The Potential Use of Cinder material blended with Fine grained Soil as a Sub base (The Case Study of Adama Awash Road)

BY; Paulos Birhanu

A Thesis Submitted To The Department Of Civil Engineering
School Of Graduate Studies,

Presented In Partial Fulfillment Of The Requirement For The Degree OfMaster Science In Civil Engineering (Geotechnical Engineering)

Office of Graduate Studies
Adama Science and Technology University

September,2023
Adama, Ethiopia

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Advisor
Dr. Argaw Asha

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Declaration

I hereby declare that this Master thesis entitled "The Potential Use of Cinder material blended with Fine grained Soil as a Sub base (The Case Study of Adama Awash Road)" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

__ Paulos Birhanu _ ____________________ ________________

Name of student Signature Date

Recommendation

we, the advisors of this thesis, hereby certify that we have read the revised version of thesis entitled "The Potential Use of Cinder material blended with Fine grained Soil as a Sub base (The Case Study of Adama Awash Road)" prepared under our guidance by Paulos Birhanu submitted in partial fulfillment of the requirements for the degree of Masters of science in Geotechnical Engineering. Therefore, we recommend the submission of the version of the thesis to the department following the applicable procedures.

Argaw Asha (PHD) ________________________ _________________

Major Advisor Signature Date

____________________ ________________________ _________________

Co-advisor Signature Date

Approval Page for thesis

We, the advisors of the thesis entitled “The Potential Use of Cinder material blended with Fine grained Soil as a Sub base (The Case Study of Adama Awash Road)” and developed by Paulos Birhanu, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

_Argaw Asha (PHD)_____	____________________	________________
Major Advisor	Signature	Date
________________________	_______________________	________________
Co-advisor	Signature	Date

Approval Page for Board Reviewers

We, the undersigned, members of the Board examiners of the thesis by Paulos Birhanu have read and evaluated the thesis entitled "The Potential Use of Cinder material blended with Fine grained Soil as a Sub base (The Case Study of Adama Awash Road)" and examined during the defense. This is, therefore, to certify that the thesis for partial fulfillment of the requirement of the degree of Master of Science in Geotechnical Engineering.

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Finally, approval and acceptance of the thesis contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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I also gratefully acknowledged the help i got from the staff of the laboratories of Ethiopian road authority Alemgena District during my stay in their laboratory.

ABSTRACT

Cinder is a highly porous pyroclastic material, which is vitric in nature, and does not meet the conventional road base and sub base specification. The cinder gravel and fine-grained soil was collected from Adama-Awash Road Area. The objective of this study was to evaluate the performance such as functional and structural conditions which influenced by factors like traffic, environment, economic and stress distribution factors of cinder and fine-grained blended soil as a sub base material. In order to have satisfactory data, samples from cinder source and fine-grained soil source collected and laboratory tests like grain size distribution, Atterberg Limit, compaction, California bearing ratio, Los angeles abrasion, absorption and linear Shrinkage was conducted in accordance with American association of State Highway and Transportation Officials (AASHTO) and Ethiopian Road Authority (ERA) manual standard specification requirement. The cinder gravel was blended with some trail proportion of 0, 7, 14, 21 and 28% of fine-grained soil by mass and tests aforementioned above conducted in the laboratory.

From the particle distribution the blending shows coarser at the start of the blending and tends to be much finer at the highest blending proportion especially the grading of the after compaction. The grading of the after compaction at 0.075 mm sieve shows 4.7% pass at cinder only blending, 7.9% pass at 7% blending, 11.1% pass at 14% blending, 14.8% pass at 21% blending and 21% pass at 28% blending. The test result showed that the California bearing ratio values of all trial proportions were more than 30% (48.5%,51.8%,63%,71% and 53.5% at 0%,7%,14%,21% and 28% blending proportion respectively) which is above the requirement of the ERA specification for sub base. However, the value decreases at 28% blending proportion, since at this trial proportion the intermediate particles were replaced by the finer particles which this trend tends to decrease the California bearing ratio value.

Based on the laboratory test results it is shown that, from both maximum dry density- percent of fine-grained soil curve and California bearing ratio -percent of fine-grained soil curve, the optimum amount of fine-grained soil required in order to improve its properties is 21 % by mass proportion which improves the maximum dry density of the cinder 1.686% to 1.751% at 21% blending proportion and California bearing ratio of the cinder 48.5% to 71%.

KEY WORDS: sub-base, Cinder Gravel, Blending of sub-base material, Optimum fine- grained

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SYMBOLS AND ABBREVIATION

AACRA – Addis Ababa City Road Authority`

AASHTO – American Association of Highway and Transportation OfficialsASTM –

American Society for Testing and Materials

CBR – California Bearing RatioDD – Dry Density

E – Easting

E.C. –Ethiopian Calendar

ERA – Ethiopia Road AuthorityGM – Grading Modules

GPS – Global Position SystemGSB – Granular Sub-Base

LS – Linear Shrinkage

LAA – Los Angeles Abrasion MDD – Maximum Dry DensityN – Northing

NNE – North-North EastNP – Non-Plastic

OMC – Optimum Moisture ContentPI – Plastic Index

SSW – South-South West

TRRL – Transport and Road Research LaboratoryUCS – Unconfined Compressive Strength

UK – United Kingdom

CHAPTER 1 INTRODUCTION

1.1 Background of the study

A nation's transportation system is its main infrastructure. A nation's economy expands at a rate that is very closely related to the growth of its transportation industry. High volumes of road networks are needed to meet the demands of industrialization and urbanization, and construction techniques should be used to achieve good roads at the lowest possible cost. The structural elements of the roads, such as subgrade, subbase, base, and surface courses, affect how well they perform. Currently, many locations lack the conventional materials needed to build roads. In recent years, coarse aggregate has replaced fine aggregates as the most valuable material in civil engineering projects, making it both rare and expensive. The uneconomical pavement construction results from the use of these conventional materials in road construction(Lulu, 2019) which investigated the tensile properties of mechanically stabilized cinder to be used as sub base material using the readily available cinder gravel and fine-grained soil found in the Durame area. The cinder material used by the above author is a red ash cinder which differs in tensile and mechanical properties from black volcanic cinder used in this study. Therefore, alternative materials must be found in order to build roads at a reasonable price.

Natural gravels are primarily among the materials that have been specified in our nation for use in the construction of sub-base courses. However, in some areas, it may be difficult to find high-quality aggregate, and there is a chance that this scares material will eventually be available, supporting the construction of rapidly expanding road infrastructure. This is required to increase the density of the poor road network, which keeps Ethiopia's economy thriving, particularly in rural areas (D. newill ,1989).

When stabilized with fine-grained soil, cement does meet the conventional sub base specification because it is a vitric, highly porous pyroclastic material. A cinder's suitability for a given use should be assessed based on its engineering features rather than by looking at it. Red, brown, grey, or black cinders can be found in a variety of colors, frequently within the same cone (Muench et al., 2017).

Pyroclastic substances known as volcanic cinders are linked to recent volcanic activity. They frequently have large concave depressions in their tops or sides where solids and gases were released during the formation of the cone, and they are found in characteristically straight-sided, cone-shaped hills (Seyfe & Geremew 2019).

Red, brown, grey, or black cinders can be found in a variety of colors, frequently within the same cone. The sizes of the cinder particles range from sand and silt to large, erratically shaped lumps with a diameter of 0.5 m. However, in some cones, particles may be more uniform and have a maximum diameter of no more than 30 mm. Other characteristic features of cinders are their light weight, their rough vesicular surface and their high porosity. They can typically be crushed under the heel because they are so frail. The relative ease with which they can be extracted from the quarry is advantageous for road construction materials; however, occasionally a bulldozer may be needed to open an operating face. Mechanical shovels or hand tools are typically sufficient for their extraction.

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, is expensive operations that limit the effectiveness of resource- constrained road construction and rehabilitation programs (Hearn et al., 2019).

The Rift Valley is the most active divergent intra-continental 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 (Aklilu and D NNEWILL, 1980).

Pyroclastic material ejected during these events has typically formed cones comprising ash, lapilli, bombs and blocks of varying vascularity. 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 (Hearn et al., 2019).

To produce an improved soil material with the desired engineering properties, soil stabilization involves changing one or more soil properties through mechanical or chemical means. The process may involve blending different soils to achieve the desired gradation or commercially available additives that can change the soil's texture, plasticity, or serve as a binder for soil cementation. If there isn't locally available material that meets the required quality, stabilizing material is crucial for the construction industry (Saravanan & Murthi, 2018).

Road pavement serves as a safe, comfortable, practical, and afforable running surface for the movement of fast-moving traffic. Its design must be able to distribute wheel loads to a level that is suitable for the surrounding soil. Horizontal layers of various materials are used to build road pavements. Each layer serves a specific purpose, and the right materials and layer thickness must be chosen for maximum effectiveness and cost-effectiveness.

Natural gravels are primarily among the materials that have been specified in our nation for use in the construction of sub-base courses. However, in some areas, it may be difficult to find high-quality aggregate, and there is a chance that this scares material will eventually be available, supporting the construction of rapidly expanding road infrastructure. This is required to increase the density of the poor road network, which keeps Ethiopia's economy thriving, particularly in rural areas (Bennert, 2005).

The secondary load-spreading layer beneath the road base is known as the sub-base. It serves as a working platform for the construction of the upper pavement layers, enables traffic stresses to be reduced to acceptable levels in the sub-grade, and acts as the layer of separation between subgrade and base course. Sub-base is an important load spreading layer in a completed pavement. 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 (Maniyazawal, 2020).

The sub-base acts as a load spreading layer, also during construction, when it carries heavy site traffic and in addition protects to a certain extent the sub-grade (as long as conditions are not too wet). Under special circumstances, it may also act as a filter or as a drainage layer.

The need to support construction traffic and paving equipment necessitates the strictest requirements in wet climatic conditions. The sub-base material needs to be more precisely specified in these circumstances. Un-saturated moisture conditions predominate and sub-base specifications may be relaxed in dry climatic conditions, areas with good drainage, and areas where the road surface remains well sealed. Therefore, the design of the layer and the anticipated moisture regime, both in service and during construction, will determine the sub-base material selection (Yitayou Eshete, 2011).

The materials used for the construction of sub-base layers shall be either:

1. Natural Gravel
2. Scoria (Cinder Gravel)
3. Weathered Rock
4. Crushed Gravel
5. Crushed Rock or Crushed Boulders
6. Recycled Pavement Material.

A road's individual layers of chosen materials are laid out and compacted to create a sturdy composite. A sub-base and capping layer road foundation is created to provide a suitable working platform for building the pavement. It also helps the pavement structure's overall load spreading capacity on thinner pavements. A layer of carefully chosen fill material called a capping layer is applied to the excavation's bottom or topmost embankment layer. These materials are frequently needed to adequately cover weak sub-grades. In order to cut costs, they are used in the lower pavement layers in place of a thick sub-base. Cost effectiveness should be evaluated by comparing them to one another (ERA pavement manual, 2013).

The sub-base serves as a foundation for the base and wearing courses, while the capping layer above the existing natural or compacted soil improves the in-situ material's structural performance (PAVEMENT DESIGN MANUAL, 2003). These materials' specifications for highway construction are found. When specifications are applied to account for the variability of the locally available primary materials, geographic variations take place.

It also consists 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. The costs associated with prospecting and testing procedures are probably outweighed by the potential advantages of using locally available cinder materials for building roads. Their use will make it easier to provide low-cost roads in Ethiopia where these materials are found if they are utilized in accordance with the recommended environmental protection measures and design criteria

The sub-base layers must be made of recycled pavement material, crushed rock or boulders, cinder gravel, weathered rock, and natural gravel. The purpose of this study was to demonstrate how cinder gravel was used to build sub bases.

The 120-kilometer-long Adama-Awash Road Project, which begins at the town of Adama, served as the basis for this study. Good sub-base material is not readily available in the majority of the area along the side of roads. However, there is a lot of cinder gravel in this area, and it is mixed with fine-grained soil to make it. This is done without using any specific ratio, without assessing the effectiveness of the blend material between the two, or without understanding how the mechanical properties of this material are altered by the mixture's use with the sub-base material (Contract document, 2008).

This thesis's goal is to assess the effectiveness of cinder and fine-grained soil as subbase materials and suggest the ideal blending ratio.

1.2 Statement of the Problem

In road infrastructure projects, the quality of the pavement materials in relation to the relevant engineering properties is crucial. Very high costs must be paid during the road construction process, which results in significant delays or cost increases, if the necessary pavement material cannot be located at a reasonable distance from the construction site. Working with locally available low-quality materials in these situations has a very significant negative impact on the road's durability and quality over time (Zerai Hadera, 2015).

For road projects, the quality of the sub-base material and its grain size distribution are 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 these situations, using subpar materials can occasionally have a significant negative impact on the durability and quality of the road over time. To make sure that projects meet the required cost and quality requirements, road construction projects must improve the quality of the materials they use. If the nearby construction site's material does not meet the requirements, it can be improved using the appropriate chemicals, such as fly ash, lime, cement, etc.

Cinder gravel is widely distributed throughout much of Ethiopia. Due to its light weight, rough circular surface, and high porosity, this material does, however, have a problem with compaction. Natural gravel, crushed rock, or recycled pavement material are some of the good sub base materials that are scarce in some areas of Ethiopia (D newill, (1989).

Utilizing these sub base materials everywhere incurs transportation costs and takes time because their distribution is only restricted in a few regions of the nation. Cinder gravels are used in places where they are available by blending with fine-grained soils without using any research-based output or ratio guidelines.

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. Natural gravel, crushed rock, or recycled pavement material are some of the good sub base materials that are scarce in some areas of Ethiopia. Utilizing these sub base materials everywhere incurs transportation costs and takes time because their distribution is only restricted in a few regions of the nation. Cinder gravels are used in places where they are available by blending with fine-grained soils without using any research-based output or ratio guidelines in different project areas. For example in this research case study area cinder material used as shoulder material without using any research-based output (Aklilu and kassaye, 1980).

1.3 Objective of the Study

1.3.1 General objective

The general objective of this research was to evaluate the performance of blend material of cinder and fine-grained soil as a sub base material.

1.3.2 Specific objectives

- To Know the properties of the fine-grained soil to be used as a stabilizer
- To determine the change in the behavior of the cinder with the blend of fine-grained soil
- To determine the acceptable blending proportion of the cinder and fine-grained soil

1.4 Research Questions

- What are the properties of the cinder material?
- What are the properties of the fine-grained soil?
- What lacks cider material to be used as a sub base material?
- How does the fine-grained soil affect the properties of the cinder material?
- What is the acceptable blending proportion

1.5 Scope and Limitation

The research tries to evaluate the performance of a cinder material and a fine-grained blended soil as a sub base material by conducting tests like graine size distribution, atterberg limit, compaction, California bearing ratio, Los angeles abrsion, absorption and linear shrinkage in accordance with AASHTO and ERA manual. The samples were collected on Adama Awash Road segment and Addis Ababa bole arabsa sites. In order to achieve the objectives methods like investigating previous researches works, field studies of the collected samples and laboratory testing was conducted.

Due to financial constraints the cinder samples were collected from one potential source throughout the road segment and limited numbers of tests like grain size distribution, Atterberg Limit, compaction, California bearing ratio, Los angeles abrasion, absorption and linear Shrinkage are conducted only to achieve the objectives of the present study. It is preferable to collect samples from various regions of Ethiopia in order to prepare proportioning guide-line on cinder gravel with fine-grained material and also to evaluate the effectiveness of volcanic cinder gravels combined with fine-grained soil as subbase materials for various Ethiopian regions, extensive experiments should be conducted there.

1.6 Significance of the study

This research will help researchers, practitioners and local contractors working in areas where there is no sufficient available sub base material.

1.7 Organization of the Thesis

The research paper organized in five chapters in addition with the appendices and references. Introduction about sub- base layer, back ground of the problem, objectives and methodology parts included in the first chapter. Chapter two covers a literature review containing location and engineering properties of volcanic cinder gravels in Ethiopia; modification of existing materials and method of stabilization; soil survey for highway purpose; related works on cinder gravel in road construction and economical aspects of blending material. In the third Chapter, the general description of the study area and the proposed material source are discussed. In the fourth Chapter the laboratory test results and discussions are presented. In Chapter five conclusions and recommendations are given. Reference materials used in the research work are appropriately sited and listed. The thesis ends with appendices which contain detail experimental results of laboratory investigation.

CHAPTER 2 LITERATURE REVIEW

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

2.1.1 Introduction

Despite being widely used in Ethiopia, volcanic cinder gravels had only occasionally been used to build roads, despite the fact that doing so would frequently result in significant cost savings. The main reason for its limited use was that these gravels frequently lacked fine material and didn't meet the accepted grading requirements. They were also reportedly challenging to compact (ERA Site investigation Manual, 2013).

Research has been conducted to provide details on the occurrence and characteristics of the volcanic cinders as part of a joint project between the Ethiopian Road Authority and the United Kingdom Transport and Road Research Laboratory with the goal of encouraging their wider use in future road construction.

The Ethiopian Road Authority(ERA) and Transport and Road Research Laboratory(TRRL, U K) started this joint research project in Ethiopia in 1975. Establishing guidelines to enable high way engineers to fully utilize locally available materials for road construction was one of the p rogram's goals (ERA Site investigation Manual, 2013).

This was thought to be especially pertinent in Ethiopia, where a lengthy program of building r ural roads is currently being developed and is anticipated to last for several years (Aklilu and kassaye, 1980).

A preliminary investigation into the location and engineering characteristics of the cinder grav els was conducted as part of a joint research project between the Ethiopian Roads Authority an d Transport and Road Research Laboratory(UK). Field surveys, laboratory research, and the e xamination of a cindergravel road were all part of the preliminary study. Grading and the size of the gravel particles are the two main elements that influence the engineering behavior of cin der gravels, according to the study. 53 samples from the field survey were subjected to particle size analysis, which showed that natural cinder gravel's grading is lacking in fine particles and falls short of the suggested base course limits.

Values between 46 and 177 were obtained from the aggregate impact test, which was conducted on 23 samples using a modified weak aggregates procedure. These results show that the cinder gravel is weak. The investigation's main conclusions are as follows:

- In order to obtain representative materials, it is crucial to sample below the weathered zone, which can reach a depth of two meters.

- The gravel road study further supports the idea that because cinder particles are weak, compaction results in particle breakdown, which enhances both grading and strength properties.
- Changes in moisture content do not affect the properties of cinder gravels; and
- The addition of locally available clayey soil to make up for the deficiency of fine materials improves the compactability and stability of cinder gravels.

Twenty different sections made up the fullscale road experiment, six of which had gravel surfa ces and the other fourteen had bitumen surfaces. The findings of the experimental sections wit h gravel surfaces demonstrated that mechanically stabilizing cinder with plastic fines can resul t in improved performance. When designed in accordance with Road Note 31, cinder gravels p erformed satisfactorily in the surface dressed sections, whether they were left untreated or mec hanically stabilized for use in base course for up to 440, 000 ESA. However, it was determine that the roadmix surfacing was insufficient to provide cinder gravel with a bituminous surface. The findings of the joint research project should be used to improve the engineering qualities o f these widely accessible natural gravels in order to investigate their potential use as a base cou rse for heavily trafficked roads. When it is expensive to import highquality aggregate and there is a long hauling distance, both the Ethiopian Roads Authority Pavement Design Manual(ER APDM)] 9 and the Addis Ababa City Road Design and Rehabilitation Manual, or APRM, advi se using stabilized locally available natural gravels (AACRA Pavement Design Manual, 2003). Although volcanic cinder gravels are widely found in Ethiopia, they have only occasionally been used to build roads, despite the fact that doing so would significantly lower the cost of building roads.

The Ethiopian Road Authority and the UK Transport and Road Research Laboratory have previously conducted research to provide information on the occurrence and characteristics of volcanic cinders with the goal of promoting their wider use in road construction.

The Ethiopian Road Authority (ERA) and Transport and Road Research Laboratory (TRRL, UK) started this joint research project in Ethiopia in 1975. Establishing guidelines to enable highway engineers to fully utilize locally available materials for road construction was one of the program's goals. This was thought to be especially pertinent in Ethiopia, where a lengthy program of building rural roads is currently underway and is anticipated to last for several year

(Girma Berhanu, 2009).

2.1.2 Definition of Volcanic Cinders

A pyroclastic, highly vesicular volcanic rock known as a cinder is one that was formed by cooling in the air from molten rock. The numerous gas bubbles that "froze" into place as the molten blob quickly cooled as it moved through the air are what cause the rock's vesicules, or bubble-like cavities. Climbers create loose, un-cemented deposits because they cooled before they hit the ground. Around their source volcanic vent, they frequently create scoria or cinder cones, two types of volcanic cone.

Pyroclastic substances known as volcanic cinders are linked to recent volcanic activity. They are found in hills with distinctively straight sides and concave depressions where solid and gas mixtures were released during the cone's formation. Within the same cone, cinders can be red, brown, grey, or black in color. The sizes of the cinder particles range from sand and silt to large, oddly shaped lumps that are 50 cm in diameter. However, in some cones, the largest size of particles may not exceed 3 cm in diameter, making them more uniform. Cement's light weight, rough vesicular surface, and high porosity are additional distinguishing characteristics. They can typically be crushed under the heel because they are so frail (Aklilu and kassaye,1980).

Although some do, the majority of cinder cones are created by the eruption of basaltic lava. Dark rocks with minerals that are rich in iron, magnesium, and calcium but deficient in potassium and sodium are created when basaltic magmas crystallize. All five elements-iron, magnesium, potassium, calcium, and sodium—are present in about equivalent levels in the minerals that are formed when andesitic magmas crystallize into rocks. Additionally, andesitic magmas contain more silicon than basaltic magmas.

Cinder cones are created by relatively small eruptions of pasty, viscous lava. The pressure buildup needed to eject thicker lava tends to create small explosive eruptions instead of flowing lava. These explosive eruptions throw droplets of lava into the air, where they cool and fall back to earth as cinders, or "tephra." The cinder cone grows as successive eruptions pile more cinders on its slopes.

The relative ease with which cinders can be extracted from the quarry is one benefit of using them as a building material for roads. Mechanical shovels or hand tools are typically sufficient for this purpose, though occasionally it may be necessary to open up an operating face.

2.1.3 General location of cinder gravel in Ethiopia

Under the auspices of TRRL and ERA, a survey was conducted, which involved the analysis of aerial photos and photo-mosaics as well as the creation of a map outlining the distribution of cinder deposits across Ethiopia.

All of the fieldwork associated with the survey was done within 150 kilometers of Addis Abeba. In close proximity to Debrezeit, Nazareth, Ziway, Butajira, and Giyon, they were clustered (Hearn et al., 2019) (see Figure 2.1).

Grass is often the only type of plant that grows at top of cinder cones, and an inspection of the exposed profiles revealed that the depth of the soil cover was only a few centimeters. However, a weathered cinder zone typically goes down around two meters. In some cones, calcium carbonate deposits cover the cinder gravels; these deposits do not cover the entire cone, but rather appear in thin, parallel white bands that are typically near to the surface.

The distinctive shape of the cinder cones made them easily identifiable on aerial photographs andaerial photographs were used both to plan the survey and subsequently in the field work (Newill &Aklilu,1980).

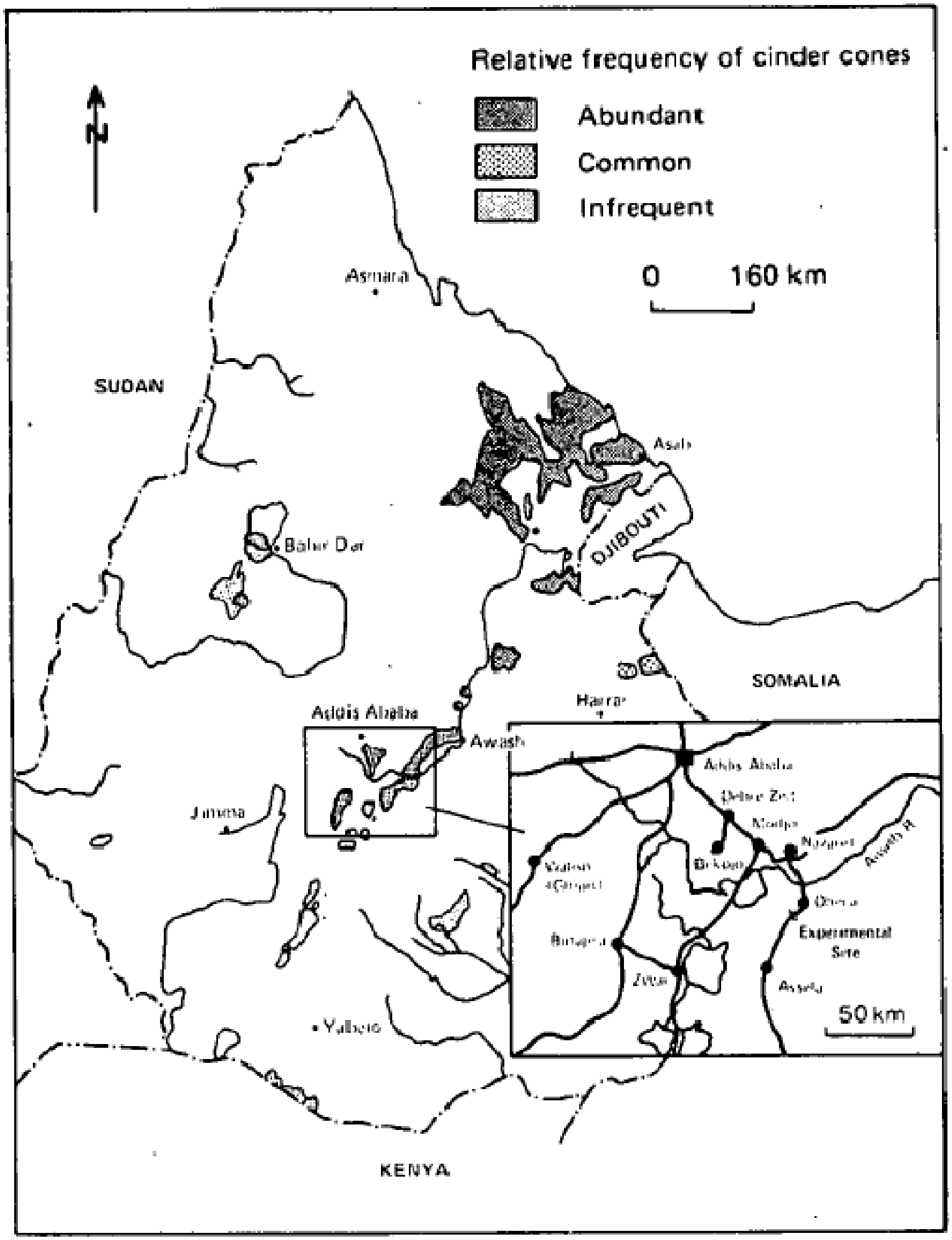

Figure 2.1 Cinder cone distribution in Ethiopia, survey area enlarged (Aklilu & Kassaye, 1980)**.**

The examination of air-photos and print lay-downs was extended to cover the whole of Ethiopia and from these and a study of areas of recent (Quaternary) volcanic on the geological map, a preliminary map was compiled showing the occurrence of cones throughout the country (see Figure 2.1).

Cinder gravels were mostly concentrated in the Rift Valley that bisects the country in a SSW-NNE direction; an indication of their frequency for each of the areas that were identified has beengiven in figure 2.1(Aklilu & Kassaye, 1980).

2.2 Soil Survey for Highway Purposes

In relation to the location, design, and construction of highways, soil surveys are conducted. When designing and building a highway, soil assessments are conducted. For the location where a highway project is to be implemented, there are many sources of information about soils generally. These sources include aerial pictures, geological and topographic maps and reports, agricultural soil maps and reports, and the previous soil survey in the region. Information from this source is significant in two respects in particular. A thorough grasp of soil characteristics and any potential engineering issues can be attained by first studying this data. Second, such information is crucial for organizing, carrying out, and deciphering the outcomes of the requisite extensive soil surveys (Makusa, 2012).

2.3 Modification of properties of existing materials

To enhance their engineering qualities, exiting materials might need to be modified. Additionally, locally accessible materials that would not otherwise meet the requirements of the general specification can be appropriately adapted to meet those requirements. Saving on the transportation of expensive resources from elsewhere also provides an economic value. Sometimes a design may need for a distinct kind of material with particular qualities, which can be accomplished through material modification (Hamisi Chengula & Kilango Mnkeni, 2021).

2.3.1 Soil stabilized roads

In order to increase the soil's bearing capacity for building roads, soil stabilization entails enhancing the shear strength characteristics of the soil. It is necessary when the construction-ready soil is unfit to support structural loads. Unless they are treated to improve their physical properties, soils typically display unfavorable engineering characteristics (USA Dep.of Army, 1997).

Stabilization can boost a soil's shear strength and manage its shrink-swell characteristics, enhancing a subgrade's ability to support pavement and its foundations. In order to raise the shear strength of the soil mass in earth structures and decrease its permeability and compressibility, soil stabilization is used. Stabilization is accomplished by incorporating chemicals into the reaction mechanism, which strengthens it and improves and maintains the moisture content of the soil. Consequently, these Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (USA Dep.of Army, 1997).

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. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Regardless of the purpose for stabilization, the desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of the project (Ejeta et al., 2017).

In order to create a hard mass that can support traffic under all circumstances, soils are combined and worked, with or without admixture, to create soil stabilization for roads. A stabilized soil must have adequate shearing strength to withstand the stresses placed on it by traffic loads in all types of weather without experiencing significant deformation in order to be considered really "stable" With an aim to lowering construction costs, local materials are used effectively while designing and building highways. Construction of bases and subbases currently makes up the majority of the use of stabilized soil mixtures. A stabilized soil base and sub-base may serve as a base for a high-type pavement that will be subjected to extremely high traffic volumes, or it may offer the support for a comparatively thin wearing surface that will be subjected to low to moderate traffic (PaulHWright, 2011).

2.3.2 Methods of Stabilization

1. Mechanical stabilization

In order to create a material that satisfies the necessary specifications, soils of two or more gradations are mixed or blended. A central facility, a borrow area, or the building site are all possible locations for the soil blending. The combined material is then dispersed and traditional methods are used to compact it to the appropriate densities. The soil-aggregate particles become interlocked as a result of mechanical stabilization during compaction. The soil-aggregate combination must be graded so that when it is compacted, a dense mass is created. a process by which additional soil or gravel is combined with the old soil to enhance the soil's grading and mechanical properties. Typically, river sand, natural gravel, silt sand, sand clays, and silt are utilized for mechanical stability (USA Dep.of Army, 1997).

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.

There are several methods used to achieve mechanical stabilization. G Paul Makusa, (2012).

1. Compaction

In order to raise soil density by exerting pressure from above, compaction normally uses a hefty weight. For this reason, equipment like sizable soil compactors with vibrating steel drums is frequently employed. Over compacting the soil should be avoided and given careful consideration in this situation because doing so causes the aggregates to be crushed and the soil to lose its engineering features.

2. Soil Reinforcement

Sometimes mechanical fixes, whether engineered or not, are used to address soil issues. Geotextiles and engineered plastic mesh are made to capture soils and help regulate soil permeability, moisture levels, and erosion. Larger aggregates like gravel, stones, and boulders are frequently used in construction projects where the extra bulk and stiffness can stop soil migration or enhance load-bearing capabilities.

3. Addition of Graded Aggregate Materials

A typical technique for enhancing a soil's designed properties is to incorporate certain aggregates that provide the soil desirable properties like greater strength or lower flexibility. This technique offers material economy, enhances the subgrade's capacity for support, and provides a work platform for the remaining structure.

4. Mechanical Remediation

This has historically been the standard method of handling contaminated soil. This method involves physically removing contaminated soil and moving it to a designated hazardous waste site away from densely populated areas. However, in recent years, chemical and bioremediation have shown to be superior options in terms of cost and environmental impact.

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

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

In order to achieve suitable densities, the mixture is typically compacted at or around OMC. In order for the available soils to provide the appropriate stability when properly compacted, mechanical stabilization aims to mix them together. For instance, in some regions, there may be too much clay, silt, or fine sand, which causes the natural soil at a particular place to have inadequate load-bearing strength. There may be nearby suitable granular resources that, when combined with the local soils, can significantly improve the soil at a lesser cost in terms of labor and resources than applying imported surface (Singh & Arora, 2017).

2. Chemical admixture stabilization

By adding various chemicals, soil can be stabilized chemically. Chemical stabilization has the main benefit of allowing for precise control over curing and setting times. However, compared to other stabilization methods, chemical stabilization is typically more expensive.

Chemicals shouldn't be applied directly to the surface during chemical soil stabilization. When mechanical techniques of stabilization are ineffective and replacing an unwanted soil with a suitable soil is either impractical or too expensive, chemical admixtures are frequently utilized to stabilize soils. Cement, lime, flay ash, and bituminous material are used in almost 90% of all chemical additive stabilization projects (Singh & Arora, 2017).

Advantages of Chemical Stabilization of Soil

- Setting time and cure time are both controllable in this stabilizing technique.
- Soils get stronger as a result.
- The soil has a higher density after being compressed.
- The soil's permeability is increased via chemical stabilization.

Disadvantages of Chemical Stabilization

- This method of stabilization is relatively expensive than the other stabilization methods.
- The treated soil may lose strength when exposed to air or ground water.
- Require extra experienced labor.

2.4 Related Works on Cinder Gravel in Road Construction

2.4.1 Experimental use of cinder gravels for roads in Ethiopia

In Ethiopia, a full-scale experiment was carried out as part of the collaboration between ERA and TRRL to assess the efficacy of volcanic cinder gravels as a surfacing material for unpaved roads and as a road base under bituminous surfaced roads.

Twenty separate portions of an experimental road stretch were built after compaction studies to identify the equipment to be utilized. During the 28-month observation period, which they carried almost 140,000 cars through, six portions were left without surfacing. The remaining 14 sections received a bitumen surface and were used to transport 150–200 vehicles each day for 7 1/2 years, or 440,000 equivalent single axles in one direction.

Throughout this time, monitoring was done by taking quantitative measurements of the road pavement's performance. The study's findings led to recommendations for the application of cinders to both paved and unpaved roadways. A particle size distribution that produces a road surface that is resistant to corrugations is suggested for unpaved roads. Cinders that have been mechanically stabilized with plastic particles work better. It is determined that, when sealed with a surface treatment and properly developed, the materials employed in this experiment are all capable of supporting more than 400,000 comparable single axles on paved roads. Cinder gravels cannot be surfaced with road mixed asphalt. Other materials, such as dry bound macadam, agglomerate, and tuff, also functioned well in addition to the cinders. In addition, it was advised that mechanical stabilizing cinders with 10% soil made of volcanic ash would make them easier to compact (D.newill and K. Aklilu,1989).

Preliminary investigation of cinder gravels by TRRL

The following are the key findings from TRRL's initial investigation on cinder gravels, which included a field survey, a laboratory study, and a review of a cinder gravel road: -

- Cinder gravels are more common than previously thought in Ethiopia; this demonstrated the usefulness of using aerial pictures in survey work and made it possible to create a preliminary map showing the distribution of cinder cones.
- It's critical to collect samples from beneath the worn zone, which can reach a depth of two meters, in order to gather representative material from cinder cones.
- The laboratory investigation revealed that, due to the weak nature of the aggregate particles, breakdown under compaction occurred with an improvement in both grading

and strength properties, even though "as dug" cinder gravels do not meet the recommended grading requirements for road base materials.

- The cinder gravels in the laboratory experiment were not impacted by variations in moisture, and even complete immersion in water only marginally decreased their strength.
- The mechanical stability of cinder gravels was increased by the addition of locally accessible plastic volcanic ash soil to make up for the lack of fine material in the grading, suggesting that this could be a useful building technique. The blended materials, unlike the natural cinders, however, lost some of their strength when they became wet. The gravel road study proved that even when trafficking was employed as a method of compaction, cinder gravels' grading and strength improved under typical road conditions.

The preliminary investigations' findings suggested that cinders would make suitable building materials for highways, particularly for gravel ones. Before recommendations for restrictions for their various uses could be made, more research had to be done in bituminous surfaced roads and gravel roads under known traffic and weather circumstances. In order to further investigate these factors, it was decided to build pilot size compaction experiments and eventually a full-scale road experiment.

Teshome (2015) studied the Use of Natural Pozzolana (Volcanic Ash) to Stabilize Cinder Gravel for a Road Base (Along the Modjo-Ziway Route) was researched. According to the study, pumice (volcanic ash) makes up 0, 4, 8, 12, 16, 20, and 24% of the mass of cinder gravel. The laboratory testing included compaction, CBR, gradation, Atterberg limit, Los Angeles abrasion, aggregate crushing value, ten percent fines value, absorption, and specific gravity. The ideal amount of natural pozzolana (volcanic ash) is 20% by mass proportion at a density of 1.76g/cc, according to laboratory test results of the moisture content vs. density relationship. The stabilized samples were kept free of water intrusion and covered with a polyethylene sheet for the curing duration of zero, three, seven, fourteen, and twenty eight days using the air curing procedure for the wet and un-soaked conditions. The range of soaked CBR grows for the ideal blending proportion from 98% to 245%, whereas the CBR increases for the un-soaked state from 118% to 307%, for curing times of 0 to 28 days.

Girma Berhanu (2009) studied base course stabilizing cinder gravel for high traffic. In two later phases, the mechanical and cement stabilization were examined in light of this investigation. In the initial phase, it was determined that 12% of fine soils was the ideal proportion to make for the shortage of fine particles in natural cinder gravels. The second step involved stabilizing a natural cinder gravel sample with 3, 5, 7, and 10% of cement by weight, both without and with 12% fine soils. According to the investigation's findings, 7% cement is the ideal quantity needed to reach the minimum UCS of 3.0 MPa stated in the ERA and AACRA pavement design standard for heavily trafficked base course without the use of fine soil. However, by mechanically stabilizing cinder gravel with 12% of fine soils prior to cement stabilization, this high cement demand was decreased to 5% cement, which is a more practical value. However, it was advised that a full-scale road experiment be conducted to examine the effectiveness of cement stabilized cinder gravel against cracking brought on by pressures caused by heat, shrinkage, and traffic.

Kassaye et al., (1987) investigated Ethiopia's experimental use of cinder gravel. According to this study, they often have weak particles, are lacking in fine material, and when large particles are broken down during compaction, a better grading and greater strength are produced. The strength and density of the compacted cinder gravels were also found to be enhanced by the addition of particles. The road inspection verified that the breakdown effect on gravel roads caused by driving is the same as what was seen in laboratory compaction testing.

As part of a collaborative road research project between the Ethiopian Transport Construction Authority and the Transport and Road Research Laboratory (UK), a full-scale experiment has been conducted in Ethiopia to assess the effectiveness of volcanic cinder gravels as the surfacing material for unpaved roads and as the road base under bituminous surfaced roads. A road experiment with 20 distinct sections was built after compaction trials were conducted to establish the type of plant to be utilized. For 28 months, six unsurfaced sections—which carried roughly 140,000 vehicles were watched and monitored. For the remaining 14 sections, a bitumen surface was installed, and they transported 150–200 vpd (Vehicles per day) for 7.5 years, totaling 440,000 esa in one direction. Throughout this time, the performance of the road pavement was monitored by obtaining quantitative measures. The study's findings led to recommendations for using cinders in both paved and unpaved roadways.

Seyfe & Geremew (2019) carried out an experimental examination by mixing cinder gravels with common crushed stone foundation course material (CSA) in proportions of cinder/CSA (10/90, 20/80, 30/70, 40/60, and 50/50) and treating with 6. 8 and 10% of cement. According to the findings of sieve analysis, aggregate crushing value (ACV), flakiness index, and California

Bearing Ratio (CBR), cinder gravels can replace 30% of crushed stone aggregate (CSA) to be used as fresh, crushed rock (GB1) material. For cement-treated cinder gravels, adding 6% and 8% cement makes them suitable for use as stabilized base course (CB2) and (CB1) base course materials, respectively, referring to their 14 day compressive strength as determined by Unified compressive strength test(UCS) test.

Yitayou Eshete (2011) investigates the effectiveness of mechanically stabilized natural cinder gravels intended for use as road sub-base material by mixing the cinder gravel with a trail proportion of 0, 5, 10, 15, 20, and 25% of fine-grained soil by mass. Various tests, including grain size distribution, Atterberg Limit, compaction, CBR, LAA, absorption, and linear shrinkage are then carried out in the laboratory. Based on the outcomes of the laboratory tests, it can be shown that the ideal percentage of fine-grained soil needed to enhance a soil's characteristics is 19% by mass proportion, as indicated by the curves for MDD-percent of fine-grained soil and CBR-percent of fine-grained soil required in order to improve its properties is 19 % by mass proportion.

Zerai Hadera (2015) conducted an experimental analysis to establish the ideal ratio for combining cinder gravel, volcanic ash, and lime in two phases. Mechanical stabilization was done in the initial phase of the experiment using different ratios of volcanic ash and cinder gravel. The ideal volume of volcanic ash to make up the lack of fine particles was calculated using the compaction method. The ideal percentage of volcanic ash in this process has been determined to be 22% by weight CBR values for cinder gravel stabilized mechanically with the recommended amount of volcanic ash were calculated at 3, 7, 14, and 28 days after the sample was wrapped in the mold with a polyethylene sheet. The test findings revealed that the CBR values for all of the days that the sample was wrapped in the mold exceeded 80%, which is what the ERA specification for road base requires, whereas the CBR values for the cinder gravel alone were discovered to be 72%. The amount of time the sample was wrapped in the mold did not, however, significantly impact the CBR readings. This phase has revealed that, as predicted, the CBR value for the soaked state is lower than that of the unsoaked condition. The second phase of the research involved simultaneous mechanical and lime stabilization, which involved mixing cinder gravel with 2% lime and 20% volcanic ash to see how the CBR would alter. When the sample was wrapped and kept in the mold for 3, 7, 14, and 28 days, soaked and unsoaked circumstances showed that the CBR values in this phase were higher than the corresponding values obtained by blending cinder with water. In contrast to the preceding phase, it was found that the CBR value in this scenario increased with time spent wrapping and maintaining the sample in the mold. Additionally, it was discovered that the CBR value after four days of soaking was higher than that of the un-soaked condition for a specific amount of time after the sample was wrapped in the mold.

Ermias Lulu (2019) investigated the tensile properties of mechanically stabilized cinder to be used as sub base material using the readily available cinder gravel and fine-grained soil found in the Durame area. As a result, in order to meet the requirements of the Ethiopia Road Authority manual, cinder gravel was mixed with some trail proportion of 0, 10, 20, and 33% of fine-grained soil by dry weight using tests like gradation, compaction, atterberg limits, free swell, specific gravity, and California Bearing Ratio (Lulu, 2019). The best amount of fine-grained soil to meet the ERA manual standard specification criteria, according to laboratory test findings, was found to be 20%. Testing in the lab on samples made with the right proportion of fine-grained soils showed that cinder gravel responded quite favorably to the treatment, as evidenced by an improvement in its gradation and flexibility.

The ideal amount of fine-grained soil is 20% by weight at a density of 1.87 g/cc, according to the results of laboratory tests on the relationship between moisture content and density. The range of the blended mix's soaked CBR increases from 64% to 97%, and the PI value decreases from zero to 0% to 6.1%.

2.4.2 Stabilization of cinder by means of bitumen or cement

Efrem did research to see if the features might be improved by stabilizing cinder with foam + 1% cement or with cement given that cinder is a problematic material. The Addis Abeba-Awash and Nazareth-Assela routes are where the cinder was found (Efrem G.E,2000).This investigation led to the suggestion that cinder is generally not suitable to serve as a surfacing material for unsurfaced roadways. This is due to the absence of fines that serve as a binder. Even so, it is employed in Ethiopia as a surfacing material, although the cinder roads there suffer from excessive gravel loss, rutting, and corrugation in the track wheel.

Due to its low crushing resistance, cinder is not regarded as being suitable as a foundation course material. In Ethiopia, tests on using cinder as a foundation course overlaid with a double surface dressing or a 50 mm thick asphalt overlay were conducted in the late 1970s. The results of compaction with a vibratory roller and a rubber tyre roller were demonstrated to be the best. The test sections were built to support 0.64 million 80 kN equivalent single axles over a 15-year span while carrying 80 to 100 commercial cars each day. Despite severe crushing of the coarse particles being seen, the test portions after two and a half years in service were still in acceptable condition. However, by the end of 1999, the parts had been badly compromised by fatigue cracking, and in some places the wearing course had completely worn out. Except for a few small potholes, the surrounding sections built with a typical crushed stone base were still in good shape. In conclusion, it can be said that using cinder as a base material or as a surface requires caution. Modifying the cinder with cement or foam bitumen may be a viable alternative in order to use it as a base (Girma Berhanu, 2009).

2.4.3 Stabilizing cinder gravels for heavily trafficked base course

Using samples gathered from quarry sites close to Alemgena and Lake Chamo, research was conducted into the improvement of natural gravels through the use of stabilizing procedures. In two later phases, mechanical and cement stabilization were examined. In the initial phase, it was determined that 12% of fine soils was the ideal proportion to make for the shortage of fine particles in natural cinder gravels. In the second stage, 3, 5, 7, and 10% of cement by mass were used to stabilize natural cinder gravel samples with, without, and with 12% fine soils. According to the findings of the analysis, the ideal quantity of cement needed to reach the minimum UCS of 3.0 MPa as stated in the ERA and AACRA pavement design standard for intensively traveled base course without adding any additional cement is found to make up 7% of fine soil. However, by mechanically stabilizing cinder gravel with 12% of fine soils prior to cement stabilization, this high cement demand was decreased to 5% cement, which is a more practical value. However, it was advised that a full-scale road experiment be conducted to examine the effectiveness of cement stabilized cinder gravel against cracking brought on by pressures caused by heat, shrinkage, and traffic.

2.5 Economical Aspects of Blending of Material

Highway engineers are required by economic necessity and the variety of physical and climatic conditions to utilize natural resources to the fullest extent possible in developing nations, where the financial adaptation of a road to special needs and the technical adaptation of that road to local conditions are two complementary factors that significantly influence planning decisions. All highway improvements must be completed as economically as feasible, including the excavation, hauling, and installation of suitable paving materials (Dr J Jha and S k Sinha 1973) .In contrast, investment in materials is typically higher in developing nations since a large portion of the roads that must be developed and maintained are generally unsurfaced and involve the installation of gravel. Therefore, it is essential for haulage distances, which make up the majority of building expenses, to be reduced in order to accomplish the most cost-effective construction and reduce later maintenance costs expense that will be reduced by utilizing the resources that are readily available locally.

Due to the adaption of criteria for road building materials that have been derived in industrialized countries with temperate climates and varied geology, locally available resources are frequently not employed as extensively throughout many developing countries as would be possible.

If the type of material is carefully chosen and regulated, more heavily traveled roads may also be built when the climate is favorable. Recent increases in the price of building roads have highlighted the importance of making the best use of these locally available resources, not only to cut costs but also to preserve those better quality materials that are frequently in short supply and valuable for specialized projects that call for construction to exacting standards (like airfields).

The application of study findings from work done by TRRL and others on design guidelines for low volume secondary and feeder roads could result in very significant savings. For instance, in Malawi, the cost of providing a crushed stone base, which is frequently the favored design option, is typically in the range of 15% of the project's overall expenses. Crushed stone base costs more than lateritic gravel, which is readily available nearby, by at least a factor of four to one. If these locally plentiful gravels can be used for the base construction, significant cost savings on the construction of low volume roads can be accomplished. The cost differential between crushed stone and the natural gravel base is substantially higher than the 4:1 quoted where sources of crushed stone are not easily accessible, which is the case in many areas of southern Africa (AIMIA Conference Boston,2006).

Compared to the use of primary materials for the same applications, the use of recycled concrete materials for capping and road sub-base can be economically advantageous. Savings of 20–30% are attainable, according to cost comparisons with primary aggregates. Depending on the location and transportation needs, these savings can vary.

In some nations, crushed concrete can be used in specific situations as a principal material substitution, frequently at a cost savings. Such material can be properly prepared using methods including screening, crushing, grading, and testing and is accessible from demolition activities.

Crushed concrete can save costs, conserve key resources, and lessen the negative effects of transportation.

With the right selection and processing, the material's performance to strengthen foundation soils can match or even exceed that of typical primary materials. Over a long period of time, the substance has only been sparingly used in the creation of paved areas and roadways. This sort of road construction method requires very high rates to be paid, which results in substantial delays or cost increases if the right sub-base material cannot be found in locations adjacent to the construction site. Low-quality materials are occasionally employed in these situations, which over time impairs the road's quality and longevity and causes quite large losses. To ensure that projects satisfy the essential cost and quality criteria, it is crucial to improve the quality of materials used in road construction projects (Bennert, 2005).

2.6 Summary of literature review

Table 2.1 summary of literature review

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It no.	Year of Publication	Author	Major Findings
1	1987	Newill, D; Robinson, R; Akililu	Cinder could be useful road constuction materials especially for gravel roads
2	2009	Girma B	Cinder can be used as a base course by mechanical stabilization (blending with fine) and cement stabilization
3	2015	Teshome T	Cinder Can be used for a road base by stabilizing a natural pozzolana (Volcanic ash)
4	2015	Zarie Hadera	Cinders properties can be used as a base course blending with volcanic ash and lime
5	2019	M.Seyfe , A.Geremew	Cinders can be used as a base course by bleding with crushed stone and cement
6	2019	Erimiyas Lulu	By mechanically stabilizing with fine-grained soil, cinders' strength characteristics can be increased and used as a base.

The executive summary demonstrates how cinder could be improved to provide a strong sub base and base course material. All authors demonstrate that cinder material has a high potential and that stabilizing this potential might make it a valuable pavement material, particularly for places with a shortage of pavement materials.

CHAPTER 3 MATERIALS AND METHODOLOGY

3.1 Geographical Location of the Project

Adama-Awash Road is located in the Eastern part of Ethiopia. It is located at 165.00 km South Eastern of Addis Ababa and starts at distance of 60.00 km from Adama city and proceeds to Adama-Awash main trunk road which covers total length of 60.00 km and terminates at Awash Sebat town after 225.00 km from Addis Ababa. The latitudinal and longitudinal location of the project is as follow: -

Adama - 8°32’29.53”N, 39°16’.21”E

Awash - 7°57’6.48”N, 39°8’1.87”E

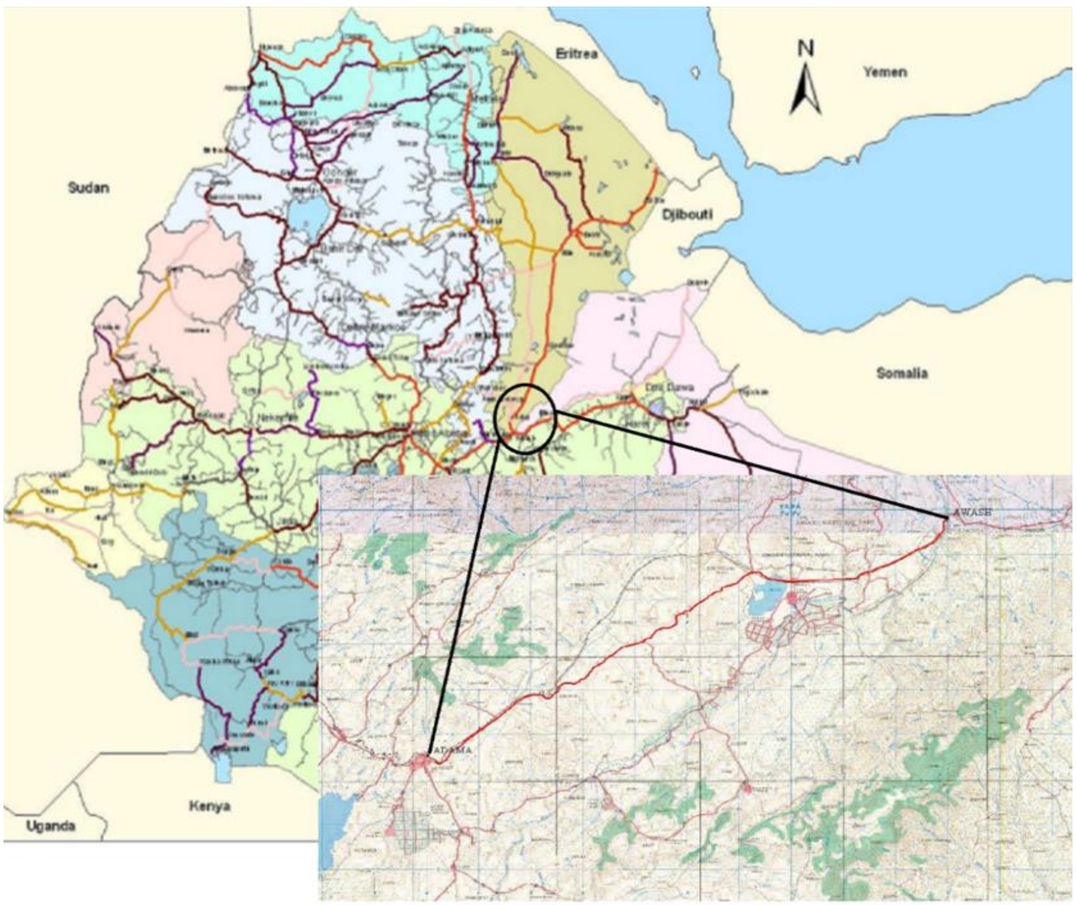


Figure 3.1 Location of the Project

3.2 Topography (Alignment and Terrain Classification)

The road alignment traverses dominantly through flat to rolling terrain. Generally, it gently descends gradually from 1443.02 m at the starting point to 879.60 m at the end point of the project road length.

The following table describes the terrain classification of the project road.

Table 3.1 Terrain Classification of the Project Road

Station	**Terrain Classification**
40+000 – 43+000	Rolling
43+000 – 55+000	Flat
55+000 – 69+200	Rolling
69+200 – 71+500	Flat
71+500 – 87+600	Rolling
87+600 – 100+000	Flat
100+000 – 102+500	Rolling
102+500 – 122+300	Flat
122+300 – 123+100	Rolling

Table 3.2 Terrain Classifications

No	Terrain Type	Length (km)	Coverage (%)
1	Flat	73.1	59.38
2	Rolling	50	40.62
3	Mountainous	0	0

3.3. Climatic Condition of the Project

The main influences of climate characteristics on pavement design relate to the moisture content of the subgrade, the need for drainage, the choice of surfacing type, design, and construction materials. To this end, the Ethiopian National Metrology Agency's 1979 climate data for the project region was gathered and utilized in the project's design and construction. The project route corridor passes through a warm, semi-desert climate known locally as "Kola" and "kefil Bereha" according to Ethiopia's 1979 climate classification. The average annual rainfall in this area is 600–700 mm. The coldest month's average temperature is over 15 oC, while the average annual rainfall ranges from 68 to 200 cm. According to this map, the project area is classified as dry Climate.

3.4 Materials

Understanding a material's qualities, behavior, and how these change over time and space is essential before choosing the best of the locally accessible materials for road building. Even though some materials may work admirably in a road pavement despite not meeting generally accepted selection criteria, the contrary may also be true in situations when the outcomes are as surprising.

The materials cinder and fine-grained soil used for this study were collected from adama awash road segment and adis abeba bole arabsa site. The cinder material potential source is located at station 77+200 of project station which is 17.2 km from project starting location or 77.2 km away from city of adama and GPS location showed N=896355.629, E=428169.729.The fine grained material is located in adis ababa bole arabsa quarry site which is 153 km away from project starting location and GPS location showed N=989423.19, E=487174.79 Contract document,(2008).

Figure 3.2 Material site for borrow material and cinder gravel respectively

3.5Methodology

To achieve the objectives of this thesis, the following methodologies have been followed.

- Literature review.
- Field work in which sampling of cinder gravels and Fine-grained soil was performed.
- Laboratory testing (Atterberg Limits, Gradation, California bearing ratio, Atterberg limit, Los Angeles Abrasion, Linear Shrinkage and specific gravity and absorption) followed by analysis whereby the engineering properties are determined.

The research follows experimental type of study which includes the following stages:

I. Sampling collection: -Cinder material and fine-grained material sampled from their sources using undisturbed sampling method from different parts of the sources.

II. Preparation of samples for each test: -

- Dry the samples and let the sample stay to dry for 3-5 days and inspect whether the samples have already dried.
- Quarter each samples using splitter
- Weighing from each sample for each test to be conducted.

III. Taking the natural untreated cinder as a control data and testing its properties using laboratory tests like Atterberg Limits, Gradation, California bearing ratio, Atterberg limit, Los Angeles Abrasion, Linear Shrinkage and specific gravity and absorption.

IV. Blending cinder with different proportion with fine grained soil and conducting laboratory tests until the blend satisfies the requirement of standard specification. From the gradation of the two materials using arithmetic calculation the optimum fine-grained soil to be used for blending is 22%. From this a trial blending scenario of 0% blending ratio, 7% blending ratio, 21% blending ratio and 28% blending ratio have been decided.

Artimethic Percent proportion calculation

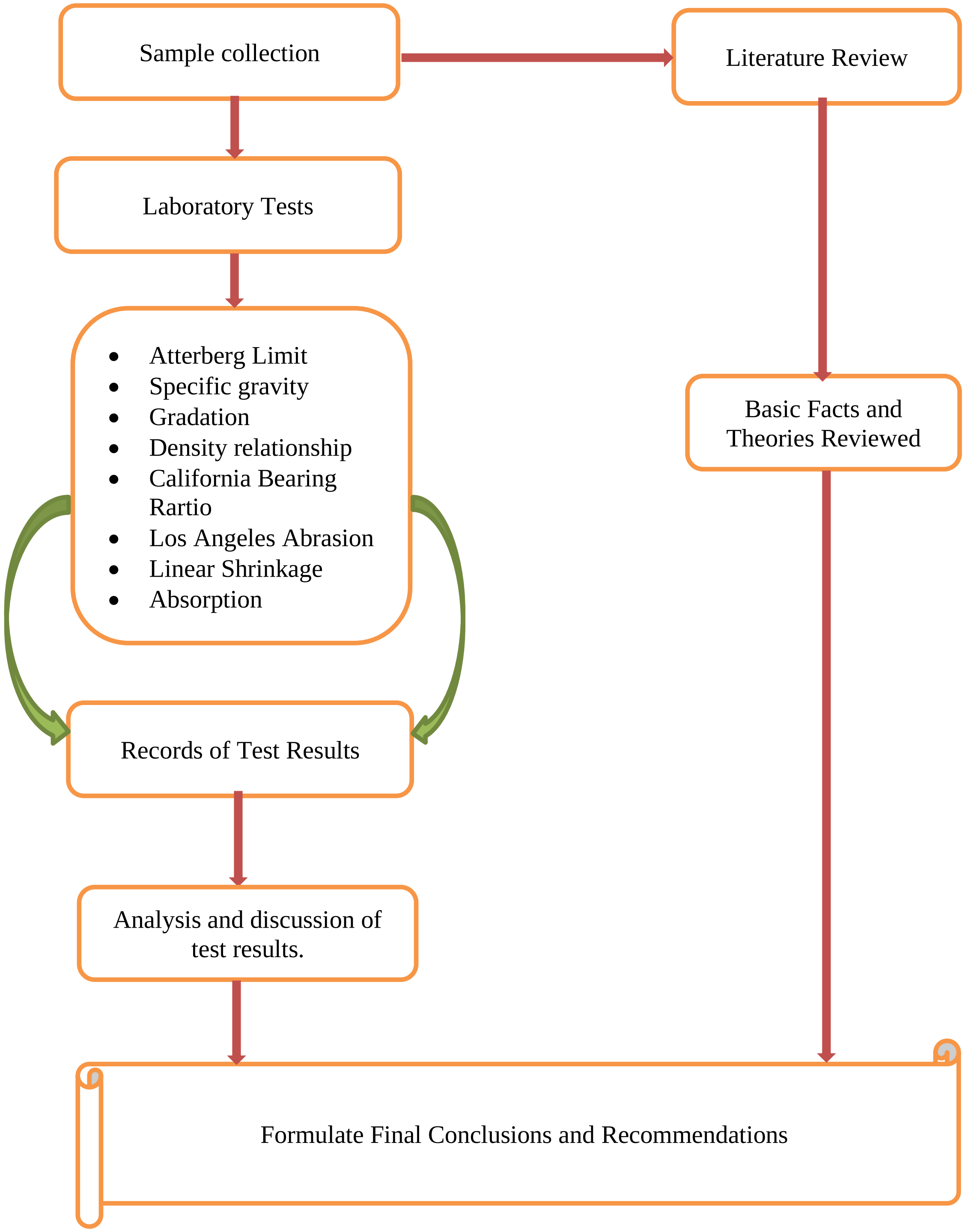
	fine	cinder			
sive size	A	B	S	S-A	S-B
37.5	100	95.13	100	0	4.87
25	91.6	81.42	80	11.6	1.42
4.75	86.3	36.97	45	41.3	8.03
1	73.4	24.98	35.5	37.9	10.52
0.425	57.2	8.71	20	37.2	11.29
0.075	37	2.82	10	27	7.18
			sum	**155**	**43.31**

Where	
A	Grading of fine aggregate
B	Grading of fine cinder
S	Average of spec limit

Percent proportion		
	%A	**22**
	%B	**78**

V. Analysis and discussion of test results.

VI. Formulation of conclusions and recommendations based on the results obtained is done.



Summarized Methodology Chart of the Study

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 General

In this section a detail investigation of serious test results followed as a part of this research will bediscussed. Standard procedures of AASHTO and ASTM have been used wherever possible.

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

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

The aims of the laboratory investigation were to:

- characterize the cinder gravel (classification and strength),
- determine the optimum amount of locally available fine-grained soil which is blended with cinder in order to make up for the deficiency of fine materials, and
- observe the improvement in CBR when cinder is blended with fine grained soil.

4.2 Material Used

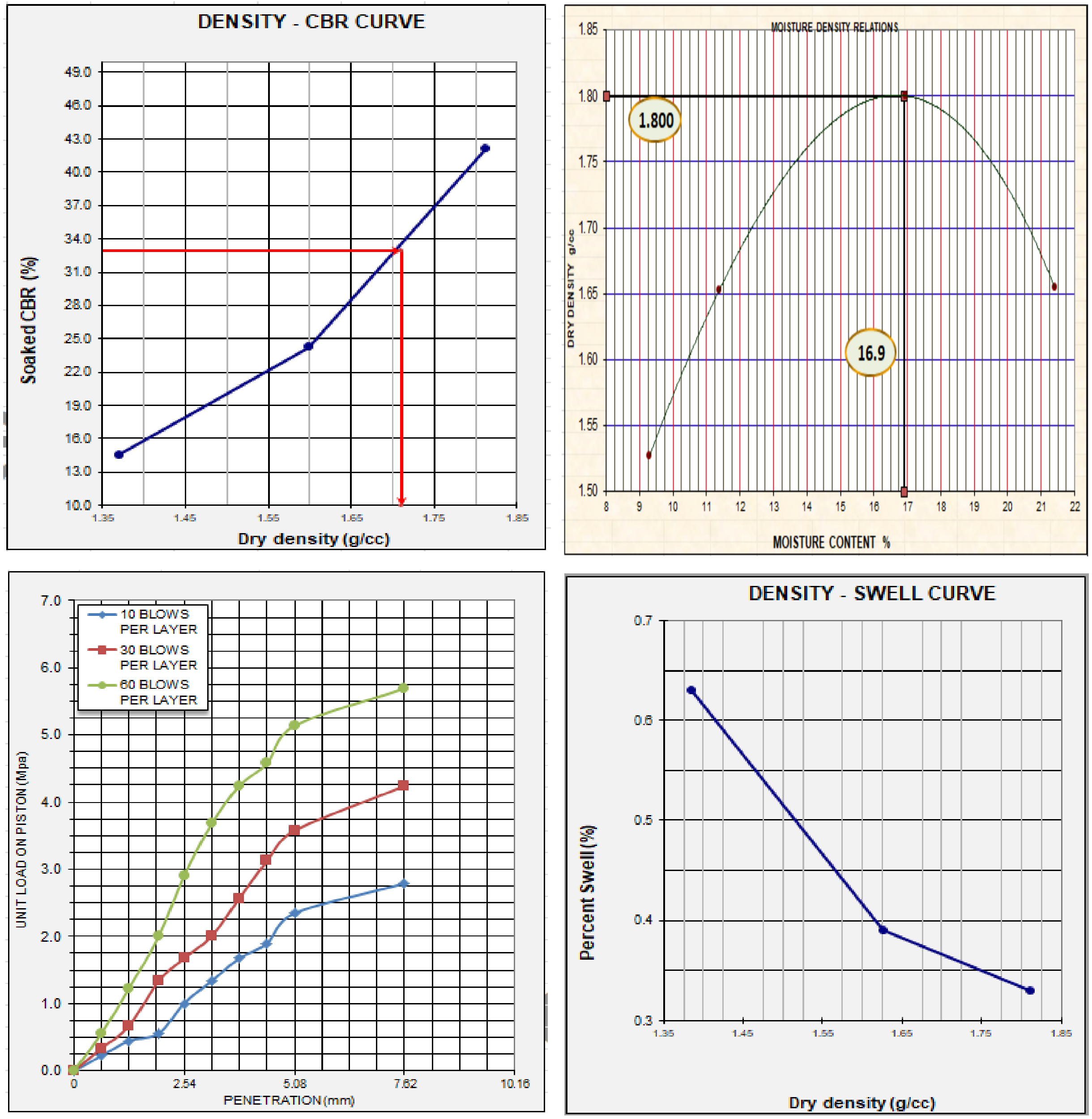
4.2.1 Fine grained soil

The tests were carried out in accordance with AASHTO T-27 method for sieve analysis, AASHTO T-180 for moisture density relation and CBR tests (AASHTO Test, 2001).

The fine-grained soils obtained at Bole Arabsa are visually classified as reddish silty clay with weathered gravel and based on the laboratory test results and AASHTO classification; falls under A-2-5. These materials were also used in the embankment and sub-grade road construction in the Bole Arabsa Project 5 Lot I and II Condominium Road project.

Table 4.1 descriptive test results of fine-grained soil used for mechanical stabilization

Type of test		Test results
Grading	Sieve size	% passing
	37.5 mm	98.32
	25 mm	91.6
	4.75 mm	86.3
	1.0 mm	73.4
	0.425 mm	57.2
	0.075 mm	37
Other Pmeters	Liquid Limit	45 %
	Plastic Limit	31.81 %
	Plastic Index	13.19%
	Specific Gravity	1.69
	Free Swell	0.45%
	CBR	33 %



BLOW	DRY DENSITY (g/cc)	CBR (%)	SWELL (%)
10	1.370	14.6	0.63
30	1.598	24.27	0.39
65	1.812	42.1	0.33
CBR AT 95% OF MDD		33 %	
SWELL AT 95% OF MDD		0.45 %	

Figure 4.1 CBR vs Density curve and Moisture density relation of fine-grained soil

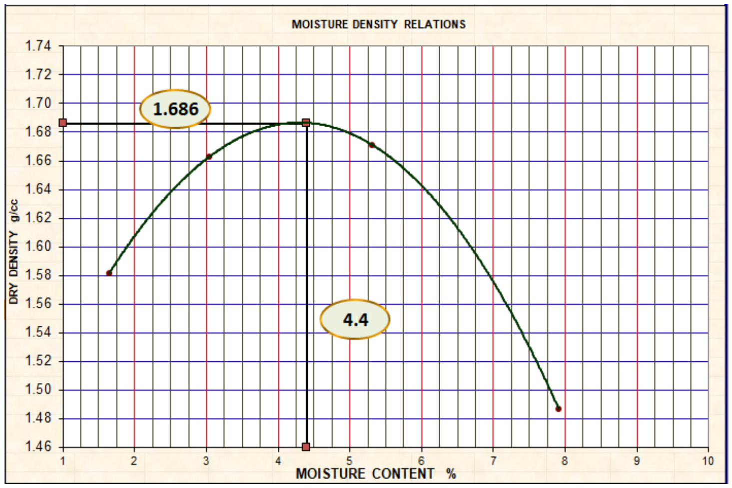
4.2.2 Cinder before Blending

The tests were carried out in accordance with AASHTO T-27 method for sieve analysis, AASHTO T-180 for moisture density relation and CBR tests(AASHTO Test, 2001).

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 less than 50 %passes through No.10 sieve and its PI zero. The cinder gravel is a weak material and has a high-water absorption capacity because of high porosity.

Table 4.2 Descriptive test results of cinder before blending

Type of test		Test results
Grading	Sieve size	% passing
	50 mm	95.13
	25 mm	81.42
	9.5 mm	53.58
	4.75 mm	36.97
	2 mm	24.98
	0.425 mm	8.71
	0.075 mm	2.82
Other Parameters	Plastic Index	NP
	Specific Gravity	1.299
	Free Swell	0.26%
	CBR	30 %
	LAA	46.8%



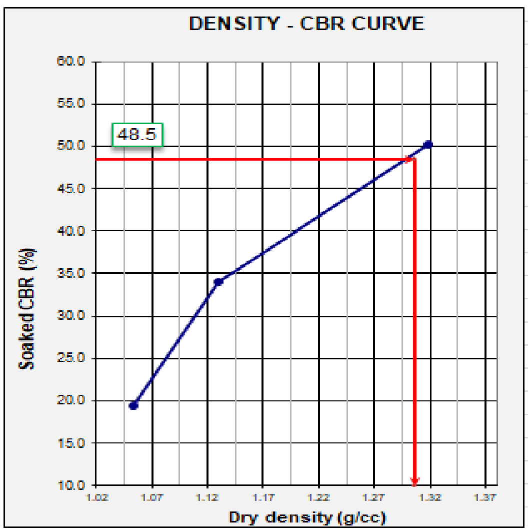


Figure 4.2 wet sieving of cinder material

4.3 Laboratory Test Results of Blended Cinder

4.3.1 Index property tests

4.3.1.1 Particle size distribution and gradation

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

According to the ERA grading limit, the material shall have a smooth continuous grading within the limits for grading A, B or C and the sub-base material shall comply with one of the grading given below in Table 4.2.

The complete sub-base shall contain no material having a maximum dimension exceeding two-third of the compacted layer thickness. Among the grading limits, grade B has almost a complete specification of percent mass passing for each sieve size. Moreover, it has a practical implementation as practiced by AACRA. Taking these advantages this thesis work is made based on grading B specification.

The grading chart of natural cinder gravel 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. Among the trail proportioning of fine-grained soil 14% and 21 % are good proportioning from gradation point of view.

From figures 4.5 to 4.9 also clearly shows that the modified AASHTO compaction method resulted in the largest amount of crushing. The laboratory investigation 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. This is needed to:

- Ensure that the finished granular surface is stable enough to carry the paving equipment without disruption of the surface.
- Ensure that the material can be compacted adequately. 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.

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.

Table 4.3 Ethiopia Road Authority grading limits for sub-base material (ERA, pavement design manual 2013)

SIEVE SIZE(mm)	**Mass Percent Passing**			
	A	B	C	D
63	100			
50	90 – 100	100	100	
37.5			80 – 100	
25	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 Specification of grain size analysis of grade B data is plotted on an aggregate grading chart, exemplified by Figure 4.1.

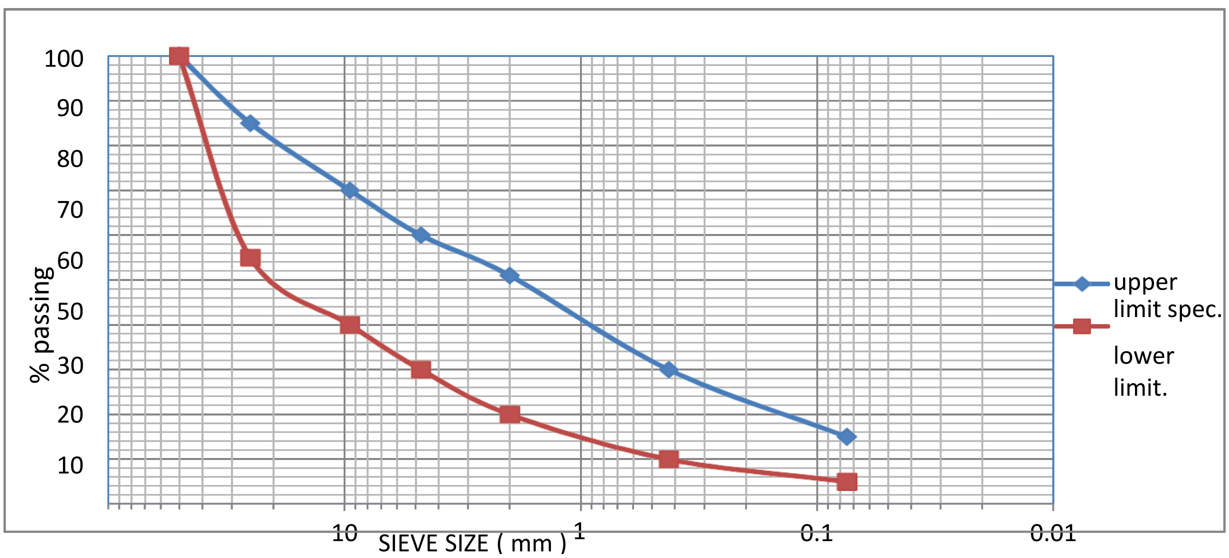


Figure 4.4 ERA Specification grade limits for grade B

Figures 4.2 to 4.7 show gradation before and after compaction of cinder gravel only and cinder

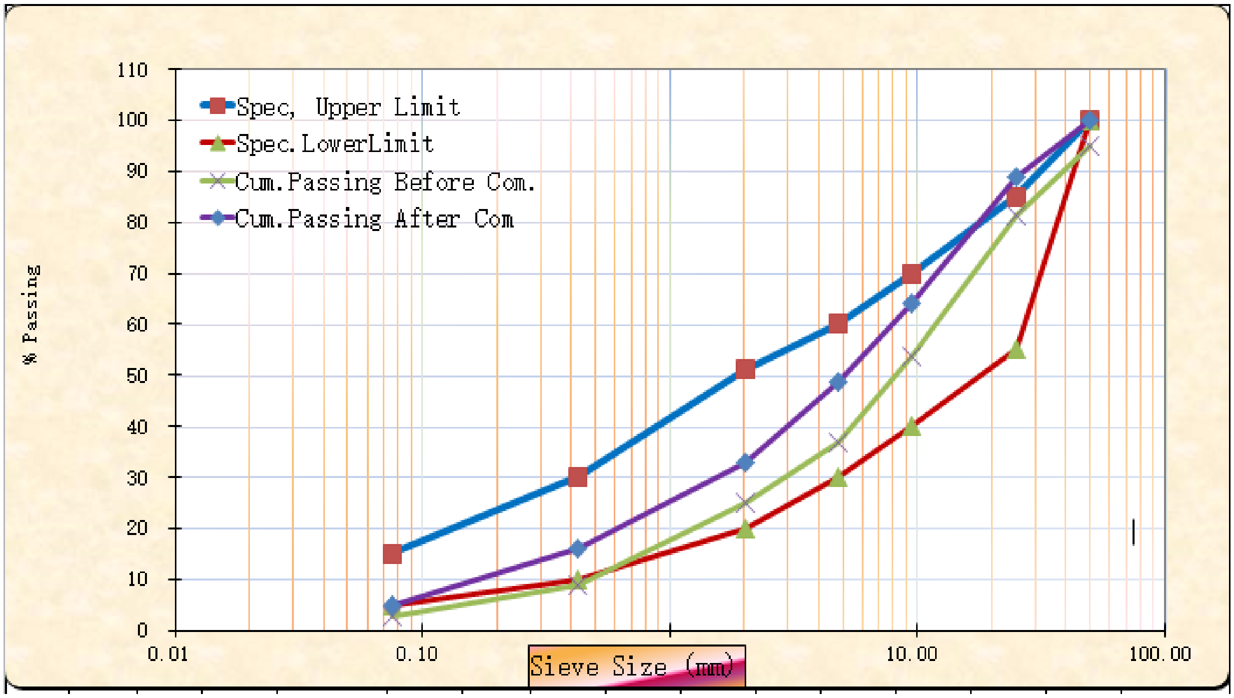


Figure 4.5 Gradation before and after compaction of natural cinder gravel only

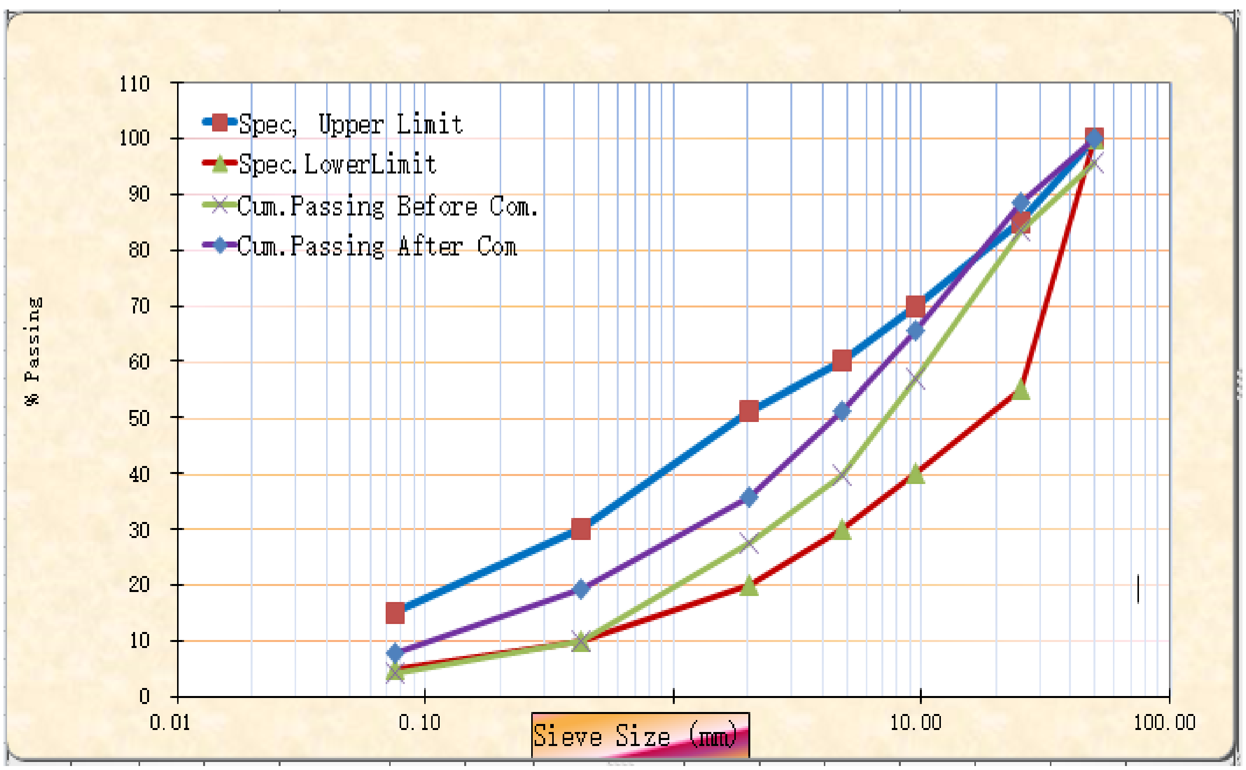


Figure 4.6 Gradation before and after compaction of cinder with 7 % fine-grained soil

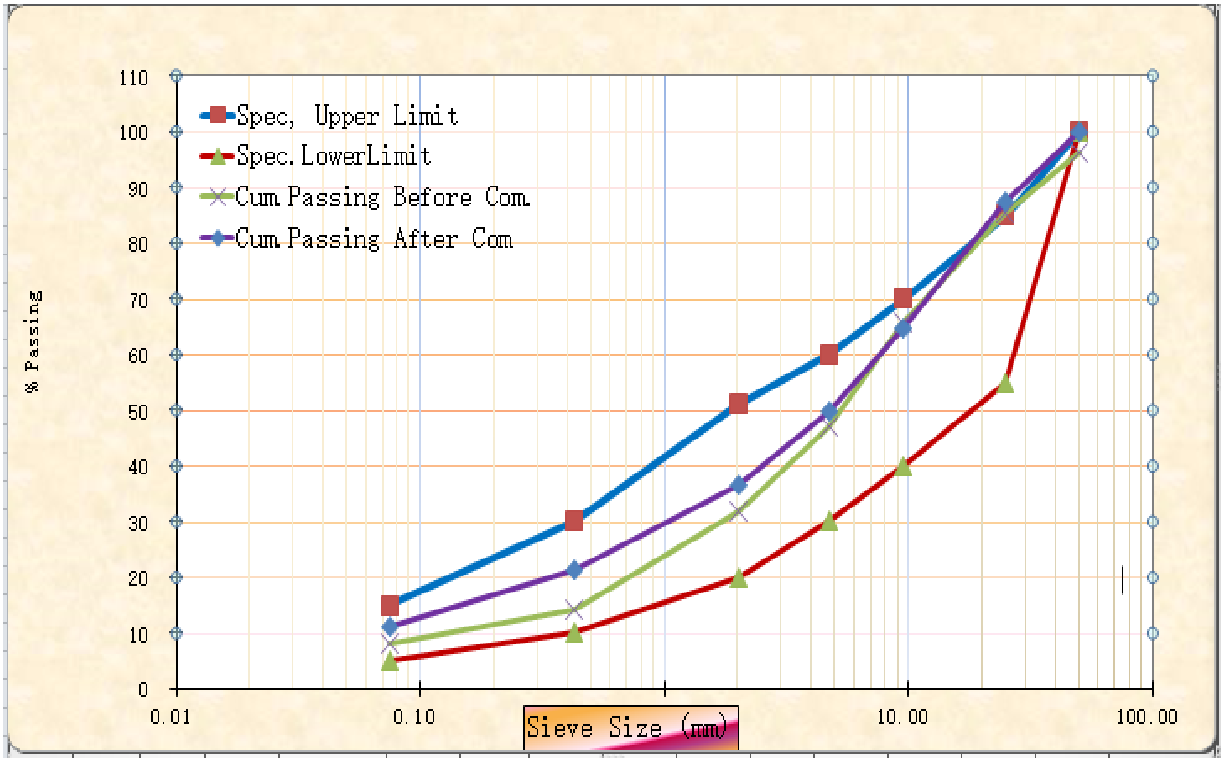


Figure 4.7 Gradation before and after compaction of cinder with 14 % fine-grained soil

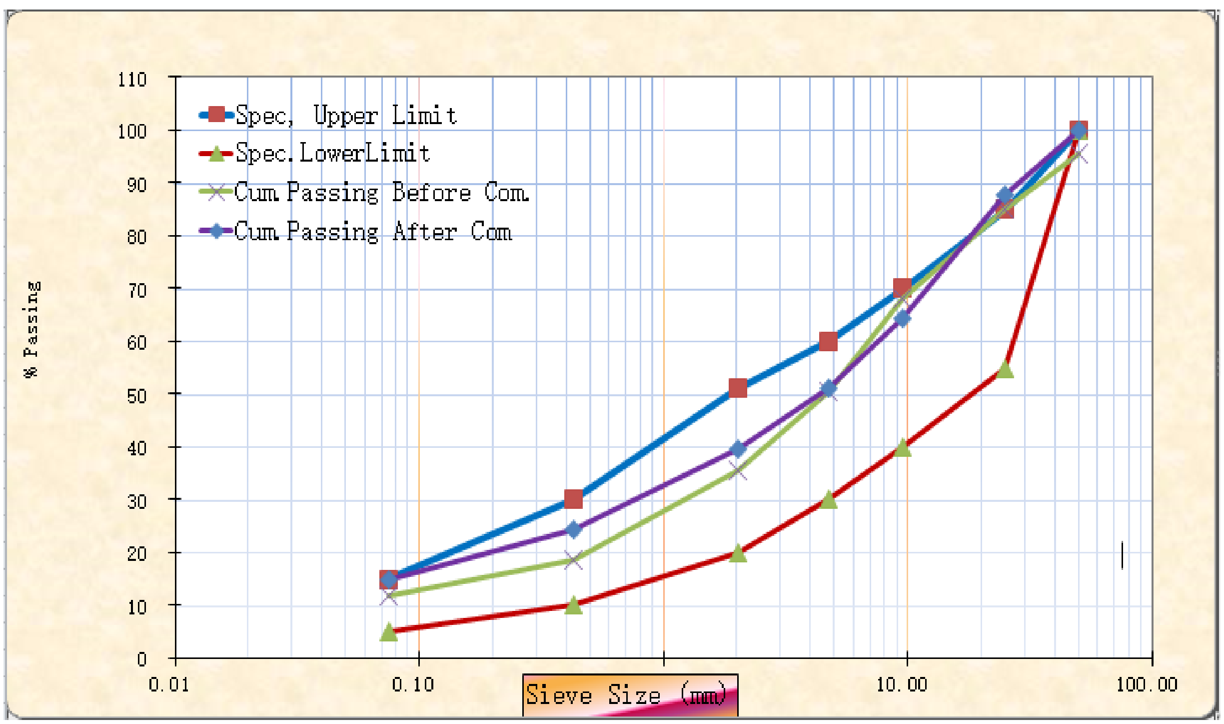


Figure 4.8 Gradation before and after compaction of cinder with 21 % fine-grained soil

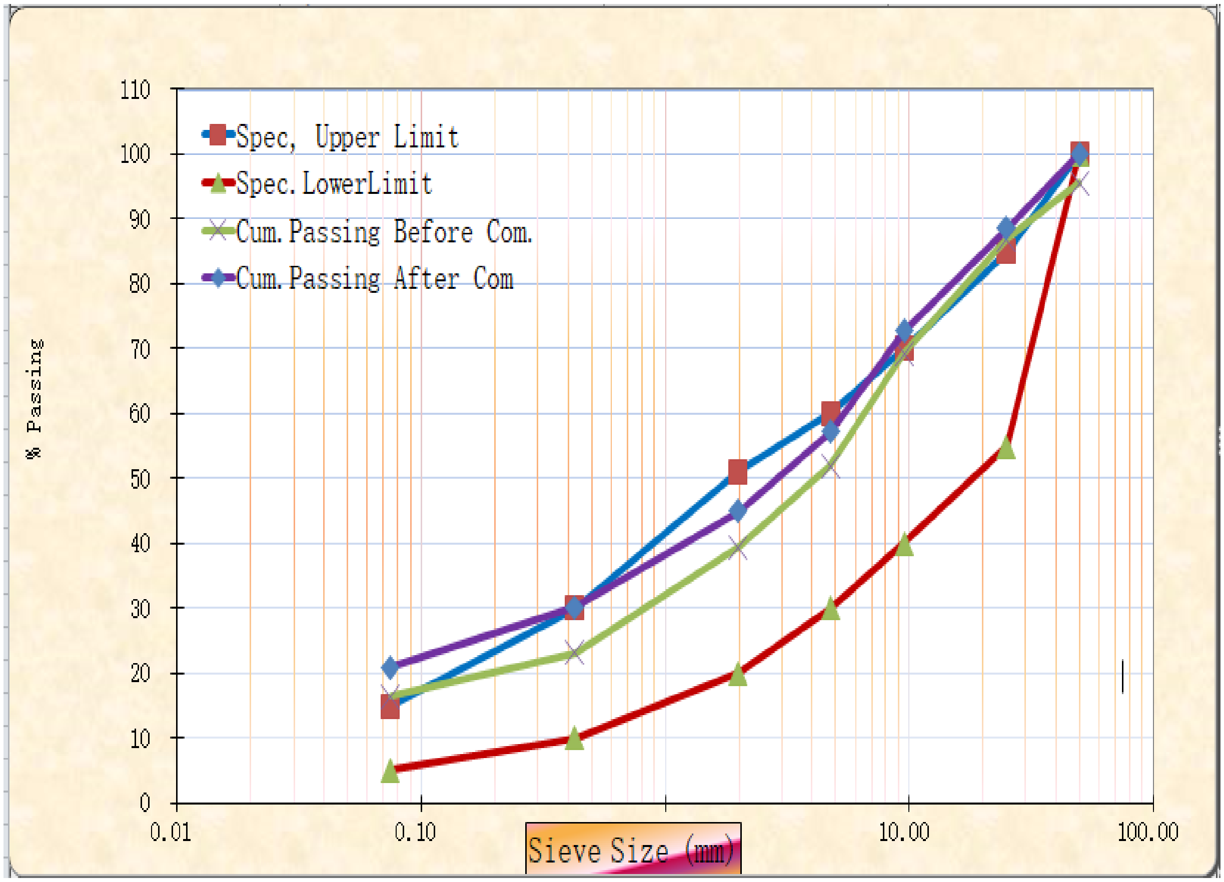


Figure 4.9 Gradation before and after compaction of cinder with 28 % fine-grained soil

4.3.1.2 Grading Modules (GM)

The Grading Modulus or GM is given by. GM = (P2,00 mm + P0,425 mm + P0,075 mm) / 100 where P2,00 mm, etc., denote the percentage retained on the indicated sieve size.

According to ERA specification, the minimum Grading Modulus shall be 1.5 except where a material, having a lower Grading Modulus but not less than 1.2, is approved for use by the Engineer.

The particle distribution of the finer material passing the 2 mm sieve has a marked effect on the compact ability and bearing strength of the material.

Table 4.4 Determination of Grading Modules value

Percent of cinder gravel	Percent of fine-grained Soil	GM
100	0	2.635
93	7	2.582
86	14	2.460
79	21	2.340
72	28	2.212

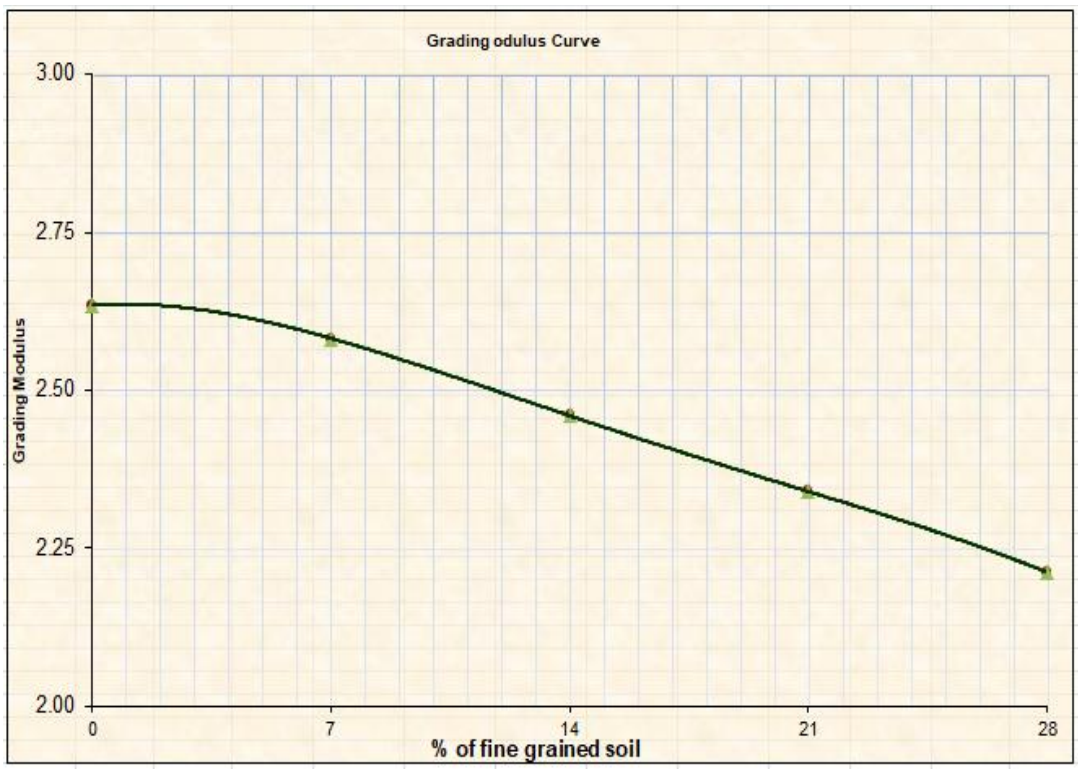


Figure 4.10 The Grading Modules with different proportion of fine-grained soil

The Grading Modules for all mix proportions is found to be above the minimum required value of1.5

4.1.3.3 Atterberg Limits

According to ERA specification, all sub-base materials shall have a maximum plasticity index of 6 when determined in accordance with AASHTO T-90. The plasticity product (PP = PI xpercentage passing the 0.075mm sieve) shall not be greater than 75%(AASHTO Test, 2001).

Table 4.5 shows that 0, 7, 14, 21 and 28 % of the blending proportion of material by mass with cinder has no plasticity characteristics and the plastic product is also zero. Therefore, all the proportions satisfy the ERA manual specification.

Table 4.5 Determination of plastic index and plastic product for blended material

Percent of fine-grained soil	Plastic index	Plasticity product
0	NP	Zero
7	NP	Zero
14	NP	Zero
21	NP	3
28	NP	5

Figure 4.11 plastic index determination

4.3.2 Moisture – Density relations by modified proctor test

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

Figure 4.12 shows that the maximum dry density increases up to 21 % of fine-grained soil proportion by mass and after that MDD goes down. This shows that the arithmetic method can beused as a good indicator, which result 22% of fine-grained soil.

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

Table 4.6 Determination of MDD & OMC with different fine-grained soil proportions

Percent of fine-grained soil	MDD(g/cc)	OMC (%)
0	1.686	4.4
7	1.689	7.0
14	1.73	10.5
21	1.751	12
28	1.739	14.5

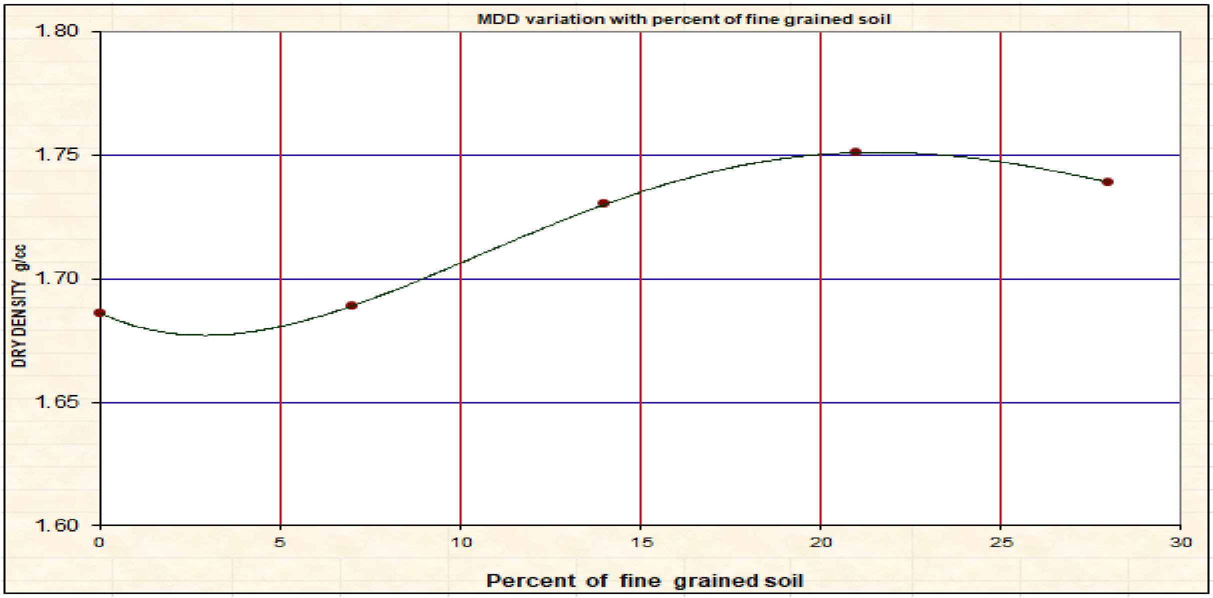


Figure 4.12 Variation of MDD with percentage of fine-grained soil mixed with cinder

4.3.3 California Bearing Ratio (CBR) test

The determination of the CBR and percent swell of cinder gravel only are presented in tables 4.7 to 4.9 and figures 4.10 to 4.12 below.

Laboratory Test Result for Cinder Gravels Only

Table 4.7 Determination of dry density before & after soaking of cinder gravel only

BLOWS	BEFORE SOAKING		AFTER SOAKING	
	DD (g/cc)	MOISTURE (%)	DD (g/cc)	MOISTURE (%)
10	1.034	11.23	1.028	21.57
30	1.13	10.66	1.083	20.78
65	1.319	11.12	1.232	18.67

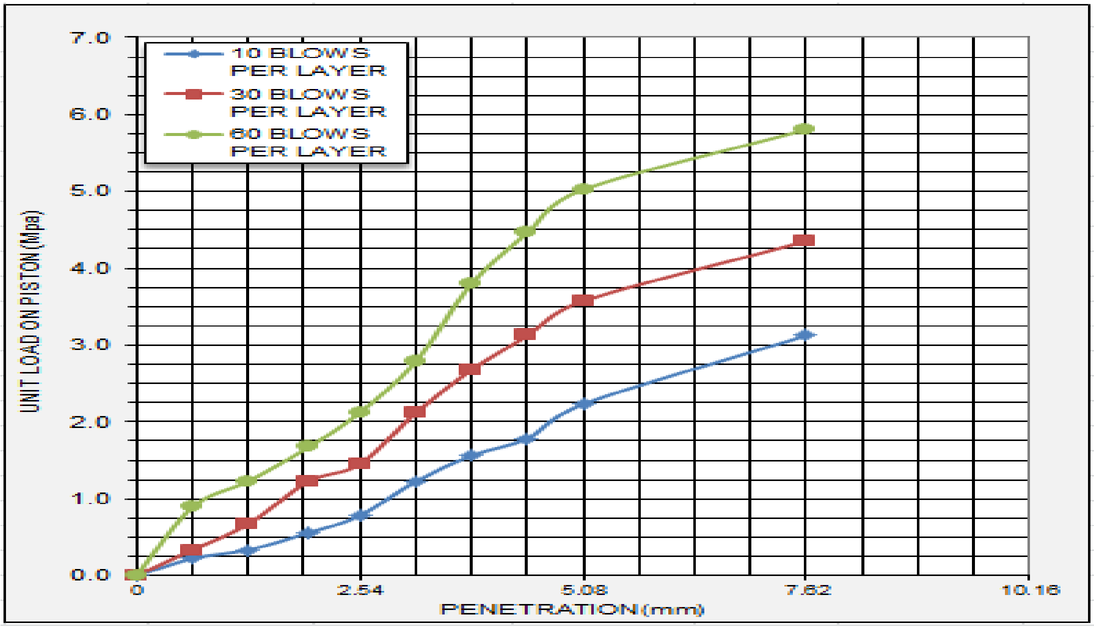


Figure 4.13 Load-penetration curves of cinder gravel only

Table 4.8 Determination of CBR & Swell (%) of cinder gravel only

No. of blows	Load (KN)		CBR		Swell (%)
	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.339	2.367	19.41	24.93	0.40
30	2.344	4.465	33.97	43.35	0.26
65	3.460	6.25	50.15	60.69	0.15

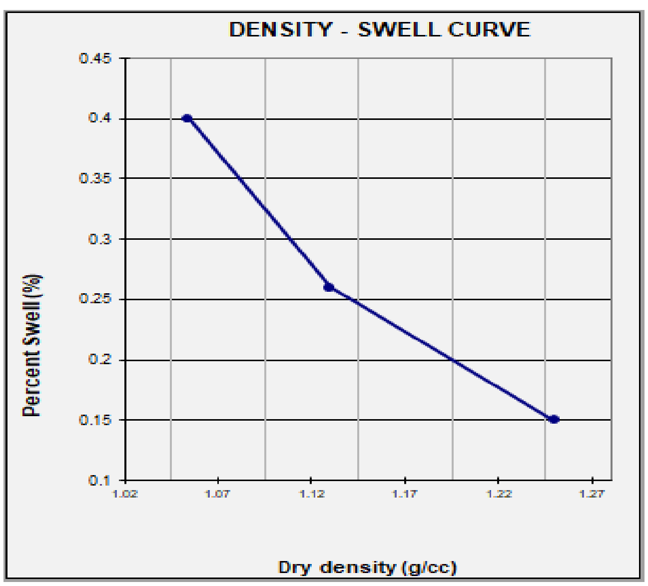


Figure 4.14 Dry density Vs percent swell of cinder gravel

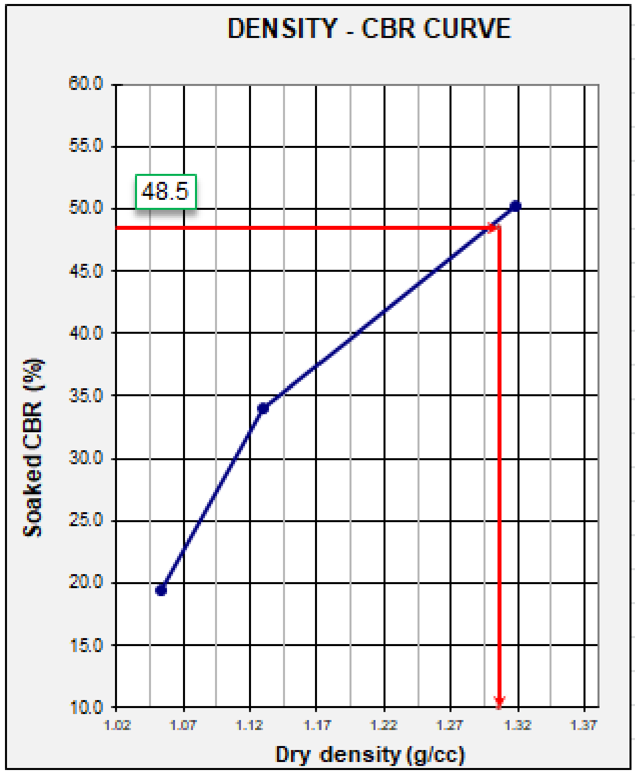


Figure 4.15 Dry Density Vs Percent CBR of cinder gravel only

Table 4.9 Determination of CBR & Swell at 95 % of MDD of cinder gravel only

BLOW	DRY DENSITY (g/cc)	CBR (%)	SWELL (%)
10	1.054	19.4	0.40
30	1.130	33.97	0.26
65	1.250	50.2	0.15
CBR AT 95% OF MDD		48.5%	
SWELL AT 95% OF MDD		0.27%	

Results of CBR and Swell percent values of the different mix proportions are given in table 4.10 and figure 4.16 below.

Table 4.10 Values of CBR and Swell percent of different proportion of fine-grained soil

Percent of fine-grained soil	CBR %	% Swell
0	48.5	0.27
7	51.8	0.34
14	63	0.66
21	71	0.84
28	53.5	1.07

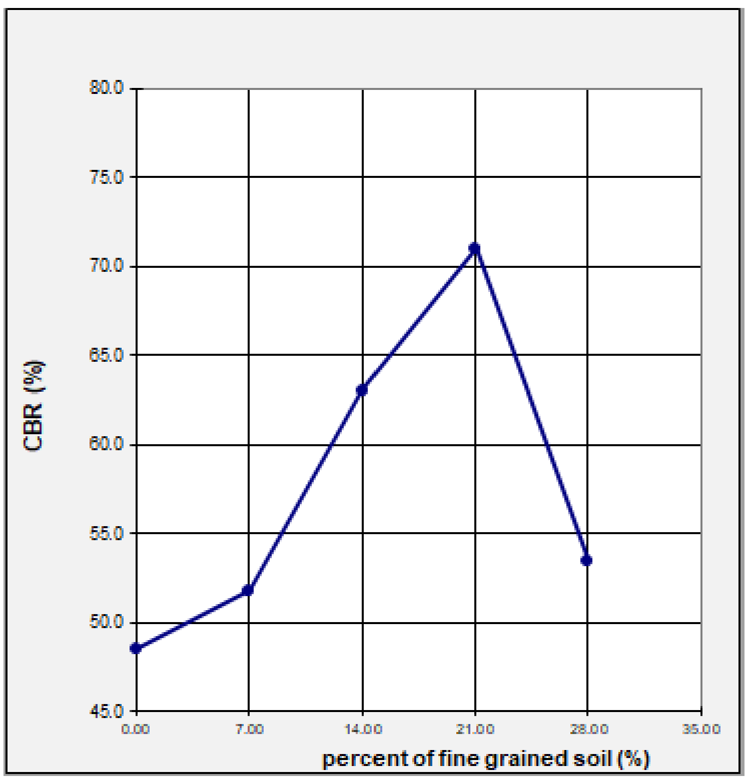


Figure 4.16 Values of CBR and Swell percent of different proportion of fine-grained soil

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.

All the results show on the above figure for 0, 7, 14, 21 & 28 % of fine-grained soil by mass satisfies the ERA manual requirements. Figure 4.14 also shows that the percentage of CBR values increases up to 21 % of fine-grained soil by mass and decreases afterwards. Compacted soil with a moisture content higher than optimum moisture content will have lower CBR value. Higher fine grained proportions needs higher amount of water which causes a decrease in the value of CBR. This trend agrees with the compaction test results.

Figure 4.17 Proctor and CBR determination

4.3.4 Abrasion resistance

This method is used to measure the hardness of the natural cinder gravel and to know its resistance during compaction. 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.

Table 4.11 below shows the average calculated values LAA for natural cinder by use of the Los Angeles Abrasion machine is 48 %. This value satisfies the ERA manual specification but shows that cinder gravel is a weak material.

Table 4.11 Resistance of Abrasion of cinder by use of the Los Angeles Abrasion machine

Designation	Trail 1	Trail 2
No. of revolutions	500	500
Total Wt.of sample tested(gm)	5004.5	5007.5
bWt.of tested sample retained on 1.7mm sieve	2672	2658
Percent Loss (%)	46.6	46.9

Average: 46.8 %

4.4 Additional Tests

4.4.1 Absorption and specific gravity

Table 4.12 Absorption and specific gravity of fine-grained

Temperature-Density Correction Factors (°C)												
°C	22	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5
k	1.000728	1.000613	1.000495	1.000375	1.000253	1.000127	1.00	0.999870	0.999738	0.999604	0.999466	0.999327

Description		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Average
A. Mass of oven dry sample(gm)		1777.5	1870						1824
B. Mass of SSD sample in air(gm)		2362	2424.5						2393
C. Mass of saturated sample in water(gm)		549	549.5						549
Water Temperature(°C)		23.0	23.0						
K		1.000495	1.000495						
Bulk sp. gravity[oven dry], G_{od}	G_{od} = A*k/(B-C)	0.981	0.998	-	-	-	-	-	0.989
Bulk sp. Gravity[SSD], G_{SSD}	G_{SSD} = B*k/(B-C)	1.303	1.294	-	-	-	-	-	1.299
App. specific gravity, G_{App}	G_{app} = A*k/(A-C)	1.448	1.417	-	-	-	-	-	1.432
Water absorption W_{ab}, %	W_{ab} = (B-A)*100/A	32.9	29.7	-	-	-	-	-	31.3

This laboratory test conducted in accordance with AASHTO T-85.

Laboratory test results showed that the absorption & specific gravity of the cinder gravel that passes sieve 4.75 mm is 11.35 % and 2.4 respectively. Therefore, the cinder gavel has high water absorption capacity because of its high porosity and it is a lightweight aggregate.

Figure 4.18 Absorption and specific gravity determination

4.4.2 Linear shrinkage

Linear shrinkage is the percentage decrease in length of a wet soil sample filled in to the standard mold when it gets fully dried, starting with a moisture content of the sample from liquid limit. The test was conducted based on BS 1377-2 standard method. To perform the test, an oven dried sample of about 150g passing through a sieve size of 425 µm is needed. Then a sample having known mass was mixed with water to attain its liquid limit. Finally, mud prepared was filled and compacted into standard mold which have greased its inner faces and put it inside an oven dry machine to remove available moisture in the soil sample and determine the compressed length of dry sample.

Table 4.13 Determination of Linear shrinkage

Percent of fine-grained soil	Linear shrinkage
0	0.24%
7	0.48%
14	0.72%
21	0.93%
28	1.44%

This laboratory test conducted in accordance with AASHTO T-92.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

By mechanically stabilizing cinder gravel with fine-grained soil to be used as a road sub-base material, the purpose of this research paper thesis was to assess the performance of the blend material made of finely ground soil.

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

- After compaction, sieve analyses were carried out, and the results show that coarser cinder gravel particles have broken down significantly.
- Because of the weak nature of cinder gravels, break down under compaction occurred with an improvement in gradation of cinder but still needs an additional fine-grained soil to achieve the ERA specification.
- The first trail can be proportioned using the arithmetic proportioning method to save time and effort.
- Blending of cinder with an optimum fine-grained soil improves its properties.
- From MDD- percent of fine-grained soil curve, the optimum amount of fine-grained soil is 21 % by mass.
- From CBR-percent of fine-grained soil curve, the optimum amount of fine-grained soil is 21 % by mass.
- The gradation curves before and after compaction fall within the ERA specification, according to the sieve analysis, which was performed by blending fine-grained soil with natural cinder gravel.

5.2 Recommendations for future work

For the case of the Adama Awash asphalt road project the current work attempted to achieve the ideal blending ratio of cinder with fine-grained soil. The current research, however, did not completely cover the cinder gravel in Ethiopia due to financial and time constraints. In light of this, it would be wise to take into account the following suggestions for using cinder gravels more effectively when building roads.

- For areas with cinder potential and a dearth of sub base material, cinder can be used to mechanically stabilize it with fine-grained soil and fine-grained soil can be a good stabilizing material.

- It is preferable to collect samples from various regions of Ethiopia in order to prepare proportioning guide-line on cinder gravel with fine-grained material and also to evaluate the effectiveness of volcanic cinder gravels combined with fine-grained soil as subbase materials for various Ethiopian regions, extensive experiments should be conducted there.
- Natural gravels, like cinder gravel, whose gradation varies significantly with compaction, require research on gradation requirements and pilot project should be conducted to assess this stabilized material's field performance. Further studies in the area of cinder gravels, which can be found in various regions of the country, can build on the results of this study.

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Appendix

Appendix-A
Descriptive test results of borrow soil

Table A-1 Atterberg Limits of fine-grained Soil

	Liquid Limit				Plastic Limit	
No. of Blows	30	22	17			
Container Number	4A	H	6		3A	17
Wt. of Container + Wet Soil (g) = (W_1)	61.10	67.70	70.90		29.70	29.70
Wt. of Container + Dry Soil (g) = (W_2)	49.40	54.30	56.70		28.40	28.30
Wt. of Container (g) = (W_3)	23.20	24.90	24.50		24.40	23.80
Weight of Moisture (g) = (W_1 - W_2) = A	11.70	13.40	14.20		1.30	1.40
Weight of Dry Soil (g) = (W_2 - W_3) = B	26.20	29.40	32.20		4.00	4.50
Moisture Content (%) = (A / B)x 100	44.66	45.58	44.10		32.50	31.11
				AV. Plas. Lim.	31.8	

Particle size Distribution(TEST METHOD AASHTO T-88)						
siev size(mm)	weight retaind	% retained	% pass	LIQUIDLIMIT=	LL	44.83
2.00 mm	140	28.00	55.88	PLASTIC LIMIT=	PL	31.81
0.425	125	25.00	36.19	PLASTICITY INDEX =	LL - PL	13.02
0.075	123	24.60	29.17	PLASTIC MODULES =	Plw	5
Total Weight Befor wash	500					

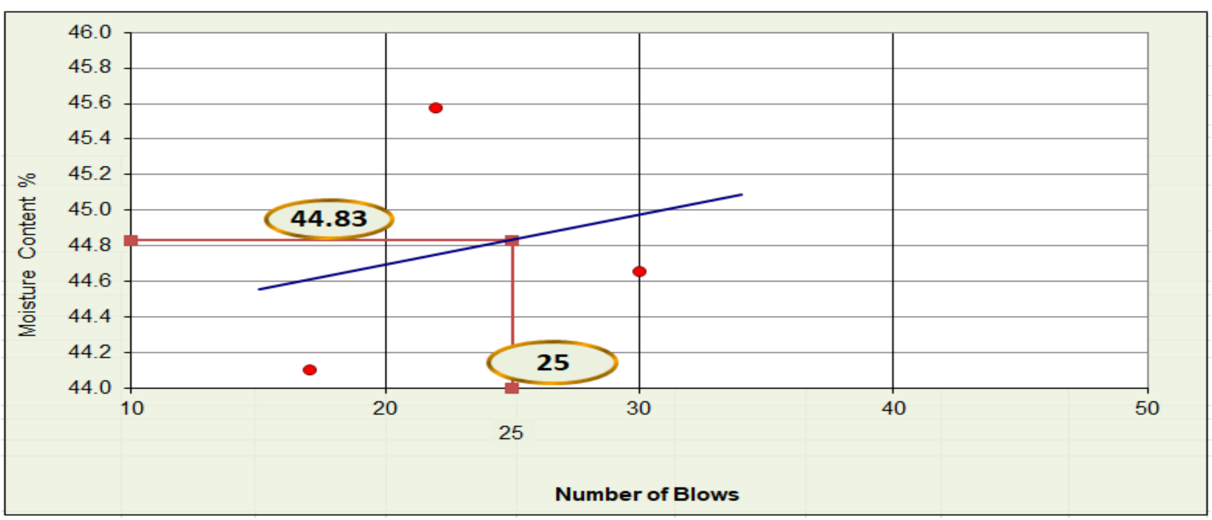


Figure A-1 Flow curve for fine grained soil

Table A-2 Sieve Analysis for fine grained soil (wet preparation method)

	Trial #1			Trial #2				Specification	
		Mass After wash	5460.0	5270.0					
AASHTO Sieve Size mm	Mass retained(g)	% retained	% pass	Mass retained(g)	% retained	% pass	Average % pass	Lower	Upper
63.0	0.0	0.00	100.00	0.0	0.00	100.00	100.00	100	100
37.5	90.0	1.65	98.35	90.0	1.71	98.29	98.32	70	100
20	970.0	17.77	80.59	960.0	18.22	80.08	80.33	50	100
4.75	760.0	13.92	66.67	850.0	16.13	63.95	65.31	30	100
1	480.0	8.79	57.88	530.0	10.06	53.89	55.88	17	75
0.425	990.0	18.13	39.74	1120.0	21.25	32.64	36.19	11	56
0.075	350.0	6.41	33.33	400.0	7.59	25.05	29.19	5	25
pan	1820.0	33.33	0.00	1320.0	25.05	0.00	**0.00**		
Total	**5460.0**			**5270.0**					

Table A-3 Determination of specific gravity for fine grained soil

Trail no	#1	#2	#3
pycnometer no	S3	S6	S12
Mass of Dry Soil	195	195	195
Mass of Pycnometer + Soil +water (M1)(g)	1700	1701.4	1699.5
Mass of pycnometer + water (M1)	1620	1621.1	1619.2
Test temperature (0C)	20	20.5	20.6
Specific gravity of soil at test temperature	1.696	1.70	1.701
correction factor	1	0.9995	0.9994
specific gravity of soil at 20 0C	1.696	1.699	1.700
Average specific gravity of cinder at 20 0C	1.698		

Table A-4 Moisture-Density relations of Soils by Modified Proctor
(Test Method of AASHTO T-180)

DENSITY	TRIAL NUMBER	1	2	3	4		
	WEIGHT OF SOIL + MOLD (g) W_1	9265.0	9525.0	9925.0	9780.0		
	WEIGHT OF MOLD (g) W_2	6740.0	6740.0	6740.0	6740.0		
	VOLUME OF MOLD (Cm^3) V	1513.0	1513.0	1513.0	1513.0		
	WEIGHT OF WET SOIL (g) $W_3 = W_1 - W_2$	2525.0	2785.0	3185.0	3040.0		
	WET DENSITY OF SOIL (g/Cm^3) $W_4 = W_3/V$	1.7	1.8	2.1	2.0		NMC
MOISTURE	CONTAINER NUMBER	6.0	D	3A	15.0		E
	WET SOIL + CONTAINER (g) a	122.2	139.5	159.0	196.4		180.6
	DRY SOIL + CONTAINER (g) b	113.9	127.7	139.5	166.2		169.2
	WEIGHT OF CONTAINER (g) c	24.6	24.0	24.4	25.1		24.6
	WEIGHT OF WATER (g) d = a-b	8.3	11.8	19.5	30.2		144.6
	WEIGHT OF DRY SOIL (g) e = b-c	89.3	103.7	115.1	141.1		11.4
	MOISTURE CONTENT (%) m= (d/e)*	9.3	11.4	16.9	21.4		7.9
DRY DENSITY OF SOIL (g/Cm3) $D_4 = W_4/(100+m)*10$		1.527	1.653	1.800	1.655		

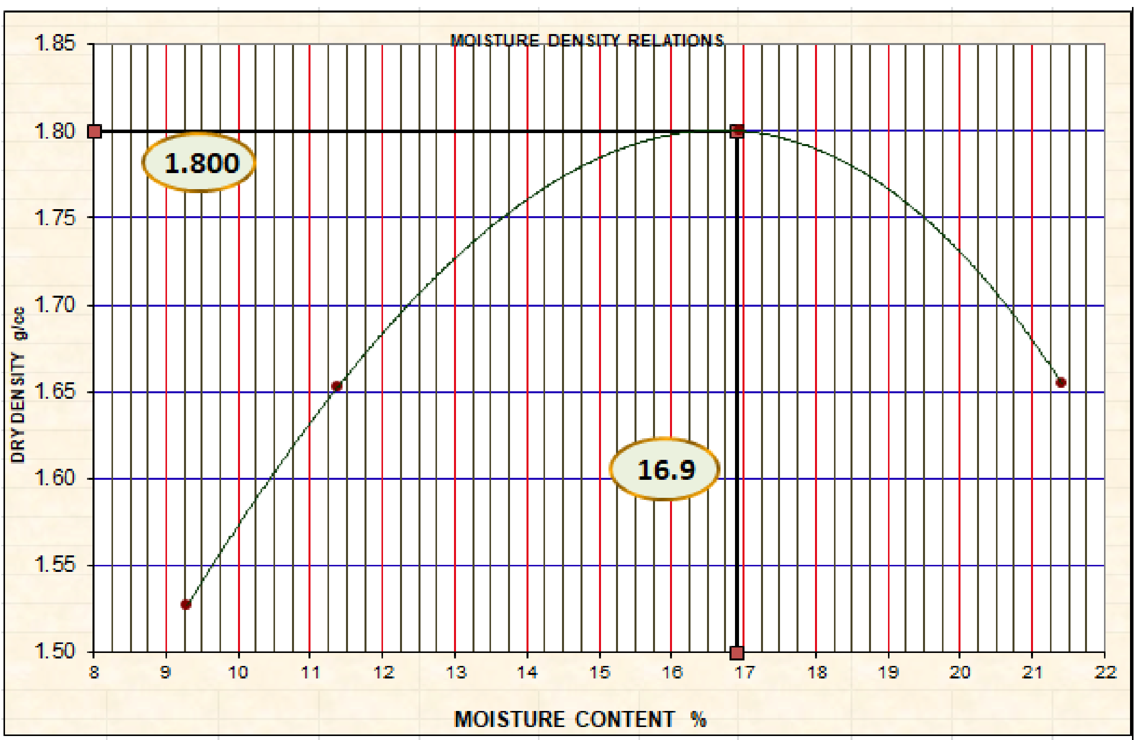


Figure A-2 Moisture-Dry Density curve of borrow soil

California Bearing Ratio (CBR) Test(Test Method of AASHTO T-193)

Table A-5 Determination of dry density before & after soaking of fine-grained soil only

BLOWS	BEFORE SOAKING		AFTER SOAKING	
	DD (g/cc)	MOISTURE (%)	DD (g/cc)	MOISTURE (%)
10	1.370	12.43	1.320	22.32
30	1.598	12.58	1.519	22.83
65	1.812	13.24	1.661	23.67

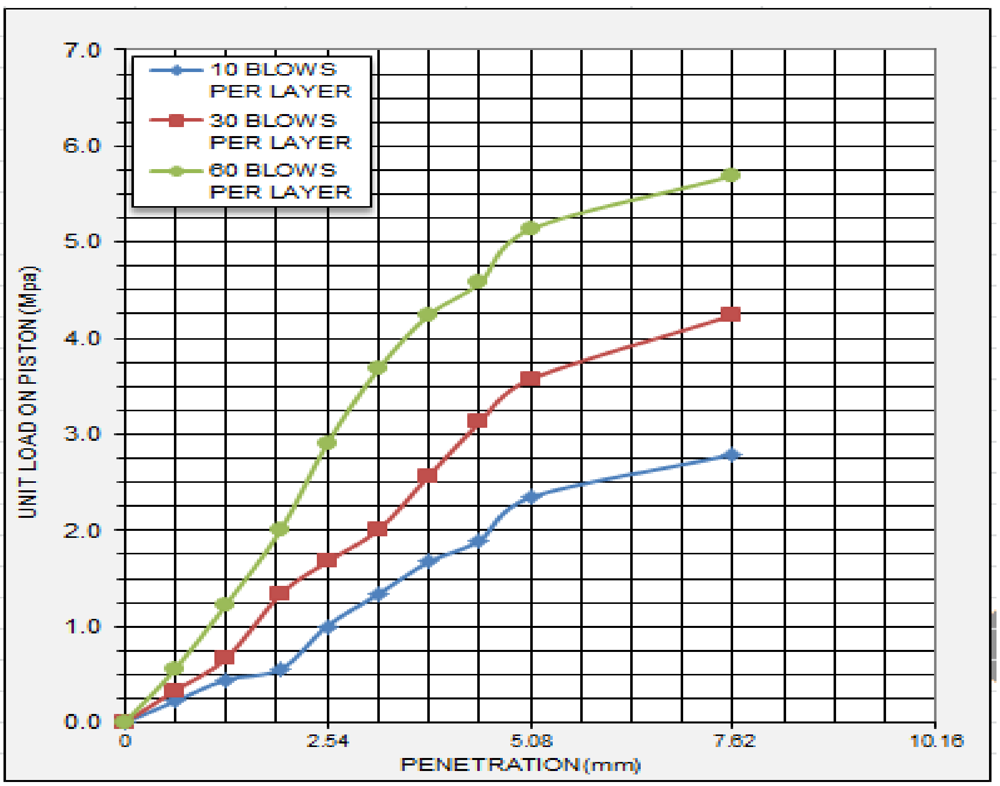
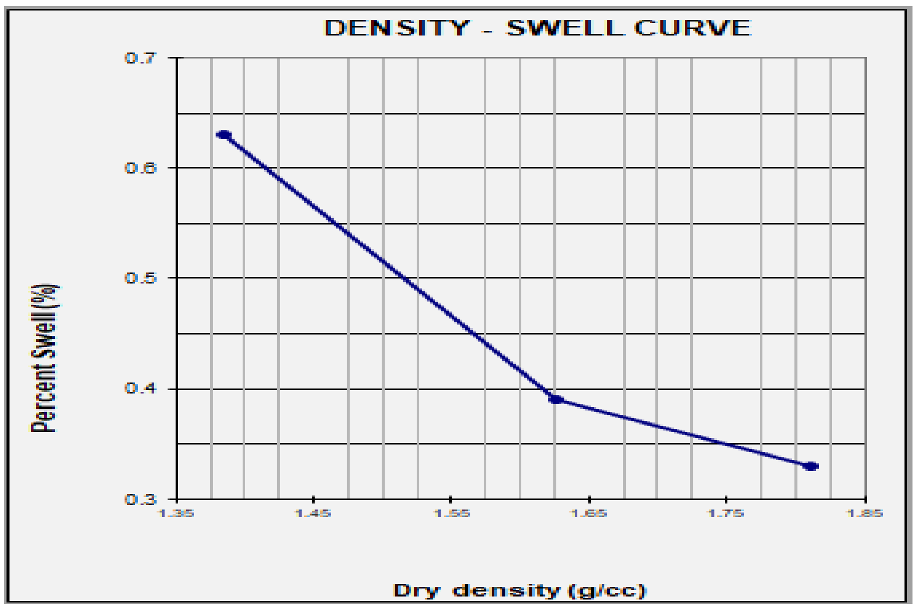


Figure A-3 Load-penetration curves of fine-grained soil only

Table A-6 Determination of CBR & Swell (%) of fine-grained soil only

BLOWS	STRESS (MPa)		CBR (%)		SWELL (%)
	2.54mm	5.08mm	2.54	5.08	
10	1.00	2.34	14.6	22.8	0.63
30	1.67	3.57	24.27	34.68	0.39
65	2.90	5.13	42.1	49.9	0.33



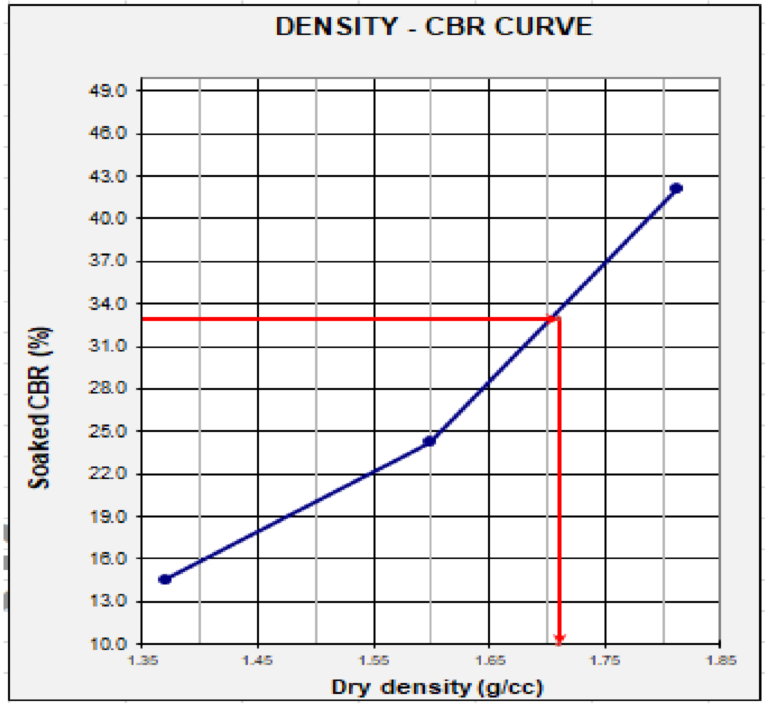


Figure A-4 Dry Density Vs Percent CBR of fine-grained soil only

Table A-7 Determination of CBR & Swell at 95 % of MDD of fine-grained soil only

BLOW	DRY DENSITY (g/cc)	CBR (%)	SWELL (%)
10	1.370	14.6	0.63
30	1.598	24.27	0.39
65	1.812	42.1	0.33
CBR AT 95% OF MDD		33 %	
SWELL AT 95% OF MDD		0.45 %	

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

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

i. Gradation Before Compaction

Gradation Cinder only									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	282.3	6.11	93.89	174.6	3.6	96.4	**95.1**	100	100
25.0	554.4	12.00	81.89	744.3	15.4	80.9	**81.4**	85	55
9.5	1160.2	25.11	56.78	1472.9	30.5	50.4	**53.6**	70	40
4.75	775.6	16.79	39.99	792.3	16.4	34.0	**37.0**	60	30
2.00	584.2	12.65	27.34	546.3	11.3	22.6	**25.0**	51	20
0.425	810.2	17.54	9.81	723.6	15.0	7.6	**8.7**	30	10
0.075	302.6	6.55	3.26	251.6	5.2	2.4	**2.8**	15	5
Pan	150.5	3.26		115.9	2.4				
Total	**4620**			**4821.5**					

ii. Gradation After Compaction

Gradation Cinder only									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	0	0.00	100.00	0	0.0	100.0	**100.0**	100	100
25.0	453	10.70	89.30	489	11.3	88.7	**89.0**	85	55
9.5	1066	25.19	64.11	1072	24.9	63.8	**63.9**	70	40
4.75	641	15.15	48.96	650	15.1	48.7	**48.8**	60	30
2.00	689	16.28	32.68	670	15.5	33.2	**32.9**	51	20
0.425	730	17.25	15.43	723.6	16.8	16.4	**15.9**	30	10
0.075	478	11.29	4.14	478	11.1	5.3	**4.7**	15	5
Pan	175	4.14		227.4	5.3				
Total	**4232**			**4310**					

Table B-2 Sieve Analysis of Sub-base material cinder gravel with 7 % fine-grained Soil

i. Gradation Before Compaction

7 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	178.2	4.12	95.88	192.6	4.5	95.5	**95.7**	100	100
25.0	528.6	12.22	83.66	519.1	12.1	83.4	**83.5**	85	55
9.5	1165.6	26.94	56.73	1123.1	26.2	57.1	**56.9**	70	40
4.75	746.2	17.25	39.48	723.6	16.9	40.2	**39.9**	60	30
2.00	522.6	12.08	27.40	546.3	12.8	27.5	**27.4**	51	20
0.425	752.8	17.40	10.00	742.6	17.3	10.1	**10.1**	30	10
0.075	248.3	5.74	4.26	251.6	5.9	4.3	**4.3**	15	5
Pan	184.5	4.26		182	4.3				
Total	**4326.8**			**4280.9**					

ii. Gradation After Compaction

7 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	0	0.00	100.00	0	0.0	100.0	**100.0**	100	100
25.0	482.3	11.71	88.29	476.9	11.3	88.7	**88.5**	85	55
9.5	931.2	22.61	65.68	987.1	23.4	65.3	**65.5**	70	40
4.75	602.1	14.62	51.06	593.9	14.1	51.2	**51.1**	60	30
2.00	642.3	15.60	35.46	638.9	15.2	36.0	**35.7**	51	20
0.425	682.2	16.57	18.89	682.4	16.2	19.8	**19.4**	30	10
0.075	462.5	11.23	7.66	497.2	11.8	8.0	**7.9**	15	5
Pan	315.5	7.66		338.9	8.0				
Total	**4118.1**			**4215.3**					

Table B-3 Sieve analysis of Sub-base material cinder gravel with 14 % fine-grained Soil

i. Gradation Before Compaction

14 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	197.2	4.08	95.92	156.8	3.3	96.7	**96.3**	100	100
25.0	512.3	10.60	85.32	522.6	11.1	85.6	**85.5**	85	55
9.5	952.1	19.70	65.62	942.1	20.0	65.6	**65.6**	70	40
4.75	891.9	18.46	47.16	867.4	18.4	47.2	**47.2**	60	30
2.00	731.5	15.14	32.02	746.9	15.8	31.4	**31.7**	51	20
0.425	876.1	18.13	13.89	782.6	16.6	14.8	**14.3**	30	10
0.075	322.1	6.67	7.23	284.7	6.0	8.7	**8.0**	15	5
Pan	349.2	7.23		411.8	8.7				
Total	**4832.4**			**4714.9**					

ii. Gradation After Compaction

14 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	0	0.00	100.00	0	0.0	100.0	**100.0**	100	100
25.0	654.3	12.42	87.58	666.1	13.1	86.9	**87.2**	85	55
9.5	1203.2	22.84	64.75	1138.4	22.4	64.5	**64.6**	70	40
4.75	783.2	14.86	49.88	743.5	14.6	49.9	**49.9**	60	30
2.00	701.4	13.31	36.57	666.8	13.1	36.8	**36.7**	51	20
0.425	784.7	14.89	21.68	793.1	15.6	21.2	**21.4**	30	10
0.075	557.6	10.58	11.09	518.4	10.2	11.0	**11.1**	15	5
Pan	584.5	11.09		560.4	11.0				
Total	**5268.9**			**5086.7**					

Table B-4 Sieve analysis of Sub-base material cinder gravel with 21 % fine-grained Soil

i. Gradation Before Compaction

21 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	201.5	4.27	95.7	224.5	4.8	95.2	**95.5**	100	100
25.0	484.2	10.25	85.5	495.4	10.6	84.6	**85.0**	85	55
9.5	843.1	17.85	67.6	755.7	16.2	68.4	**68.0**	70	40
4.75	852.2	18.05	49.6	808.4	17.3	51.2	**50.4**	60	30
2.00	688.6	14.58	35.0	694.9	14.9	36.3	**35.6**	51	20
0.425	815.7	17.27	17.7	792.5	16.9	19.3	**18.5**	30	10
0.075	298.5	6.32	11.4	332.1	7.1	12.2	**11.8**	15	5
Pan	538.8	11.41		572.7	12.2				
Total	**4722.6**			**4676.2**					

ii. Gradation After compaction

21 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	0	0.00	100.0	0	0.0	100.0	**100**	100	100
25.0	677.6	12.50	87.5	649.6	12.0	88.0	**87.7**	85	55
9.5	1282.9	23.66	63.8	1247.7	23.1	64.9	**64.4**	70	40
4.75	745.5	13.75	50.1	677.9	12.5	52.4	**51.2**	60	30
2.00	606.9	11.19	38.9	658.7	12.2	40.2	**39.6**	51	20
0.425	833.8	15.38	23.5	815	15.1	25.1	**24.3**	30	10
0.075	507.6	9.36	14.2	519.7	9.6	15.5	**14.8**	15	5
Pan	767.3	14.15		840.3	15.5				
Total	**5421.6**			**5408.9**					

Table B-5 Sieve analysis of Sub-base material cinder gravel with 28 % fine-grained Soil

i. Gradation Before Compaction

28 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	188.8	4.27	95.7	204.4	4.6	95.4	**95.6**	100	100
25.0	364.8	8.25	87.5	410.4	9.1	86.3	**86.9**	85	55
9.5	804.1	18.18	69.3	765.7	17.1	69.2	**69.3**	70	40
4.75	782.8	17.70	51.6	756.8	16.9	52.4	**52.0**	60	30
2.00	782.8	13.09	38.5	542.1	12.1	40.3	**39.4**	51	20
0.425	578.9	16.34	22.2	733.2	16.3	23.9	**23.1**	30	10
0.075	722.6	6.19	16.0	322.1	7.2	16.8	**16.4**	15	5
Pan	273.7	16.00		752.2	16.8				
Total	**4423.3**			**4486.9**					

ii. Gradation After Compaction

28 % Blending									
	Trial A			Trial B					
sieve size (mm)	Wt Retained	% Retained	% Cum.Passing	Wt Retained	% Retained	% Cum.Passing	Average % Passing	Spec. Upper Limit	Spec. Lower Limit
50.0	0	0.00	100.0	0	0.0	100.0	**100**	100	100
25.0	685.3	11.89	88.1	625.8	11.0	89.0	**88.6**	85	55
9.5	906.3	15.72	72.4	906.3	15.9	73.0	**72.7**	70	40
4.75	892.3	15.48	56.9	892.3	15.7	57.3	**57.1**	60	30
2.00	696.9	12.09	44.8	696.9	12.3	45.1	**45.0**	51	20
0.425	844.2	14.64	30.2	844.2	14.9	30.2	**30.2**	30	10
0.075	538.9	9.35	20.8	521.3	9.2	21.1	**21.0**	15	5
Pan	1201.5	20.84		1197.5	21.1				
Total	**5765.4**			**5684.3**					

Appendix-C
Moisture-Density relation by modified proctor test

Table C-1 Moisture-Density relations for cinder gravel only

DENSITY	TRIAL NUMBER	1	2	3	4		
	WEIGHT OF SOIL + MOLD (g) W_1	18866.4	19090.4	19189.1	18859.9		
	WEIGHT OF MOLD (g) W_2	15457	15457	15457	15457		
	VOLUME OF MOLD (Cm^3) V	2121	2121	2121	2121		
	WEIGHT OF WET SOIL (g) $W_3 = W_1 - W_2$	3,410	3,634	3,733	3,403		
	WET DENSITY OF SOIL (g/Cm^3) $W_4 = W_3/V$	1.608	1.713	1.760	1.605		NMC
MOISTURE	CONTAINER NUMBER	D3	D11	D8	D10		1
	WET SOIL + CONTAINER (g) a	411.1	422.9	441.2	400.7		192.50
	DRY SOIL + CONTAINER (g) b	405.6	412.6	422.6	376.5		190.9
	WEIGHT OF CONTAINER (g) c	71.3	73.5	73	70.6		27.5
	WEIGHT OF WATER (g) d = a-b	5.5	10.3	18.6	24.2		1.6
	WEIGHT OF DRY SOIL (g) e = b-c	334.3	339.1	349.6	305.9		163.4
	MOISTURE CONTENT (%) m= (d/e)*100	1.6	3.04	5.32	7.91		0.98
DRY DENSITY OF SOIL (g/Cm3) $D_d = W_4/(100+m)*100$		1.582	1.663	1.671	1.487		

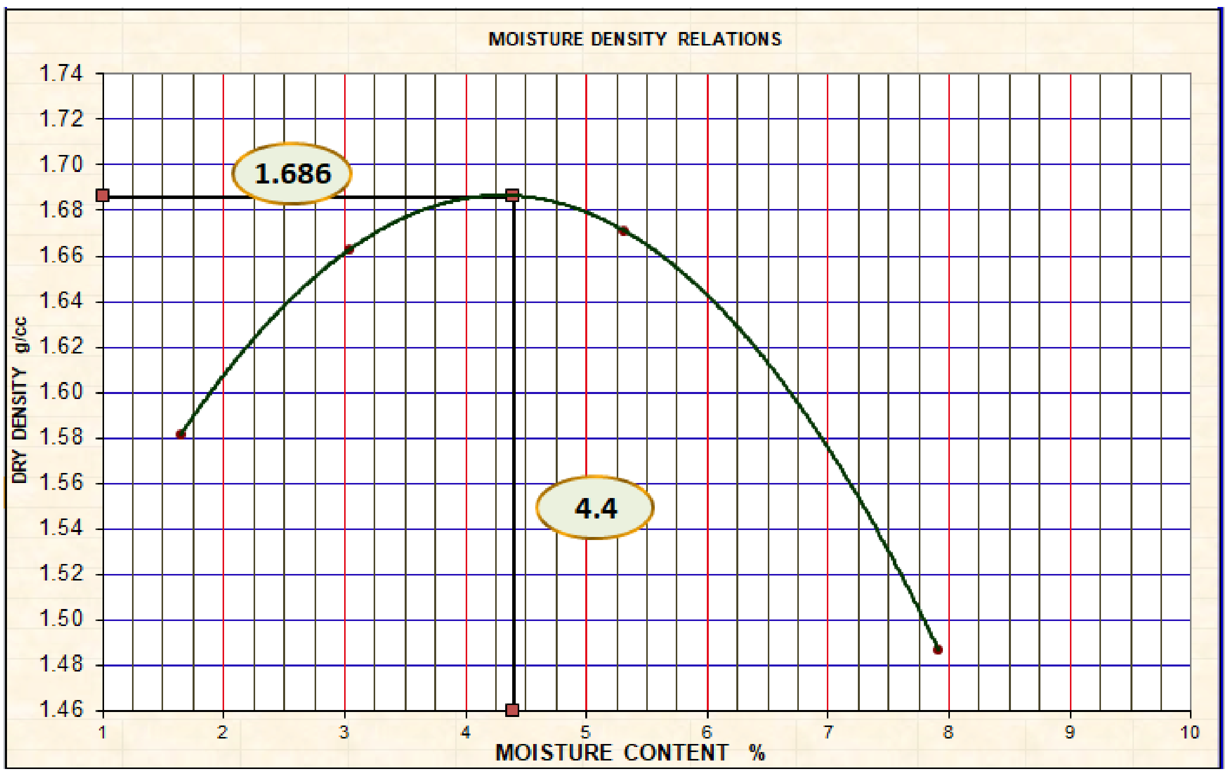


Figure C-1 Moisture-Dry density curve for cinder gravel only

Table C-2 Moisture-Density relations for cinder gravel with 7 % fine-grained Soil

DENSITY	TRIAL NUMBER			1	2	3	4		
	WEIGHT OF SOIL + MOLD	(g)	W_1	18942.6	19208.3	19296.1	18989.6		
	WEIGHT OF MOLD	(g)	W_2	15457	15457	15457	15457		
	VOLUME OF MOLD	(Cm^3)	V	2121	2121	2121	2121		
	WEIGHT OF WET SOIL	(g)	$W_3 = W_1 - W_2$	3,486	3,752	3,840	3,533		
	WET DENSITY OF SOIL	(g/Cm^3)	$W_d = W_3/V$	1.644	1.769	1.810	1.666		NMC
MOISTURE	CONTAINER NUMBER			D5	D6	D2	D8		1
	WET SOIL + CONTAINER	(g)	a	422.6	432.1	436.4	419.6		234.50
	DRY SOIL + CONTAINER	(g)	b	412.6	412.5	410.6	387.5		231.4
	WEIGHT OF CONTAINER	(g)	c	69.8	70.2	71.4	73		25.6
	WEIGHT OF WATER	(g)	d = a-b	10.0	19.6	25.8	32.1		3.1
	WEIGHT OF DRY SOIL	(g)	e = b-c	342.8	342.3	339.2	314.5		205.8
	MOISTURE CONTENT	**(%)**	**m= (d/e)*100**	2.9	5.73	7.61	10.21		1.51
DRY DENSITY OF SOIL		(g/Cm3)	$D_d = W_d/(100+m)*100$	1.597	1.673	1.682	1.511		

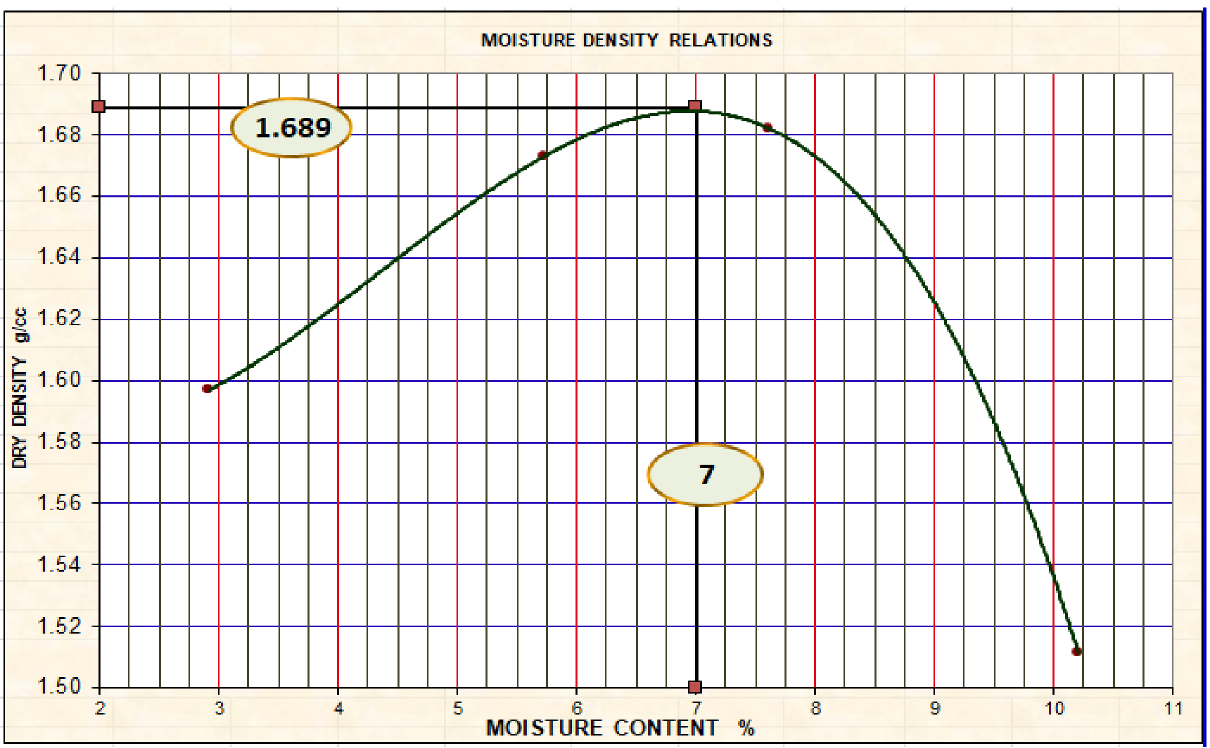


Figure C-2 Moisture-Dry density curve for cinder gravel with 7 % fine-grained Soil

Table C-3 Moisture-Density relations for cinder gravel with 14 % fine-grained Soil

DENSITY	TRIAL NUMBER	1	2	3	4		
	WEIGHT OF SOIL + MOLD (g) W_1	19016.5	19356.2	19522.3	19010.4		
	WEIGHT OF MOLD (g) W_2	15457	15457	15457	15457		
	VOLUME OF MOLD (Cm^3) V	2121	2121	2121	2121		
	WEIGHT OF WET SOIL (g) $W_3 = W_1 - W_2$	3,560	3,900	4,066	3,554		
	WET DENSITY OF SOIL (g/Cm^3) $W_4 = W_3/V$	1.678	1.839	1.917	1.676		NMC
MOISTURE	CONTAINER NUMBER	D3	D11	D8	D10		1
	WET SOIL + CONTAINER (g) a	434	439	444	443		217.40
	DRY SOIL + CONTAINER (g) b	419	412	405	392		211.4
	WEIGHT OF CONTAINER (g) c	71	74	73	71		26.1
	WEIGHT OF WATER (g) d = a-b	14.9	26.7	38.9	50.9		6.0
	WEIGHT OF DRY SOIL (g) e = b-c	347.3	338.7	332.2	321.0		185.3
	MOISTURE CONTENT (%) m= (d/e)*100	4.3	7.88	11.71	15.86		3.24
DRY DENSITY OF SOIL	**(g/Cm3) $D_d = W_4/(100+m)*100$**	1.609	1.704	1.716	1.446		

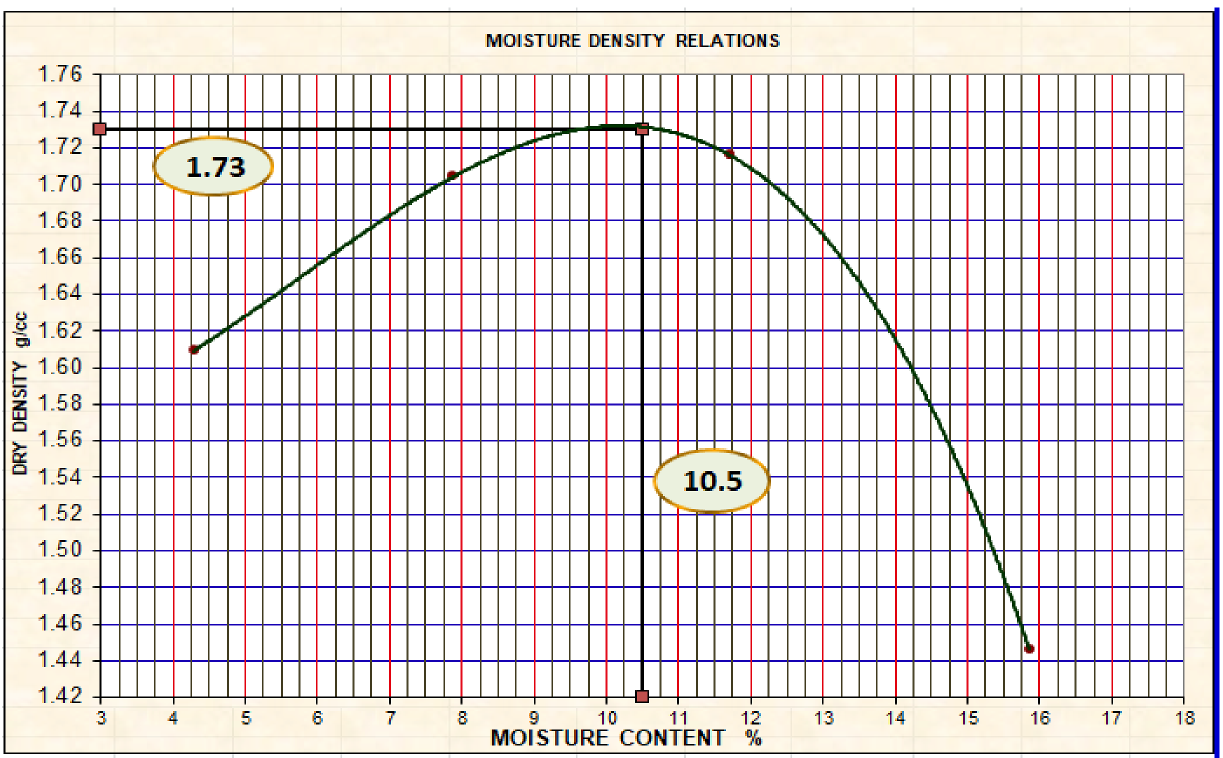


Figure C-3 Moisture-Dry density curve for cinder gravel with 14 % fine-grained Soil

Table C-4 Moisture-Density relations for cinder gravel with 21 % fine-grained Soil

DENSITY	TRIAL NUMBER	1	2	3	4		
	WEIGHT OF SOIL + MOLD (g) W_1	19100.5	19412.5	19619.1	19110.5		
	WEIGHT OF MOLD (g) W_2	15457	15457	15457	15457		
	VOLUME OF MOLD (Cm^3) V	2121	2121	2121	2121		
	WEIGHT OF WET SOIL (g) $W_3 = W_1 - W_2$	3,644	3,956	4,163	3,654		
	WET DENSITY OF SOIL (g/Cm^3) $W_4 = W_3/V$	1.718	1.865	1.963	1.723		NMC
MOISTURE	CONTAINER NUMBER	D3	D11	D2	D8		1
	WET SOIL + CONTAINER (g) a	425.600	428.900	431.500	436.100		219.40
	DRY SOIL + CONTAINER (g) b	406.600	400.600	390.600	380.100		210.9
	WEIGHT OF CONTAINER (g) c	69.800	70.200	71.400	73.000		26.1
	WEIGHT OF WATER (g) d = a-b	19.000	28.300	40.900	56.000		8.5
	WEIGHT OF DRY SOIL (g) e = b-c	336.8	330.4	319.2	307.1		184.8
	MOISTURE CONTENT (%) m= (d/e)*100	5.6	8.57	12.81	18.24		4.60
DRY DENSITY OF SOIL	**(g/Cm3) $D_d = W_4/(100+m)*100$**	1.626	1.718	1.740	1.457		

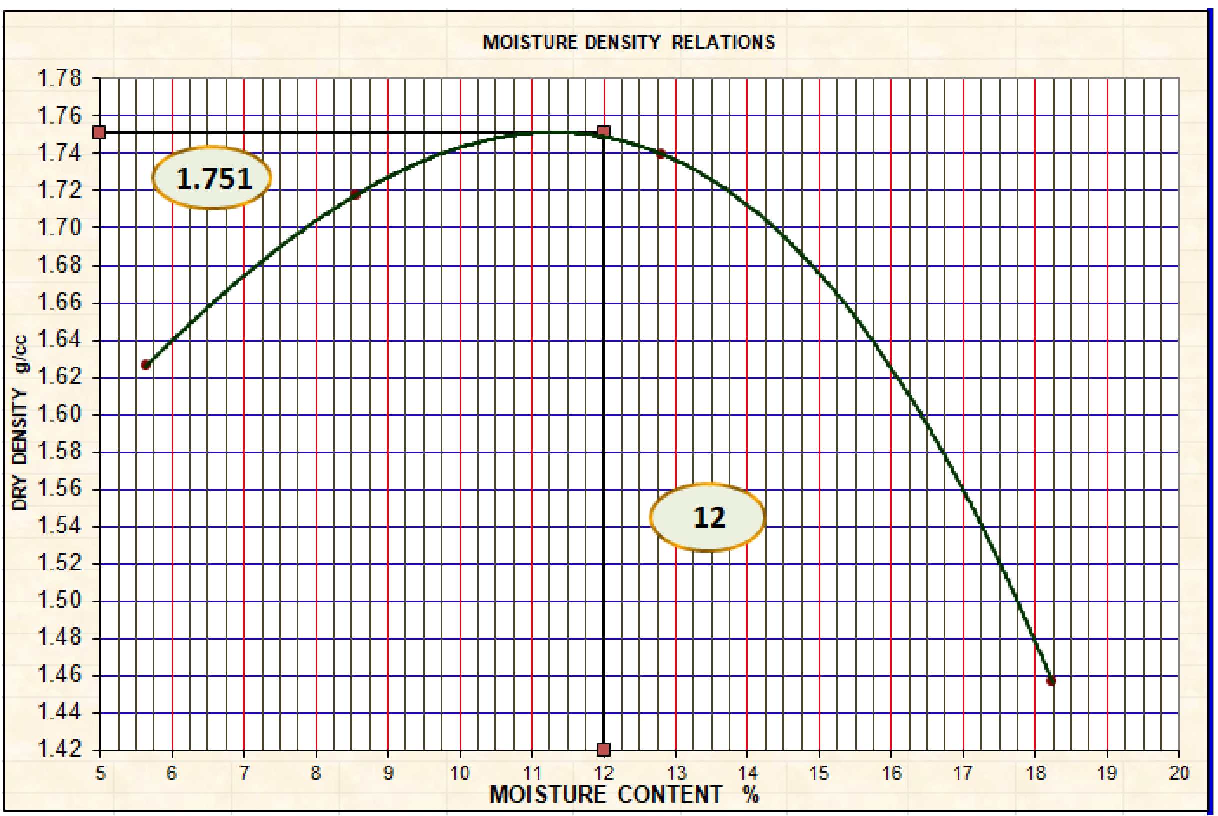


Figure C-4 Moisture-Dry density curve for cinder gravel with 21 % fine-grained Soil

Table C-5 Moisture-Density relations for cinder gravel with 28 % fine-grained Soil

DENSITY	TRIAL NUMBER	1	2	3	4		
	WEIGHT OF SOIL + MOLD (g) W_1	19223.4	19543.6	19752.5	19312.4		
	WEIGHT OF MOLD (g) W_2	15457	15457	15457	15457		
	VOLUME OF MOLD (Cm^3) V	2121	2121	2121	2121		
	WEIGHT OF WET SOIL (g) $W_3 = W_1 - W_2$	3,767	4,087	4,296	3,856		
	WET DENSITY OF SOIL (g/Cm^3) $W_4 = W_3/V$	1.776	1.927	2.025	1.818		NMC
MOISTURE	CONTAINER NUMBER	D5	D6	D2	D8		1
	WET SOIL + CONTAINER (g) a	431.600	438.600	441.700	446.700		237.60
	DRY SOIL + CONTAINER (g) b	405.400	400.700	392.700	385.600		226.5
	WEIGHT OF CONTAINER (g) c	69.800	70.200	71.400	73.000		26.1
	WEIGHT OF WATER (g) d = a-b	26.2	37.9	49.0	61.1		11.1
	WEIGHT OF DRY SOIL (g) e = b-c	335.6	330.5	321.3	312.6		200.4
	MOISTURE CONTENT (%) m= (d/e)*100	7.8	11.47	15.25	19.55		5.54
DRY DENSITY OF SOIL (g/Cm3) $D_d = W_4/(100+m)*100$		1.647	1.729	1.757	1.521		

Figure C-5 Moisture-Dry density curve for cinder gravel with 28 % fine-grained Soil

Appendix-D
California Bearing Ratio (CBR) test results

All the CBR tests were conducted on the following values

Ring Calibration Factor	= 46.945 N/div
Plunger Area	= 1935 mm2
Rate of strain	= 1.27 mm/min
Rammer Wt	= 4.54 kg
Diameter of Mold	=152.4 mm
Volume of Mold	= 2124 cm3

Table D-1 Determination of dry density before & after soaking of cinder with 7 % fine grained soil

Maximum Dry Density as per AASHTO T 180 MDD, [g/cc]	1.689	Optimum Moisture content as per AASTHO T 180 OMC, [%]	7.0	Ring factor [kN/div.]	0.216

DENSITY DETERMINATION						
SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
A. MOLD NUMBER	A		B		C	
B. WEIGHT OF SOIL + MOLD (gm)	9867	10152	9912	10122	10762	11023
C. WEIGHT OF MOLD (gm)	6872	6872	6839	6839	6847	6847
D. WEIGHT OF SOIL (gm) = [B - C]	2995.0	3280.0	3073.0	3283.0	3915.0	4176.0
E. VOLUME OF MOLD (cc)	2121	2121	2121	2121	2121	2121
F. WET DENSITY OF SOIL (g/cc) = [D/E]	1.412	1.546	1.449	1.548	1.846	1.969
DRY DENSITY OF SOIL (g/cc) = [F*100/(MC+100)]	1.274	1.265	1.304	1.263	1.668	1.610

MOISTURE DETERMINATION									
SOAKING CONDITION	10 Blows			30 Blows			65 Blows		
	BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
		TOP 1 in.	AVG.		TOP 1 in.	AVG.		TOP 1 in.	AVG.
CONTAINER NUMBER	D3	D2		D2	D5		D12	D3	
G. WET SOIL + CONTAINER (gm)	410.6	442.7		396	469.8		427.7	451.3	
H. DRY SOIL + CONTAINER (gm)	377.2	375.2		363.5	396		393.5	382.3	
I. WEIGHT OF WATER (gm) = [G-H]	33.4	67.5		32.5	73.8		34.2	69.0	
J.WEIGHT OF CONTAINER (gm)	68.3	71.3		71.3	68.3		72.8	72.8	
K. WEIGHT OF DRY SOIL (gm) = [H-J]	308.9	303.9		292.2	327.7		320.7	309.5	
L. MOISTURE CONTENT (%) = [I/K]*100	10.81	22.21		11.12	22.52		10.66	22.29	

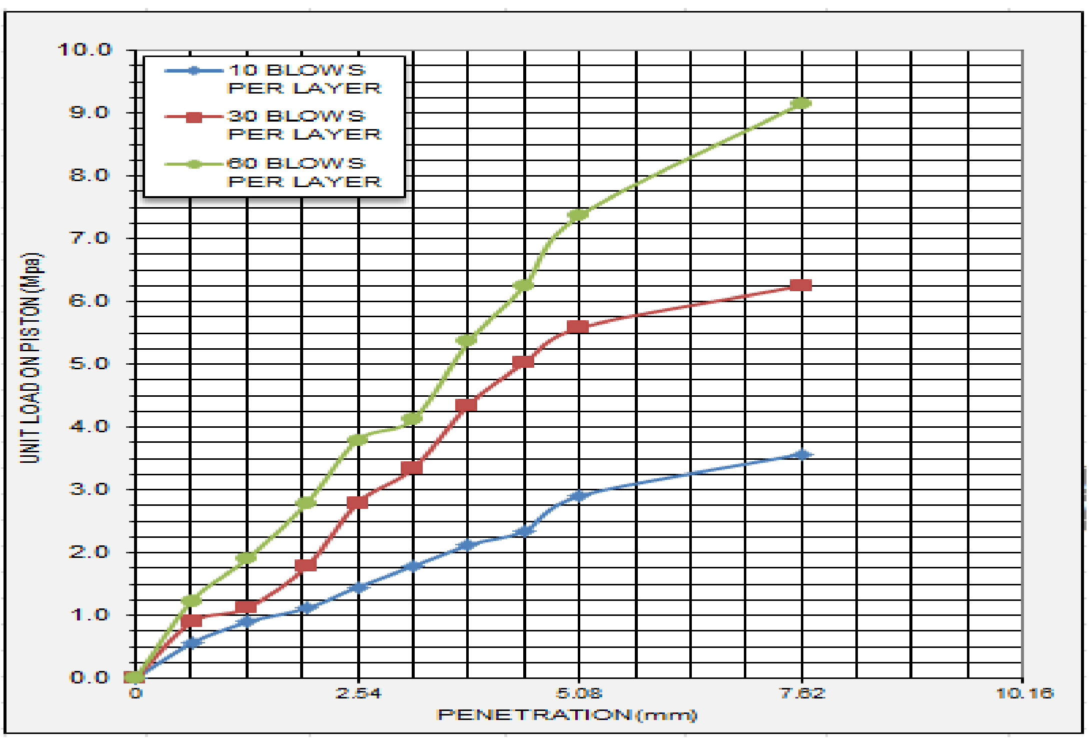


Figure D-1 Load-penetration curves of cinder gravel with 7 % fine-grained soi

Table D-2 Determination of CBR & Swell (%) of cinder with 7 % fine-grained soil

NO OF BLOW	LOAD (KN)		CBR(%)		SWELL %
	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.45	2.90	21.0	28.2	0.52
30	2.79	5.58	40.44	54.19	0.32
65	3.80	7.37	55.0	71.5	0.19

DRY DENSITY Vs SOCKED CBR			
NO OF BLOWS	10	30	65
DRY DENSITY	1.274	1.304	1.668
SOCKED CBR	21.0	40.44	55.0

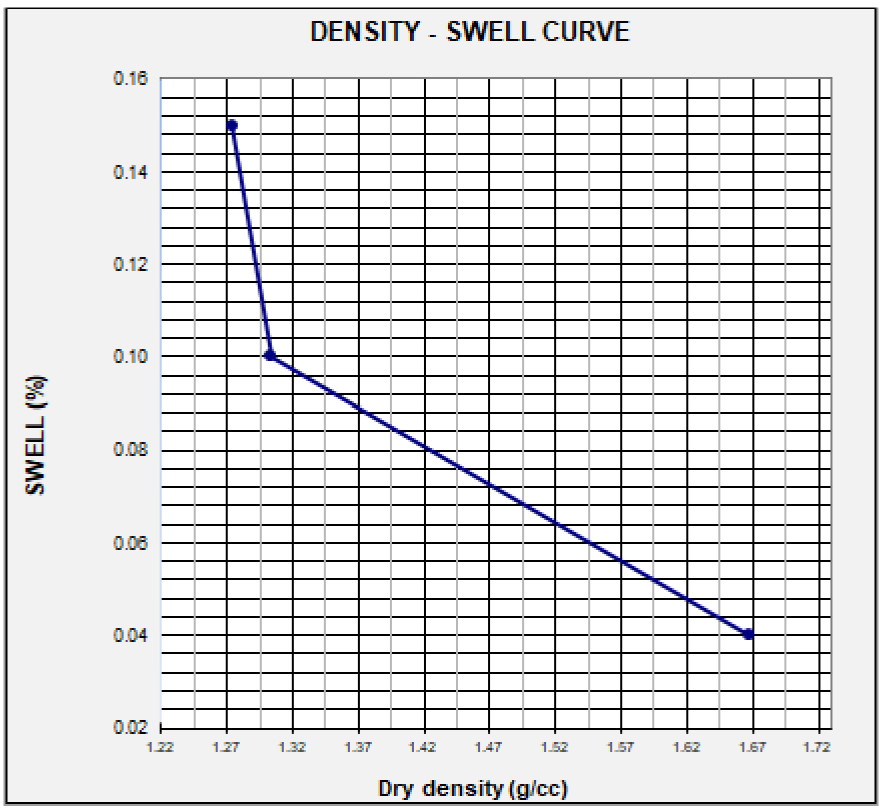


Figure D-2 Dry Density Vs percent swell of cinder with 7% fine-grained soil

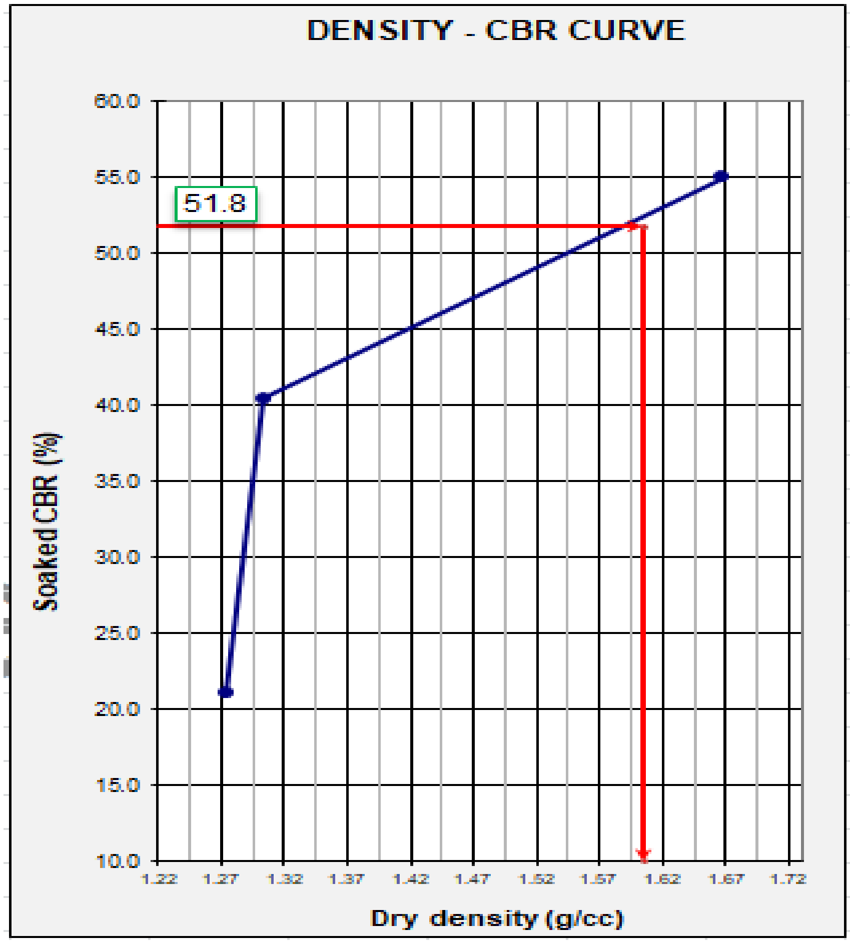


Figure D-3 Dry Density Vs percent CBR of cinder with 7 % fine-grained soil

Table D-3 Determination of CBR & Swell at 95 % of MDD of cinder with 7 % fine-grained soil

MDD (g/cc) :	1.6890
OMC (%) :	7.0
SWELL (%)	0.3
95% of MDD(g/cc)	1.6046
CBR at 95% of MDD	51.8

Table D-4 Determination of dry density before & after soaking of cinder with 14 % fine-grained

Maximum Dry Density as per AASHTO T 180 MDD, [g/cc]	1.73	Optimum Moisture content as per AASTHO T 180 OMC, [%]	10.5	Ring factor [kN/div.]	0.216

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
A. MOLD NUMBER	A		B		C	
B. WEIGHT OF SOIL + MOLD (gm)	10122	10323	10531	10667	10925	11212
C. WEIGHT OF MOLD (gm)	6872	6872	6839	6839	6847	6847
D. WEIGHT OF SOIL (gm) = [B - C]	3250.0	3451.0	3692.0	3828.0	4078.0	4365.0
E. VOLUME OF MOLD (cc)	2121	2121	2121	2121	2121	2121
F. WET DENSITY OF SOIL (g/cc) = [D/E]	1.532	1.627	1.741	1.805	1.923	2.058
DRY DENSITY OF SOIL (g/cc) = [F*100/(MC+100)]	1.373	1.338	1.545	1.477	1.729	1.682

MOISTURE DETERMINATION

SOAKING CONDITION	10 Blows			30 Blows			65 Blows		
	BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
		TOP 1 in.	AVG.		TOP 1 in.	AVG.		TOP 1 in.	AVG.
CONTAINER NUMBER	D3	D2		D2	D5		D12	D3	
G. WET SOIL + CONTAINER (gm)	406	420		410	415		400	412	
H. DRY SOIL + CONTAINER (gm)	371	358		372	352		367	350	
I. WEIGHT OF WATER (gm) = [G-H]	35.0	62.0		38.0	63.0		33.0	62.0	
J. WEIGHT OF CONTAINER (gm)	68.3	71.3		71.3	68.3		72.8	72.8	
K. WEIGHT OF DRY SOIL (gm) = [H-J]	302.7	286.7		300.7	283.7		294.2	277.2	
L. MOISTURE CONTENT (%) = [I/K]*100	11.56	21.63		12.64	22.21		11.22	22.37	

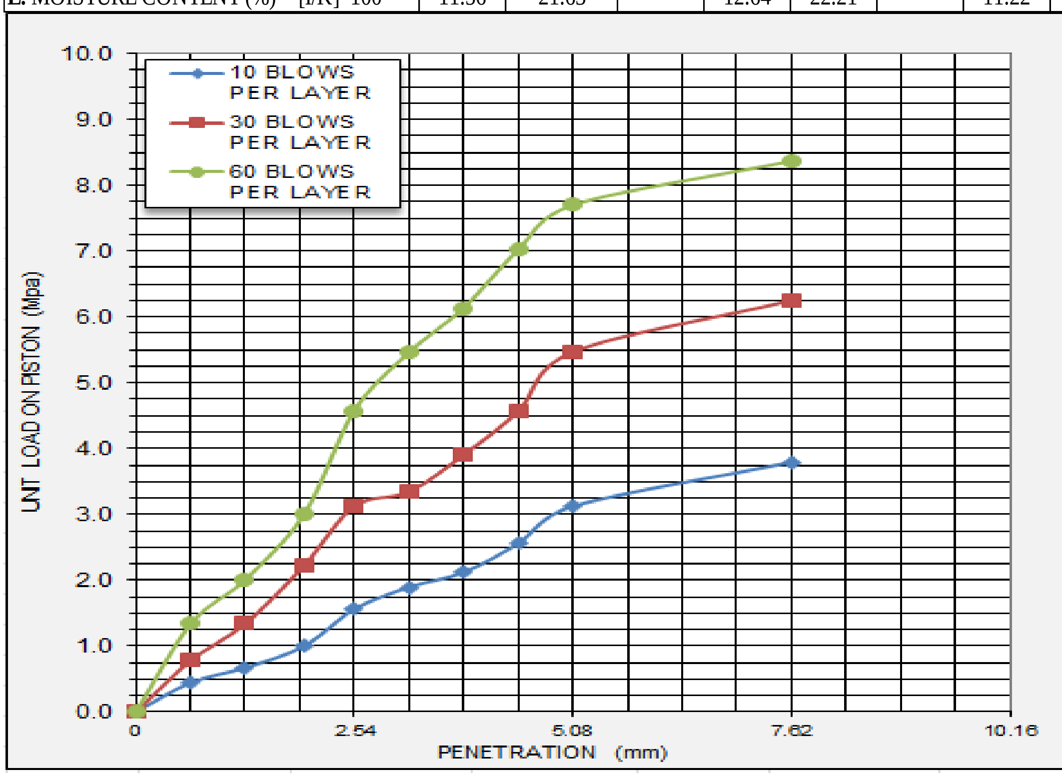


Figure D-4 Load-penetration curves of cinder gravel with 14 % fine-grained soil

Table D-5 Determination of CBR & Swell (%) of cinder with 14 % fine-grained soil

NO OF BLOWS	LOAD (KN)		CBR(%)		SWELL %
	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.56	3.13	22.6	30.3	0.85
30	3.13	5.47	45.30	53.10	0.66
65	4.58	7.70	66.3	74.8	0.47

DRY DENSITY Vs SOCKED CBR			
NO OF BLOWS	10	30	65
DRY DENSITY	1.338	1.477	1.682
SOCKED CBR	22.6	45.30	66.3

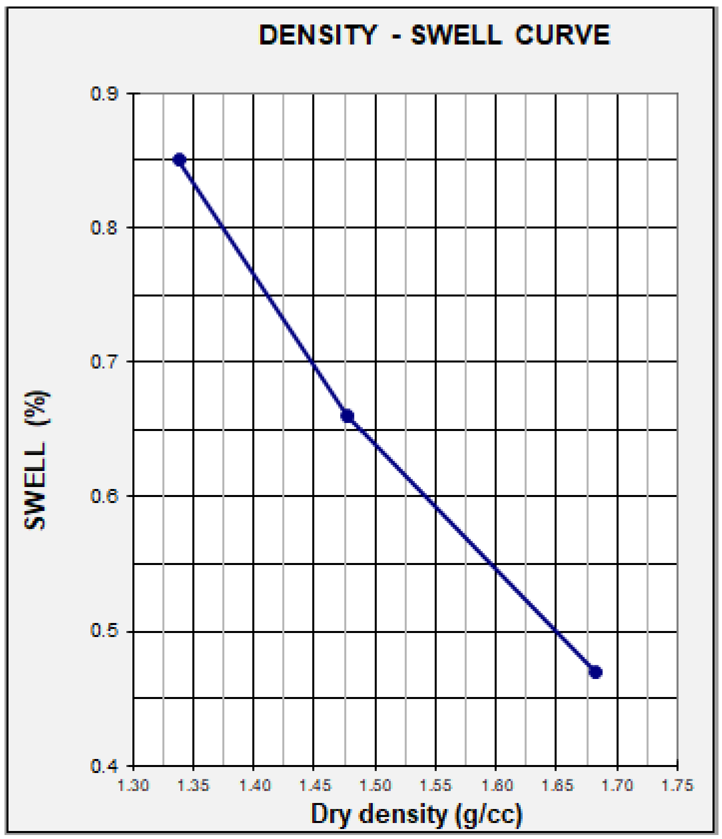


Figure D-5 Dry Density Vs percent swell of cinder with 14 % fine-grained soil

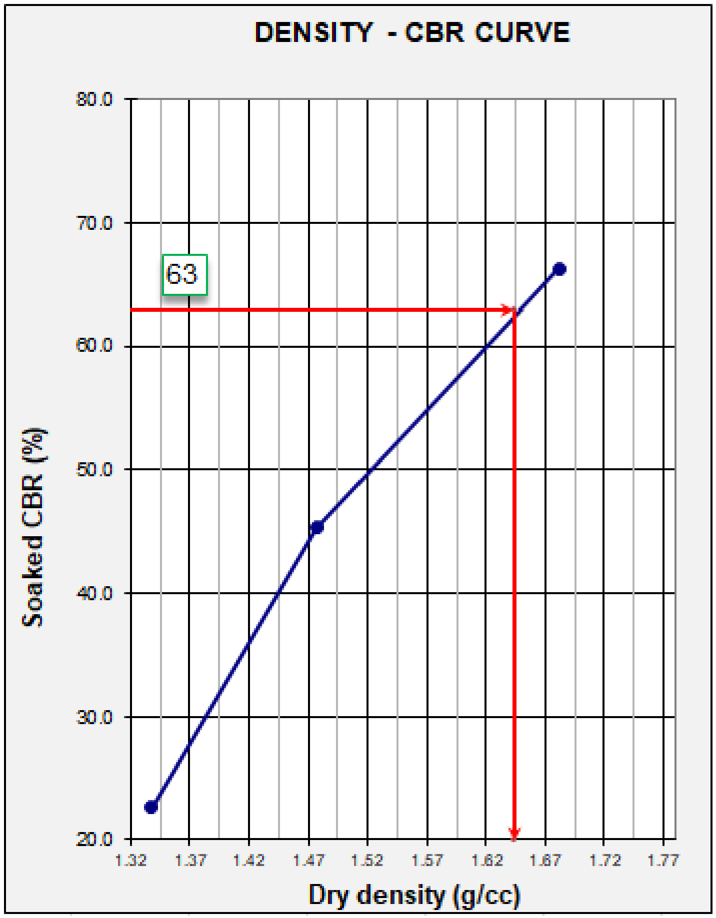


Figure D-6 Dry Density Vs percent CBR of cinder with 14 % fine-grained soil

Table D-6 Determination of CBR & Swell at 95 % of MDD of cinder with 14 % fine-grained soil

MDD (g/cc) :	1.7300
OMC (%) :	10.5
SWELL (%) :	0.66
95% of MDD(g/cc)	1.6435
CBR at 95% of MDD	63

Table D-7 Determination of dry density before & after soaking of cinder with 21 %

Maximum Dry Density as per AASHTO T 180 MDD, [g/cc]	**1.765**	Optimum Moisture content as per AASTHO T 180 OMC, [%]	**14.5**	Ring factor [kN/div.]	0.216

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
A. MOLD NUMBER	A		B		C	
B. WEIGHT OF SOIL + MOLD (gm)	9832	9934	10315	10297	10995	11234
C. WEIGHT OF MOLD (gm)	6872	6872	6839	6839	6847	6847
D. WEIGHT OF SOIL (gm) = [B - C]	2960.0	3062.0	3476.0	3458.0	4148.0	4387.0
E. VOLUME OF MOLD (cc)	2121	2121	2121	2121	2121	2121
F. WET DENSITY OF SOIL (g/cc) = [D/E]	1.396	1.444	1.639	1.630	1.956	2.068
DRY DENSITY OF SOIL (g/cc) = [F*100/(MC+100)]	1.243	1.106	1.461	1.325	1.741	1.679

MOISTURE DETERMINATION

SOAKING CONDITION	10 Blows			30 Blows			65 Blows		
	BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
		TOP 1 in.	AVG.		TOP 1 in.	AVG.		TOP 1 in.	AVG.
CONTAINER NUMBER	D3	D2		D2	D5		D12	D3	
G. WET SOIL + CONTAINER (gm)	425	430		375	378		410	413	
H. DRY SOIL + CONTAINER (gm)	386	346		342	320		373	349	
I. WEIGHT OF WATER (gm) = [G-H]	39.0	84.0		33.0	58.0		37.0	64.0	
J.WEIGHT OF CONTAINER (gm)	68.3	71.3		71.3	68.3		72.8	72.8	
K. WEIGHT OF DRY SOIL (gm) = [H-J]	317.7	274.7		270.7	251.7		300.2	276.2	
L. MOISTURE CONTENT (%) = [I/K]*100	12.28	30.58		12.19	23.04		12.33	23.17	

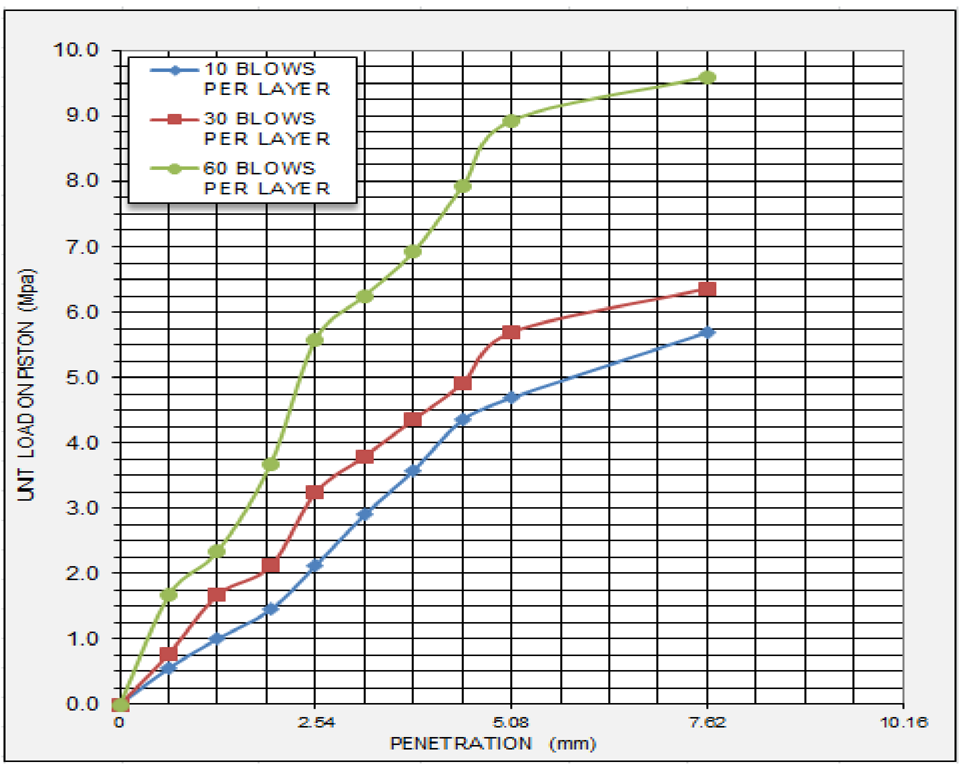


Figure D-7 Load-penetration curves of cinder gravel with 21 % fine-grained soil

Table D-8 Determination of CBR & Swell (%) of cinder with 21 % fine-grained soil

NO OF BLOWS	LOAD (KN)		CBR(%)		SWELL %
	2.54mm	5.08mm	2.54mm	5.08mm	
10	2.12	4.69	30.7	45.5	1.01
30	3.24	5.69	46.92	55.27	0.84
65	5.58	8.93	80.9	86.7	0.66

DRY DENSITY Vs SOCKED CBR			
NO OF BLOWS	10	30	65
DRY DENSITY	1.243	1.461	1.741
SOCKED CBR	30.7	46.92	80.9

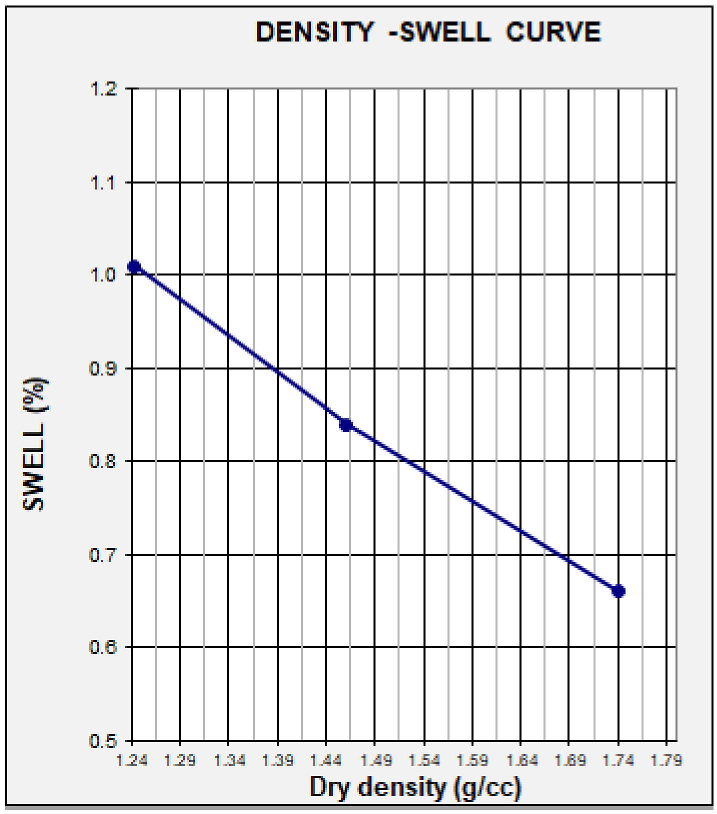


Figure D-8 Dry Density Vs percent swell of cinder with 21% fine-grained soil

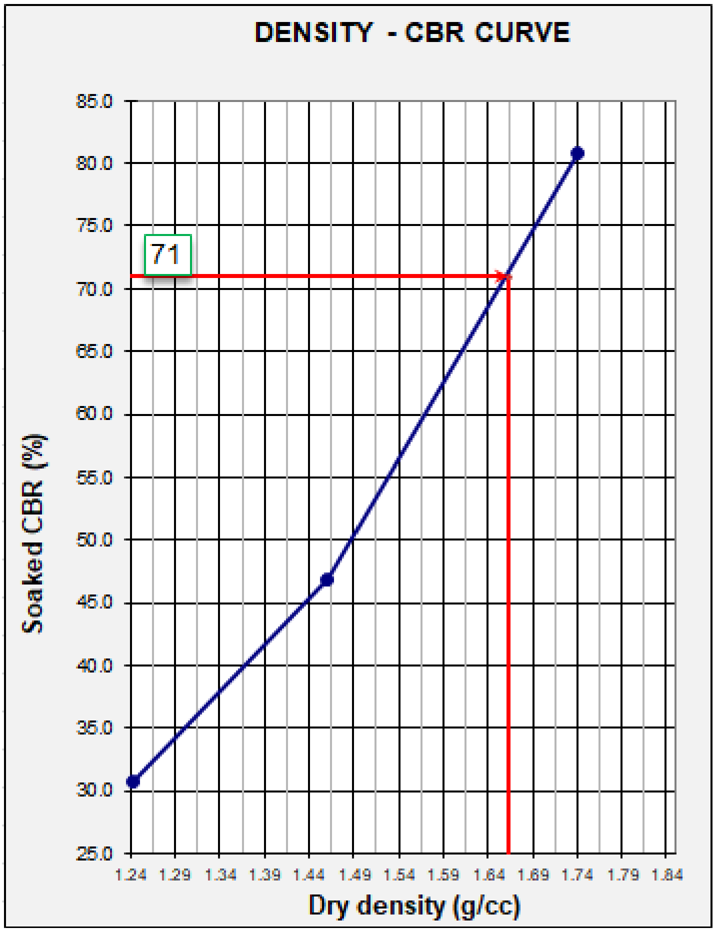


Figure D-9 Dry Density Vs percent CBR of cinder with 21% fine-grained soil

Table D-9 Determination of CBR & Swell at 95 % of MDD of cinder with 21 % fine-grained soil

MDD (g/cc) :	1.7510
OMC (%) :	12.0
SWELL (%) :	0.84
95% of MDD(g/cc)	1.6635
CBR at 95% of MDD	71

Table D-10 Determination of dry density before & after soaking of cinder with 28% fine grained soil

Maximum Dry Density as per AASHTO T 180 MDD, [g/cc]	**1.765**	Optimum Moisture content as per AASTHO T 180 OMC, [%]	**14.5**	Ring factor [kN/div.]	0.216

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
A. MOLD NUMBER	A		B		C	
B. WEIGHT OF SOIL + MOLD (gm)	10213	10234	10823	11010	11547	11807
C. WEIGHT OF MOLD (gm)	6872	6872	6839	6839	6847	6847
D. WEIGHT OF SOIL (gm) = [B - C]	3251.0	3362.0	3984.0	4171.0	4700.0	4960.0
E. VOLUME OF MOLD (cc)	2121	2121	2121	2121	2121	2121
F. WET DENSITY OF SOIL (g/cc) = [D/E]	1.533	1.585	1.878	1.967	2.216	2.339
DRY DENSITY OF SOIL (g/cc) = [F*100/(MC+100)]	1.365	1.299	1.671	1.604	1.973	1.902

MOISTURE DETERMINATION

SOAKING CONDITION	10 Blows			30 Blows			65 Blows		
	BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
		TOP 1 in.	AVG.		TOP 1 in.	AVG.		TOP 1 in.	AVG.
CONTAINER NUMBER	D3	D2		D2	D5		D12	D3	
G. WET SOIL + CONTAINER (gm)	415	420		425	432		410	416	
H. DRY SOIL + CONTAINER (gm)	377	357		386	365		373	352	
I. WEIGHT OF WATER (gm) = [G-H]	38.0	63.0		39.0	67.0		37.0	64.0	
J.WEIGHT OF CONTAINER (gm)	68.3	71.3		71.3	68.3		72.8	72.8	
K. WEIGHT OF DRY SOIL (gm) = [H-J]	308.7	285.7		314.7	296.7		300.2	279.2	
L. MOISTURE CONTENT (%) = [I/K]*100	12.31	22.05		12.39	22.58		12.33	22.92	

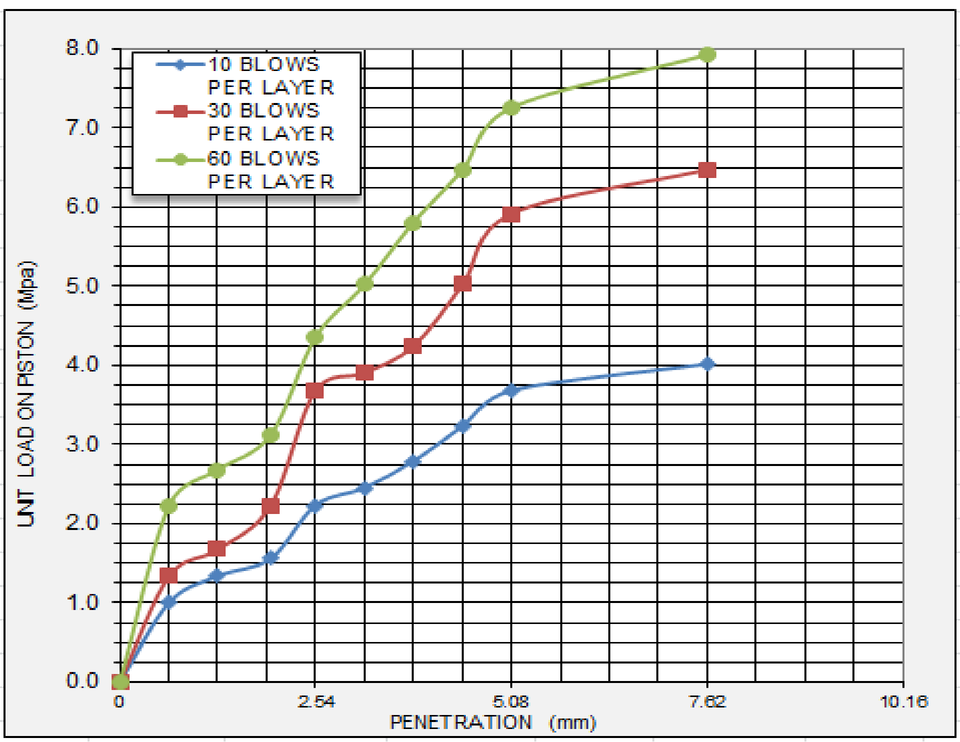


Figure D-10 Load-penetration curves of cinder gravel with 28 % fine-grained soil

Table D-11 Determination of CBR & Swell (%) of cinder with 28% fine-grained soil

NO OF BLOWS	LOAD (KN)		CBR(%)		SWELL
	2.54mm	5.08mm	2.54mm	5.08mm	%
10	2.23	3.68	32.4	35.8	1.31
30	3.68	5.92	53.39	57.44	1.08
65	4.35	7.26	63.1	70.4	0.82

DRY DENSITY Vs SOCKED CBR			
NO OF BLOWS	10	30	65
DRY DENSITY	1.365	1.671	1.973
SOCKED CBR	32.4	53.39	63.1

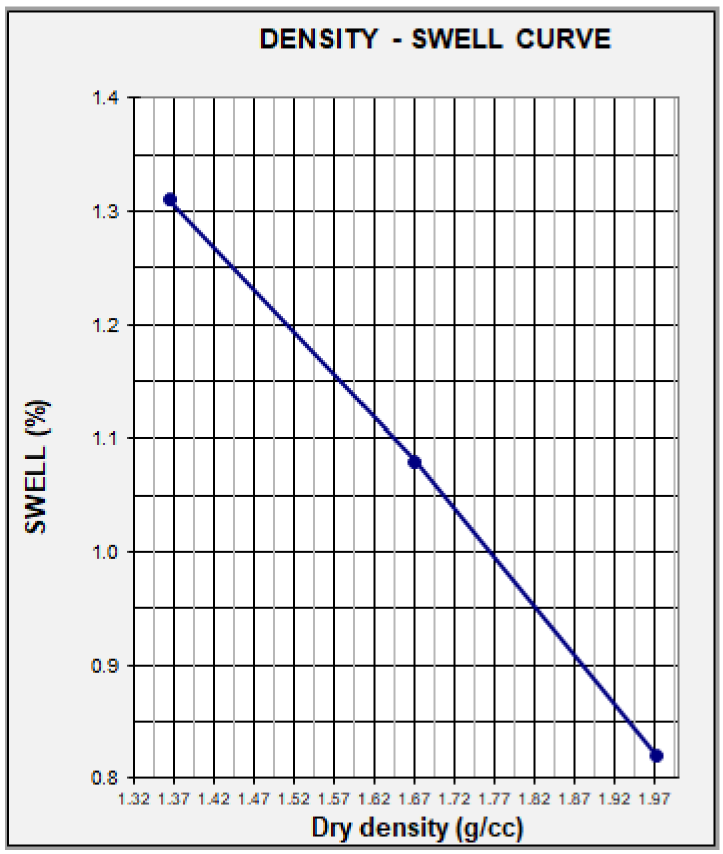


Figure D-11 Dry Density Vs percent swell of cinder with 28% fine-grained soil

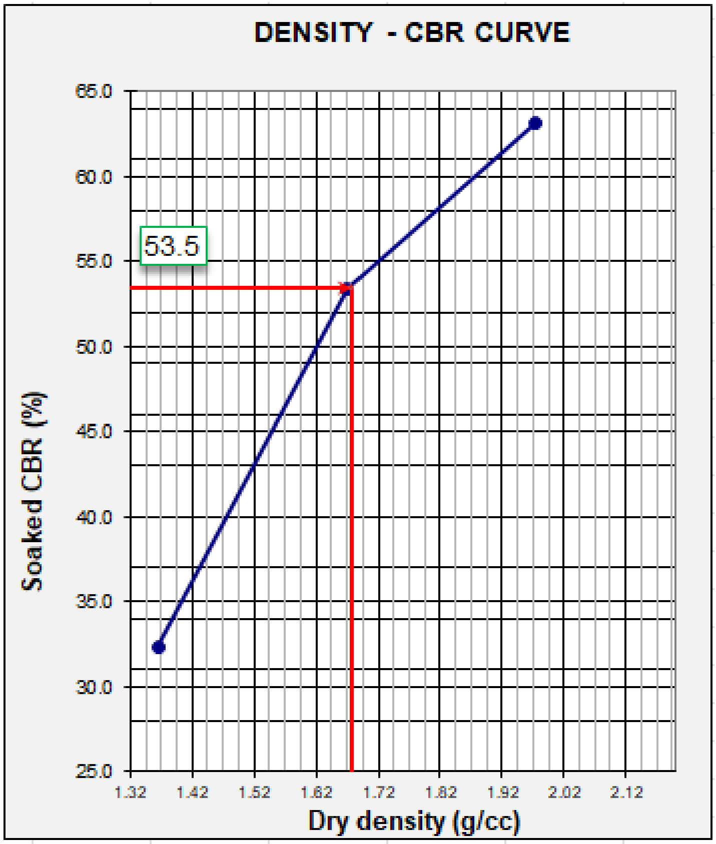


Figure D-12 Dry Density Vs percent CBR of cinder with 28% fine-grained soil

Table D-12 Determination of CBR & Swell at 95 % of MDD of cinder with 28 %

MDD (g/cc) :	1.7650
OMC (%) :	14.5
SWELL (%) :	1.07
95% of MDD(g/cc)	1.6768
CBR at 95% of MDD	53.5

Appendix-E
Additional Test Result

Table E-1 Absorption and Specific gravity of natural cinder gravel (materials < 4.75mm

Temperature-Density Correction Factors (°C)												
°C	22	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5
k	1.000728	1.000613	1.000495	1.000375	1.000253	1.000127	1.00	0.999870	0.999738	0.999604	0.999466	0.999327

Description		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Average
A. Mass of oven dry sample(gm)		1777.5	1870						1824
B. Mass of SSD sample in air(gm)		2362	2424.5						2393
C. Mass of saturated sample in water(gm)		549	549.5						549
Water Temperature(°C)		23.0	23.0						
K		1.000495	1.000495						
Bulk sp. gravity[oven dry], G_{od}	$G_{od} = A*k/(B-C)$	0.981	0.998	-	-	-	-	-	0.989
Bulk sp. Gravity[SSD], G_{SSD}	$G_{SSD} = B*k/(B-C)$	1.303	1.294	-	-	-	-	-	1.299
App. specific gravity, G_{App}	$G_{app} = A*k/(A-C)$	1.448	1.417	-	-	-	-	-	1.432
Water absorption W_{ab}, %	$W_{ab} = (B-A)*100/A$	32.9	29.7	-	-	-	-	-	31.3

Table E-2 Determination of Linear shrinkage values

% fine	L (mm)	Lo(mm)	LS %
0	139.8	140	0.24%
7	139.5	140	0.48%
14	139.2	140	0.72%
21	138.8	140	0.93%
28	138.4	140	1.44%