.9	15.8
	DRY DENSITY OF SOIL, (5/(100+12))*100, (g/cc)	1.720	1.742	1.770	1.741

MDD = 1.77 g/cc

OMC = 14 %

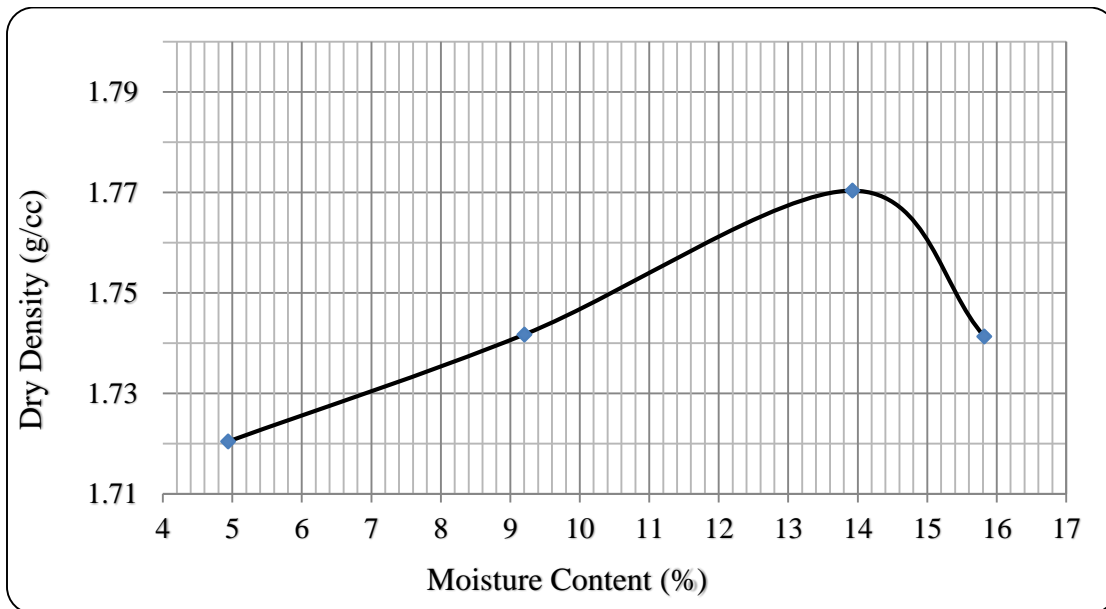


Figure B- 4: Moisture-Dry density curve for cinder gravel with 33% fine-grained Soil

Appendix C
California Bearing Ratio (CBR) test results

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

All the CBR tests were conducted on the following values

Ring Calibration Factor = 43.115 N/div
Plunger Area = 1935 mm ²
Rate of strain = 1.27 mm/min
Rammer Weight = 4.54 kg
Diameter of Mold = 152.4 mm
Volume of Mold = 2036 cm ³
Standard stress(2.54 mm) = 6.9 N/mm ²
Standard stress (5.08 mm) = 10.3 N/mm ²

Table C- 1: Penetration Test result of cinder with 10 % fine-grained soil

Penetration (mm)	10 Blows			30 Blows			65 Blows		CBR %
	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	
0	0	0.0		0	0.0		0	0.0	
0.64	15	0.6		50	2.2		208	9.0	
1.27	28	1.2		98	4.2		274	11.8	
1.96	42	1.8		145	6.3		310	13.4	
2.54	52	2.2	16.5	181	7.8	58.4	355	15.3	114.6
3.18	57	2.5		198	8.5		410	17.7	
3.81	62	2.7		225	9.7		454	19.6	
4.45	69	3.0		258	11.1		501	21.6	
5.08	75	3.2	16.1	270	11.6	58.2	525	22.6	113.4
7.62	94	4.1		330	14.2		584	25.2	
10.2	115	5.0		380	16.4		620	26.7	

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table C- 2: Determination of dry density before & after soaking of cinder with 10 % fine-grained soil

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.503	7.8	1.47	20.4
30	1.613	6.4	1.57	18.0
65	1.747	8.1	1.63	16.7

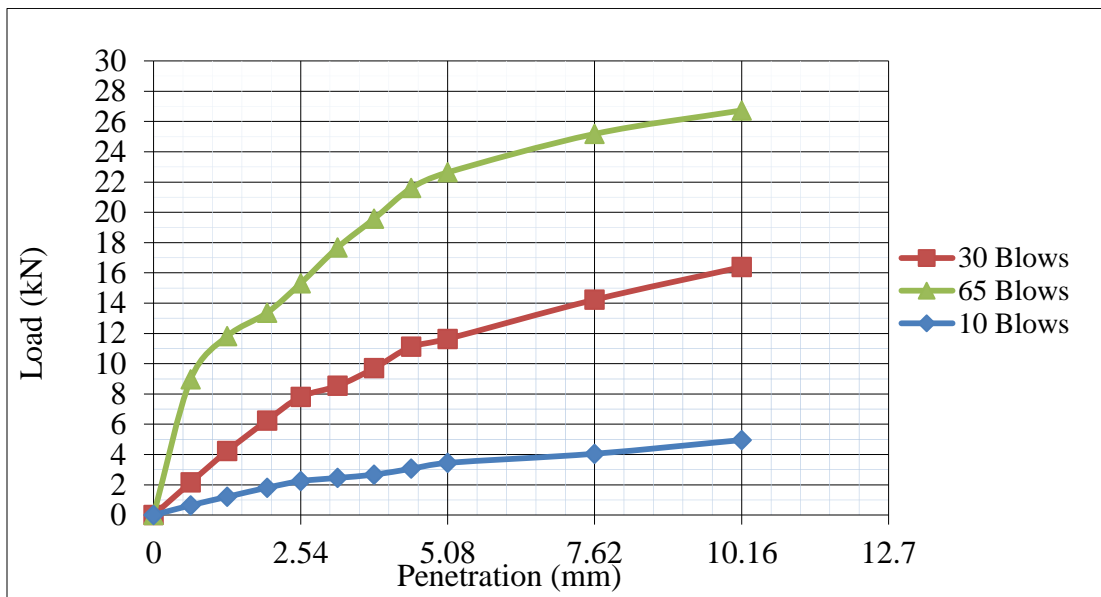


Figure C- 1: Load-penetration curves of cinder gravel with 10 % fine-grained soil

Table C- 3: Determination of CBR & Swell (%) of cinder with 10 % fine-grained soil

BLOWS	LOAD (kN)		CBR (%)		Swell (%)
	2.54mm	5.08mm	2.54mm	5.08mm	
10	2.20	3.40	16.5	17.10	0.11
30	7.80	11.60	58.4	58.20	0.05
65	15.30	22.60	114.6	113.40	0.02

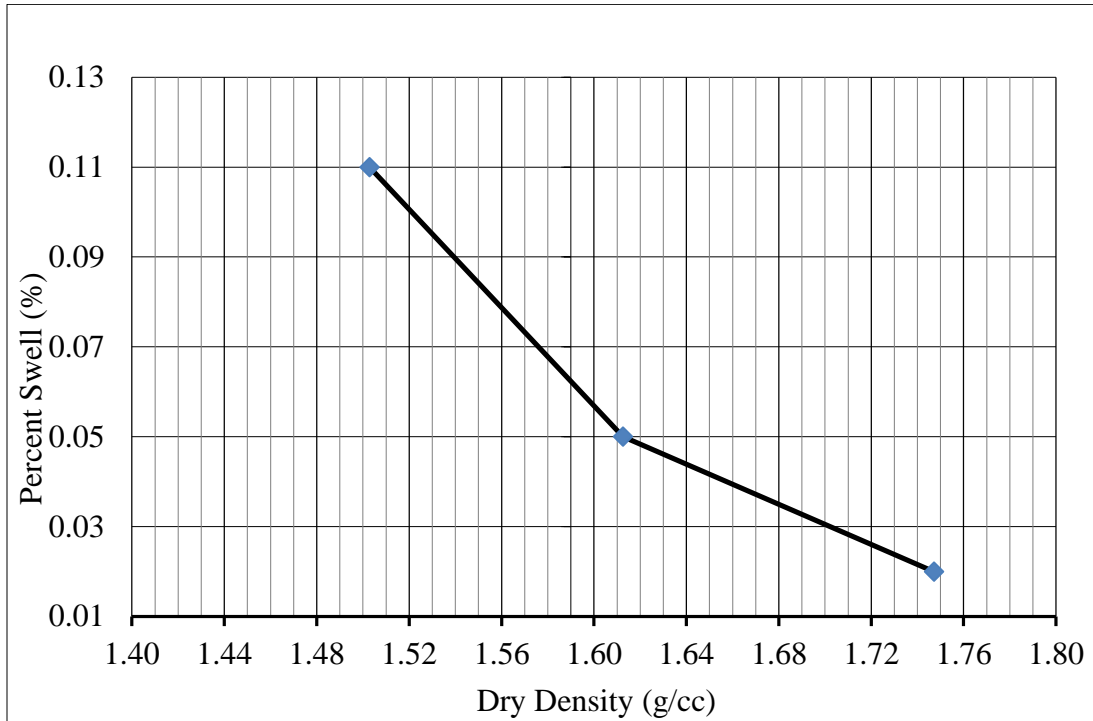


Figure C- 2: Dry Density Vs percent swell of cinder with 10 % fine-grained soil

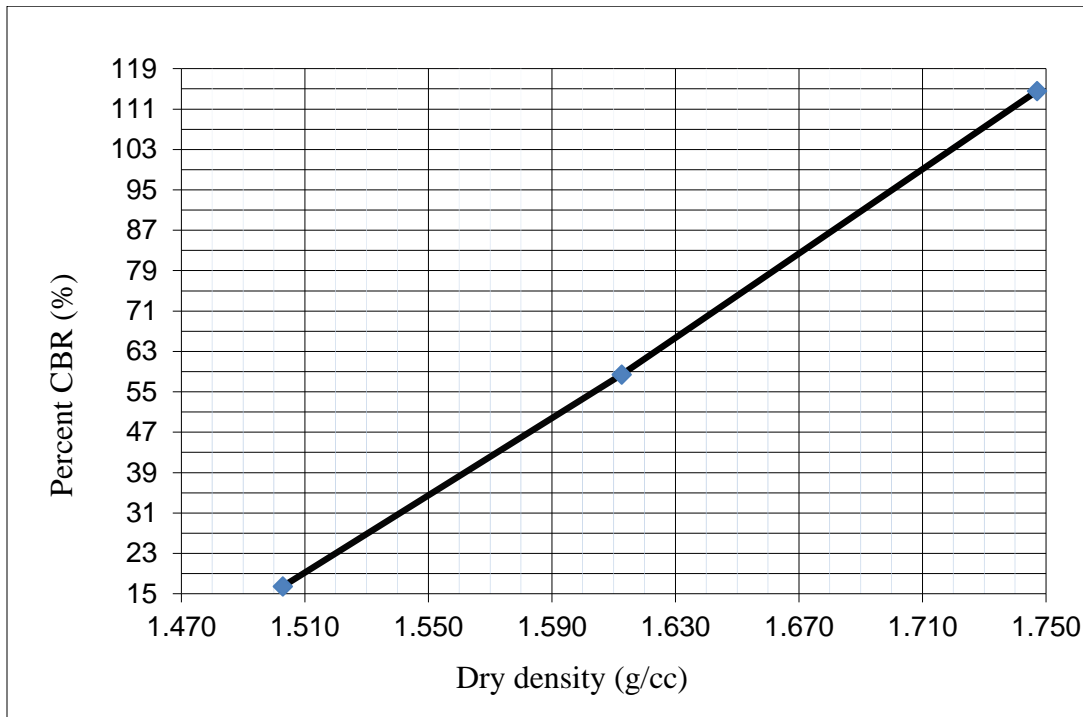


Figure C - 3 Dry Density Vs percent CBR of cinder with 10 % fine-grained soil

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table C - 4: Determination of CBR & Swell at 95 % of MDD of cinder with 10 % fine-grained soil

Blow	Dry Density (g/cc)	CBR (%)	Swell (%)
10	1.503	16.50	0.11
30	1.613	58.40	0.05
65	1.747	114.60	0.02
OMC (%)			6.5
MDD (g/cc)			1.74
95 % of MDD (%)			1.65
CBR at 95 % of MDD (%):			72
Percent Swell (%):			0.06

Table C- 5: Penetration Test result of cinder with 20 % fine-grained soil

Penetration (mm)	10 Blows			30 Blows			65 Blows		CBR %
	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	
0	0	0.00		0	0.00		0	0.00	
0.64	12	0.52		55	2.37		112	4.83	
1.27	27	1.16		106	4.57		215	9.27	
1.96	38	1.64		163	7.03		290	12.50	
2.54	48	2.07	15.7	209	9.01	67.4	370	15.95	119.8
3.18	51	2.20		242	10.43		410	17.68	
3.81	54	2.33		265	11.43		452	19.49	
4.45	63	2.72		285	12.29		485	20.91	
5.08	68	2.93	14.6	300	12.93	64.7	524	22.59	113.4
7.62	100	4.31		366	15.78		600	25.87	
10.2	131	5.65		410	17.68		672	28.97	

Table C - 6: Determination of dry density before & after soaking of cinder with 20 % fine-grained soil

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.536	10.8	1.54	18.8
30	1.673	10.5	1.69	15.6
65	1.890	8.4	1.81	18.0

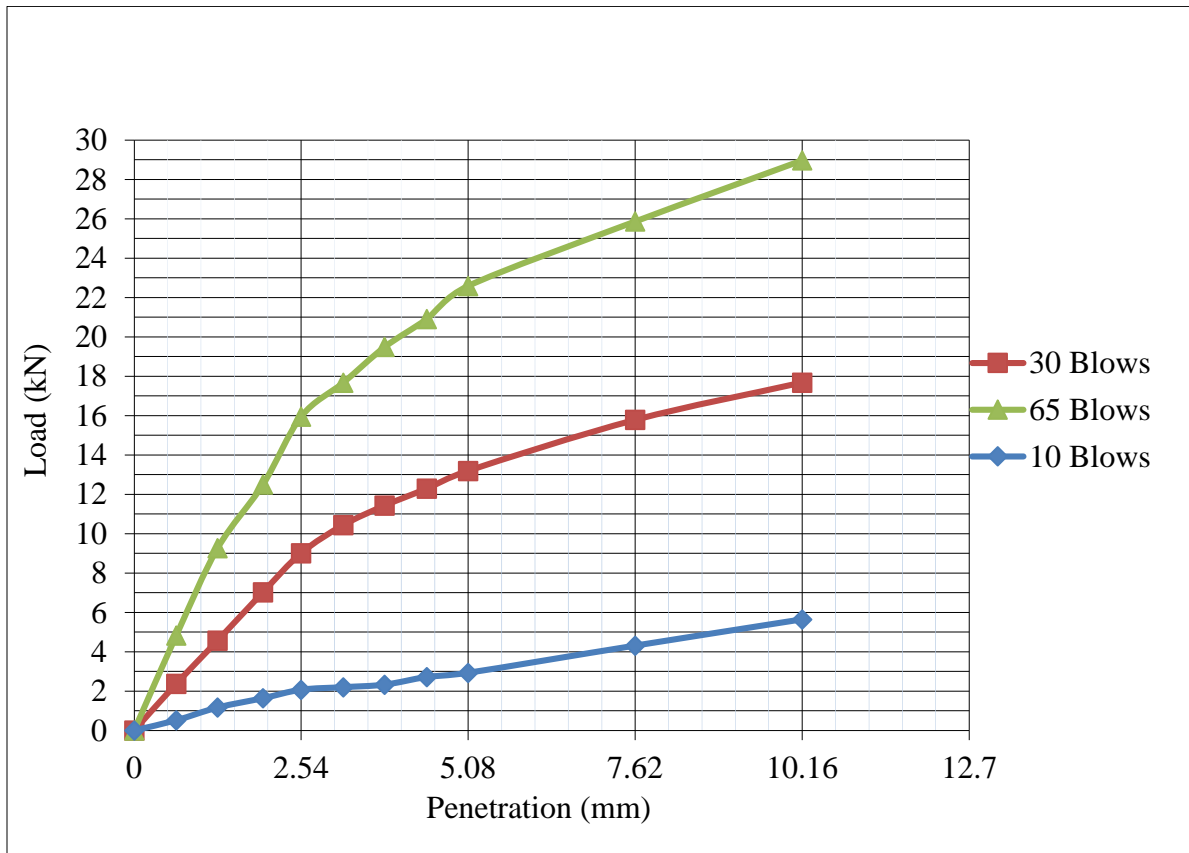


Figure C- 4: Load-penetration curves of cinder gravel with 20 % fine-grained soil

Table C- 7: Determination of CBR & Swell (%) of cinder with 20 % fine-grained soil

BLOWS	LOAD (kN)		CBR (%)		Swell (%)
	2.54mm	5.08mm	2.54mm	5.08mm	
10	2.00	2.90	15.0	14.60	0.26
30	9.00	13.20	67.4	66.20	0.15
65	16.00	22.60	119.8	113.40	0.05

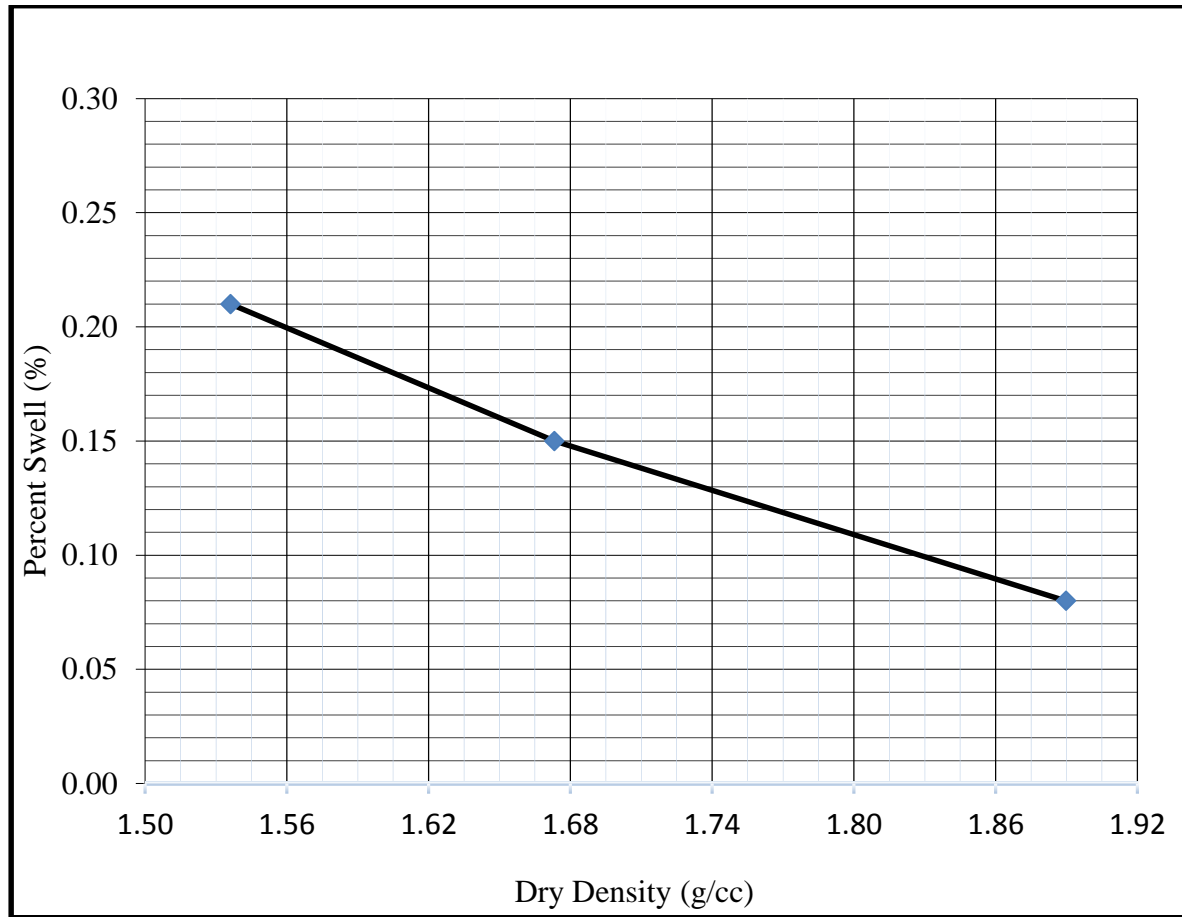


Figure C - 5: Dry Density Vs percent swell of cinder with 20% fine-grained soil



Figure C – 6: Dry Density Vs percent CBR of cinder with 20 % fine-grained soil

Table C - 8: Determination of CBR & Swell at 95 % of MDD of cinder with 20 % fine-grained soil

Blow	Dry Density (g/cc)	CBR (%)	Swell (%)
10	1.536	15.70	0.21
30	1.673	67.40	0.15
65	1.890	119.80	0.08
OMC (%)			11.8
MDD (g/cc)			1.87
95 % of MDD (%)			1.78
CBR at 95 % of MDD (%):			97
Percent Swell (%):			0.15

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Table C- 9: Penetration Test result of cinder with 33 % fine-grained soil

Penetration (mm)	10 Blows			30 Blows			65 Blows		CBR %
	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	CBR %	Dial Rdg (Div.)	Load (kN)	
0	0	0.00		0	0.00		0	0.00	
0.64	31	1.34		30	1.29		82	3.54	
1.27	48	2.07		85	3.66		154	6.64	
1.96	80	3.45		165	7.11		264	11.38	
2.54	104	4.48	33.7	215	9.27	69.7	305	13.15	98.9
3.18	115	4.96		245	10.56		335	14.44	
3.81	135	5.82		262	11.30		385	16.60	
4.45	140	6.04		295	12.72		420	18.11	
5.08	150	6.47	32.6	313	13.50	67.7	443	19.10	95.8
7.62	185	7.98		350	15.09		502	21.64	
10.2	221	9.53		392	16.90		556	23.97	

Table C - 10: Determination of dry density before & after soaking of cinder with 33 % fine-grained soil

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.615	13.6	1.63	18.8
30	1.707	12.7	1.73	15.6
65	1.803	13.9	1.79	18.0

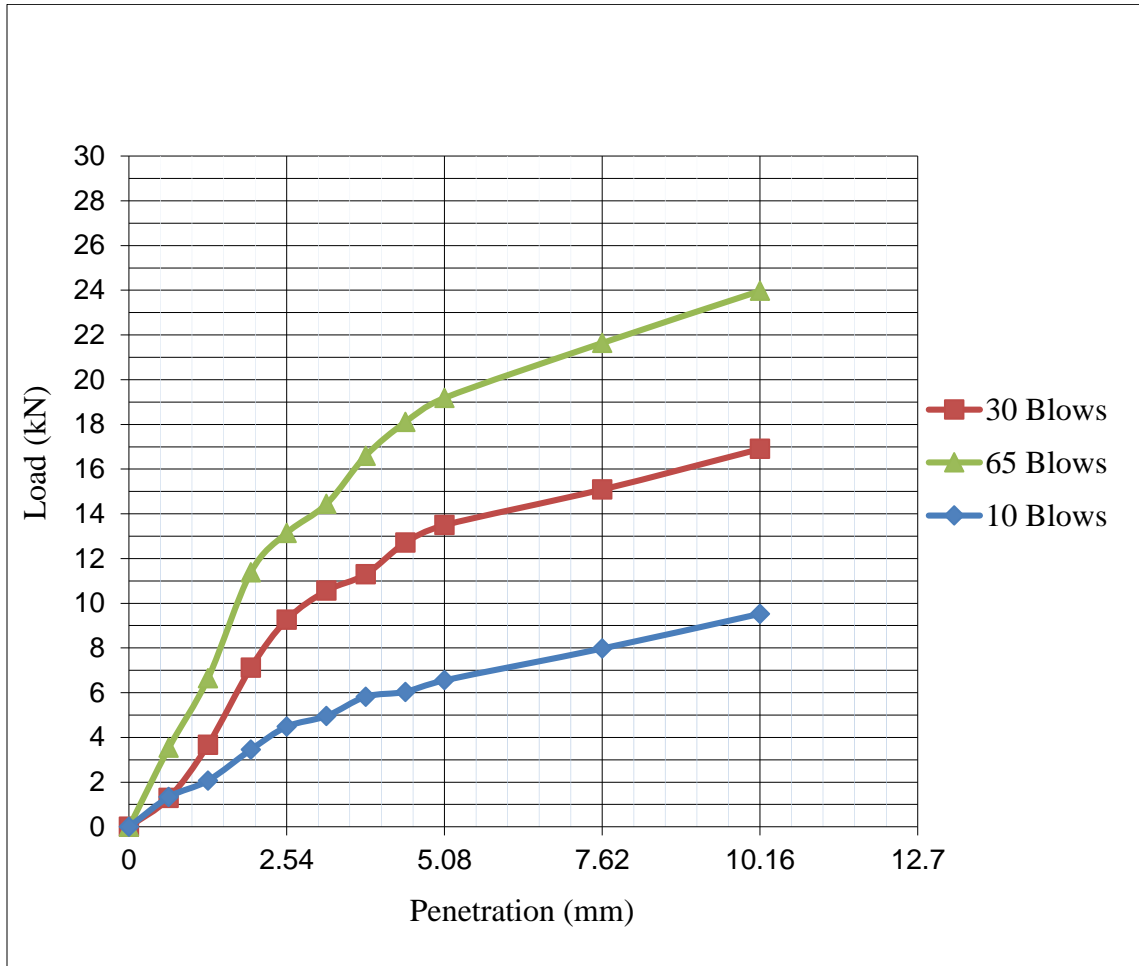


Figure C- 7: Load-penetration curves of cinder gravel with 20 % fine-grained soil

Table C- 11: Determination of CBR & Swell (%) of cinder with 33% fine-grained soil

BLOWS	LOAD (kN)		CBR (%)		Swell (%)
	2.54mm	5.08mm	2.54mm	5.08mm	
10	4.50	6.60	33.7	33.10	0.46
30	9.30	13.50	69.7	67.70	0.28
65	13.20	19.20	98.9	96.30	0.12

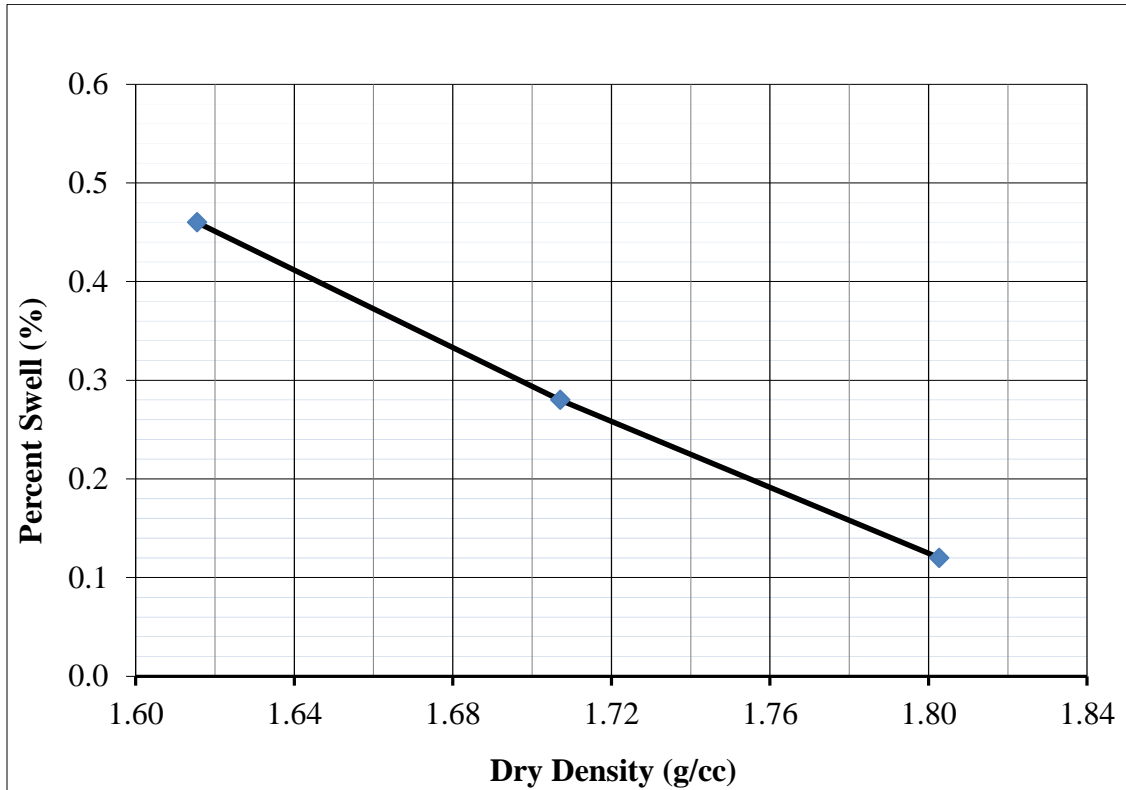


Figure C – 8: Dry Density Vs percent swell of cinder with 33 % fine-grained soil

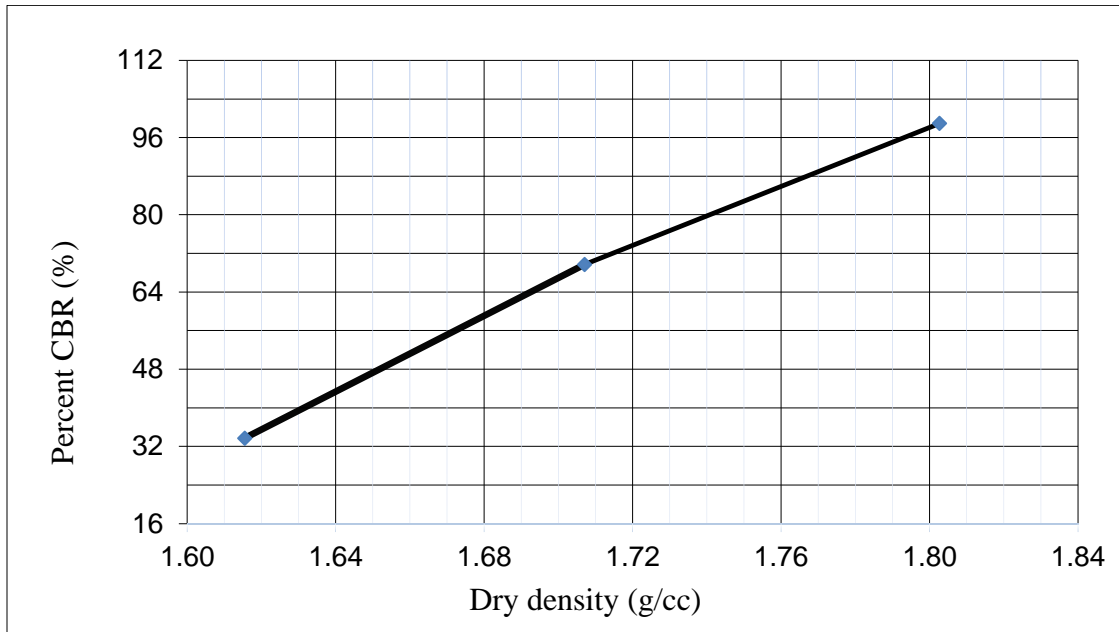


Figure C-9: Dry Density Vs percent CBR of cinder with 33 % fine-grained soil

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Table C- 12: Determination of CBR & Swell at 95 % of MDD of cinder with 33% fine-grained soil

Blow	Dry Density (g/cc)	CBR (%)	Swell (%)
10	1.615	33.70	0.46
30	1.707	69.70	0.28
65	1.803	98.90	0.12
OMC (%)			14
MDD (g/cc)			1.77
95 % of MDD (%)			1.68
CBR at 95 % of MDD (%):			60
Percent Swell (%):			0.29

Appendix D
Grading Limits of different proportion fine-grained soil with
cinder

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

The method used for the sieve analysis was wet sieve method

Table D - 1: Sieve analysis of Sub-base material only cinder gravel

i) Gradation before Compaction

Total weight before washing (gm) =		5000			Specification Limit	
Total weight after washing (gm) =		4950				
Loss(gm) =		50				
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	0	0.00	100.00	90	100
1"	25	1540	30.80	69.20	51	80
4	4.75	2070	41.40	27.80	35	70
200	0.075	1285	25.70	2.10	5	15
pan	-	105	2.1	0		

ii) Gradation After Compaction

Total weight before washing (gm) =		3425			Specification Limit	
Total weight after washing (gm) =		3091				
Loss(gm) =		334				
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	0	0.00	100.00	90	100
1"	25	308	8.99	91.01	51	80
4	4.75	1242	36.26	54.74	35	70
200	0.075	1387	40.50	14.24	5	15
pan	-	485	14.16	0		

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table D - 2: Sieve Analysis of Sub-base material cinder gravel with 10 % fine-grained Soil

i) Gradation before Compaction

Total weight before washing (gm) =		5000			Specification Limit	
Total weight after washing (gm) =		4780				
Loss(gm) =		220				
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	0	0.00	100.00	90	100
1"	25	1360	27.20	72.80	51	80
4	4.75	2200	44.00	28.80	35	70
200	0.075	1070	21.40	7.40	5	15
pan	-	370	7.4	0		

ii) Gradation after Compaction

Total weight before washing (gm) =		3877			Specification Limit	
Total weight after washing (gm) =		3545.33				
Loss(gm) =		332.67				
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	0	0.00	100.00	90	100
1"	25	259.5	6.69	93.31	51	80
4	4.75	1655	42.69	50.62	35	70
200	0.075	1604.83	41.39	9.23	5	15
pan	-	357.67	9.22	0		

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table D - 3: Sieve Analysis of Sub-base material cinder gravel with 20 % fine-grained Soil

i) Gradation before Compaction

Total weight before washing (gm) =		10268			Specification Limit	
Total weight after washing (gm) =		9665				
Loss(gm) =		603				
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	407	3.96	96.04	90	100
1"	25	2220	21.62	74.42	51	80
4	4.75	3369	32.81	41.60	35	70
200	0.075	3022	29.43	12.17	5	15
pan	-	1250	12.16	0		

ii) Gradation after Compaction

Total weight before washing (gm) =		4385			Specification Limit	
Total weight after washing (gm) =		3834				
Loss(gm) =		551				
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	0	0.00	100.00	90	100
1"	25	1002	22.85	77.15	51	80
4	4.75	1169	26.66	50.49	35	70
200	0.075	1610	36.72	13.77	5	15
pan	-	604	13.76	0		

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table D - 4: Sieve Analysis of Sub-base material cinder gravel with 33 % fine-grained Soil

i) Gradation before Compaction

Total weight before washing (gm) =			10400		Specification Limit	
Total weight after washing (gm) =			8767			
Loss(gm) =			1633			
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	157	1.51	98.49	90	100
1"	25	2506	24.10	74.39	51	80
4	4.75	3128	30.08	44.32	35	70
200	0.075	2890	27.79	16.53	5	15
pan	-	1719	16.52	0		

ii) Gradation after Compaction

Total weight before washing (gm) =			4644		Specification Limit	
Total weight after washing (gm) =			3798.5			
Loss(gm) =			845.5			
Sieve No.	Sieve Sizes (mm)	Mass of Retained soil (g)	Percentage Retained (%)	Cumulative percentage Passing (%)	Lower	Upper
2 ½"	63	0	0.00	100.00	100	100
2"	50	0	0.00	100.00	90	100
1"	25	577.5	12.44	87.56	51	80
4	4.75	1622	34.93	52.64	35	70
200	0.075	1428	30.75	21.89	5	15
pan	-	1016.5	21.88	0		

Appendix E

Atterberg Limits of different proportion fine-grained soil with cinder

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table E - 1: Atterberg Limit for cinder gravel with 20 % fine-grained Soil after compaction

Test No.	LIQUID LIMIT			PLASTIC LIMIT	
	1	2	3	1	2
Number of blows	33	26	18		
Container No.	A	B	C	G	I
Wet Soil+Cont (g)	55.40	54.4	54.6	25.4	25.4
Dry Soil+Cont (g)	47.8	47.00	46.90	24.65	24.70
Mass Container (g)	17.2	17.8	17.7	21.30	21.5
Mass Moisture (g)	7.60	7.4	7.7	0.75	0.70
Mass Dry Soil (g)	30.6	29.2	29.2	3.35	3.20
Moisture Content (%)	24.84	25.34	26.37	22.39	21.88
Average	25.52			22.13	

LIQUID LIMIT :	25.6
PLASTIC LIMIT :	22.13
PLASTICITY INDEX :	3.5
% pass of 0.075mm	12.57
PP= PI*% pass of 0.075mm (Max.=75)	44

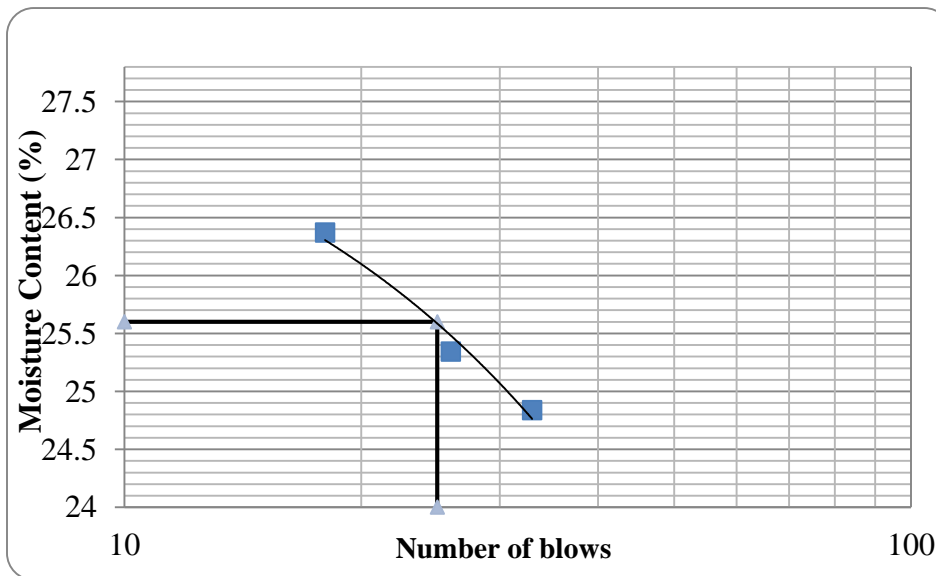


Table E - 1: Flow curve for cinder gravel with 20 % fine-grained Soil

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table E - 2: Atterberg Limit for cinder gravel with 33 % fine-grained Soil after compaction

Test No.	LIQUID LIMIT			PLASTIC LIMIT	
	1	2	3	1	2
Number of blows	32	28	22		
Container No.	D	B4	A	C	J
Wet Soil+Cont (g)	56.90	55.4	57	25.4	25.4
Dry Soil+Cont (g)	48.5	47.05	48.00	24.00	24.10
Mass Container (g)	19.8	19.4	19	18.30	18.8
Mass Moisture (g)	8.4	8.35	9	1.40	1.30
Mass Dry Soil (g)	28.7	27.65	29	5.70	5.30
Moisture Content (%)	29.27	30.20	31.03	24.56	24.53
Average	30.17			24.54	

LIQUID LIMIT :	30.60
PLASTIC LIMIT :	24.54
PLASTICITY INDEX :	6.1
% pass of 0.075mm	16.53
PP= PI*% pass of 0.075mm (Max.=75)	100.83

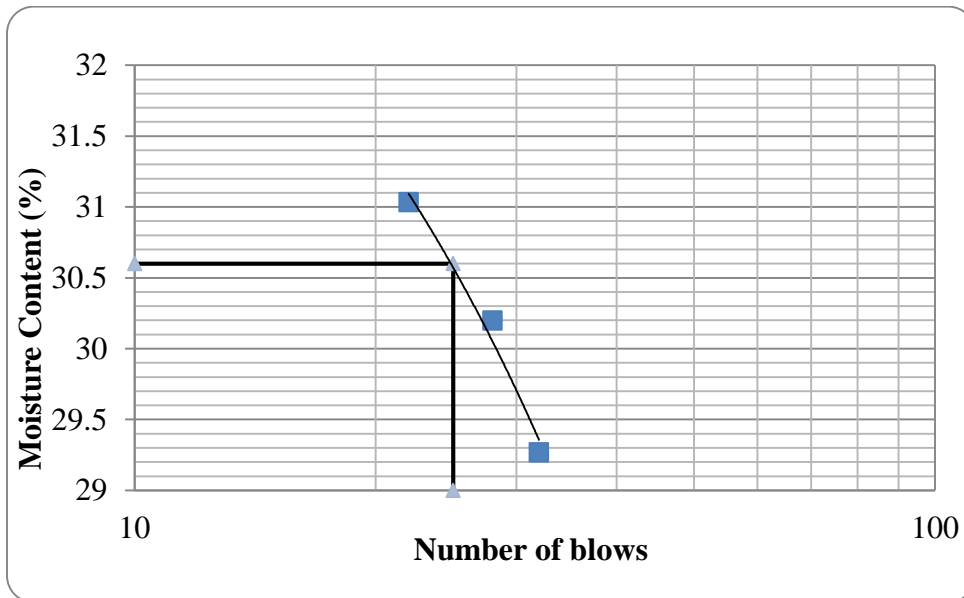


Table E - 2: Flow curve for cinder gravel with 33 % fine-grained Soil

Appendix F

Free swell test of different proportion fine-grained soil with cinder

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table F-1: Free swell test for cinder gravel with 10 % fine-grained Soil

Test No.	Initial volume (cc)	Final volume (after 24hr) (cc)	Difference	% Swell	Average
1	10	10.2	0.2	2	3
2	10	10.4	0.4	4	

Table F-2: Free swell test for cinder gravel with 20 % fine-grained Soil

Test No.	Initial volume (cc)	Final volume (after 24hr) (cc)	Difference	% Swell	Average
1	10	10.75	0.75	7.5	6.25
2	10	10.5	0.5	5	

Table F-3: Free swell test for cinder gravel with 33 % fine-grained Soil

Test No.	Initial volume (cc)	Final volume (after 24hr) (cc)	Difference	% Swell	Average
1	10	11	1	10	12.5
2	10	11.5	1.5	15	

Appendix G
Test results of cinder gravel from quarry site

Table G-1: Determination of dry density before & after soaking

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.469	3.3	1.45	11.3
30	1.624	4.8	1.57	10.1
65	1.723	3.2	1.69	5.0

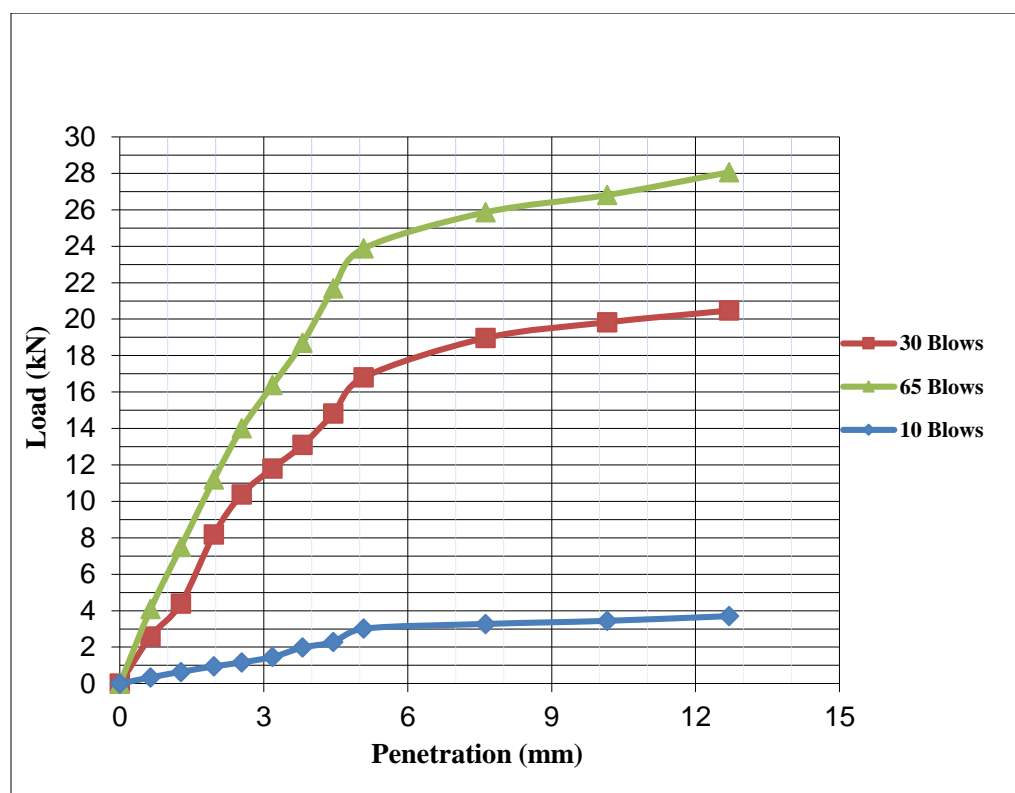


Figure G-1: Load-penetration curves of cinder gravel only

Table G-2: Determination of CBR & Swell (%)

LOAD (kN)		CBR (%)		Swell (%)
2.54mm	5.08mm	2.54mm	5.08mm	
1.20	3.00	9.0	15.10	0.06
10.40	16.80	77.9	84.30	0.03
14.00	23.90	104.9	119.90	0.01

Table G-3: Determination of CBR & Swell at 95 % of MDD of cinder gravel only

Blow	Dry Density (g/cc)	CBR (%)	Swell (%)
10	1.469	9.00	0.06
30	1.624	77.90	0.03
65	1.723	104.90	0.01
OMC (%)			2.3
MDD (g/cc)			1.67
95 % of MDD (%)			1.59
CBR at 95 % of MDD (%):			64.0
Percent Swell (%):			0.033

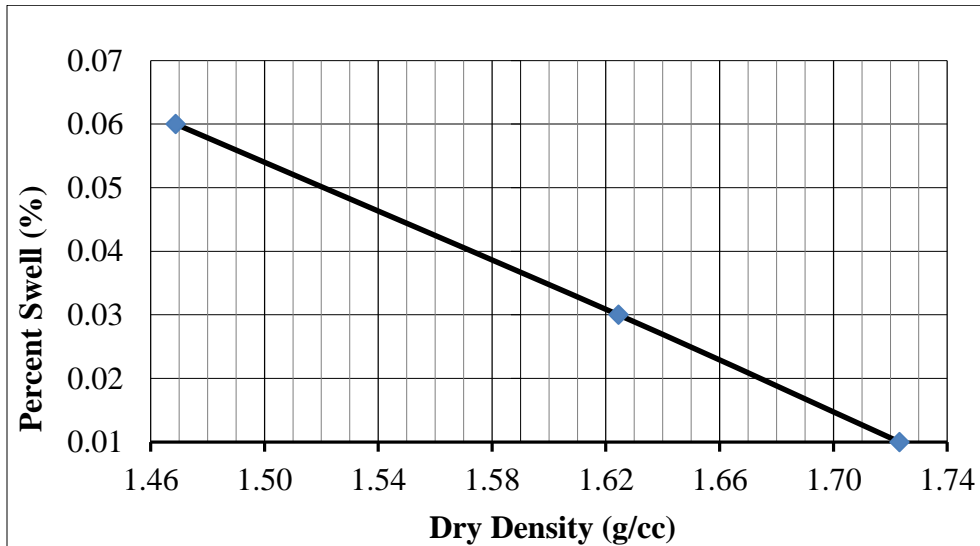


Figure G-2: Dry density Vs percent swell

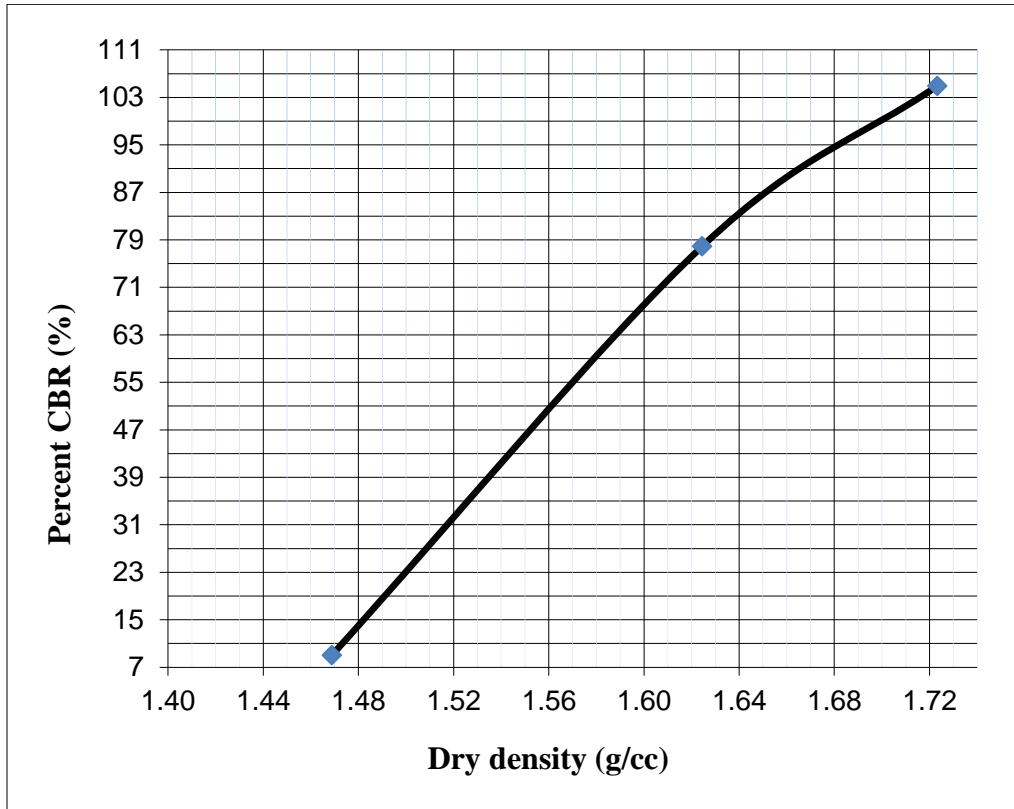


Figure G-3: Dry Density Vs Percent CBR

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

Test No.	1	2
A) Original Mass of Test Sampling	5000	5000
B) Final Mass of Test Sample after 500 Revolution (Retained on NO. 12 Sieve(1.70mm)),gm	2725	2711
C) mass of sample pass sieve no.12 (1.70mm) (A-B) gm	2275	2289
D) Percentage of Wear/Loss ,C/A*100 %	45.50	45.78
F) Average of LAA (T1+T2)/N %	45.60%	

The Potential Use of Cinder as a Sub base Material Blended With Fine Grained Soil

Table G-5 Specific gravity test result for Cinder gravel only

Mass of empty ,clean pycnometer	gm	M ₁	47.5	63.4
Mass of empty pycnometer +dry soil	gm	M ₂	57.5	73.4
Mass of pycnometer + dry soil +water	gm	M ₃	153	168.7
Mass of pycnometer + water	gm	M ₄	147.1	162.8
Temperature	C ⁰		23	22.5
G _T			0.9993	0.9995
Specific gravity	$G = \frac{GT \times (M_2 - M_1)}{(M_2 - M_1) + (M_4 - M_3)}$		2.41	2.47
			2.44	

Table G-6 Absorption test result for cinder only

Weight of saturated, surface dry Cinder gravel in air	gm	W ₁	450	400
Weight of dry Cinder gravel	gm	W ₂	394	347
Weight of absorbed water	gm	W ₃	56	53
Absorption (%)	$= \frac{(W_1 - W_2)}{(W_1)}$		12.44	13.25
			12.85	