Addis Ababa University
School of graduate studies
College of natural science

Blending of volcanic cinder and natural gravel for sub-base road construction

A case study of Gelan Asphalt Road Project Addis Ababa,

A Thesis submitted to School of graduate studies Addis Ababa University

In partial fulfillment of the requirements for the degree of masters in Engineering Geology

By Gebretsadik Mesfin

June, 2015

<u>Signature paper</u>

Addis Ababa University
School of Graduate Studies

This is to certify that the thesis prepared by **Gebretsadik Mesfin**, entitled: ***Blending of volcanic cinder and natural gravel for sub-base road construction, case study of Gelan asphalt road Project, Addis Ababa,* Ethiopia** and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Engineering Geology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRUCT

Blending of Volcanic Cinder and Natural Gravel for Sub-Base Road Construction, a Case Study of Gelan asphalt project, Addis Ababa, Ethiopia.

Gebrestadik Mesfin

Addis Ababa University, June, 2015

Pavement design is aimed for achieving a pavement structure which is economical, comfortable and yet safe to travel by motorist; and which minimizes development of pavement distress features during the design life of the pavement. However, inappropriate selection of road materials for construction may cause early pavement failure.

Low quality or out-of-specification materials are usually available from local sources. If there is appropriate treatment of the materials or/and structural design, the optimum use of local materials can be permitted, the construction can be accelerated and significant monetary benefits can be realized.Acccordingly in this study it was attempted to define the requirement related to blending of some volcanic cinder gravel from south east of Addis Ababa for Gelan Asphalt road project.

The performance of mechanically blended volcanic cinder with natural gravel was evaluated in meeting Ethiopian Road Authority (ERA) manual specification. The cinder gravel was blended with some trial proportions of 1:1, 2:1 and 3:2 weathered natural gravel by mass and different test including grain size distribution, Attereber limit, California Bearing ratio Linear shrinkage, Loss Angeles Abrasion and perographic analysis has been conducted.

Results showed that blending of 50% of natural gravel with 50% volcanic cinder, and 67% natural gravel with 33% of volcanic cinder has no plasticity characteristic and its plastic product is zero. However blending of 60% of weathered natural gravel with 40% of volcanic cinder improves its index properties and readily can be used for sub-base road construction as far as it satisfies ERA sub-base materials requirements.

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Gebretsadik Mesfin

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Lists of Abbreviations

AACRA	Addis Ababa City Road Administration
AASHTO	American Association of Highway and Transportation Officials
AAU	Addis Ababa University
AAWSA	Addis Ababa Water and sanitation agency
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CSE	Central Statics of Ethiopia
C1	Cinder one
C2	Cinder two
C3	Cinder three
DD	Dry Density
E	Easting
E.C	Ethiopian Calendar
ERA	Ethiopia Road Authority
ERA	Ethiopian Road Authority
FAO	Food and Agricultural Organization
GSE	Geological Survey of Ethiopia
GPS	Global Position System
GM	Grading Modules
GM	Grading Modules
Gm/cm^3	Gram per centimeter cubic
LS	Linear Shrinkage
LL	Liquid Limit
LAA	Los Angeles Abrasion
MER	Main Ethiopian rift valley
MDD	Maximum Dry Density
MDD	Maximum Dry Density
Gn	Natural Gravel
N	Northing
NNE	North-North East
OMC	Optimum Moisture Content
PI	plastic index
SNNP	Southern nation and nationality people

TRRL	Transport and Road Research Laboratory
UK	United Kingdom
UN	United nation
UTM	Universal Transverse Mercator

CHAPTER ONE
INTRODUCTION

1.1 General

People travel for some reasons although airway, railway, seaway and highway are for traveling; highway is preferred since it is more economic than others, especially for shorter distance. Highway pavement types can be categorized into two groups, as flexible pavements and rigid pavements. Flexible pavements are those which are surfaced with bituminous (or asphalt) materials. Rigid pavements are composed of a Portland cement concrete surface course (Saltan and Findik, 2007).

Flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low .Adherence to this design principle makes possible the use of local materials and usually results in a most economical design. This is particularly valid in regions where high-quality materials are expensive but local materials of inferior quality are available (Saltan and Findik, 2007).

The typical flexible pavement structure is consists of surface course, base and sub-base layers. Surface course is the top layer and thus layer comes in contact with the traffic. It may be composed of one or several different hot mix asphalt (HMA) sub layers. Base course is the layer directly below the HMA layer and generally consists of aggregate. Sub-base course is the layer (or layers) under the base layer and upper the sub grade.

The sub-base can be lower quality because it is located at a greater distance from wearing surface and the stresses it receives are therefore less intense. Due to the fact that, local and waste materials which are the most economic among others, can be used at the sub-base (Saltan and Findik, 2007).

For many designs the main function of the sub-base of a flexible pavement is to reduce the construction cost. The objective is to achieve required pavement thickness with the possible economic materials. The entire thickness could be constructed with a high-quality material such as that used in the base course. However, it is generally preferred to make the base thinner and substitute a sub-base layer of poorer quality material, although the total pavement thickness may have to be increased. The poorer the quality of the material that is used, the greater will be the thickness required to tolerate and transmit the stresses(ERA, 2002).

Another function of sub-base is to provide a transition layer between the material of the base course, which is generally coarse-grained, and that of the sub grade, which is usually much finer. The sub-base also serves to absorb detrimental deformations in the sub grade such as volume changes associated with variations in water content, which might eventually be reflected in the pavement surface (ERA, 2002).

Another function of the sub-base is to drain off any water that infiltrates from the surface and to prevent water from the fill from rising towards the base course due to capillarity. of these factors, the structural and economic ones are common to all sub-bases. The others depend partly on specific circumstances and partly on the material that is used in the sub-base (ERA, 2002).

According to the Ethiopian Road Authority (ERA,2002) and Addis Ababa City Road Authority (AACRA,2003) pavement design manual material such as volcanic cinder, natural gravel, crushed aggregate, recycled pavement material and crushed weathered rock are specified as source of sub-base material. Therefore, volcanic cinder gravels are one of the marginal earth materials the present research project is carried out by taking the case of Gelan asphalt road project which is 4.5km long.

In most of the area and along the side of the road, selected sub-base material is not available Even though there is abundant distribution of cinder gravel material which can be used as a sub-base. Since cinder materials which are found within the study are varied in terms of color, grain size distribution, degree of weathering and depositional event the objective of the present research is to investigate the performance of cinder blended with natural gravel as sub-base material and propose the best blending proportion.

It is intended to investigate if there is any variation in engineering performance of volcanic cinder within the same source. This is to make a detail investigation during cinder material selection either within the same or different sources in order to meet the desired specification. For this purpose, cinder and natural gravel samples were collected from the study area and Dukem respectively. Generally flexible pavement has the following layers according to fig.1.1given below.

Figure 1:1Typical cross-section of conventional flexible pavement

1.2 Background of the Problem

In road infrastructure projects, the quality of the sub-base material and its grain size distribution are very important. If appropriate sub-base material cannot be found close to the construction site, then very high prices have to be paid during construction process. This causes significant delays or cost increases of the construction project. In such cases, sometimes work with low-quality materials affects the road quality and durability over time (Yitayou, 2011).

In such circumstance improving the quality of materials is very important, in order to ensure that the project meet the necessary cost and quality standard. If materials found close to the construction project do not meet the specifications, materials can be improved with suitable chemicals and earth materials (Girma, 2009).

Within the main Ethiopian rift valley, there is widely distributed cinder gravel associated with the recent volcanic activities (Newill et al., 1987). But for many decade their significance to the road construction sector and other infrastructure were limited. This is due to limited scientific research on cinder materials for different construction purpose, and weak engineering performance due to its light weight, rough circular surface, lack of fine grained soil and high porosity (ERA and TRRL, 1975).

Since the distribution of selected sub base materials such as natural gravel, recycled pavement material and crushed rock are not evenly distributed, using these materials everywhere will increase transportation cost and it is time consuming (ERA, 2002).

For this reason, in some construction project where the occurrence of volcanic cinder gravel is dominant while sub-base materials are scarce currently they are using it by mixing with locally available earth material that can significantly increase its engineering property without having any research based output and background (Yitayou ,2011).

Therefore, this research will emphases on blending of volcanic cinder with natural gravel a case study of Gelan Asphalt road project, Addis Ababa, in order to evaluate its engineering characteristic before and after blending at different proportion.

1.3 Objective of the Research

1.3.1 General objective

- To assess the suitability of volcanic cinder gravel for sub- base at Gelan Asphalt road construction project.

1.3.1 Specific objective.

Within the framework of the above general objective, the following specific objectives are given.

- To define the requirements related to blending of some volcanic cinder gravel to be used as a sub base material.
- To characterize the index properties of blended cinder materials at different proportion.
- To provide suitable recommendation based on the present research for future road construction.

1.4 Methodology of the Research.

To achieve the objective of the present research the following methodology have been implemented.

- Literature review to have an overview of geological, geomorphologic, hydro-geological and engineering geological condition of the road site and the surrounding areas

- Collection of previous works related to the occurrence, distribution and location of Volcanic cinder cone in Ethiopia and its relevance for road construction.
- Preparation of over simplified different maps of the study area from secondary data obtained from various institutions and company.
- Collection of Sub-surface soil data during the assessment of sub grade soil classification.
- Collection of different manuals and standards which are important for field sampling, laboratory test and presentation of test results during determination of various index laboratory tests.
- Field works to overview the land use land cover, physiographic and geologic setup of the study.
- Collection of natural and volcanic cinder samples from quarry area, stock pile and test pit and to determine various index properties.
- Petrographic analysis of volcanic cinder cone from different location of the same source has been done in order to determine its mineral composition.
- Detailed index laboratory test based on the specification and manuals have been carried out.
- Based on the result obtained from various index laboratory tests such as California bearing ratio (CBR), Atterberg limit, Linear Shrinkage(LS) and Loss Angeles Abrasion(LAA) the suitability of volcanic cinder material for sub-base, and its remedial measures to improve their property has been clearly described.
- Finally recommendation has been given on how, in what proportion should blending carried out, recommendation has been also given how cinders should be mixed during construction.

1.4.1 Generalized layout of methodology

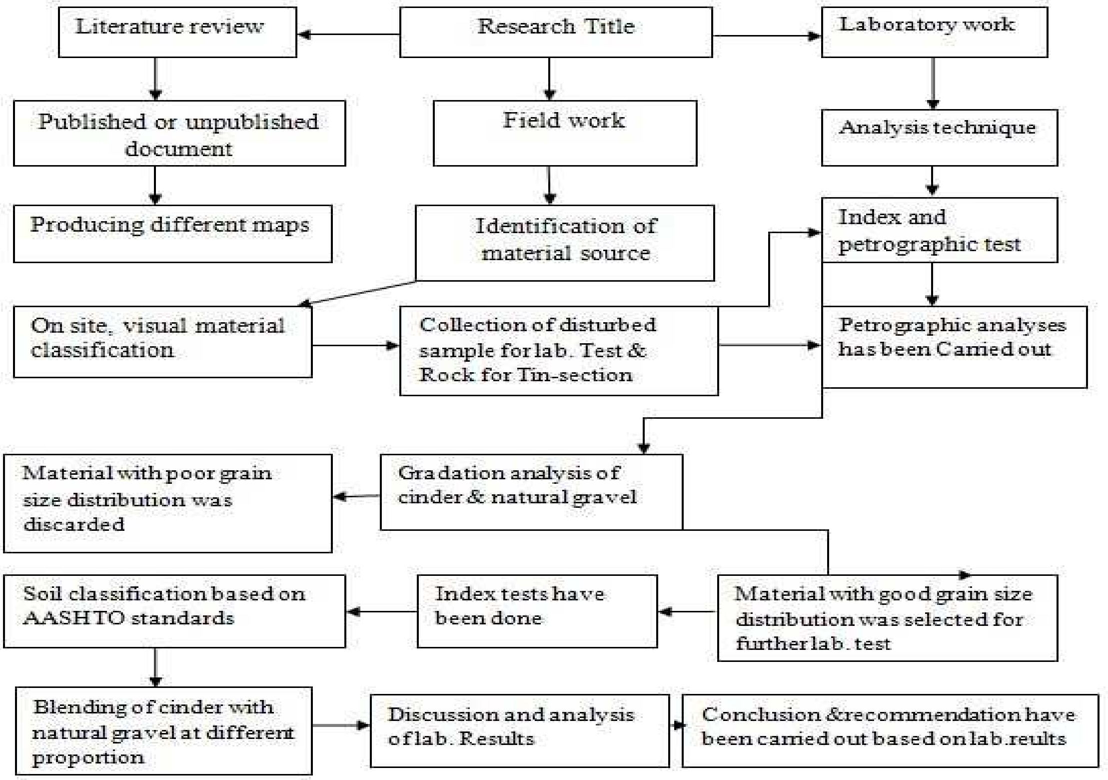


Fig.1.2 General Methodology

1.5 Materials

For the present study various supporting tools were utilized to carry out the research.

- ✓ Topo-sheets have been used to prepare the location map of the study area.
- ✓ Geological Map of the Akaki-Beseka at a scale of 1:250,000 have been used to extract the general geology of the study area.
- ✓ AASHTO Soil classification system was used to determine the soil type of both cinder and natural gravel obtained from different source.
- ✓ Global Mapper12 have been utilized to make the 3d physiographic feature of the project area.
- ✓ Google Earth have been utilized during the bird eye view of the road segment and its slope profile
- ✓ Arc Gis has been employed to prepare geological map, soil map, slope map land use land cover, drainage map
- ✓ Coral draw12 was also employed during the preparation of some graphic works
- ✓ Starter soft ware was used for the preparation of some geologic borehole data
- ✓ Surfer soft ware was used for the preparation of contour map of the study area

1.6 Significance of the Research

From this research paper the results may be of great importance in economic feasibility, construction time and providing a basic back ground to enable highway engineers, Geotechnical engineers to make full use of locally-available materials during road construction in area where suitable sub-base material is scarce while volcanic cinders are presence. It resolves the constraint of construction materials through efficient use which depend on the recommendations.

The present study will also be a good background for geotechnical engineers, highway engineers, and engineering geologist who area involved in construction material assessment for different construction sector as well as supervisions.

This research could also initiate or support further related research especially during the construction of light and rural gravel roads where the quality and quantity of selected sub-base materials are scarce while cinder materials occurrence dominantly.

1.7 Limitation of the Research

All efforts are being made to perform the present study systematically with adequate scientific input and realistic facts. However, these efforts were made under limitation of resources and financial constraints. Because of limitation of finance, many potential sources of cinder sites could not be characterized. Furthermore, since laboratory test takes long time it was hard to do more sample testings from different source.

1.8. Organization of the Thesis

The present research involves the following chapters and is presented as follows:-

Chapter: I covers the introduction of pavement types, importance and type of material used. Additionally, it covers objectives, methodologies, application of the result and limitations of the research and finally, the scheme of presentation.

Chapter: II presents literature reviews containing location and engineering properties of volcanic cinder gravels in Ethiopia; modification of existing materials and method of stabilization; material survey for sub base road construction purpose; related works on cinder gravel in road construction and economical aspects of blending material.

Chapter: III deals with the study area through sub topics discussing about the location, topography and geomorphology, drainage pattern and hydrogeology, regional geology, land use land cover and climate of the study area.

Chapter: IV deals with index properties and other laboratory test of none blending natural and cinder gravels.

Chapter: V deals with blending of natural and cinder gravel at different proportion which brings the desired standard requirements.

Chapter: VI deals with conclusion and recommendations that includes scientific and logical recommendations.

CHAPTER TWO

LITERATU REREVIEW

2.1. Introduction

The performance of flexible pavements depends on many factors such as structural adequacy of the pavements, properties of materials used, traffic loading, climatic conditions and construction practices. Previous research has found that much of the distress experienced in flexible pavements can be traced to the problems encountered in base materials (Biraj, 2010).

Normally, the use of high-quality base materials is required for pavement construction and rehabilitation to comply with the standard specifications. However, the reserves of high-quality materials are diminishing in some regions and the long-distance hauled-in materials would result in high transportation costs. This situation has required the use of local sources of base materials in pavement construction.

Local materials may be out-of-specification with respect to the standard specifications for roadway base/sub-base. Under many current standard specifications, a base material can be considered out-of-specification for a variety of reasons (inadequate gradation, inadequate plasticity, inadequate strength etc.) (Biraj, 2010).

In many cases, local base supplies miss these specifications by a small margin. Since the criteria set in the current specifications are experienced-based, some of the parameters used to classify base materials may be less significant than others. With appropriate treatment or structural design, many of these out-of-specification materials can perform adequately for rural gravel road, low-volume roads and some time for asphalt road projects. these materials should be capable of providing low-cost base and sub-base in roads that are subjected to low traffic levels but high axle loads(Biraj, 2010).

Studies conducted by the Ethiopian Road Authority and the United Kingdom Transport and Road Research Laboratory (ERA,TRRL.,1975) indicates that, locally available material such as volcanic cinder gravel can play a crucial role in terms of cost saving, pavement performance, resource management and environment protection. Based on the above fact in this research it was attempted to characterize one of the locally available base materials, i.e. volcanic cinder for sub-base road construction and a remedial measure has been proposed based on the index test results.

2.2 Origin of volcanic cinder

According to Cas, and Wright (1988). The science of volcanology has grown rapidly, particularly in the last 50 years. Both field and laboratory studies have greatly expanded the understanding of eruptive rocks and eruptive processes.

The formation and preservation of highly vesicular rocks involve the interaction of a large number of variables, including temperature, viscosity, gas pressure, and diffusion rates within the erupting magma and external conditions such as wall rock permeability, water influx, vent blockage, wind conditions, and whether the eruption is sub aerial or subaqueous. None of these is constant and may change significantly, even during a single eruptive event (Casey et al, 2006).

Basaltic magmas tend to be more fluid than more silicic magma and, as they near the surface, degas quickly without generating a stable vesicular structure. Even after vesicle formation, scoria particles may be fluid enough to collapse on impact or to adhere to each other, forming a dense mass rather than a friable, porous deposit.

Silicic magmas are less fluid and offer less opportunity for gas escape and the collapse of vesicle walls. Conditions that reduce gas escape such as high magma viscosity, impermeable wall rock, or a blocked vent may lead to eruptions explosive enough to shatter the vesicle walls, generating a fine ash rather than a vesicular particle.

Pumice particles entrained in a pyroclastic flow maybe reheated enough to soften and collapse in to none vesicular glass. The unconsolidated nature and low density of pumice and scoria deposits make them readily susceptible to erosion, and the extremely large surface area of their vesicular particles promotes rapid chemical weathering. As a result, most deposits of pumice and scoria are geologically young, rarely more than a few million years old and often only a few thousand years old (Fisher,1961).

2.3 Mineral Composition of volcanic cinder

Volcanic Cinder is typically basaltic to andesitic with a composition of approximately 50% to 60% SiO_2. Cinder may contain phenocrysts of feldspars and composition of approximately various ferromagnesian minerals that crystallized in magma before eruption. Fragments of rock through which the magma has passed may be entrained in the melt and wall rock may be fragmented and admixed during an explosive eruption. Some scoria fragments have lithic fragment cores.

Cinders are primarily pyroclastic (fragmental) products of volcanic eruptions. Several classification systems differing in various details have been proposed for pyroclasts and pyroclastic deposits based on particle size (Fisher, 1961; Schmid,1981; Cas and Wright, 1988).

2.4 Manifestation of volcanic cinder gravel.

Cinder cones are steep-sided, often symmetrical mountains that occasionally occur singly but more commonly they are found in clusters in a linear arrangement associated with geological faults and recent lava flows.

The rock pieces, or cinders, that form cinder cones are primarily fragments of basalt. Cinders vary in grain size, color often within the same cone and may be red, brown, grey or black. During an eruption, the force of volcanic gases ejects the cinders into the air then the cinders fall and pile up into a cone shape around the volcano. A cinder cone is relatively small because the accumulation of loose cinders creates an unstable pile of debris, prone to collapse under its own weight (fisher, 1961).

They are rather small volcanic landforms with diameters ranging from 100 m to about 2.5 km and heights from 30 to 500 m with slopes to about 30° (Wood, 1980a, 1980b). Heights and slope angles are degraded with age and erosion. Cinder cones formed from a single vent can be nearly circular, but elongate forms can develop under strong prevailing wind conditions or from fissure eruptions or multiple vent eruptions. Variations in color from red to black are often concentric around the vent. Cinders are black initially, but those deposited near the vent are subject to heating after deposition, causing oxidation of iron to shades of brown and red (Osburn,1982).

Most cinder cones are considered monogenetic volcanoes, meaning that they erupt only once for a short period and then become extinct (Schmid, 1981). Other characteristic features of cinders are their light weight, their rough vesicular surface, deficiency in fine grain material and their high porosity. Usually they are weak enough to be crushed under the heel, relative ease with which they can be dug from the quarry. A mechanical shovel or hand tools are usually adequate for their extraction although occasionally a bulldozer may be required to open up a working face.

2.5 Uses of Volcanic Cinder

Scoria and cinder may be associated with many eruptive styles, but deposits exploited commercially are nearly all cinder cone (Osburn, 1982).

Cinder and scoria are also used in the same construction applications as gravel and crushed rock: base courses, road surfacing, asphalt aggregate, and railroad ballast. Cinder for these purposes must meet the same specifications as any other aggregate material, including abrasion resistance, immersion disintegration, and aggregate degradation. Cinders that qualify have a higher density than those used for lightweight concrete. The friable, fragmental nature of cinder deposits results in much lower production costs than from non-vesicular rock that must be crushed (Osburn, 1982).

2.6 The Location of Volcanic Cinder Gravel in Ethiopia

Volcanic cinders are widely distributed within the main Ethiopian rift valley associated to recent volcanic activities (Newill and Kassaye Aklilu, 1980). A survey were made by TRRL and ERA which included the examination of aerial photograph, photo-mosaics and the preparation of a map showing the distribution of cinder deposits throughout Ethiopia.

Field visits in connection with the survey were also carried out within a distance of 150 km of Addis Ababa. Based on the research volcanic cinder occurred extensively within the main Ethiopian rift valley (TRRL, 1977).

In addition to the easily distinguishable shape of cinder material from aerial photo, Cinder cones rarely support any vegetation other than grasses (Lawrance, 1975). This is because due to the influence of slope and its high porosity, decomposed soil materials are seasonally washed away from any direction of the cone side and deposited somewhere else. Additionally shape of cinders as well as geology also plays a vital role in the bare feature of cinder. According to the map given as fig.2.1 most cinders are concentrated in a SSW, NNE direction of the main Ethiopian rift valley.

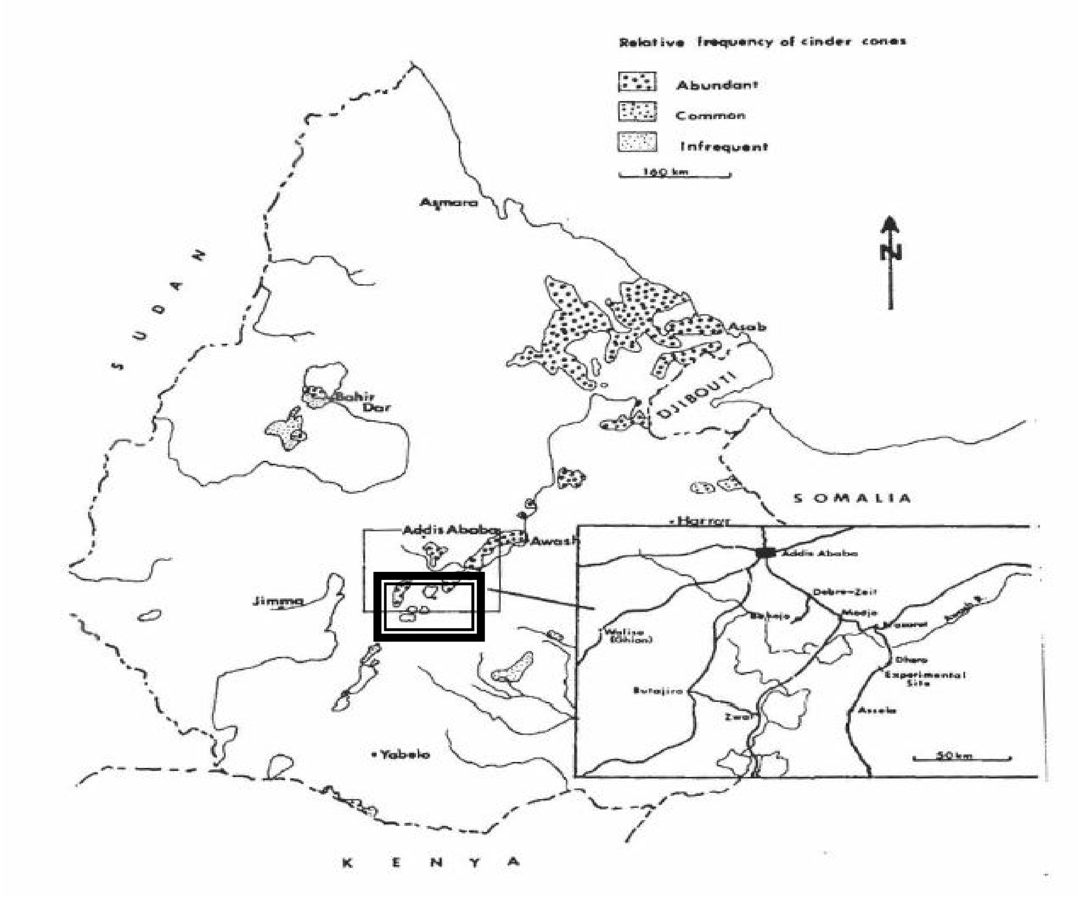


Figure 2.1 Cinder cone distributions in Ethiopia (Source ERA&TRRL, 1975)

2.7 Material Survey for Sub-Base Road Construction by ERA.

Soil analysis and laboratory test results indicates that most of the sub grade material of Addis Ababa and its surrounding is heavy clay and silty clay in nature, and a substantial area of the city is occupied by black cotton soil. Since those materials have very low bearing capacity, high group index value, high water absorbing capacity and frequent volume change this could severely affect the pavement structure.

Within the research project material survey was carried out considering the project location, design and construction purpose, few secondary data such as Geological map, Topographic map, Arial photo and some previous work were available regarding the project site. such source of information are very helpful in better understanding the soil condition and related engineering problem that may encounter during and after construction. Secondly such information will help in planning, conducting and interpreting of the result of soil survey for design and construction. This may also assist in minimizing detail laboratory and field work regarding any construction project.

Along the road segment the sub grade soil strength is assessed using the laboratory CBR values obtained at its maximum dry density. Based on the soil extension survey and CBR test results the entire road sections are the same. Thus, road segments which are going to have asphalt surfacing are considered as one section. From the test result of the sub grade soil; the design CBR of the sub grade is S_1 (i.e. having CBR value less than or equal to 2%).

According to the previous work and other ongoing project near to the project site indicates that due to very problematic nature of expansive sub grade soil the overlaying sub-base material is transported from Dukem and Bole Bulbula area which is economically not viable.

Table 2.1 CBR value of the existing sub grade soil.

Road Station	% CBR Value	Road Station	% CBR Value	Road Station	% CBR Value
00+00	4.0	01+200	4.0	02+400	2.0
00+300	4.0	01+500	2.0	02+700	4.0
00+600	4.0	01+800	2.0	03+00	2.0
00+900	4.0	02+100	2.0	03+300	2.0

2.8 Modification of existing material properties

The road network comprises a huge national asset that requires commitment to appropriate standards for design, construction and maintenance in order to provide a high level of service.

Naturally occurring gravels which do not normally meet the normal specifications for sub base material have occasionally been used successfully (SANRA, 2011).

This is because locally available materials, which are not satisfying general specification requirement, need some modification to become acceptable. This also serves the purpose of economy in terms of saving of haulage of costly materials from elsewhere. Sometimes, design may require special purpose material having specific properties which can be achieved through material modification (AACRA, 2003).

2.8.1 Methods of Modification

Modification of existing material can be broadly classified in two main groups.

2.8.1A Mechanical Stabilization

A mechanical stabilization is method by which a soil or gravel is mixed with the original material in order to improve the grading and mechanical characteristics of the soil. Earth materials used for mechanical stabilization include sand, natural gravel, silt sand, silt clay, crushed quarry products and waste quarry products, volcanic cinders. The principal properties affecting the stability of compacted base or sub base material are internal friction and cohesion. Internal friction is mainly dependent on the characteristics of the coarser soil particles, i.e. gravel, sand and silt sizes (ERA, 2002).

The cohesion, shrinkage, swelling and compressibility are mainly associated with the quantity and nature of the clay friction as indicated by plastic properties. Preliminary mix design of mechanical stabilization is based on particle size distribution (gradation) and plastic properties (Biraj, 2010).

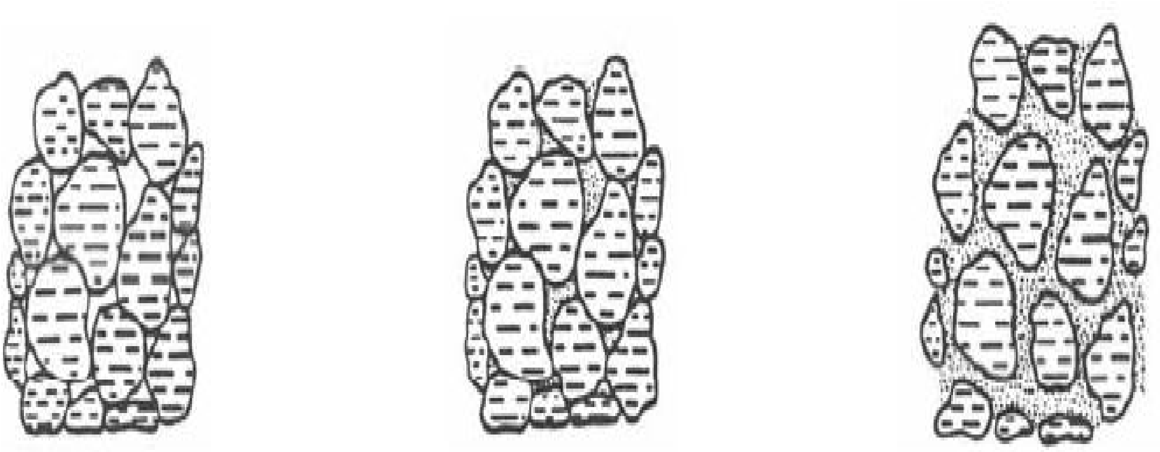
This method produces an interlocking of soil and aggregate particles. The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted. Mechanical stabilization can be accomplished by uniformly mixing the material and then compact the mixture. As an alternative, additional fines or aggregates may be blended before compaction to form a uniform, well graded, dense soil-aggregate mixture after compaction. The choice of methods should be based on the gradation of the material (Biraj, 2010).

The soil and aggregate mixture will normally be compacted at or near OMC to obtain satisfactory densities. The objective of mechanical stabilization is to blend available soils so that, when properly compacted, they give the desired stability. In some construction project for instance existing earth material may have low engineering performance due to many factors. However, at a distance suitable earth material may occur that may be mixed with existing material that can significantly improve the engineering properties of the soil at much lower cost, time, equipment and materials than transporting from elsewhere (ERA, 2002). Generally, during material stabilization proper gradation, proper control of the mixture content and a satisfactory binder soils are the governing factor (ERA, 2002).

2.8.2 Particle size distribution and interaction with moisture of soils and granular materials

The packing arrangement of a material is usually represented by the grain size distribution of the particle. Lack of fine or coarse grain particle or being dominant can produce a distortion curve resulting in un satisfactory stability and compaction. Therefore an improvement of grain size distribution of the material can give a uniform strength, uniform mixing and desired compaction (Yitayou, 2011).

The shear strength or resistance of the aggregate material against the applied traffic load is due to grain to grain contact between two grain particles. If the grain size is well distributed all the void space between particles will fill and then results in high density, low permeability, high shear resistance and ease to handle during construction time.
According to Molenarr,2010 Fig.2.2 indicates Soils and granular materials consist of an arrangement of particles in between can have the following three physical states of soil-aggregate mixtures.



Aggregate without fine (A) Aggregate with sufficient fines (B) higher amount of fine (C)

Fig. 2.2 shows three physical states of soil aggregate mixtures

Table 2.2 shows physical state of soil-aggregate mixtures

A. aggregate with no fines	B. aggregate with sufficient fines	C. aggregate with great amount of fines
Grain-Grain contact	Grain-to-grain contact With increased resistance destroyed, aggregate Against deformation	Grain-to-grain contact With increased resistance destroyed, aggregate Against deformation 'floating' in soil
Have variable density	Increased density	Decreased density
It is pervious	Practically impervious	Practically impervious
Non –frost susceptible	Frost-susceptible	Frost-susceptible
High stability if confined, Low stability if it is unconfined	High stability in Low stability Confined, low if confined or unconfined Unconfined conditions	Low stability
Not affected by adverse water condition	Not affected by adverse water condition	Greatly affected by Adverse water condition
Very difficult to compact	Moderately difficult to Not difficult to compact	Not difficult to Compact.

According to the (AACRA,2003) and ERA,2002) pavement design manual, gradation of material expects to have continuous smooth curve without having an excess or lack of certain particle. Basically, the distribution of fine or coarse grain particle depends on the weathering degree, type of environment and mineralogy of the parent rock.

Table 2.3 ERA Grading requirment for sub base material

Sieve size, mm	% of Mass passing			
	A	B	C	D
63	100	-		-
50	9-100	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	-	20-51		25-51
1.18			17-75	
0.425	-	10-30		15-30
O.3			9-50	
0.075	5-15	5-15	5-25	5.15

2.8.2B Proportioning

Aggregate mixtures are difficult to design and build satisfactorily without laboratory control. A rough estimate of the proper proportions of available soils in the field is possible and depends on manual and visual inspection. Several trial mixtures should be made until this consistency is obtained. The proportion of each of the two aggregate should be carefully noted. Proportion can be done either of the following two methods (AACRA, 2003).

A. Graphical proportioning method
B. Arithmetical proportion method

B. Arithmetical proportioning

In this method the actual gradation of soils A and B in their respective columns are recorded, average the gradation limits and record in the column labeled "S". Next, determine the absolute value of S-A and S-B for each sieve size and record in the columns labeled "(S-A) "and "(S-B)", respectively. Finally, sum columns (S-A) and (S-B) to determine the percent of soil A or B in the final mix, use the formula (Yitayou, 2011).

% A =∑ B÷∑A+∑B ×10 and B =∑A÷∑A+∑B ×100.

Table 2.4 shows arithmetical gradation of two different soils for final mix design.

Gra.A	*Gra.B*	*Aver.S*	*|S-A|*	*|S-B|*	*%A=∑B÷∑A+∑B ×100*	*%B = ∑A÷∑A+∑B ×100*

2.8.1B Chemical stabilization

Chemical admixtures are often used to stabilize earth material when mechanical methods of stabilization are inadequate and replacing an undesirable soil with a desirable soil is not possible or is too cost. Mostly chemicals such as cement, lime, fly ash and bituminous are most common practice (ERA, 2002).

2.9 Economic significance of blending of two aggregates

Economic necessity and the variety of physical and climatic conditions require highway engineers to make the best use of available natural resources. In countries like Ethiopia, where the economic adaptation of a road to special needs and its technical adaptation to local conditions are two complementary aspects greatly influence planning decisions.

The excavation, haulage, and laying of satisfactory pavement materials must be accomplished as economically as possible for all highway projects. However, in developing countries, where a high percentage of the roads to be built and maintained are primarily unsurfaced and involve a gravel placement which required higher materials investment. Therefore, in order to achieve the most cost-effective Construction and lower subsequent maintenance costs, it is necessary for haulage distances, which form the major item of expense, should minimize by using locally available materials (Molenaar, 2010).

For this reason recent increases in the costs of road construction material have further emphasized the need to make optimum use of locally occurring resources, not only to reduce expenditure, but also to conserve those better quality materials which are frequently in short supply and of value for special projects that require construction to high specifications. Therefore, giving much emphasis to improve low quality locally available earth material during road construction can play significance role in project cost reduction and time constraints (Girma, 2009).

CHAPTER THREE

THE STUDY AREA

3.1 Introduction

Roads forms an integral and important part of any transportation system. A road network should be efficient in order to maximize economic and social benefits. It plays a significant role in achieving national development and contributing to the overall performance and social functioning of the community. It is acknowledged that roads enhance mobility, taking people out of isolation and therefore helps in bringing prosperity in general (Collins &Ciesielski1994).

The present research was selected because the study area is under high urbanization process such as construction of high rising condominium site, high population flow, construction of different industries and construction of accessibility roads for the smooth mobilization of people from place to place. However, road construction material in this specified study area is very scarce despite of spatter cone. For this reason this research was primarily focused on blending of volcanic cinder gravel for the application of sub-base road construction.

3.1.1 Location

The Akaki-Beseka map sheet (NC37-14) is located in the central part of Ethiopia covering parts of Oromia and SNNP Regional stats. Geographically, it is found within UTM-Zone 37 bounded by 9^0 latitude and 39^0 longitude respectively (GSE, 2010).

Akaki-Kaliti is located within this map sheet to the southern parts of Addis Ababa at an altitude range from 2100m- 2500m a.s.l. and it is 20 km far from the city’s center. Its population is estimated as 220,740 with 114,095 female and 106,645 male (CSA, 1999). Most of the Kebeles/woredas are found at the out skirts of the city.

The sub city is an industrial zone where 60% of metal, paints, garment and food processing industries of Addis Ababa are found. The high urbanization associated with population flow to Akaki-Kality, being the industrial zone of Addis Ababa influenced the city administration to designate the area as one of the 10 sub-cities in 2005.The research (road) project is found within this sub city which links the condominium with Ethio-Djbuti main road. It has 4km length and 21m width of asphalt road.

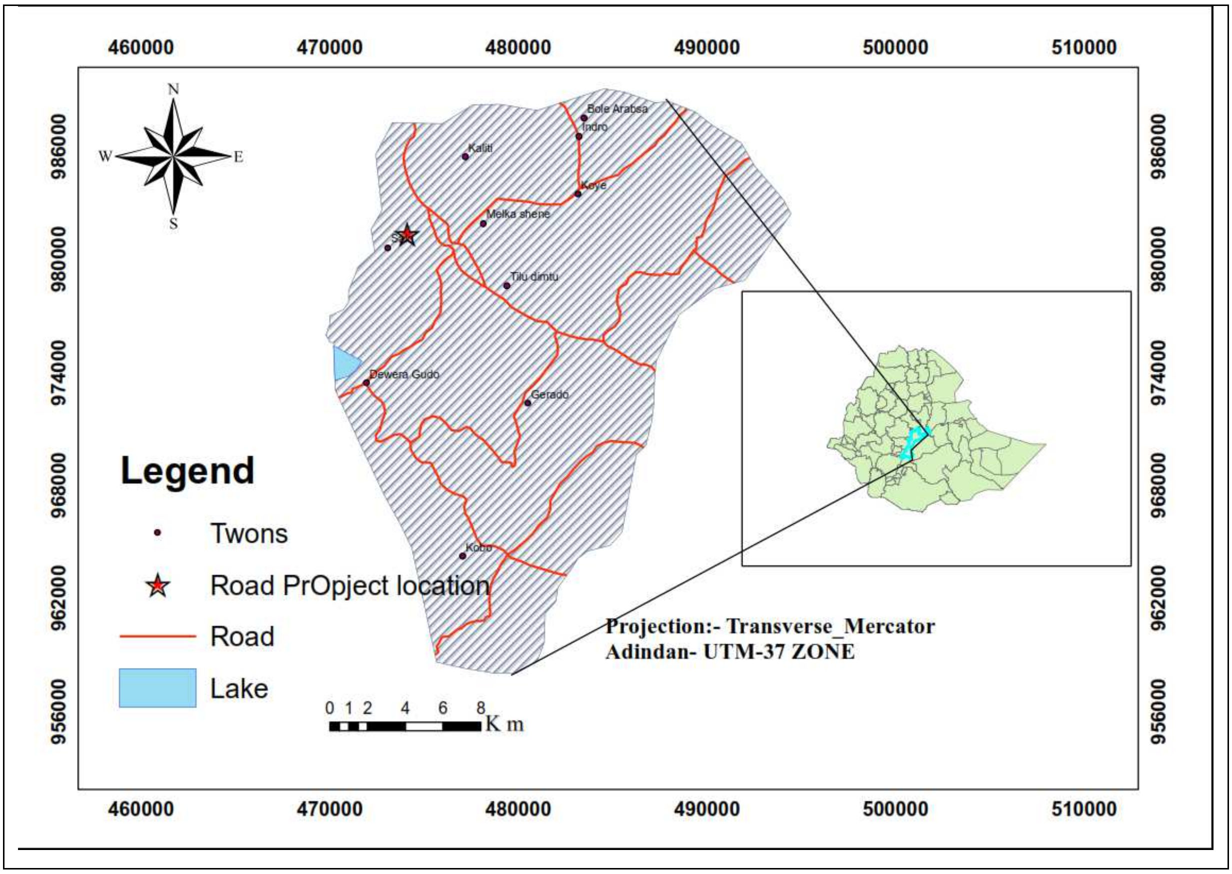


Fig 3.1 Location and Accessibility map of the study area

Fig.3.2 shows the plane view of the proposed road project taken from satellite image

Fig. 3.2: Plane view and elevation profile of the road segment from Googole Earth

3.1.2 Accessibility

The stud area could be accessed through the Addis Ababa-Mojo asphalt road and other gravel roads which emanate from the main highway to different localities and areas within the the study area.

3.1.3 Physiograpy

Ethiopia can be divided into four major physiographic regions widely known as the Western plateau, Southern plateau, the Main Ethiopian Rift and Afar Depression (Tefera Mengesha et al., 1996). The existing land form of the area is a cumulative result of volcanic, tectonic, erosion and depositional events.

Geomorphologicaly the study area is found within the western highland plateaus and characterized by varied topography ranging from plain lowland to slightly rugged terrains. Mostly it is bounded by volcanic mountains such as mountain Yerer from north east, Furi from South west, Zikwala from South east and the Entoto ridge from the north.The elevation generally decreases from the Entoto ridge (north) towards the south part of the research project i.e. from 2950 m -1600 m a.s.l, respectively. Moreover, it is not uncommon to see sharp changes in the inclination of the slope and elevation within the research area. The stream of the study area generally drains from the elevated surrounding mountains like Mt. Mt. Furi and from Mt.Yerer and other elevated area as given below in fig3.4..

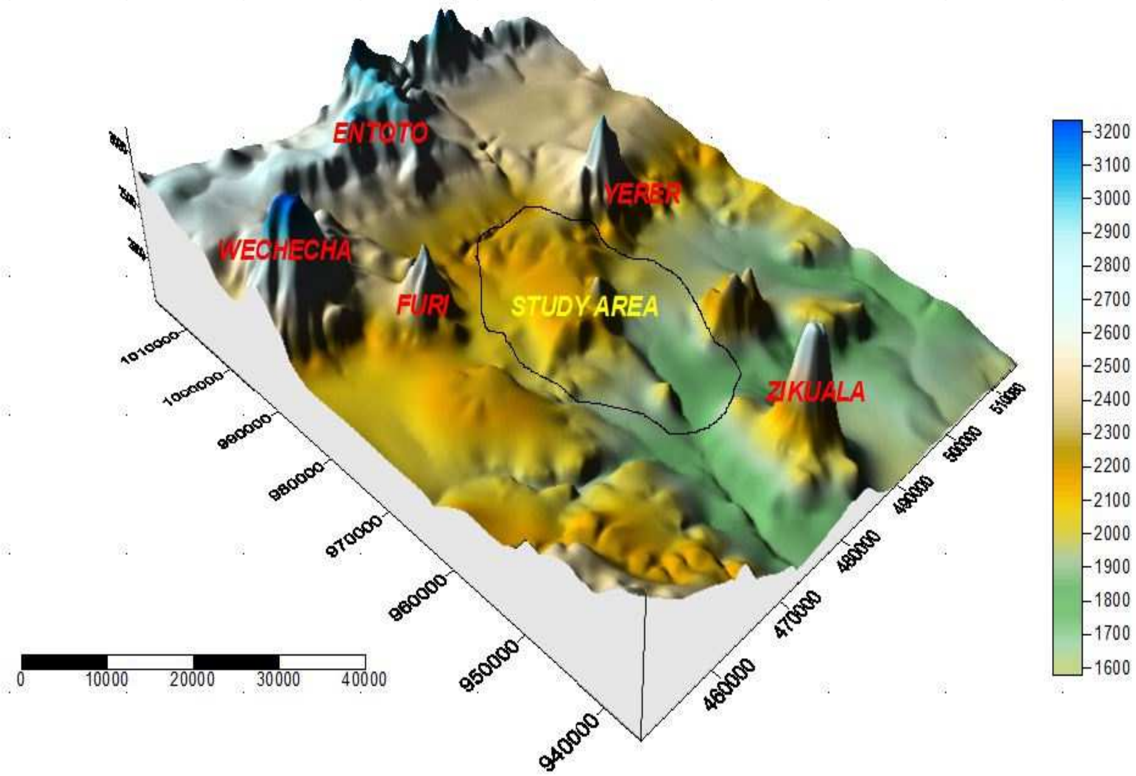


Fig.3.3 Geophysiography of the study area

3.2 General Geology of the study area

Extensive areas of the highlands of Ethiopia on both sides of the rift valley are covered by neogene (Trap series) volcanic rocks which are mainly basalts with subordinate acidic rocks. Within the rift valley, subsequent to the formation of the rift valley, the Trap series were overlain by a variety of younger volcanic rocks of basalts, ignimbrites and Rhyolites (Tesfaye Chernet, 1993).

The Geology of Akaki-Beseka and its surrounding sheet can be traced from Precambrian to the recent (GSE, 2010).Based on geological map of Akaka-Beseka prepared by the (GSE, 2009) at the scale of 1:250,000 the geology of the research area is generally summarized as follow in table 3.1.

Table 3.1 Geologic time formation of the study area.

Cenozoic Era	Quaternary	Pleistocene		Holocene
		Pyroclastic and pumice deposit(Qtp) Scoria fallout (Qts) Chefe donsa pyroclastic (Ncp) Wechecha Trachayte (Nwt)	(Eaa) Lacustrine sediments (QU2S)	1. Alluvium (Qus)
	Neogene	Oligocene	Miocene	Pliocene
			Addis Ababa basalt (Eaa)	1.Welded pyroclastic flow (Nwp) 2.Welded to partially welded pyroclastic flow (Npp)

3.2.1 Alluvium (Qus)

Exposure of this unit is occurred dominantly within the research project as well as along the road alignment. This unit commonly occupies depressions such as calderas, grabens, crater floors, base of escarpments and wide flat basin. Compositionally it consists of reworked material of volcanic origin sand, silt and clay sized particle which are the result of transportation and deposition by running water. These units also include boulders of basalt, rhyolite and scoria, thick black to brown and reddish brown soils.

3.2.2 Scoria fallout (QTS)

Exposure of this unit is found to the North east, central and east of the project areas as given in fig.3.5. It usually forms unevenly distributed cinder cones and sometimes broad based gentle sloping circular to elliptical hills. It is dark brown, reddish grey color, vesicular coarse grained rock.

Fig.3.4 Saelo scoria fallout/ Volcanic cinder

3.2.3 Welded to partially welded Pyroclastic flows (NPP)

Exposure of this unit is found south east, and north east of the project area. It is light to dark-grey in fresh samples and reddish to yellow to pink in weathered ones. It is fine grained; densely welded rock containing vitrophyric fiamme and lithic fragments with associated rhyolitic lava flows incorporated with ash and an welded tuffs.

3.2.4 Welded Pyroclastic flow (NWP)

Found at the north and North West of the project area. It is light to dark-grey in fresh samples and reddish to yellow to pink in weathered ones. It is fine grained, densely welded containing vitrophyric fiamme and lithic fragments with associated rhyolite lava flows interleaved with ash and unwelded tuffs.

3.2.5. Addis Ababa Basalt (EAA)

From ground verification as it is given in fig.3.6 it is found to the north and western portion of the study area. It is dark color fine-grained rock mainly composed of plagioclase, pyroxene and opaques.Generally, it is fresh, compact fine grained rock, but in places, it shows vesicular cavity filled with secondary minerals.

Fig.3.6 Exposure of Addis Ababa basalt

3.2.6 Pyroclastic and pumice deposit (QTP)

Mainly occurred at the western, central eastern parts and south east of the study area. It is light to dark-grey in fresh samples and reddish to yellow to pink in weathered ones. It is fine grained, poorly welded rock containing vitrophyric fiamme and lithic fragments with associated rhyolite lava flows interleaved with pumice, and un welded Tuff. Ground verification of this exposure or outcrop is given in fig.3.7 below.

Fig.3.7 Exposure of Pumice deposit

3.2.7 Wechecha Trachayte (Nwt)

Exposure of this unit is found to the north, north east and south east portion of the study area. This unit is composed of trachyte and pyroclastic material. In outcrop, trachyte is coarse-grained, light gray, brown-grey to dark-grey in fresh samples to pinkish yellow to reddish brown in weathered one.

3.2.8 Chefe Donsa Pyroclastic Deposits (Ncp)

Exposure of this unit is found to south, and north as well as North West part of the study area. It is light to dark-grey in fresh samples and reddish to yellow to pink in weathered one. It is fine grained, poorly welded rock containing vitrophyric fiamme and lithic Fragments with associated rhyolitic lava flows interleaved with ash and unwelded tuffs

3.2.9 Lacustrine Sediments (Q2us)

This unit is found to north east direction of the study area and it forms flat-lying topography and marshy areas. It consists of loose, brown to grey color sand and silt. Generally fig.3.8 shows lithology of the study area.

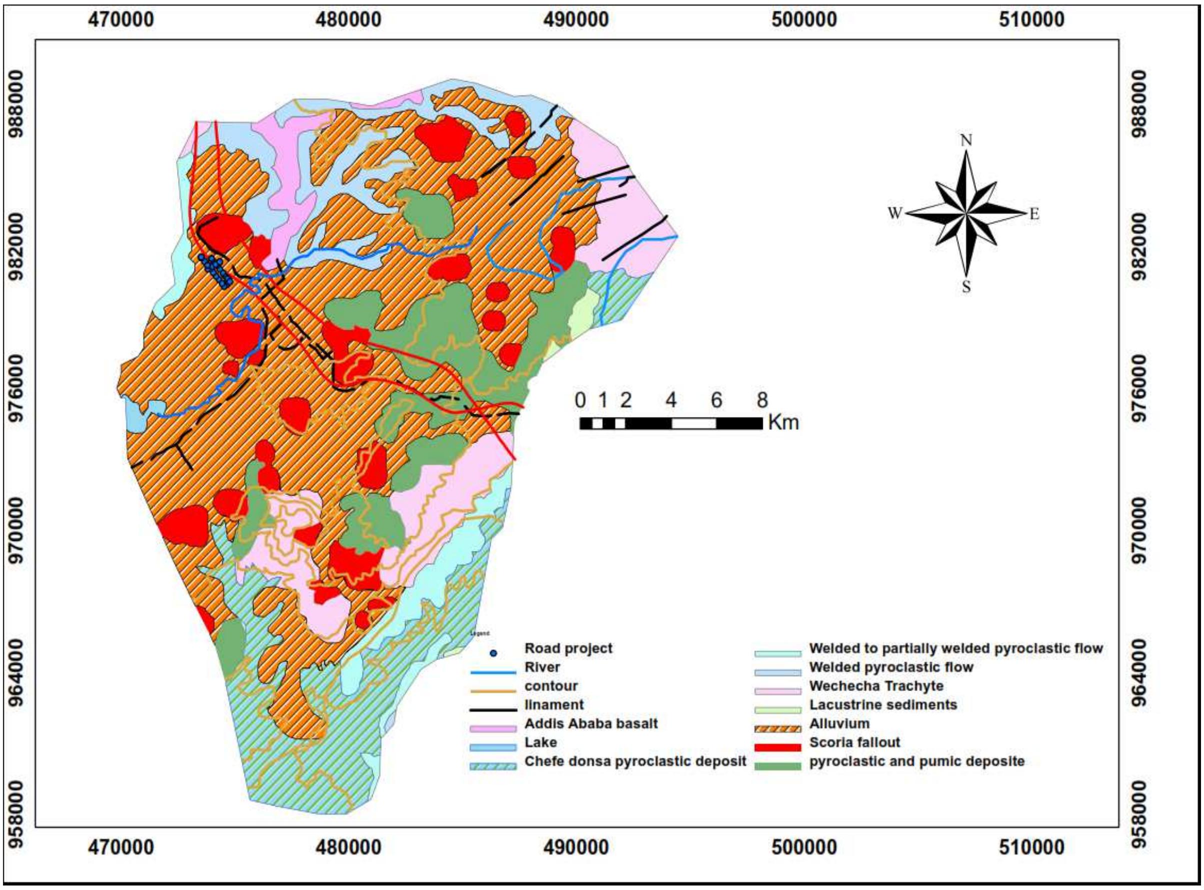


Fig 3.8 Geological map of the study area. (Source: - GSE, 2009.)

3.4 Drainage Pattern and Hydrogeology

3.4.1 Drainage Pattern

Addis Ababa lies within the Awash River Basin. The water divide between Awash Basin and Blue Nile Basin lies on the top of Intoto Ridge (Tamiru alemayehu, 2006).

The study area is crossed by two main rivers, i.e. the Big Akaki River from the eastern and the Small Akaki river from the west. The Big Akaki River flows from the Legedadi dam and the Small Akaki River flows from the Gefersa and both of these River drains to the Aba Samuel Lake (Tamiru alemayehu, 2006).

The drainage pattern is governed by the geology and physiographic set up of the area. From fig.3.11 the density of the streams is reduced compared to the north and eastern part of city and the main rivers show meandering type of flow this is due to the decrease in the gradient of the valley floor.

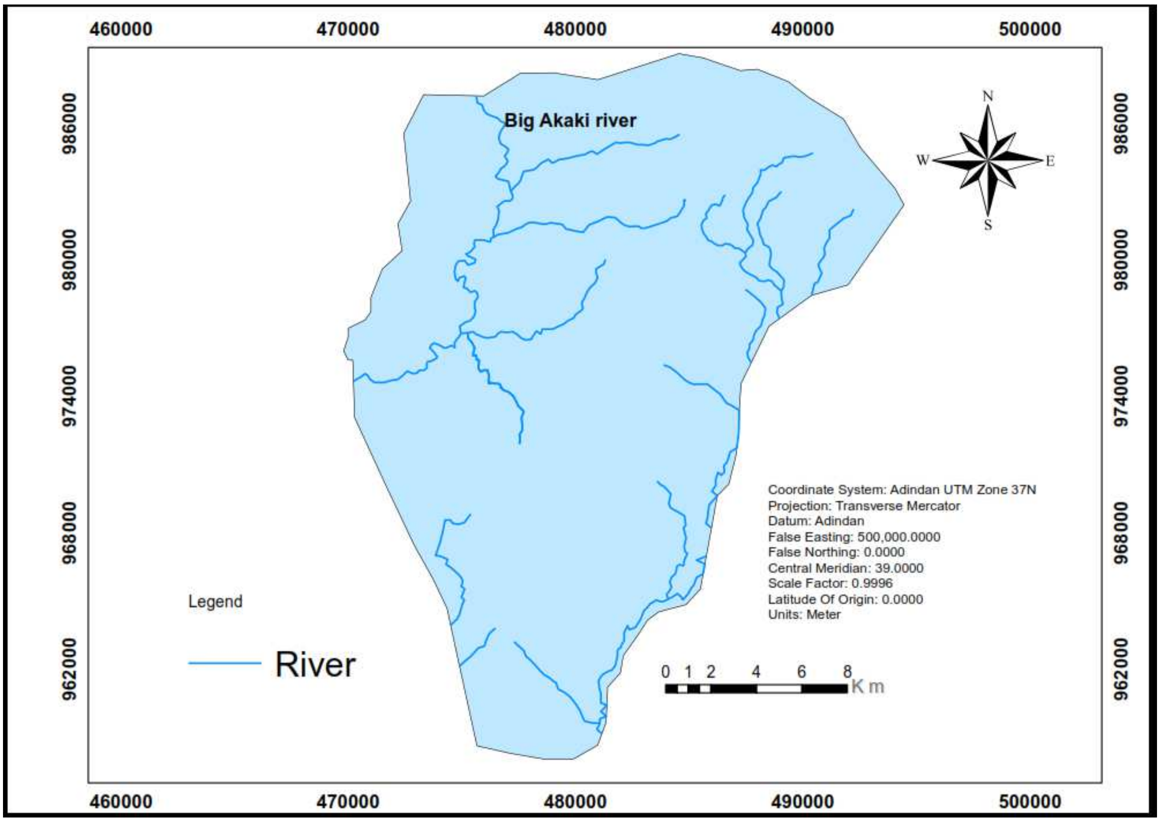


Fig 3.11 Drianage map of the study area

3.4.2 Hydrogeology

The major ground water aquifers in Addis Ababa and its surrounding are basalts, rhyolites, trachyte, scoria, trachyte basalts, welded tuffs, unwelded tuffs and the unconsolidated materials of volcanic origin as depicted from boreholes previously drilled for water supply. According to AAU & AAWSA, (2003) the main aquifers in Addis Ababa area can be categorized into three groups which includes hallow aquifers of the weathered volcanic rocks and alluvial sediments along the river courses, deep aquifers of the fractured volcanic rocks that tap fresh ground water and thermal aquifers along Filwoha fault. From borehole data obtained from the Akaki water well field the major ground water aquifer can be categorized under Shallow as well as deep aquifer. Basalts are the major water bearing zone in the area due to its fracture porosity where as unconsolidated volcanic sand alluvial sediment under favorable conditions stores water. The black cotton soils in the south of Addis Ababa act as impervious material (Tamiru Alemayehu, 2006).

Table 3.2 litho logical log of PW2

Depth	Litho logy
0-6	Brownish Clay soil
6-10	Trachy Basalt
10-12	Rhyolite
12-50	Moderately weathered and fractured Basalt
50-70	Highly weathered and fractured Basalt
70-106	Ignimbrite
106-124	Moderately weathered and fractured Basalt
124-142	Trachy Basalt
142-184	Moderately weathered and fractured Basalt
184-332	Moderately weathered Scoraceous Basalt
332-346	Ignimbrite
346-366	Moderately weathered Scoraceous Basalt
366-392	Ignimbrite
392-402	Moderately weathered Scoraceous Basalt
402-464	Weathered and fractured Rhyolite
464-522	Highly weathered and fractured Scoraceous Basalt
522-532	Ignimbrite
532-550	Trachy Basalt

Table 3.2 to table 3.4 shows borehole lithological description from Akaki well field in order to have a clear frame work about the major water bearing formation obtained during production well drilling.

Table 3.3 Lithological log of PW3

DEPTH		Litho logic description
FROM	TO	
0	30	Black to Brown clay
30	94	Fractured & weathered scoracious basalt
94	136	Fractured & weathered basalt
136	148	tuff
148	230	Fractured & weathered scoracious basalt
230	268	Fractured & weathered rhyolite
268	334	Fractured & weathered basalt
334	370	Fractured & weathered scoracious basalt
370	374	tuff
374	448	Fractured & weathered scoracious basalt
448	450	Fractured & weathered basalt
450	456	tuff
456	492	Fractured & weathered scoracious basalt
492	506	Fractured & weathered basalt
506	514	Slightly fractured basalt

Table 3.4 litho logical description of PW1

HOLE ID	FROM	TO	LITHOLOGIC DESCRIPTION
PW1	0	6	Brownish clay
PW1	6	10	Trachy basalt
PW1	10	50	Moderately weathered &fractured basalt
PW1	50	70	Highly weathered &fractured basalt
PW1	70	106	Ignimbrite
PW1	106	124	Moderately weathered &fractured basalt
PW1	124	142	Trachy basalt
PW1	142	184	Moderately weathered &fractured basalt
PW1	184	332	Moderately weathered scoracious basalt
PW1	332	346	Ignimbrite
PW1	346	366	Moderately weathered scoracious basalt
PW1	366	392	Ignimbrite
PW1	392	406	Moderately weathered scoracious basalt

N.B:- P1refers to production well one, P2 refers to production well two and P3 refers to production well three.

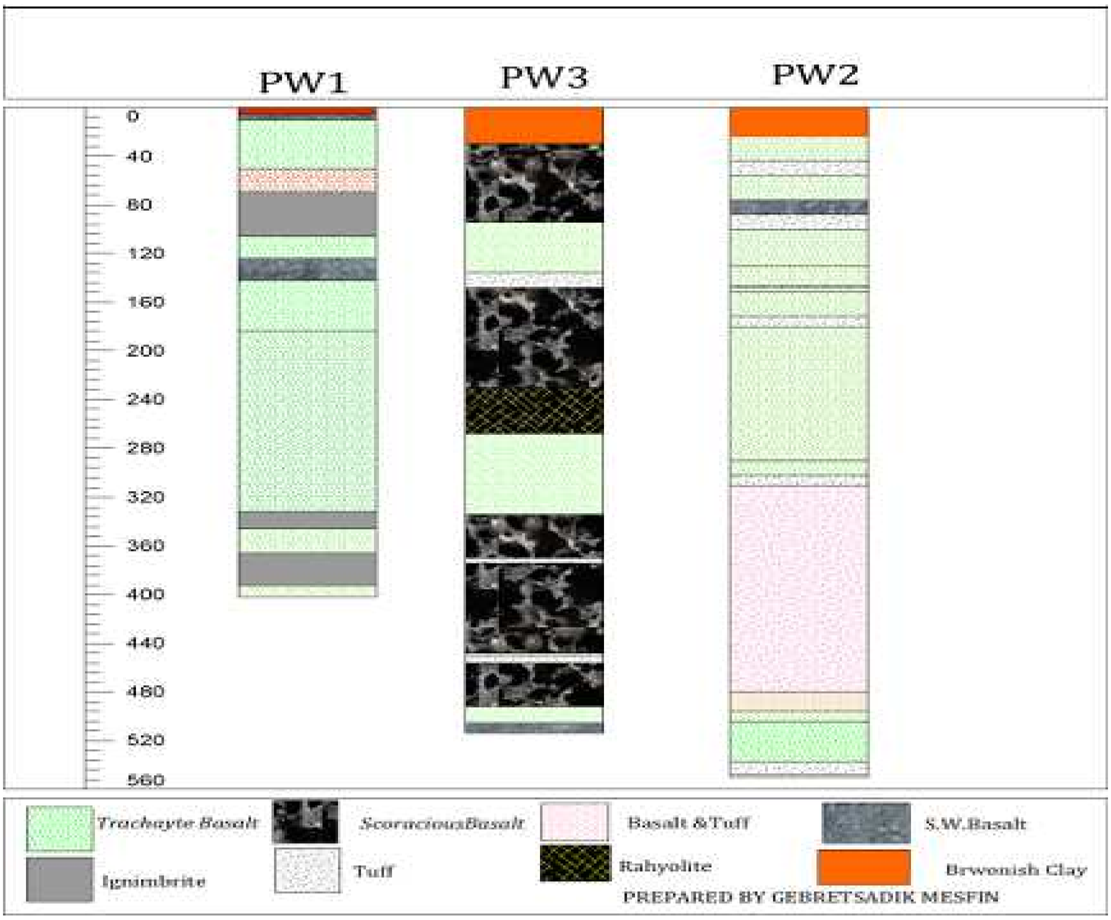


Fig 3.12 Geological cross-section from Akaki well field.

Fig.3.12 is a cross section of three borehole data i.e.P1, P2, P3 obtained from Akaki well field. Based on this data most of the fresh ground water of the study area is found within the weathered and fractured basalt such as trachyte, scoria and ignimbrite.

Table 3.5 location of borehole data

Coordinate(Adindand)	P1	P2	P3
Easting	480517	477195	479403
northing	972361	985445	978599

3.4.3 Temperature and Rain fall of the study area

3.4.3.1 Rain fall

The study area, lying in a tropical climate, classified as wet, humid region with a mean annual rainfall of 1000-1400 mm per year (Ethiopian Meteorological Authority, 1981). There are two seasons of rainfall. The first rainy season spans from late May to late September and the second from mid of March to mid of April. February to May is the warmest month, while the coldest month is July and August.

During the current thesis work rain fall data have been collected for the study area from 2000-2013.Accordingly mean annual rain fall of the study area is found 736.4-1306mm per year.

The rainy season of Ethiopia is mainly occur during the summer months of June to September particularly in the month of July and August where most portion of the country gets the heaviest rain fall. The rain is moderate during the months of October to May with the annual distribution being influenced by the south-west equatorial westerly wind originating from Indian Ocean. The short rain occurs between March and April (AAU& AAWSA, 2003).

The mean monthly and annual mean rainfalls of Akaki Beseka (1964-1998) were also determined from metrological data adopted from report (AAWSA and AAU, 2003).

Table 3.5 Mean monthly and annual rain fall of the study area (1964-1998)

Month	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	A.M
Akaki	14	43.7	660	95	66.5	129	271	303.8	141	24	4.3	3.4	1154

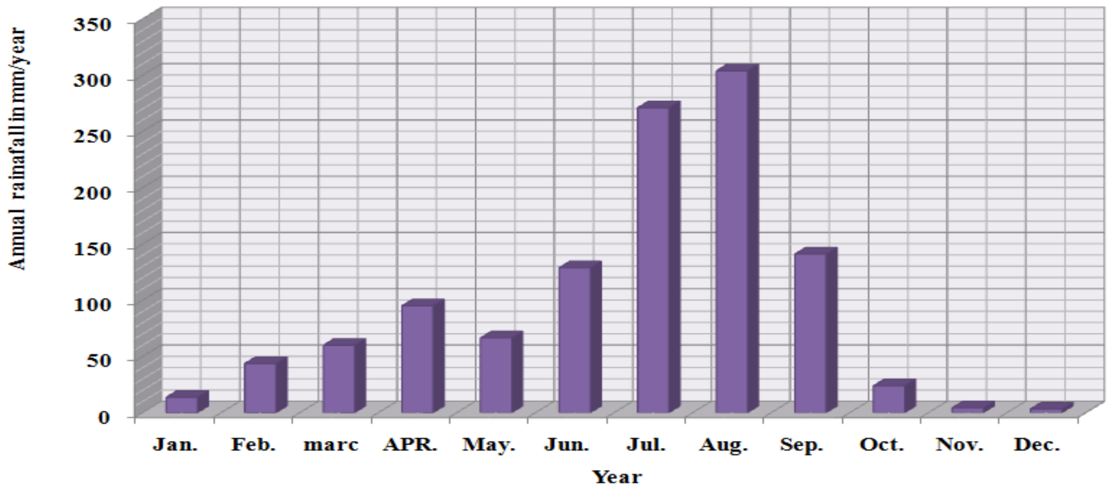


Fig 3.13 Mean monthly rain fall of the study area (1964-1998).

As it was shown above the precipitation occurs throughout the years and shows variation in amount from season to season.

Table 3.6 Annual mean rain fall of the study area (2000-2013)

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Tota
Rain fall in mm	15.8	16	51.3	91.7	69	109	235	243	125	11	9	7.4	983

From table 3.6 June to September is the highest annual rain fall recived, from January to late may moderate rainfall while October to December it is the lowest rainfall.

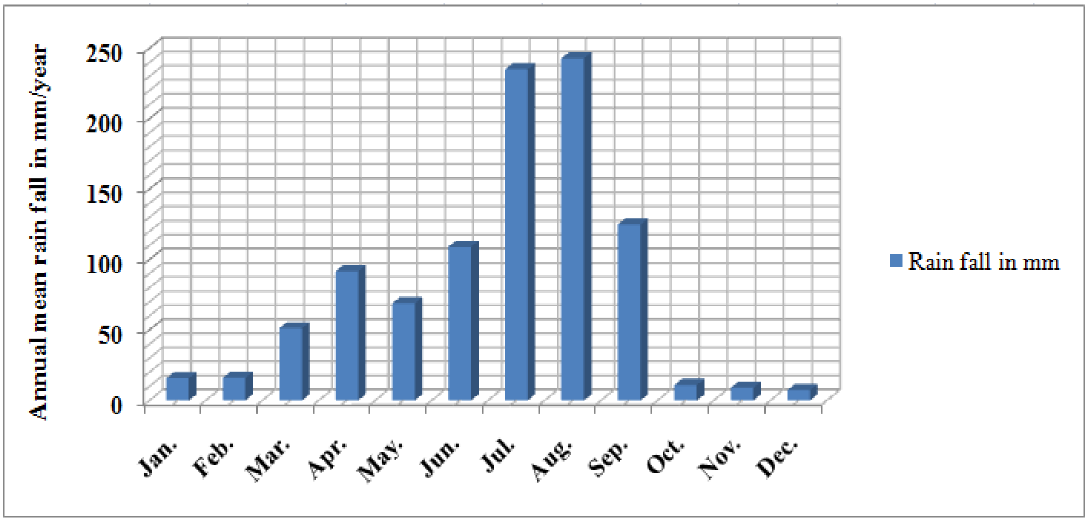


Fig.3.14 distribution of precipitation at Akaki area from 2000-2013

3.4.3.2 Temperature

Temperature is an important aspect of climate and can be used to grade climatic zones. Based on the altitude and mean annual temperatures of the study area fall under category of temperate climate (GSE, 2010). February to May is the warmest month, while the coldest month is July and August. A long term (2000-2013) data for Akaki stations show that the average monthly maximum temperature of the study area is about 28.53O_c and the minimum is 11.8O_c.

Table 3.7 Mean minimum and maximum temperature at Akaki from 2000-2013

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Av. Mean Max.temperature in O_c	26.76	25.41	28.1	27.96	28.53	26.66	24.33	22.28	25.23	26.37	26.08	25.89
Av. Mean Min.temperature in O_c	12.63	13.32	13.98	14.99	15.44	14.38	13.97	14.01	14.01	13.19	13.22	11.8

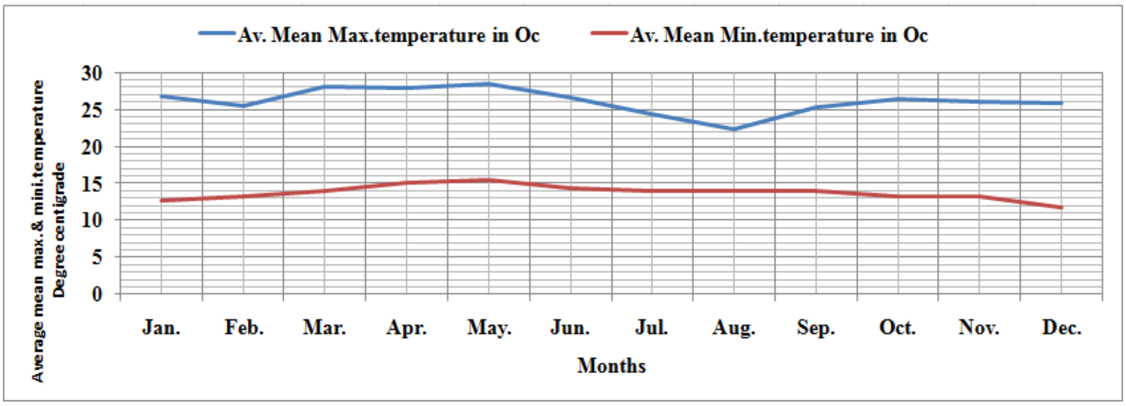


Fig 3.15 Average mean maximum. and minimum temperature of the study area.

3.5 Slope of the study area

Based on the field observation and the slope map prepared from DEM, 2000 the study area generally shows flat to undulating topography. Except few mountains such as Furi, wechecha and Yerer the study area is generally occupied by flat topography with minimum and maximum slope value of 1 and 5 degree respectively minimum and. Slope value represents the minimum while 2-4 degree medium and 5 degree maximum slope of the study area.

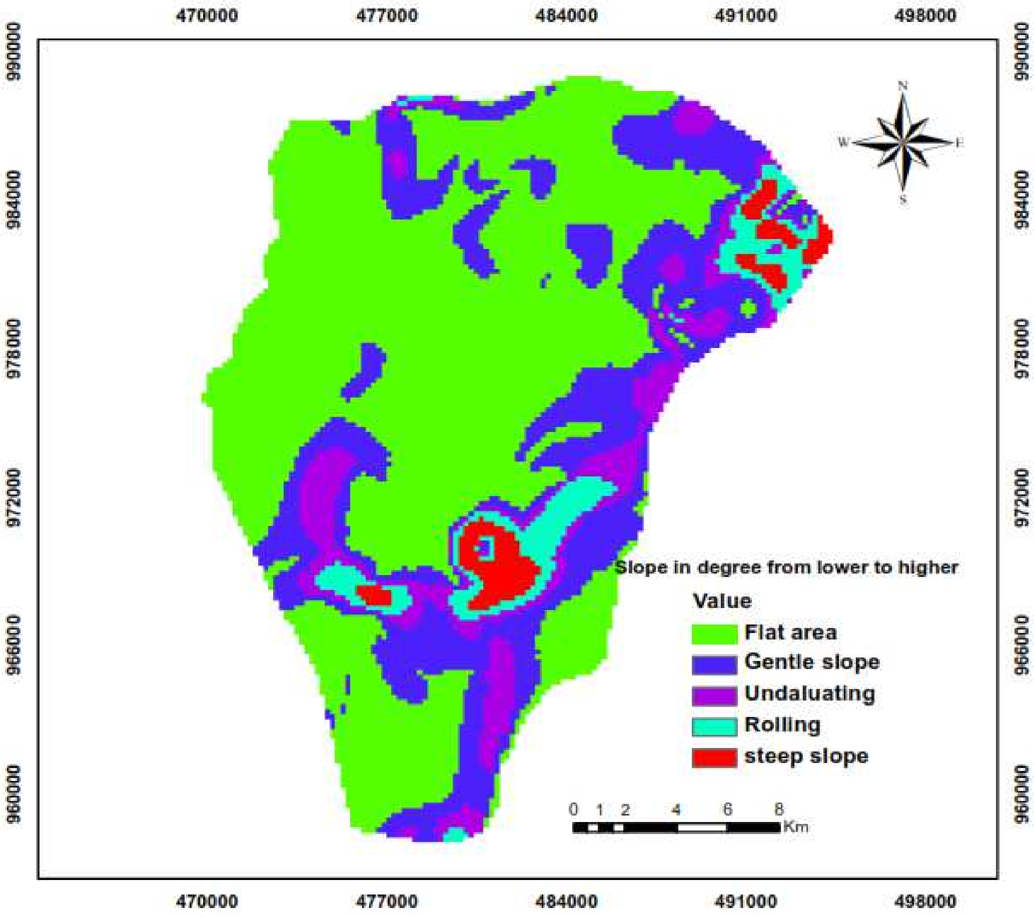


Fig 3.16 Slope of the study area from digital elevation model (DEM, 2000)

3.6 Soil of the study area

The wide ranges of topographic and climatic factors, parent material and land use have resulted in extreme variability of soils (FAO, 1984e). According to the Ministry of Agriculture about 19 soil types are identified throughout the country (MOA, 2000).

The soil development in Addis Ababa and its surroundings are mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remain in places and form residual soils or transported and deposited in the low lying flat lands and depressions (Tamiru Alemayehu et al, 2006).

The development of soils is mainly dependent on the type of rock from which they are derived and the condition of the depositions directed by climate and geomorphological position. The highlands are dominated by shallow black to gray silty soil derived from the volcanic rock. The river valleys and their main tributaries are covered by silty to sandy soil and alluvial depositions.

In the localities where the topography is plain to gentle there is thick soil profile. The type of parent material and the length of time to which the parent material is subjected to weathering, control the variation in the thickness of soil. Thus, old basic and acidic rocks that outcrop in the central, western and south western parts of Addis Ababa are weathered and form thick soil profile.

In places where young basalt and welded tuffs occur, the thickness of the soil cover is reduced. Hence, the area is bounded by high rising volcanic mountain from the north the Enttoto, from the west Furi, from the east mountain Zikwala all the weathered acidic or basic soil material is transported and being deposited at the low lying area of the study area. According to the FAO,(1984e) soil classification system, chromic levisols, Eutricfluvisols, leptosols, calcic xerosols, pelic vertisols and Orthi solchanks soil are found within the study area. Detail description of each soil group is given in Table3.8.

Table 3.8 soil of the study area

Soil Group	Depth	Color	Texture	Structure	Consistence	Drainage
Leptosols	Shallow to very shallow	Brown to yellowish Brown	Loam/clay	Sub angular blocky	Firm to slightly hard/ Friable; slightly sticky & Slightly plastic	Well
Chromic Luvisols	shallow	Brown/reddish brown	Clay/Silty clay	Subanngular blocky	Friable to firm, sticky and slightly plastic	Well
Pelic Vertisols	Deep to very deep	Dark grey black	Clay	Sub angular/Angular blocky	Hard to firm, very sticky and Very plastic	Imperfect to poor
Calcicxerosols	deep	Dark to grey	silty	angular	Hard to firm	well
OrthicSolonchanks	deep	Dark grey	Silty to clay	sub angular	Slightly sticky	poor
Eutricfluvisols	shallow	Variable	Clay/Silty clay	Weak to massive		Well

Source: - (world textural soil classification)

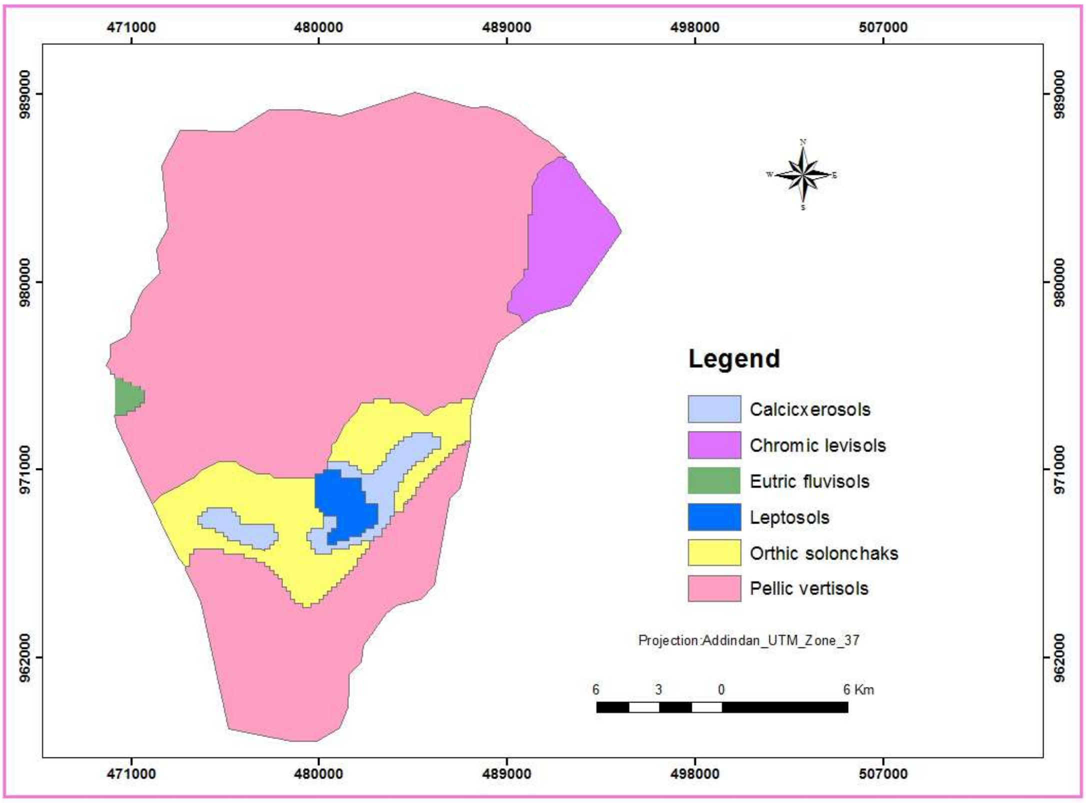


Fig. 3.17 shows soil map of the study area Source :-(FAO, 1984e)

3.7 Land use and Land cover

The land use and land cover have shown the general increase in the built-up areas in the city and is characterized by horizontal physical expansion against crop, forest and grasslands. Even though this phenomenon is expected, the highest rate of built-up area expansion against highest rate of forest and cropland decline entails the sustainability of the provisioning, regulating, and supporting services of the ecological resources in threat-urban areas is in question (AAU and AAWSA, 2003).

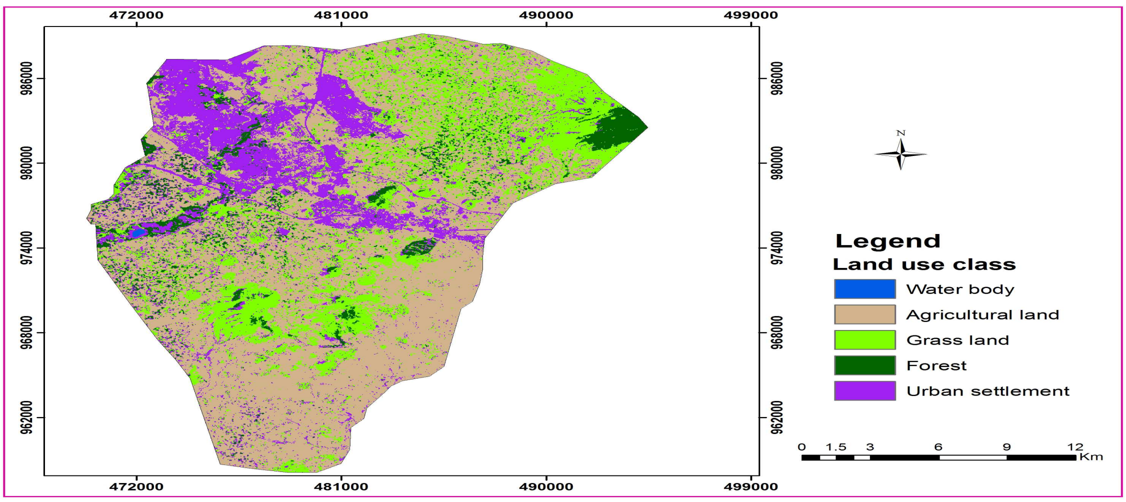


Fig.3.19 land use and land cover of the study area Source :(Land Sat8, 2008)

3.8 Proposed sub base material

Material assessment includes visiting the possible source by traveling on foot for verifying the source. In Addis Ababa sub base material is obtained from fractured and weathered basalt and cinder (scoria). Weathered rock particularly basalt, which can be found in a weathered state as an out crop or inter bedded in acidic volcanic of the Ashengi group basalts is the main source of natural gravel. Depending on the quality of the material sometimes it can be used as a capping layer (highly decomposed basalt) and moderately fractured and weathered as a sub base.

Natural gravel from scoria (cinder cones), which are restricted in south east and south west of Addis Ababa City is also a good source of sub base. The research road project is found south east of Addis Ababa where, volcanic cinder gravels area concentrated than the natural gravel. The proposed natural gravel to be used as a sub base is transported from Dukem crusher site (18km) far from the road project where as cinders are found close (<300m) as described in plate 3.4 below. Therefore, from the principle of using locally available material, traffic, hauling distance and the objective to know the science of blending volcanic cinder with natural gravel at different proportion was proposed.

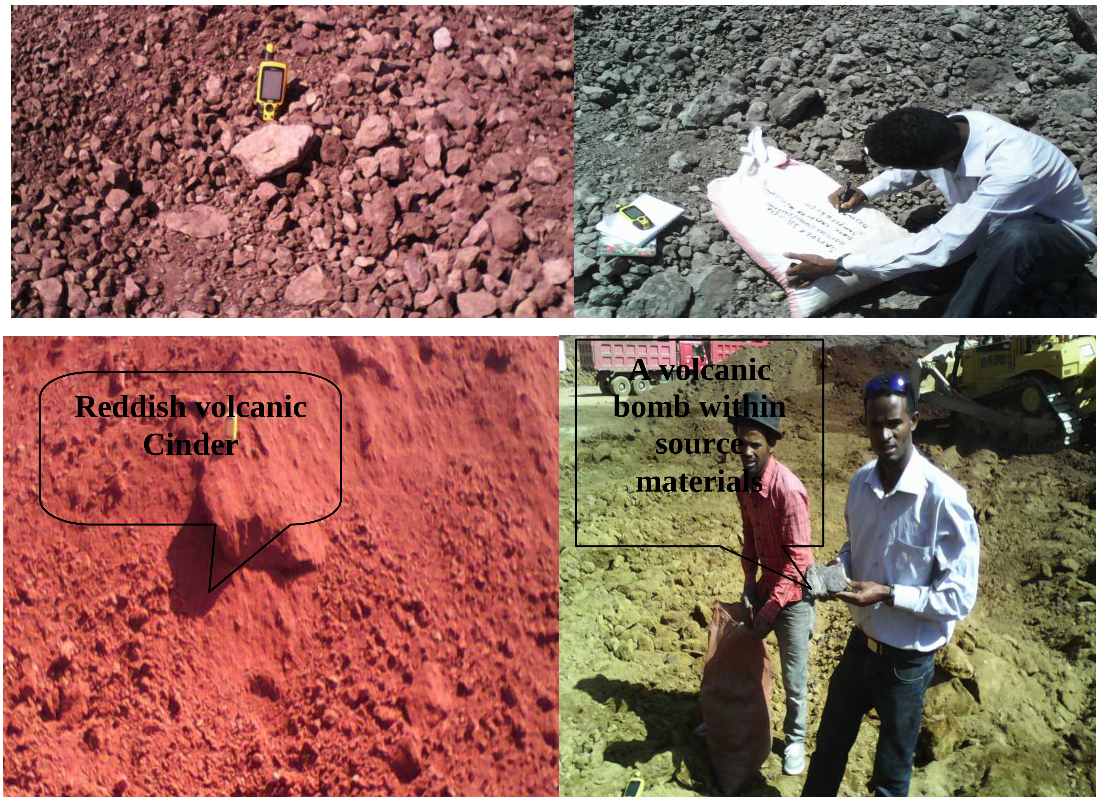


Plate 3.4 Sampling of natural gravel and Cinder from Dukem as well as Gelan site from Quarry.

CHAPTER FOUR

Laboratory Tests of Cinder and Natural Gravel

4.1 Introduction

The suitability of using marginal materials in base or sub base road construction is often assured by performing different laboratory tests which help in determining their physical and engineering properties, as well as compaction characteristics. This chapter gives a detailed description of the laboratory tests that was performed to assess the quality of volcanic cinder materials for sub-base road construction.

4.2 Properties of the Volcanic Cinder

Scoria cones and associated basaltic flows are the most visible feature of the Main Ethiopian rift valley (Bekele Abebe et al., 2007; Peccerillo et al., 2003). In some area, scoria cones are dominantly located along faults and extensional fractures, frequently forming linear chains (Mohr, 1967).

Favorable stress conditions that develop at fault tips are thought to facilitate magma ascent and scoria cone eruption (Casey et al., 2006). Scoria cones are found in various states of preservation within the Wonji Fault Belt (both in terms of natural erosion and mining for aggregate) but are particularly fresh around the Bosetti–Fantale region where a magma fissuring event occurred in the 19th Century (Mohr, 1962; Williams et al., 2004). However, within the research area since there is no clear feature of structural fault it is very difficult to understand the relation of cinder cone with fault structures. Generally, within the study area volcanic cinders have some linear feature while others are randomly distributed. Cinders show variation in shape, elevation, color, grain size, depositional gradation and weathering degree within the same cinder deposit as well as those from different source.

The cones are scarcely covered with grass, shrub and acacia which make them easily identifiable from aerial photograph and field observation. The color varies among reddish, brown to grey and dark. Cinder is highly fractured and can be excavated manually. The aggregate size varies from 0.75 mm to as big as 500 mm (blocks or boulders). Sometimes it is possible to get uniformly graded cinder between 20 – 30 mm (Rooney et al, 2010). The gradation depends on the amount of weathering of the material. This means that material close to the surface will most probably be finer graded than material that is retrieved at a greater depth.

Observations made during the field survey indicated that the two most important factors likely to affect the engineering behavior of the cinder gravels were the grading and the strength of the gravel particles. The aims of the laboratory investigation on cinder gravels are therefore to determine:-

- ✓ Their grading to classify and evaluate the engineering properties.
- ✓ Their strengths and densities at different levels of compaction
- ✓ The effect of compaction on grading.
- ✓ The effect of adding locally available natural gravel to make up for the deficiency of fine material, plastic index and level of compaction in grading of cinders
- ✓ The effect of moisture on engineering properties of cinder gravel

.

4.3 In-situ Cinder description

Reliable description of soil as they occur in the field is the key to the first assessment of these engineering properties. On site material description should engage at least five basic descriptive terminologies (Jennig and Brink, 1961). The important descriptors of soils are moisture condition, color, consistency, structure, soil type and origin.

4.3.1 Moisture condition

Moisture content assessment has been carried out during sampling of volcanic cinder in order to determine the sensitivity of material to water as well as to know the ground water level of the project area. However, volcanic cinder materials are found dry this is probably due to the presence of higher vesicles which leads to higher porosity. The dry condition of volcanic cinder may affect their index properties.

4.3. 2 Color

During sampling of volcanic cinder color variation is observed. This variation might be due to change in degree of weathering (physical), chemical alteration such us oxidation of iron containing minerals. Dark to gray, reddish and brown to yellowish color are the most frequently observed. Generally, color is important for describing the soil and for correlating the same layer in different source in the same general area(Jennig and Brink, 1961).

4.3. 3 Consistency

Since cinder materials are pyroclastic products which are obtained due to some energetic eruption they are highly fractured and can be easily dug by man power.Generaly, it consists of friable coarse grain gravel and sometimes very large lithic fragments (Jennig and Brink, 1961).

4.3.4 Structure

Volcanic cinder are generally associated with fault structures or erupted through zone of plane weakness. Due to this it is expected to posses some structural features which indicates their eruption mechanism. However, the source material contains only large amount of vesicles which are resulted due to degassing, large volcanic bombs, alteration /calcite infilling, the presence of thin layers of ash deposit especially at lower depth and some depositional gradation (Jennig and Brink, 1961).

4. 3.5 Soil type

Physically cinders are dominated by coarse grained material with randomly distributed volcanic bombs. Sometimes it shows some gradation when we go further deep from the surface it becomes coarse grained. This may result in an even grain size distribution between coarse and fine grain material which leads to poor gradation of cinder (Jennig and Brink, 1961).

4. 3.6 Origin

Based on the grain size, vesicles, shape, light weight and other physical parameters cinders are pyroclastic material (Jennig and Brink, 1961).

Table 4.1 shows on site material description.

Material type	Moisture content	Color	Origin	Soil type	Structure
Cinder one	Dry	Reddish	Pyroclastic	Gravel	1.vesicles 2.Calcite infilling 3.Volcanic ash layer & volcanic bombs
Cinder two	Dry	Brown	Pyroclastic		1.vesicles 2.Calcite infilling 3. Volcanic ash layer & volcanic
Cinder three	Dry	Reddish to gray	Pyroclastic	Gravel	1.vesicles 2.Calcite infilling 3.Depositional gradation 4.Volcanic bombs
N.gravel	Dry	Brown to pinkish	Igneous	Silty clay gravel	1.Fractured and jointed

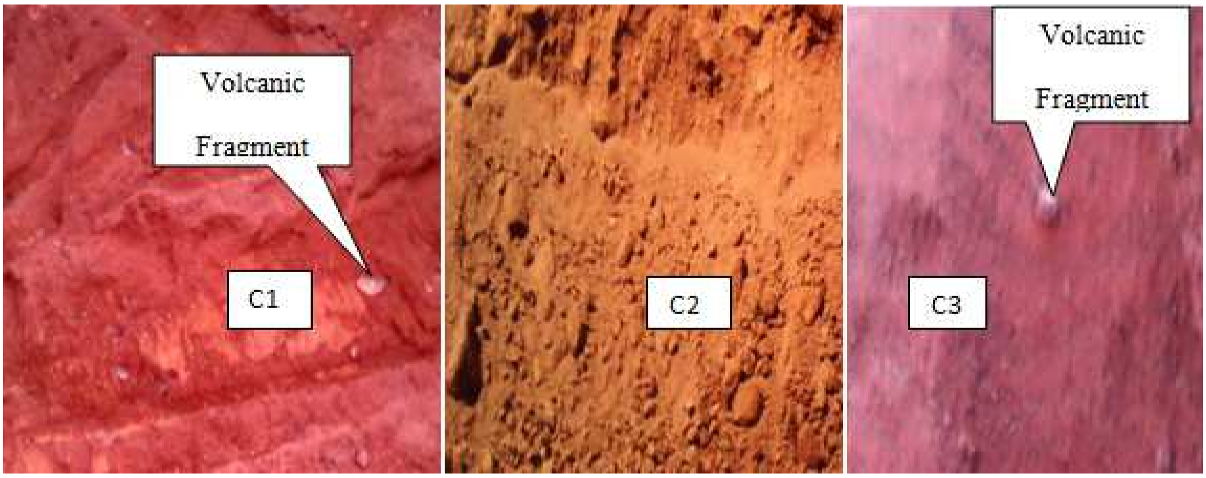


Plate.4.1 Three various cinder in terms of color and grain size within the same source

4.4 Sampling Procedures

For the purpose of quality or index test sampling of disturbed sample from various location of the same source have been takes place. In order to be representative samples were collected from different depth of the source. This may probably decrease the sampling error and enhance the consistency of the test results. Generally the following sampling procedure adopted during the present research is shown in fig.4.2.

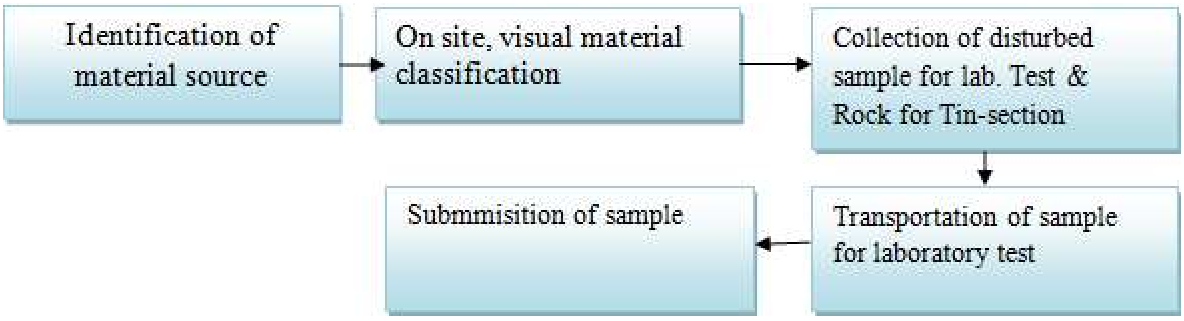


Fig.4.2 Shows sampling procedures during the research.

4.5 Index Tests of Natural Gravel used for Mechanical Stabilization

4.5.1 Sieve Analysis and Gradation of Natural Gravel

Sieve analysis is a simple but proven method of separating bulk materials of all kinds into size fractions and ascertains the particle size and distribution through weighing the single fractions. The analysis of soils by particle size provides a useful engineering classification system from which a considerable amount of empirical data can be obtained. This can be performed in either wet or dry condition. Usually sieving processes are carried out on dry material for quick material estimation. However, when dry sieving cannot produce an adequate degree of separation between the individual fractions and wet sieving is preferable (SANRA, 2011). Based on this, grading analysis was carried out on natural gravel based on ERA grading manual (ERA, 2002). According to the sieve analysis from A-D grade the following result were obtained.

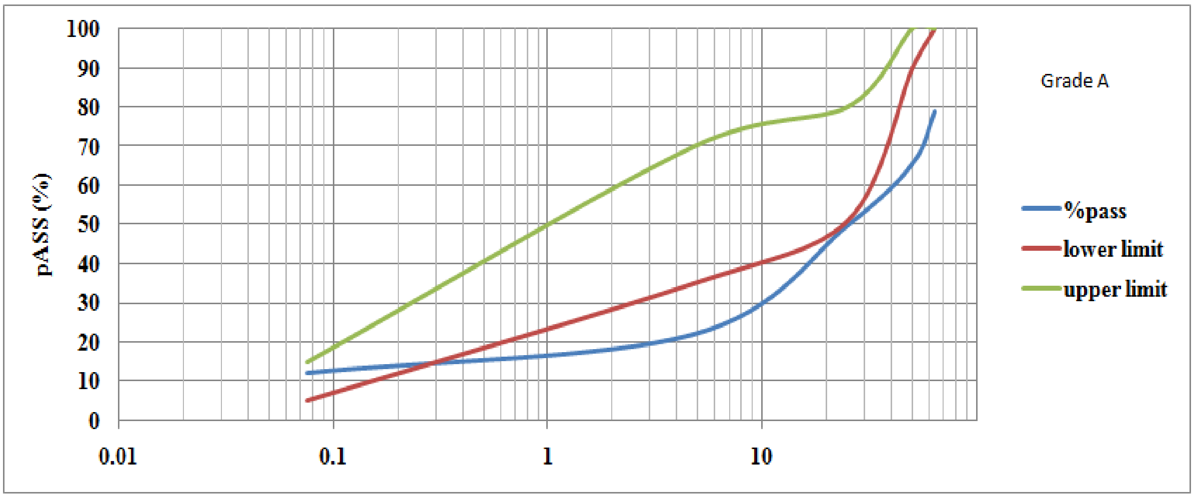


Fig .4.3 Grade A sieve results`

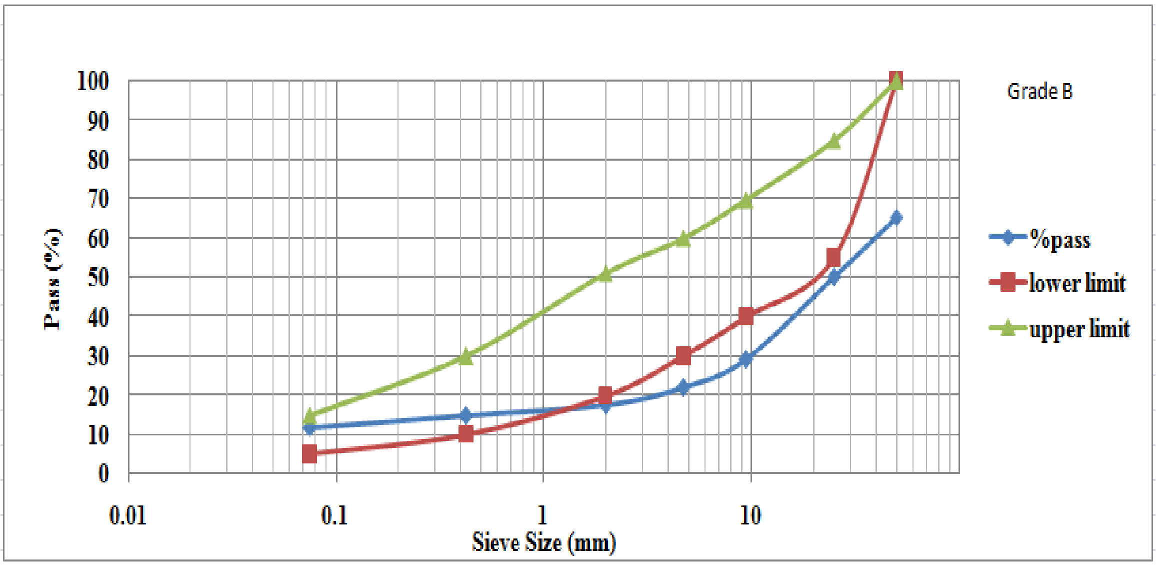


Fig.4.4 Grade B sieve results

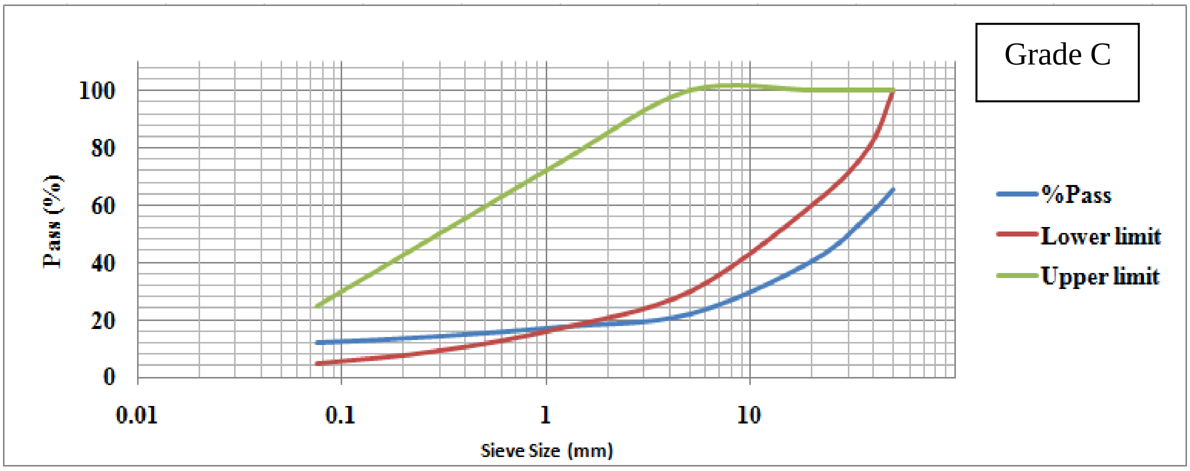


Fig.4.5 Grade C of sieve results

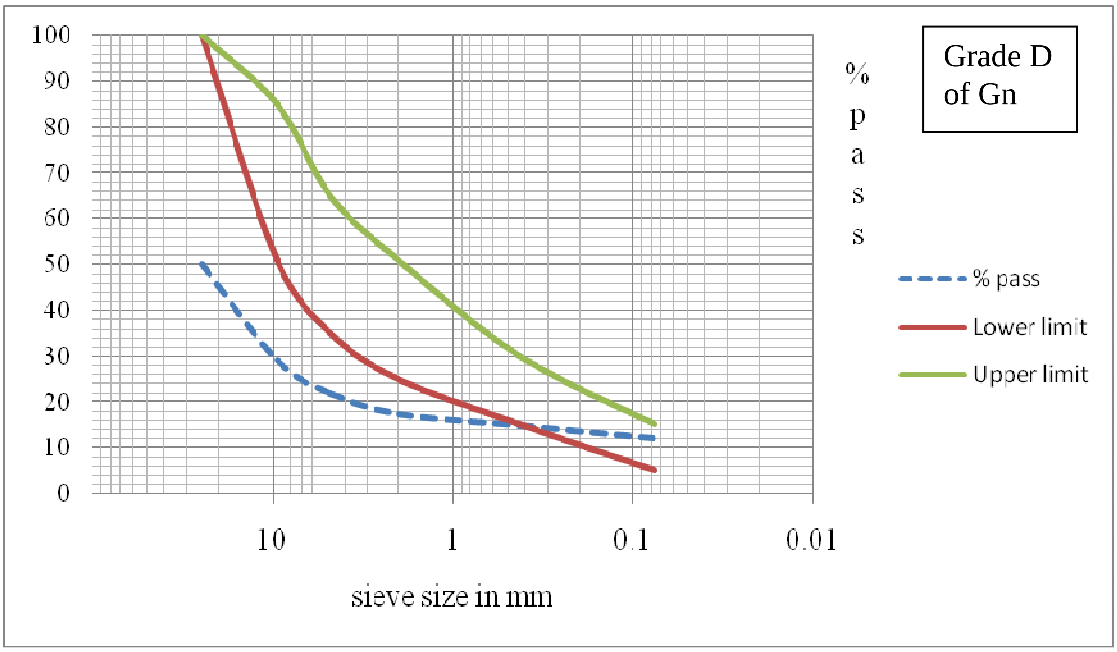


Fig.4.6 Grade D sieve result

4.6 Atterberg Limit

Plasticity is an important factor in the performance of a gravel wearing course for the following reasons. Material with plasticity that is too low tends to loosen quickly as a result of diminished bonding and the rate of gravel loses is generally very high. Loose material is pushed off into the drains or washed away by run-off or blown away by wind when dry (Yitayou Eshete,2011).

High gravel lose reduces regravelling cycle periods causing high maintenance cost and general whole life costs. High plasticity on the other hand causes the wearing course to be slippery when wet and the material may soften to an extent where the gravel layer may actually deform and fail instantly under traffic load (Yitayou Eshete, 2011).

Generally the relationship among liquid limit (LL), plastic limit (PL), and plastic index (PI) of a given soil material can be expressed in the following given equation and the relationship between No. of blows and % of Moisture content is given in fig.4.7 below.

LL=PL+PI……………………………………………………………………………….4.1

LL =27+25=52%

PI =LL-PL……………………………………………………………………………….4.2

PI =52-27 =25%

PL =LL-PI……………………………………………………………………………….4.3

PL =52-25= 27%

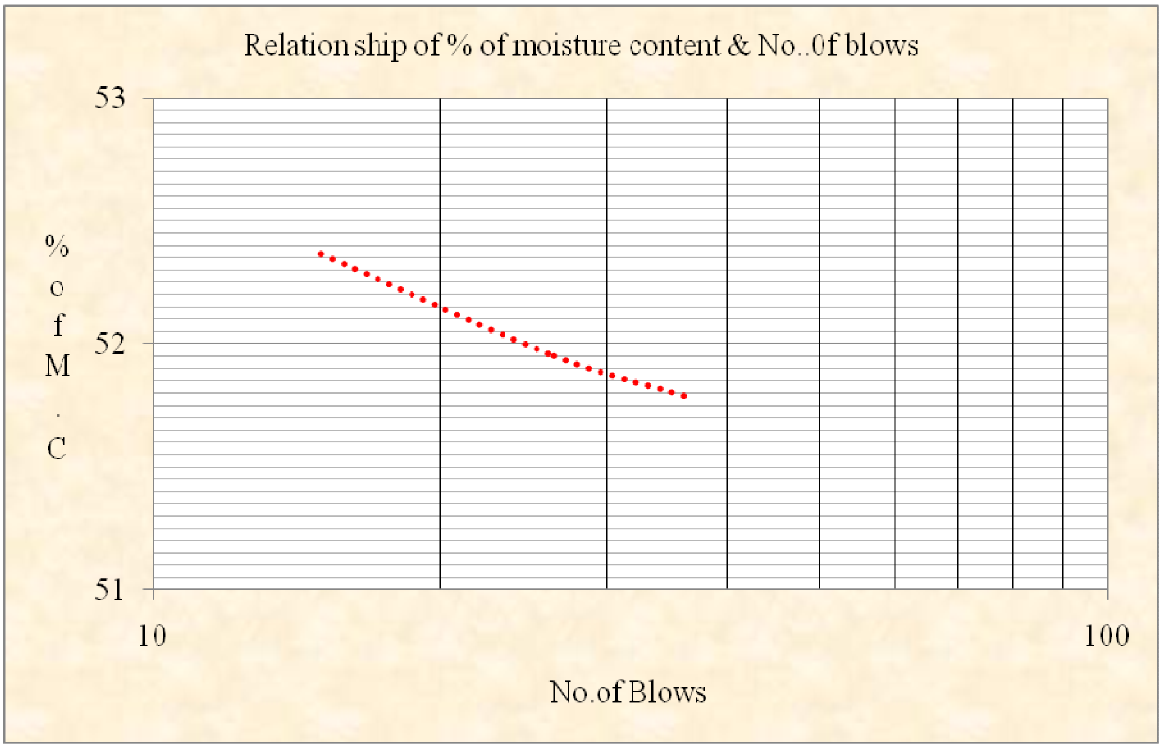


Fig.4.7 Relationship between % of Moisture content and N. of blows

4.7 California bearing capacity of natural gravel (CBR)

For gravels and soils of G4 and lesser quality the CBR is carried out on compacted specimens of the material(ASTM,1988).

The method uses soil particles that pass 19 mm size and provides CBR value of a material at optimum water content. The specimen shall be soaked prior to penetration. This test simulates the prospective actual condition at the surface of the sub-base. A surcharge is placed on the surface to represent the mass of pavement material above sub-base. The sample is soaked to simulate its weakest condition in the field. Expansion of the sample is measured during soaking to check for potential swelling (ASTM, 1988).

For this reason, three point CBR has been conducted on natural gravel in order to determine its bearing capacity before blending. Consequently the result obtained from three point CBR analysis natural gravel which is obtained from dukem area generally have low bearing capacity of 13, 22 and 23 with 10,30 65 number of blows.

This indicates natural gravel consists of low bearing capacity, higher plasticity index of clay or very fine material which changes their engineering properties seasonally and leads to adversely influence the pavement structure.

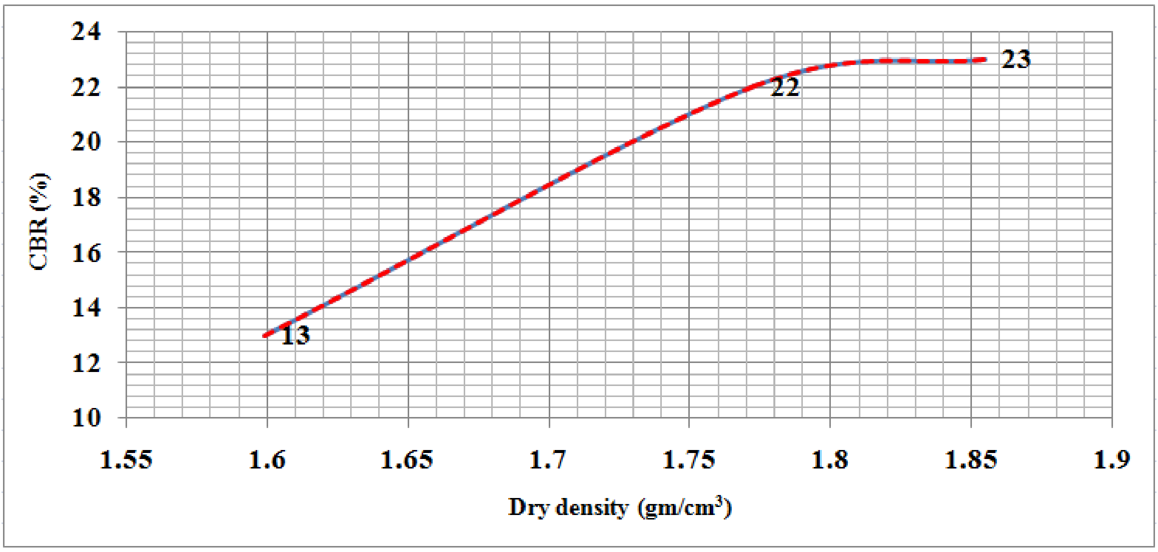


Fig.4.8 CBR-Density relationships of natural gravel

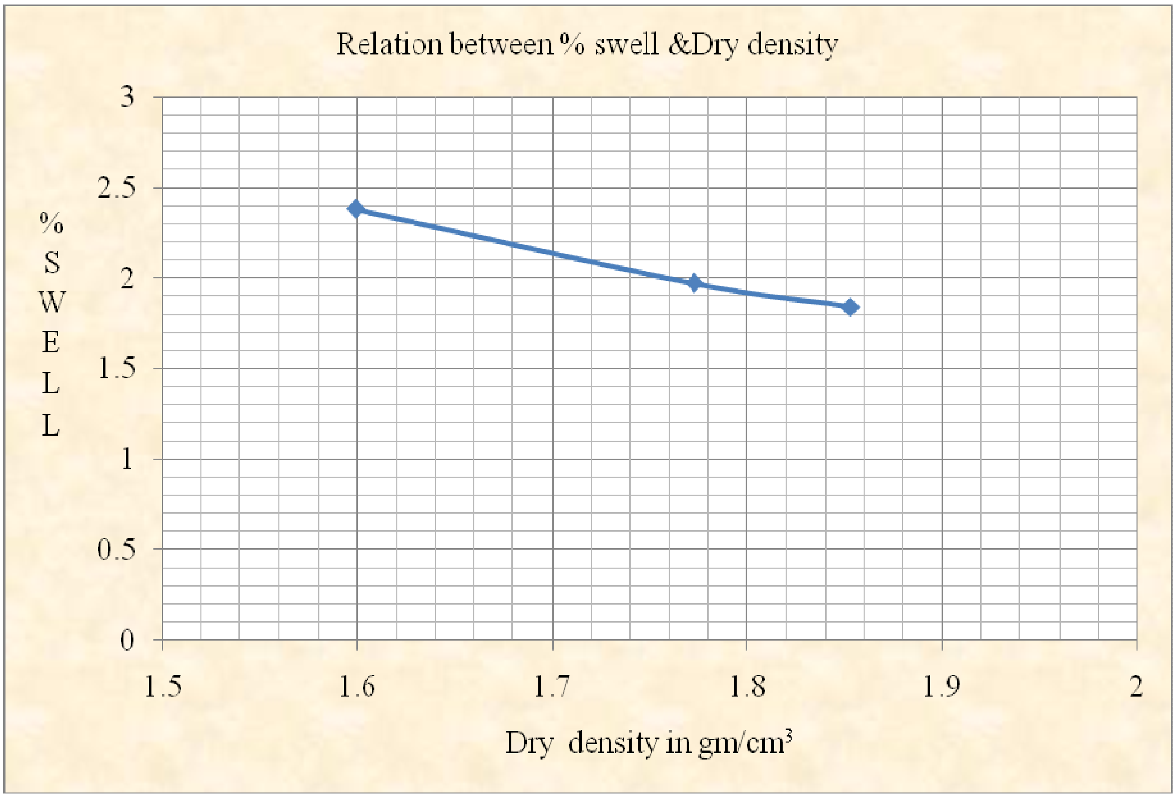


Fig.4.9 shows relationship between % swell and dry density of natural gravel

4.8 Index Test of Volcanic cinder Gravel

4.8.1 Sieve analysis and gradation of volcanic cinder gravel

Sieve and grading modulus analysis were carried out on three cinder gravels obtained from the same source, but different location and depth. Based on the result obtained from ASTM grain size analysis and grading modulus calculation three of the cinder materials have higher proportion of coarse grained material than fine ones.

This means materials with higher proportion of coarse grained have grain to grain contact which is difficult during compaction, highly pervious which adversely affect the rest of pavement structures. This clearly indicate that the grain size distribution of those material is not uniform and at the same time dose not fulfill the ERA grading requirements for sub-base road construction. But materials which do not have well grain size distribution it does not mean they are weak unless it is confirmed by other index test parameters. For this reason, among the three cinder gravel sample number two (cinder two) were relatively have good grain size distribution and satisfy the grading requirement.

Based on index test result cinder gravels are classified as A-1-a (0) soil group because in gradation test, less than 15% pass through sieve no.200, less than, 30% passes through sieve no.40 and less than 50% passes sieve no.10 with zero plastic index. Those material consisting of predominant of stone fragment, gravel either with or without a well-graded binder of fine material.

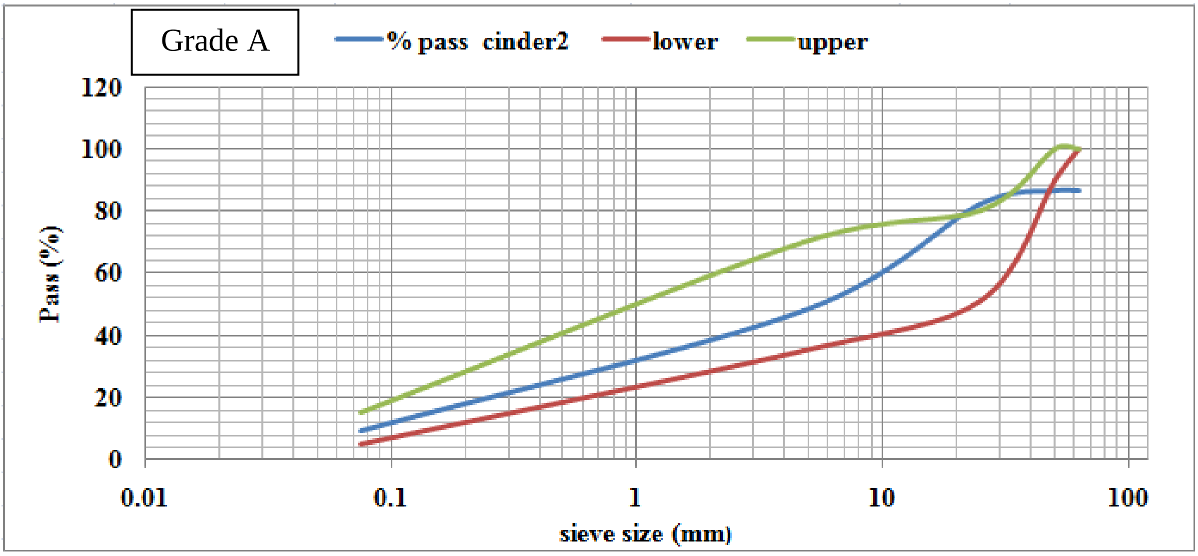


Fig .4.10 ERA grade envelope for grad A

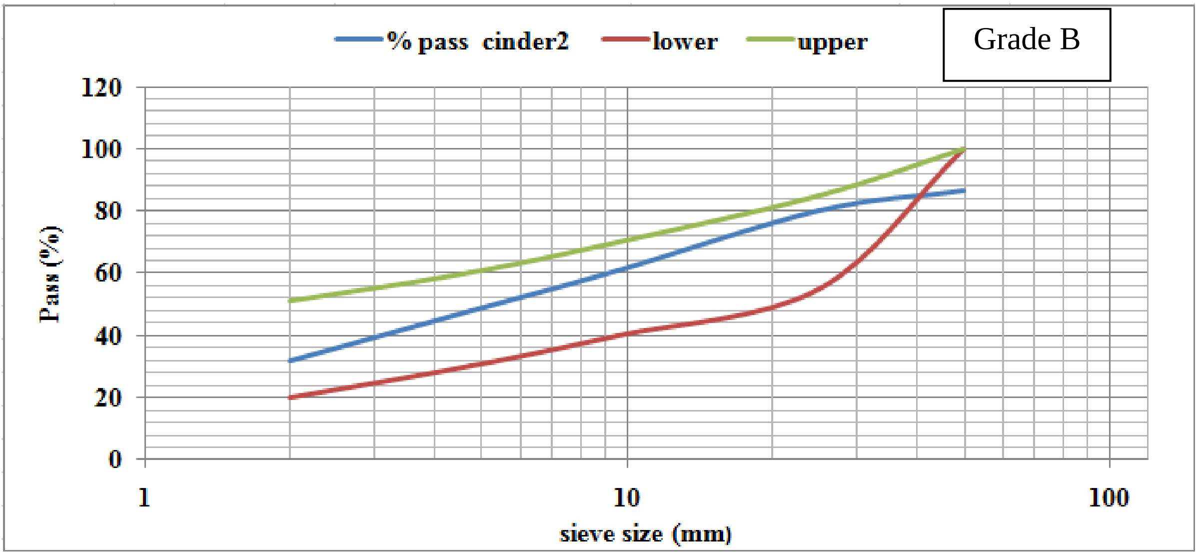


Fig .4.11 ERA grade envelope for grad B

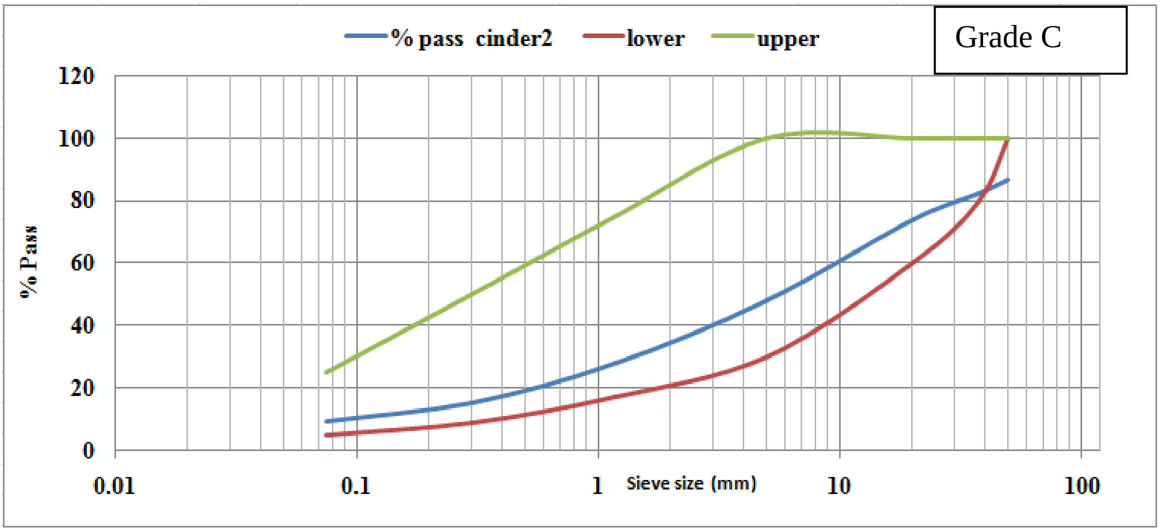


Fig .4.12 ERA grade envelope for grad C

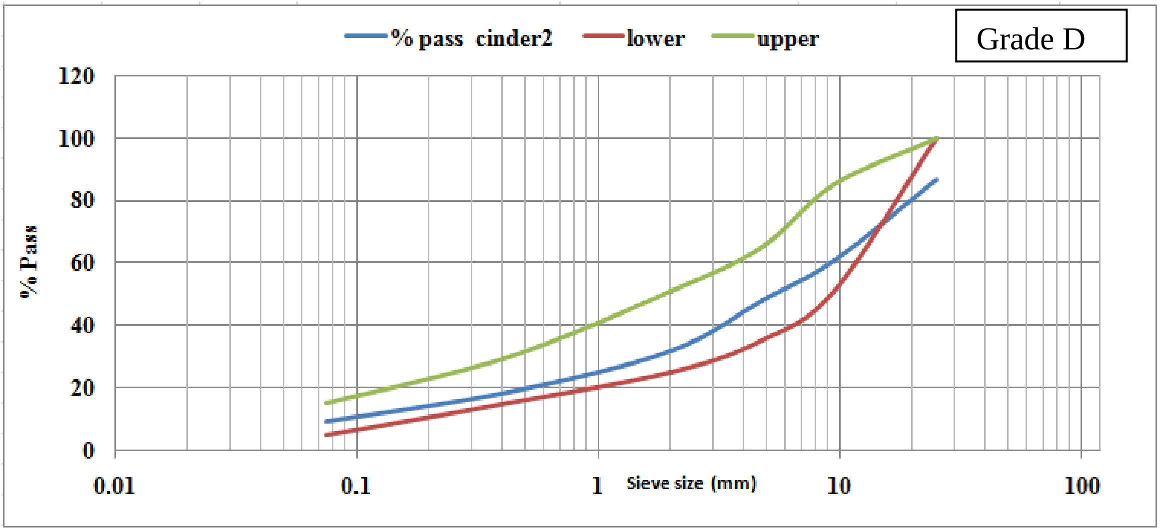


Fig .4.13 ERA grade envelope for grade D

According to ERA grading manual, material to be used as sub-base shall have a smooth continuous grading within the limits for grading A, B or C. Generally 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. Therefore this thesis work is done based on grading B specification. The upper and lower grain size limit of Grade B material is plotted as follow:-

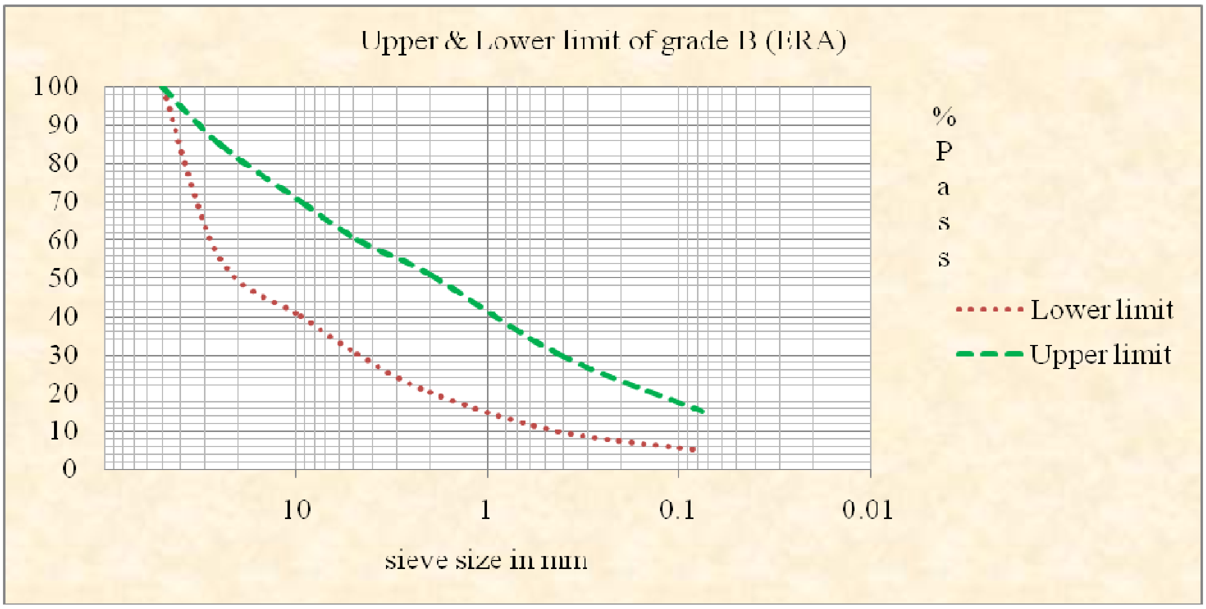


Fig.4.14 ERA Upper and lower limit of grad B sub-base material

Table 4.2 ERA grading for sub-base material

Sieve size, mm	% of Mass passing			
	A	B	C	D
63	100	-		-
50	9-100	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	-	20-51		25-51
1.18			17-75	
0.425	-	10-30		15-30
O.3			9-50	
0.075	5-15	5-15	5-25	5.15

4.8.2 Atterburg Limit

An assessment of plasticity index and plasticity limit of cinder material was takes place in order to determine its moisture content as well as to anticipate the plasticity nature. However volcanic cinder was found non plastic due to money reasons.

It may be due to the absence of fine or any other clay material; its highly pervious nature may result in very low water holding capacity or generally those few fine grained soil which are found within cinder material have no plasticity nature and may behave as silt and sand.

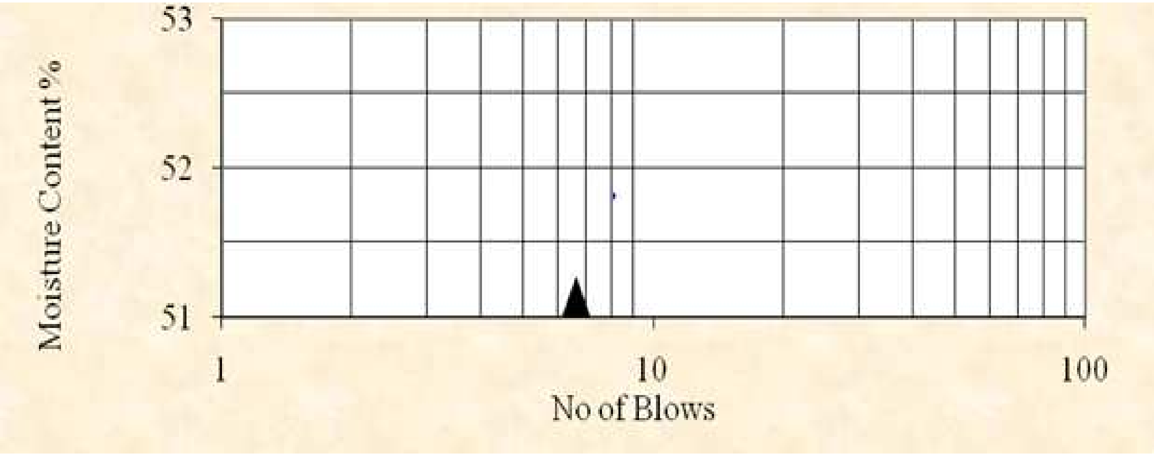


Fig .4.15 Shows %of moisture content and No. of blows of cinder gravel

4.9 California Bearing Ratio (CBR).

Three pint CBR has been carried out similar to the natural gravel in order to anticipate the bearing capacity of cinder material at the worst condition. Accordingly cinder samples were socked prior for four days in order to see the impact of moisture on bearing capacity of cinder and in order to determine its swelling potential. This test simulates the prospective actual condition at the surface of the sub-base.

Based on the result, the bearing capacity of cinder gravels show an increment of CBR value as the number of blows increase. Additionally the swelling potential of cinder material is very low which means the CBR and swelling potential of cinder material is not affected by the moisture content.

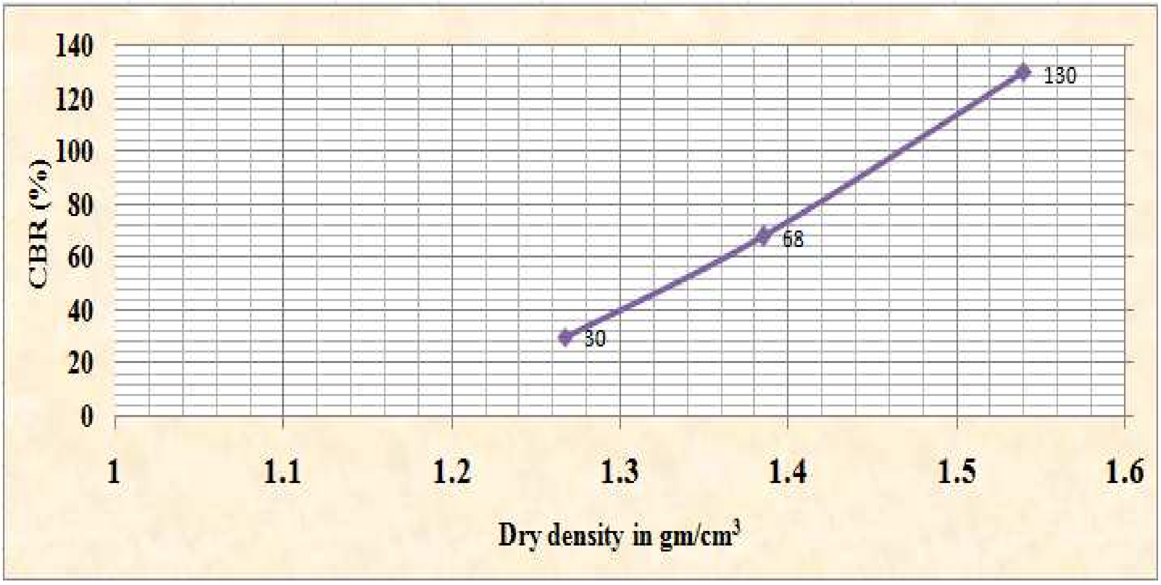


Fig.4.16 Shows % of CBR and Dry density cinder gravel

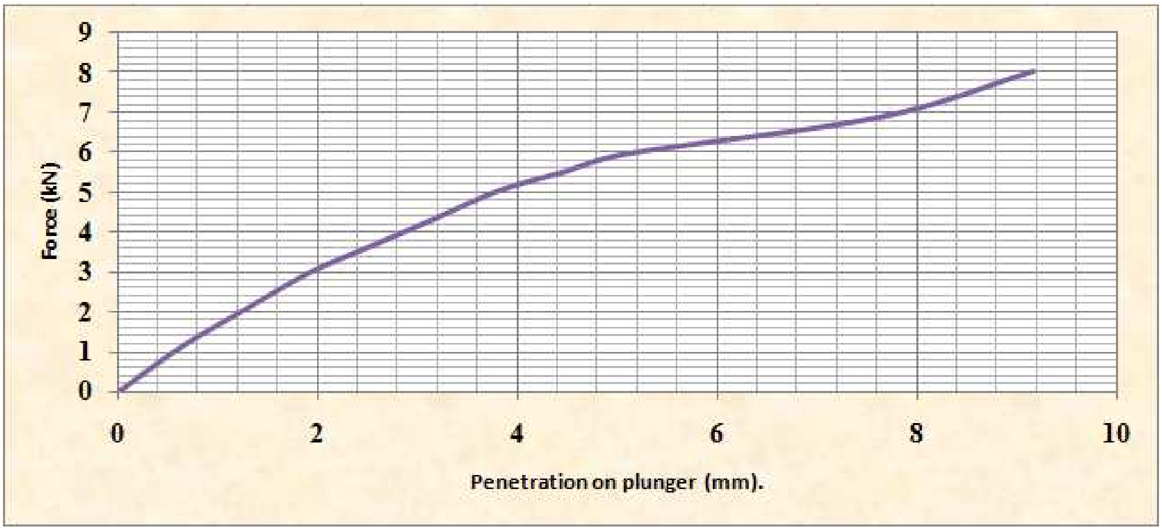


Fig.4.17 shows relationship between load and penetration at 10 blows

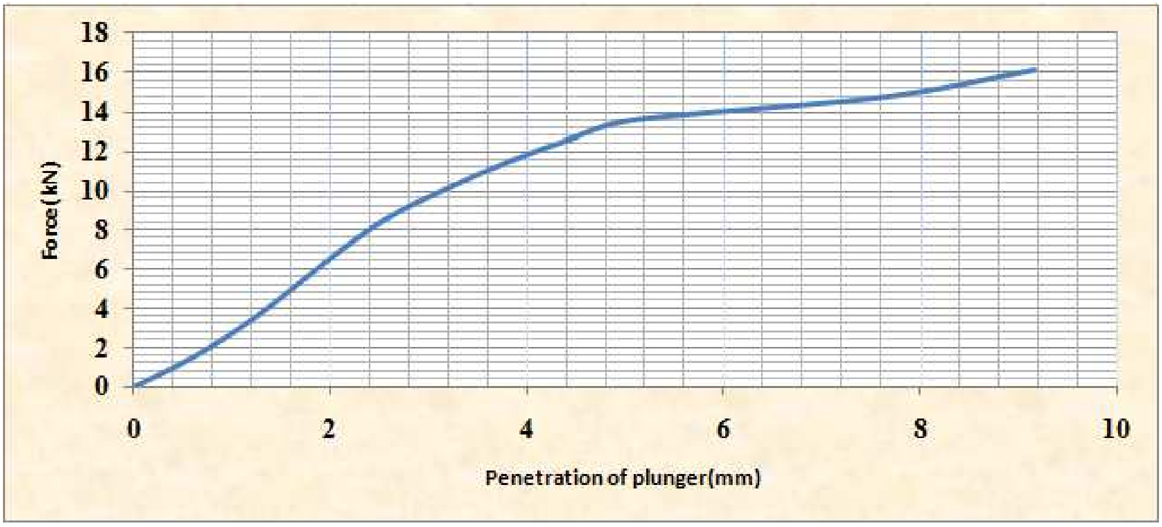


Fig.4.18 shows relationship between load and penetration at 30 blows

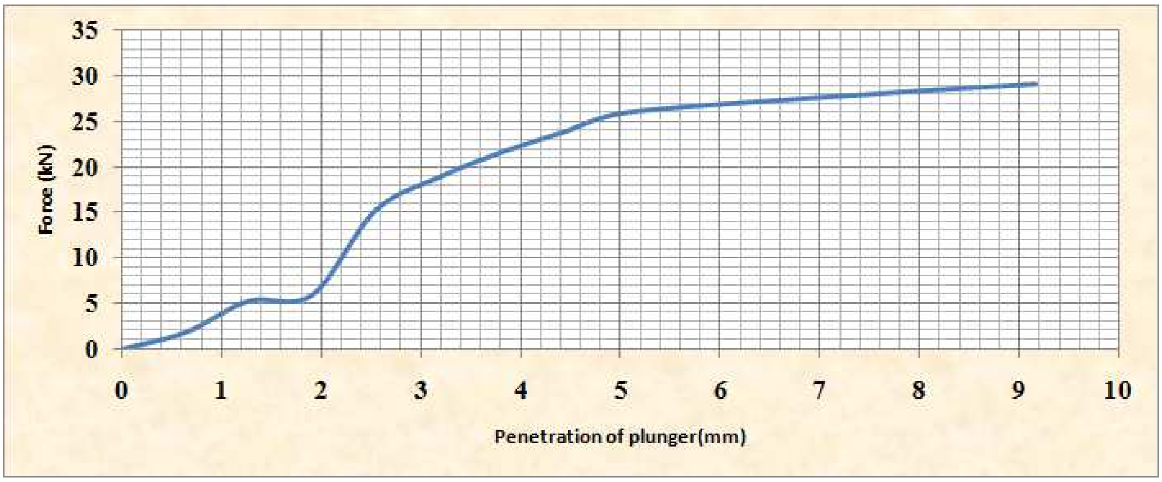


Fig.4.19 shows relationship between load and penetration at 65 blows

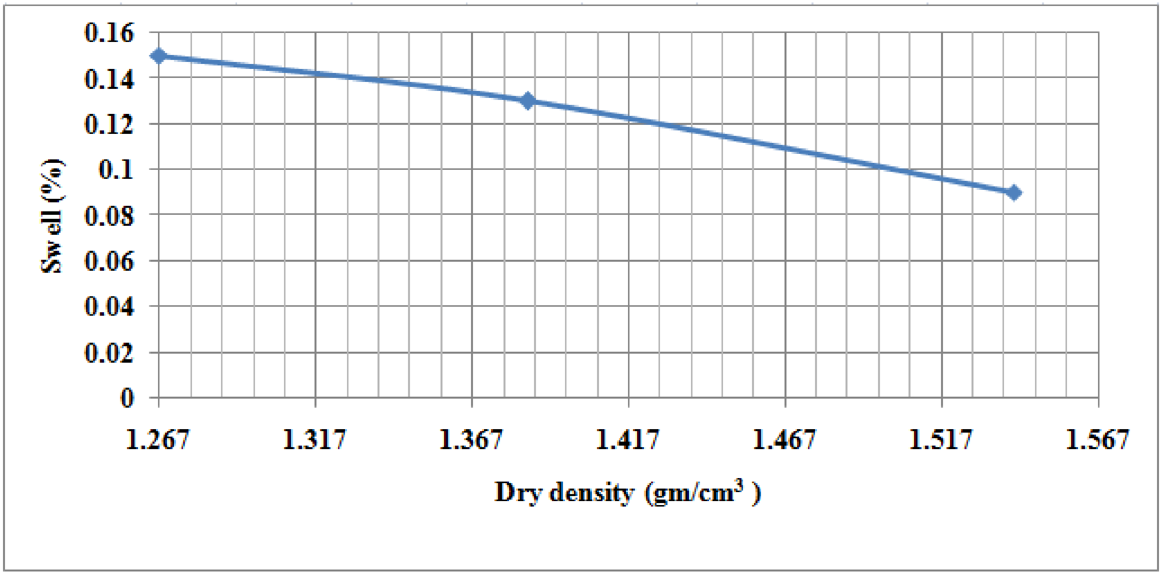


Fig.4.20 Shows relationship between %swell &dry density of cinder gravel

4.10 Summary

Natural gravel is obtained from Dukem area somewhere 18km far from the research project. On site it was described as pinkish to gray color, moderately weathered fine to medium grained silty clay gravel material. However,in addition to onsite material description other index tests have been done in order to classify the soil systematically.

Based on the result obtained from ASTM (sieve or gradation) and grading modulus calculation natural gravel has higher proportion of coarse grain material even though it contains significance amount of silty clay material. This can be proved from the result of Atterberg limit which has 25% plasticity index, 11% of linear shrinkage, and 32% of Loss Angeles Abrasion.

Three pint CBR test were also done in order to determine bearing capacity of natural gravel. Even if natural gravel shows some increment of CBR value as the number of blows increase from 10 to 30 and from 30 to 65 the material remained still below ERA bearing capacity requirements for sub-base road construction.

Based on AASHTO soil classification system natural gravel are classified as A-2-7 (0) soil group because during sieve analysis the amount of material that pass sieve No.200 (0,075mm) were less than 35% with 25% plastic index and 52% liquid limit.

Because soils with a very high LL could not be classified accurate enough by means of the system described above, a group index of the sample has been determined and it is found to be zero.

According to the results obtained from Attereberg limit test, cinder gravels are none plastic. This conforms cinders have lack of fine grain, clay or any other cementing materials and the tendency to behave as plastic is very low. Indirectly it has grain to grain contact, with dominant void space between grains and it is hard to compact it. Since such kind of material does not satisfy ERA sub-base requirement the material should be modified in order to improve its quality.

Three- point CBR test was also performed in order to estimate the bearing capacity of cinder gravel. Cinders were priory soaked for four day to anticipate their bearing capacity at the worst condition. However, analysis from the result clearly showed as compaction trail increased from 10 blows to 30 blows and from 30 blows to 65 blows CBR value also from 30 to 60 and 130 respectively increases.

This is probably because the cinder materials are weak in nature due to dominant vesicular ground mass. Therefore, due to repeated compaction of heavy load, vesicles may easily break and produce substantial amount of fine grain which drastically improve its compaction and strength.

Other quality tests have also been carried out to generally characterize cinder gravel for the proposed application such as LAA and LS. LAA &LS are very helpful for assessing the abrasive nature, swelling and shrinkage characteristics of a given sample.

Accordingly cinders have high abrasive nature i.e. 53% due to its weak nature and very low linear shrinkage limit i.e.3% due to lack of clayey or fine grain materials.

Finally, as seen from the index test results volcanic cinder and natural gravel are marginal material which is difficult to use for sub-base construction. Therefore, this research is particularly focused on blending of volcanic cinder with natural gravel at different proportion.

5. Petrographic analysis of volcanic cinder

5.1 Hand specimen's description.

Scoria and cinders are pyroclastic materials which are leucocratic (CI <30), completely glassy, fine grained, aphyric texture with dominant amount of vesicular cavities. Those materials are slightly weathered, affected by hydrothermal alteration due to the presence of calcite infilling within the cavities and sometimes around big pyroclastic bombs (wood, 1908b).

5.2 Thin Sections

Scoria and cinders are typically basaltic to andesitic.i.e. (high in Fe, Mg ,Ca but low Na, K, and equal amount of Fe, Mg, K. Na as well as Ca) respectively. It has approximately 50% to 60% of Sio_2.cinder contains phenocryst of feldspar and various ferromagnesian minerals that crystallized in the magma prior to eruption. Fragments of rock through which the magma has passed may be entered in the melt and wall rock may be fragmented and admixed during eruption. It has also some lithic fragment cores (wood, 1908b).

5.2.1 Mineral Composition of volcanic cinder

In order to determine the mineralogical content, texture and other petro graphic analysis of cinder two hand specimens were collected from different location of the source .i.e. hand specimen BL-A from 981968 East and 474103 north and hand specimen RE-B from 9822148 east and473761 north.

5.2.2 Petrographic analysis of hand specimen BL-A.

In principle volcanic cinders are expecting to have a basaltic mineral composition. However, according to the thin section observation or analysis made cinder materials are generally occupied by porphiritic phenocryst of plagioclase (Albite) with euhedral to sub hedral crystal structures, accessory mineral phases (opaque Fe Ti oxides) groundmass and lithic fragment/volcanic fragment, very rare olivine and quartz. Generally, it is highly affected by alteration and stained from Fe-Mg containing minerals such as olivine, pyroxene and may be from hornblende.

Under petrograpihic microscope, volcanic cinder shows phenocrysts of plagioclase feldspar especially (Albite) with some zoning, euhedral to Sub hedral crystal shape and 1.5mm-3mm size.

Similarly, sample Id BL-A contains fractured ground mass of plagioclase, olivine, opaque and other very large lithic fragments. The size and shape of ground mass minerals can reach from 0.5 mm -1 mm while lithic fragments have rounded shape and up to 5mm size. Generally, sample Id BL-A have prophetic texture, with very low degree of alteration which in filled in some fractured structures and stained materials. Volcanic cinder varies in color, mineral composition and grain size. Accordingly, sample number BL-A contains modal abundances of quartz = 1%, Albite (Plagioclase) = 10-15%, Ground mass = 30-40%, lithic fragment = 25-35%, opaque = 3%, and olivine = 1%. From the thin section analysis it is observed that volcanic cinder are dominated by lithic fragments, ground mass minerals and phenocrysts of plagioclase crystals with medium to coarse grain size. Therefore, from the modal mineral composition and other textural features the rock may be named as porphyritic basalt.

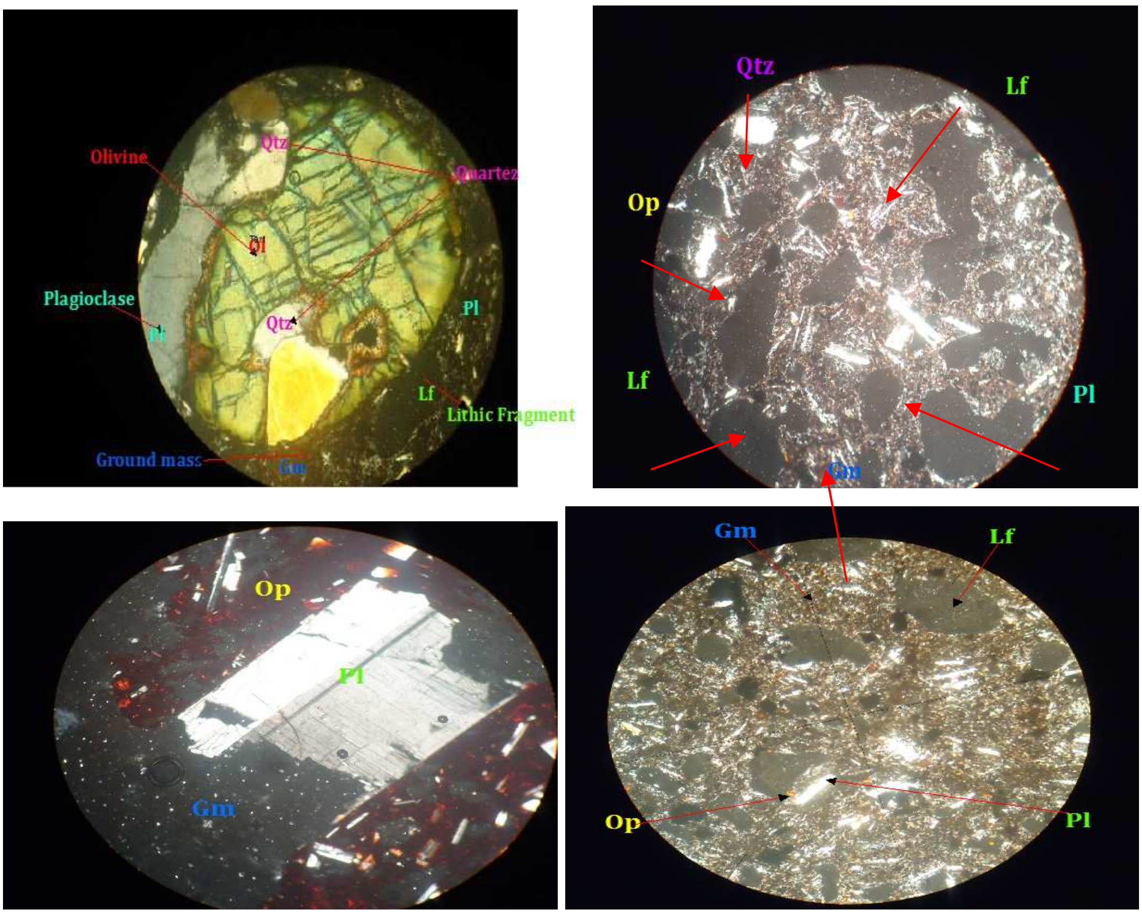


Plate. 3.9 Thin-section of scoria (BL-A), 10x10 =100X

5.2.3 Petrographic analysis of hand specimen RE-B.

Volcanic cinders are generally basaltic in their mineral composition. However, according to the thin section observation or analysis made cinder materials are generally occupied by porphyritic phenocrysts of plagioclase (Albite) with euhedral to sub hedral crystal structures, accessory mineral phases (opaque Fe Ti oxides) groundmass and lithic fragment/volcanic fragment, very rare olivine. Generally it highly affected by alteration and stained from Fe-Mg containing minerals such as olivine, pyroxene and may be from hornblende.

Under petrograpihic microscope, volcanic cinder shows phenocrysts of plagioclase feldspar especially (Albite) with some zoning, euhedral to sub-hedral crystal shape and1.5mm-5mm size.

Similarly, sample id RE-B contains fractured ground mass of plagioclase, olivine, opaque and other very large lithic fragments. The size and shape of ground mass minerals is generally less than 1 mm while lithic fragments have rounded shape and up to 5mm size.
Generally, sample id BL-A have prophetic texture, with very low degree of alteration which in filled in some fractured structures and stained materials. Volcanic cinder varies in color, mineral composition and grain size. Accordingly, sample number BL-A contains modal abundances of Albite (Plagioclase) = 20-25%, Ground mass = 40%, lithic fragment = 20%, opaque = 13%, and olivine = 2%. From the thin section analysis we observed that volcanic cinder are dominated by lithic fragments ,ground mass minerals and phenocrysts of plagioclase crystals with medium to coarse grain size. So from the modal mineral composition and other textural features the Rock may be named as Porphiritic basalt as it is given in plate3.10.

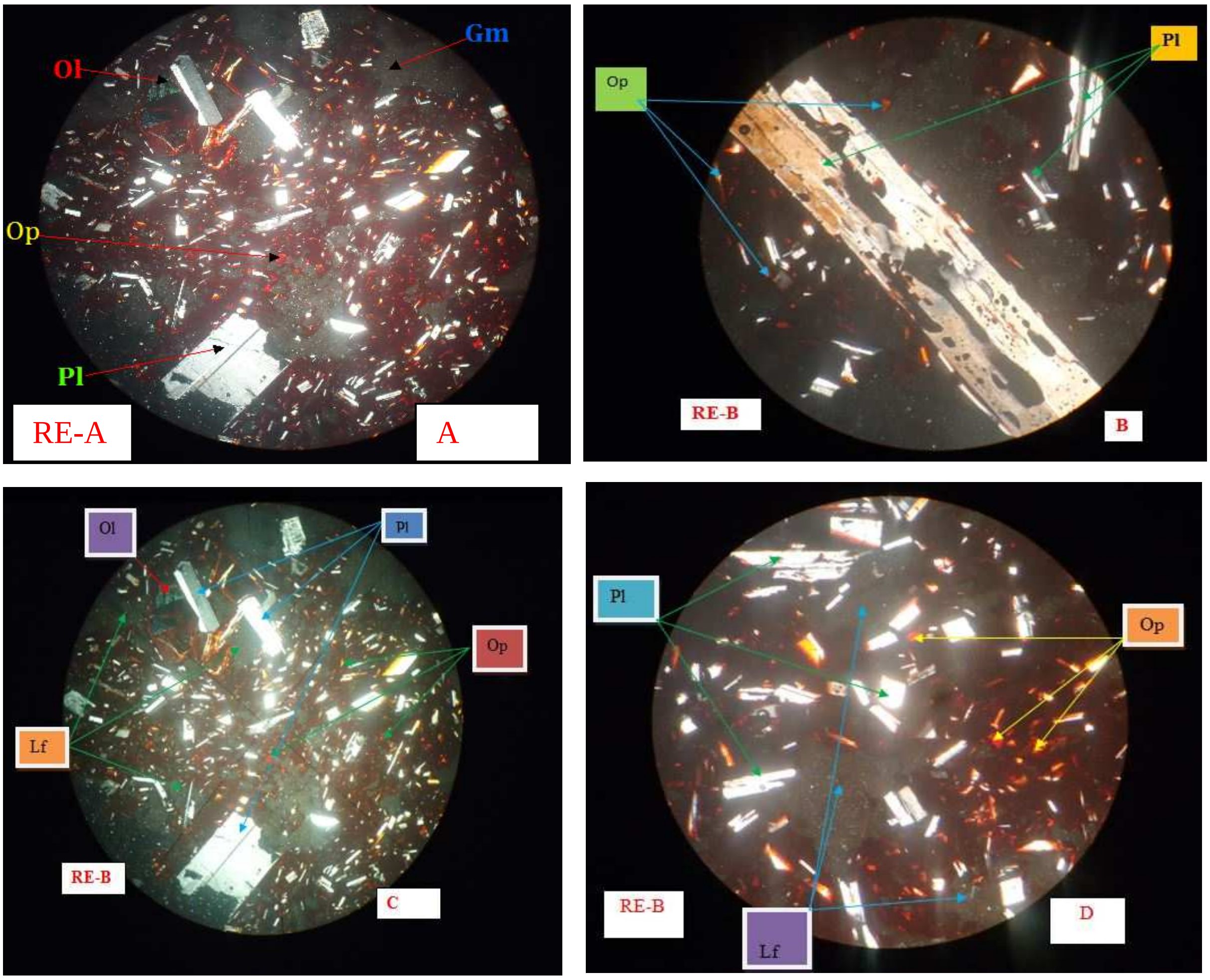


Plate 3.10 Thin-section of (RE-B), 10X10 =100X

CHAPTER FIVE

BLENDING 0F VOLCANIC CINDER WITH NATURAL GRAVEL

5.1 Blending

Cinder gravels are abundant source of road building materials however, do not always meet the quality requirements for sub-base and are frequently rejected in favor of expensive alternatives. However, these alternatives are often not locally available and the transportation of large quantities in heavy vehicles is expensive and consequently large financial and environmental benefits can be achieved if the properties of locally available materials such as natural cinder gravels can be improved by blending techniques and used with confidence (Girma Birhanu, 2009).

For this reason a research has been carried out on three volcanic cinder samples obtained from the same source but different location and depth to be used as a sub-base. Two samples were taken from the same source, depth but different locations where as the third cinder samples have been collected from the same source but different location and depth. Subsequent to the sampling preliminary gradation analyses have been carried out among three cinder samples in order to determine their grain size distribution. Based on the results obtained from sieve analysis cinder material which have better grain size distribution was selected for index quality test before blending.

According to the results obtained from index test in chapter four cinder materials were found out of specification and proposed for blending with weathered natural gravel which was hauled from Dukem area. Therefore, this chapter will mainly focused on blending of cinder material with natural gravel in order to be used as a sub-base material. It was expected that, this may possibly play a significant role in improving the index quality of cinder gravel and the project cost minimize.

5.2 Particle size distribution and gradation of blended cinder gravel (1:1)

The particular packing arrangement for a material is normally represented by the particle size distribution (gradation) curve based on proportions (by mass) passing successive sieves. A lack of coarse or finer particles would produce an unbalanced gradation or distorted gradation curve resulting in poor mechanical stability and unsatisfactory compaction Yitayou Eshete,2011. Therefore, an improvement in gradation and in the reduction of oversized material will result in more uniform strength development, uniform mixing and compaction (Yitayu, 2011).

Grading of material is very helpful to determine relative grain size distribution, to know maximum grain size and amount of fine grain size present. Sometimes if there is density difference between two materials the grading envelope may not be smooth and apparent gaps may occur (SANRA, 2011).

For that reason in order to improve their index property for the proposed use volcanic cinder and natural gravel have been blended and a wet sieve analysis was carried out. This blending process is expected to influence the density, CBR and economy of the project.

The sieve and gradation analysis of blended volcanic cinder gravel obviously indicate grain size distribution is to some extent below the lower limit but still dominated by coarse grained material. This leads to lesser amount of fine grained soil material to pass sieve number 200. (0.075mm).

The MDD of cinder gravel before blending increases from 1.537gm/cm^3 to 1.955gm/cm^3 while The OMC decreases from 20% to 12%. Similarly, bearing capacity, grading modulus of volcanic cinder increase from 130% to 150% and from 2.4 to 2.63 , respectively.

Finally from Atterberg limit test result cinder material after blending with 50% of natural gravel becomes non-plastic. Since plasticity is an important parameter during road construction for compaction effort the material has to be fulfill the requirement by further blending trial/process. Table5.1 gives gradation after blending of cinder gravel (1:1).

Table.5.1 % Pass before & after blending of cinder with 50 % of natural gravel

ERA test sieve in mm for Grade B	%Pass after blending	%lower limit	%upper limit	% pass of cinder Before B.	% pass of natural G.B.B
50	100	100	100	86.5	65.4
25	90.6	55	85	80.2	50
9.5	41.8	40	70	60.9	29.1
4.75	27.7	30	60	48	21.9
2	17.8	20	51	31.8	17.4
0.425	11.7	10	30	18.8	14.8
0.075	6.7	5	15	9.1	12

Fig.5.1 Gradation after blending of cinder with 50 % of natural gravel

Table 5.2 shows CBR comparison before after blending (1:1)

Test results	ERA desirable limit	1 cinder:1gravel	Cinder only	N.gravel only
Grading modulus	Minimum 1.5	2.63	2.4	2.56
OMC	-	12%	20%	16%
MDD	-	1.955gm/cm^3	1.573gm/cm^3	1.869gm/cm^3
CBR	>40%	150	130	22
AASHTO soil		A-1-a(0)	A-1-a(0)	A-2-7(o)

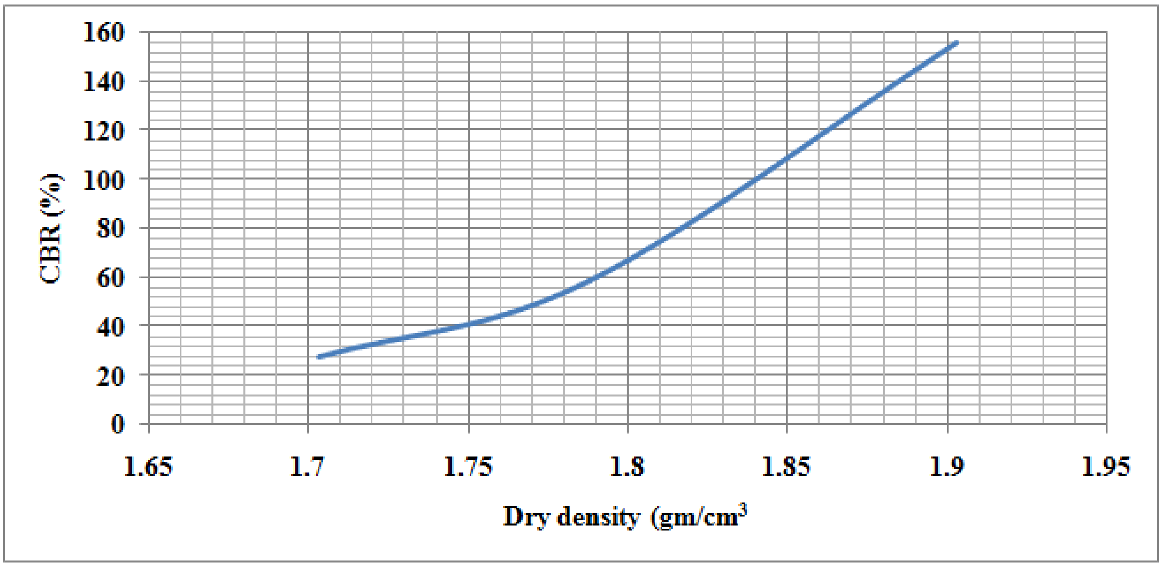


Fig.5.2 shows the relationship between % CBR and Dry density of blended cinder (1:1)

According to the CBR value from fig.5.2 blending of 50% of natural gravel and 50% of cinder have higher value than the standard specification given by ERA for sub base road construction.

5.3 Gradation analysis of natural gravel blended with volcanic cinder (2:1)

Since grain size distribution is an important parameter in grain size analysis further blending proportion or trial has been carried out until it satisfy the grading requirement. Based on this two natural gravel with one cinder gravel has been mixed and quarter of the sample under goes wet sieving analysis.

The result obtained from wet sieve analysis confirms so far the blended material could not include within the specified grading envelope. Even though the amount of fine grained material that pass sieve number 200, (0.075mm) increases from 6.7% to 9% the material is mainly occupied by coarse grain.

Maximum dry density of blended cinder gravel decrease from 1.955gm/cm^3 to 1.835gm/cm^3 as the amount of natural gravel increase. This leads to relative increment of swelling potential. Additionally optimum moisture content increases from 12% to 21% where as bearing capacity decreases from 150% to 75%.

Generally, from Atterbereg limit test result those materials are non-plastic and according to the AASHTO soil classification it is grouped as A-1.a (0). Table 5.3 shows a gradation comparison between 2:1, cinder only and natural gravel.

Table 5.3 Sieve analysis before and after blending (2:1)

ERA test sieve in mm for Grade B	%Pass after Blending (2:1)	% lower limit	% upper limit	% pass of cinder Before B.	%pass of natural G.B.B
50	92	100	100	86.5	65.4
25	66.1	55	85	80.2	50
9.5	34.8	40	70	60.9	29.1
4.75	24.4	30	60	48	21.9
2	16.6	20	51	31.8	17.4
0.425	12	10	30	18.8	14.8
0.075	9	5	15	9.1	12

From fig.5.3 and fig.5.4 given below blending of 1:1 and 2:1 still does not satisfy the ERA grading requirement for the sub-base road construction. From 0.08mm-1mm the gradation value is below the lower limit and dominated by relatively fine grain while from 1mm-9mm it still below the lower limit and dominated by coarse grained. From 9mm to 20mm and 11mm- 30mm it is within the envelope however, dominated by coarse grained.

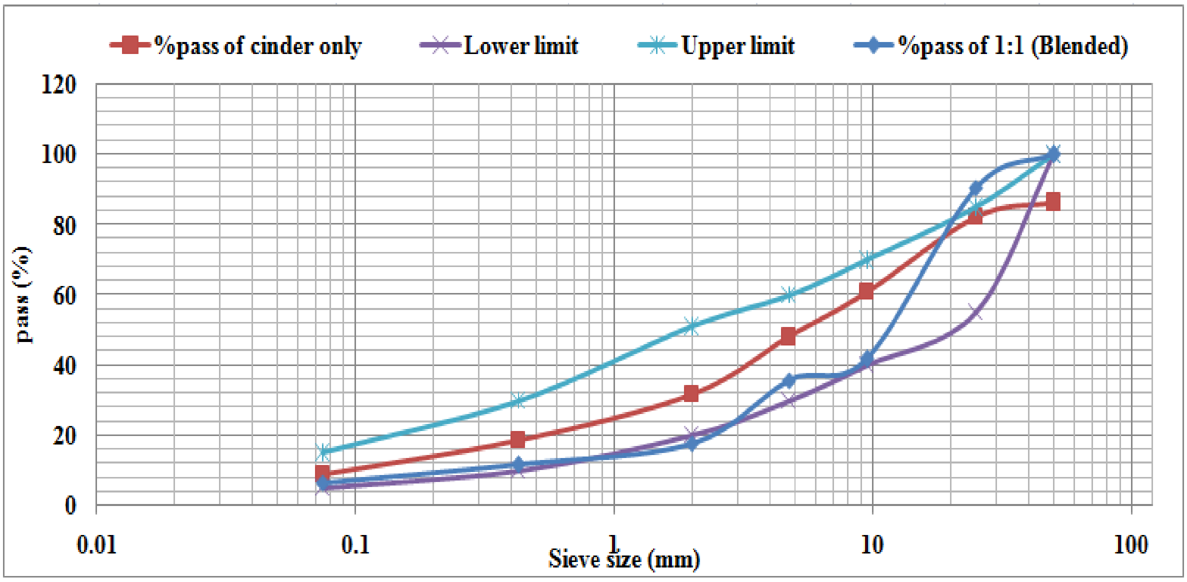


Fig.5.3 Gradation before and after blending of cinder gravel (1:1) as well as cinder only

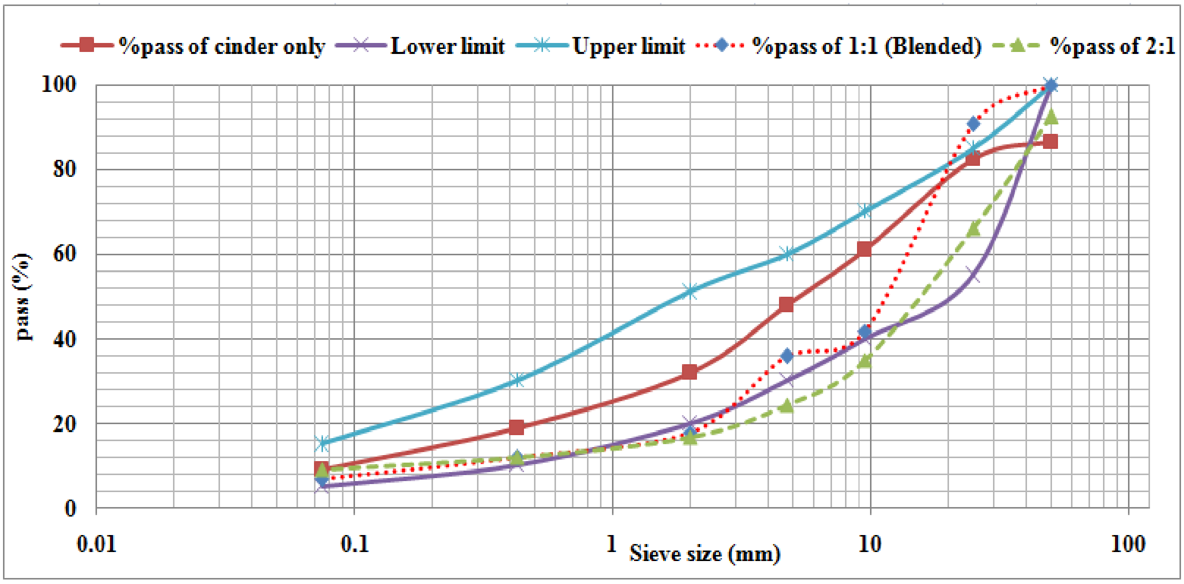


Fig.5.4 grading comparison between 2:1 &1:1

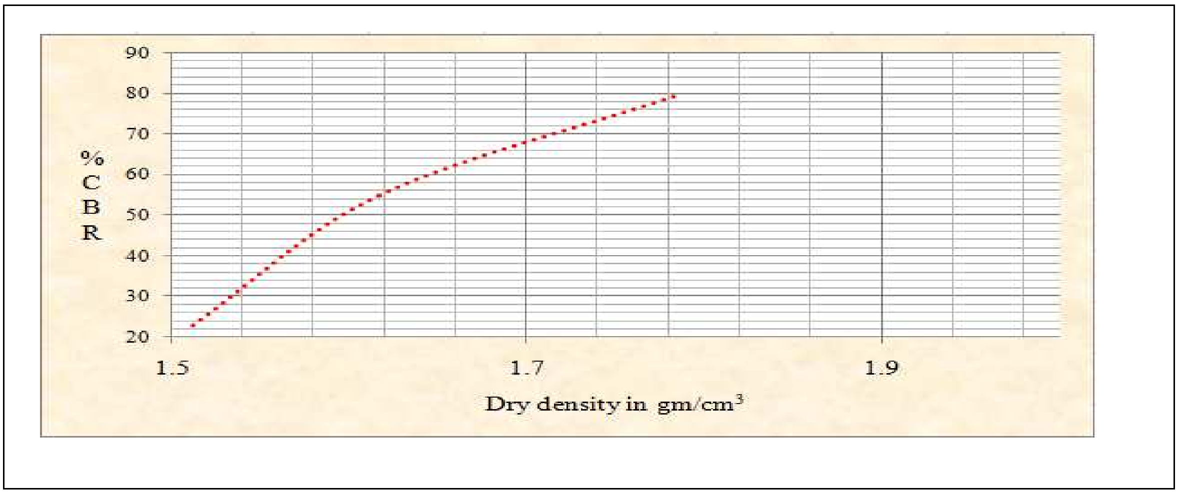


Fig.5.5 % CBR and dry density of blended cinder (2:1)

Table 5.4 CBR comparison before and after blending of 1:1, 2:1 and 3:2

Test results	ERA desirable limit	One cinder : One natural gravel	Two natural gravel :One cinder gravel	Three natural : Two cinder
Grading modulus	Minimum 1.5	2.63	2.6	2.46
OMC	-	12%	21%	13%
MDD	-	1.955gm/cm^3	1.835gm/cm^3	1.935gm/cm^3
CBR	>40%	150	75	79
AASHTO soil		A-1-a(0)	A-1-a(0)	A-2-4(0)

5.4 Gradation analysis of natural gravel blended with volcanic cinder (3:2)

The result obtained from blending of two natural gravel and one volcanic cinder could not satisfy the grading requirement as well as its plastic index. As a result a third trial proportion has been done with three weathered natural gravel and two volcanic cinders.

According to the result obtained from gradation analysis mixing of three natural gravel with two volcanic cinders has a complete grading envelope. The number of fine grained material that passes sieve number 200, (0.075mm) increased from 9% to 12.3%. However from grading modulus calculation and the amount material retained on successive sieve still the material is dominated by coarse grained material.

The bearing capacity and maximum dry density also show slight increment. From Attereburg limit test result mixing of three natural gravels with two volcanic cinders greatly improve the plasticity index of volcanic cinder. Generally, from the Atterberug limit test result and AASHTO soil classification system blended material were found with plasticity index of 10 and A-2-4(0) soil group.

Table.5.5 % Pass after blending of cinder with 60 % of natural gravel

ERA test sieve in mm	%Pass after blending Grade (B)	% lower limit	% upper limit
50	100	100	100
25	81.5	55	85
9.5	49.8	40	70
4.75	35.7	30	60
2	24.4	20	51
0.425	17.3	10	30
0.075	12.3	5	15

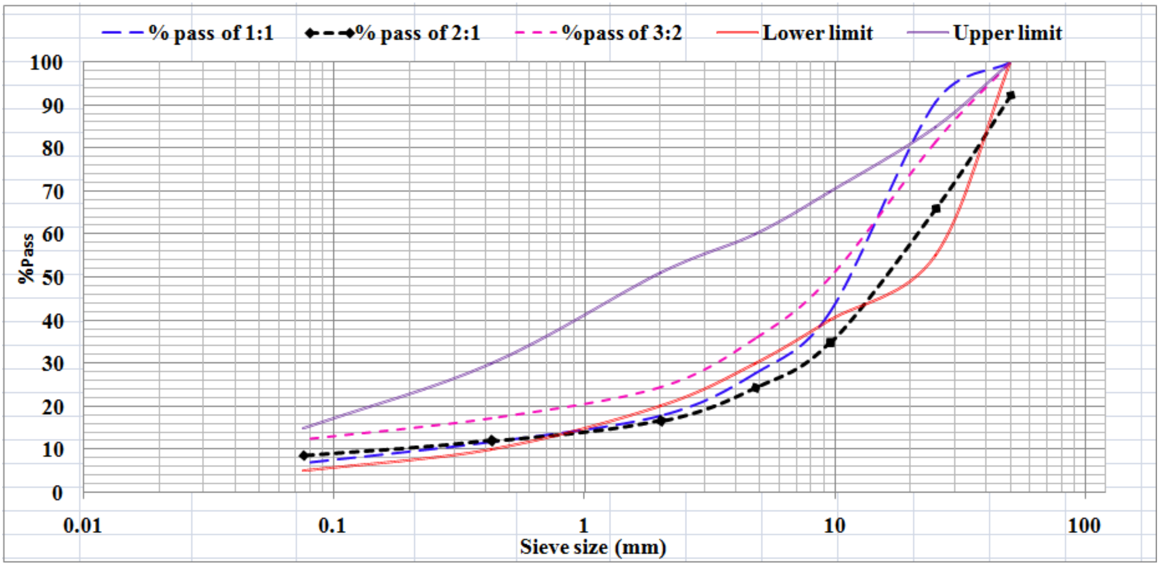


Fig. 5.6 shows comparison between percent pass blended cinder at 1:1, 2:1 & 3:2

As we can see clearly from fig.5.6 and fig.5.7 blending of three natural gravel and two volcanic cinders improve its grading and satisfy the grading requirements. Furthermore the bearing capacity as well as dry density slightly increased. If a given samples of sub-base materials have smooth and continuous gradation within the required envelope then those material is expected to have a fair proportion or grain size distribution.

It is expected the open space which are found between grain to grain contact and any void space is filled by these fine grain material. This result in better shear resistance against the applied traffic load on the pavement structure, produce better compaction characteristic and becomes less pervious for the rest of pavement structures.

5.5 Grading Modulus of Natural Gravel Blended With Volcanic Cinder (3:2)

Grading Modules (GM) is the cumulative percentages by mass of material in a representative sample of aggregate, gravel or soil retained on the 2.00 mm, 0.425 mm and 0.075 mm sieves, divided by 100. It gives an indication of the relationship between fine and coarse material in a gravel mix. Thus, material with a high Grading Modulus (> 2.0) would indicate that it is coarsely graded and of relatively good quality, while material with a low Grading Modulus would be indicative of material with finer grain sizes, with poorer road building quality (ERA,2002).

According to ERA grading manual for sub-bas material, the minimum Grading Modulus shall be 1.5 except where a material having a lower grading modulus but less than 1.2, is approved for use by the engineer.

$$GM = \frac{\%\text{ retained on 2mm} + \%\text{ retained on 0.425mm} + \%\text{ retained on 0.075mm}}{100}$$

Table.5.6 Determination of Grading Modules values at different percent of natural gravel

% Cinder &Ng added		Grading modulus after blending			
% of Cinder Gravel	%of Ng.	Cinder	N.gravel	Blended (3:2	Quality
100	0	2.4	-	-	excellent
0	100	-	2.56	-	excellent
50	50	-	-	2.00	very good
67	33	-	-	2.6	excellent
60	40	-	-	2.46	excellent

From table5.6 the grading modulus value before and after blending of cinder and natural gravel is higher than 2. This indicates the material is dominated by coarse grain but still it is good quality for sub-base road construction.

5.6 Atterberg Limits of natural gravel blended with volcanic cinder (3:2)

An assessment of plasticity characteristics of mechanically stabilized volcanic material was carried out in order to determine its liquid limit and plasticity index. This is because plasticity index is an important index property of soil during road construction (SANRA, 2011).

Generally plasticity is an important factor in the performance of a gravel wearing course for the following reasons. Material with plasticity that is too low tends to loosen quickly as a result of diminished bonding and the rate of gravel loses is generally very high. Loose material is pushed off into the drains or washed away by run-off or blown away by wind when dry (SANRA, 2011).

High gravel lose reduces re gravelling cycle periods causing high maintenance cost and general whole life costs. High plasticity on the other hand causes the wearing course to be slippery when wet and the material may soften to an extent where the gravel layer may actually deform and fail instantly under traffic (Yitayou Eshete, 2011).

According to the result obtained from Attereberg limit test blended volcanic cinder gravel progressively improves its plasticity index from the previous blending trial proportion.This implies stabilization of natural gravel with volcanic cinder produces considerable amount of fine or clay material which improves plasticity of volcanic cinder.

Table5.7 presents us the plastic limit, plastic index, liquid limit and plastic product of the stabilized material.

Table.5.7 Attereberg limit test result of blended cinder gravel (3:2)

Plasticity index(PI)	10
Liquid limit (LL)	35
Plastic limit (PL)	25
Plastic product (pp)	% pass of sieve 0.075mm x PI =120

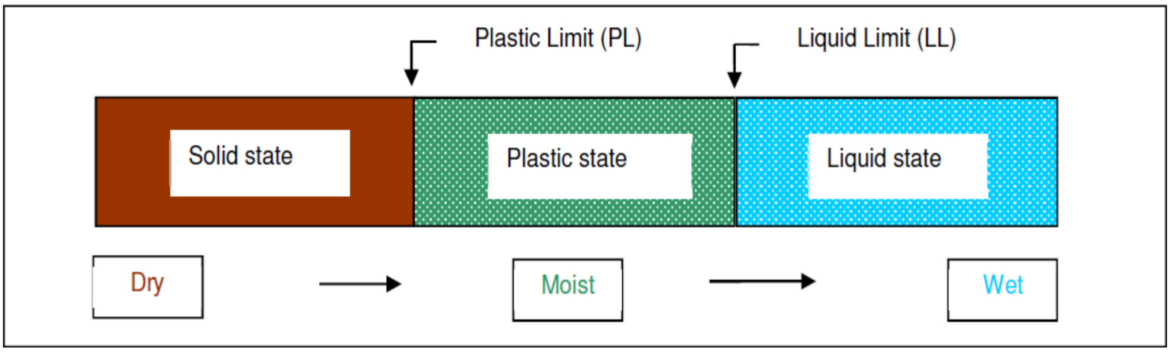


Fig.5.7 Atterberg Limits

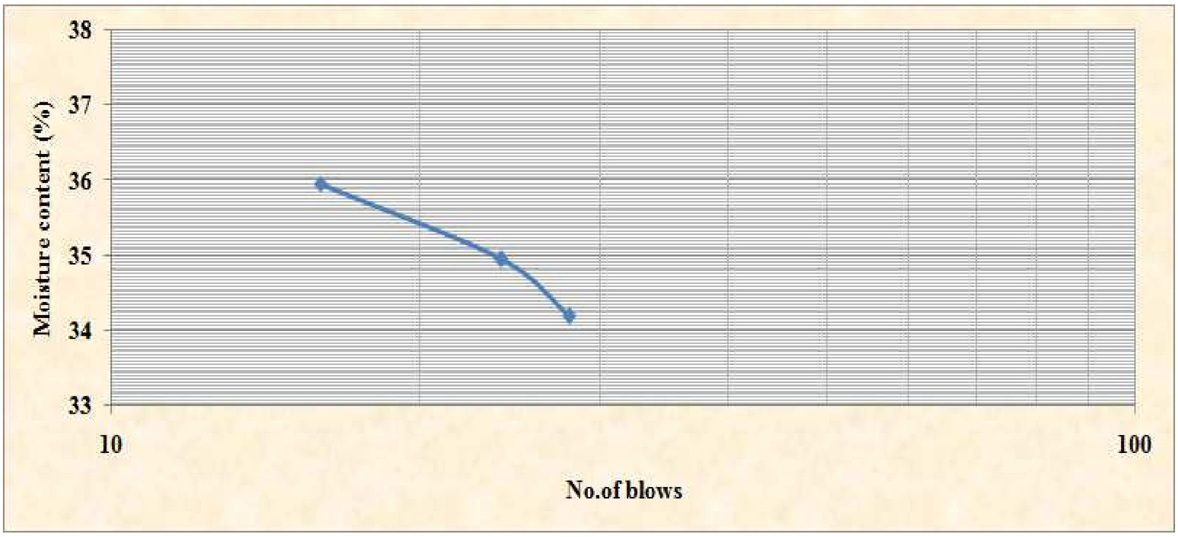


Fig.5.8 shows a graph of moisture content vs. no. of blows on log. Scale

Fig.5.7 and table 5.8 shows the three physical state of soil and the relationship of moisture content and number of blows of blended cinder (3:2). Accordingly as the number of blows increases the moisture content getting decreased. This is because the void space occupied by either water or by air is reduced due to compaction.

Table.5.8 Determination of plastic index and plastic product for blended material

% of natural gravel(added)	Plastic index (PI)	Plastic Product
0	None plastic	Zero
50	None plastic	Zero
67	None plastic	Zero
60	10%	120

From table 5.8 blending of 50% and 67% of natural gravel does not improve its plasticity of as well as plastic product of cinder material. However addition of 60% natural gravel results in plasticity of 10 and plastic product of 120 and this satisfy the ERA requirement for sub-base construction.

5.7 California Bearing Ratio of Natural Gravel Blended with Volcanic (3:2)

AASHTO is a standard method of test for the bearing capacity ratio of a given soil material. This method is used to evaluate the potential strength of sub grade, sub-base and base course material, including recycled materials for use in road and airfield pavements.

Covers laboratory determination of the CBR of a compacted or undisturbed sample of soil. A surcharge is placed on the surface to represent the mass of pavement material above sub-base. The sample is soaked to simulate its weakest condition in the field and at the same time expansion of the sample is measured during soaking to check for potential swelling.

The results of these tests are compared with the results of “standard “materials and serve as input values to empirically based design methods. Most of these tests still are in use because of advantages as ease of performance, applicability to a wide variety of soil materials and extensive correlation with research on soil stability and soil behavior beneath pavements.

Based on the Ethiopian Road Authority manual (ERA, 2002), for sub-base material the minimum soaked CBR value should be 30% when determined in accordance with the requirements of AASHTO T-193. The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D (AASHTO, 1993). Fig.5.9 is a standard diagrammatic representation of CBR equipment with sample contained in a mold with surcharge weight on top.

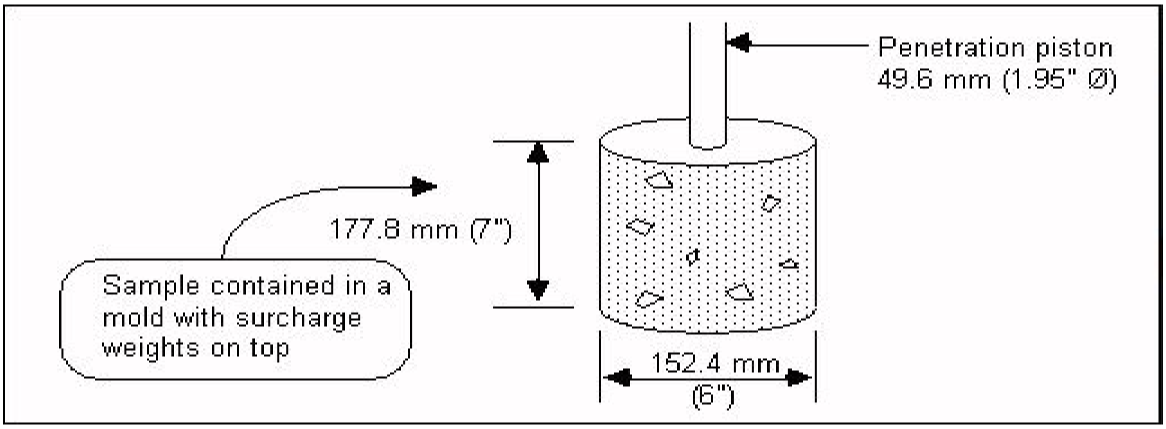


Fig.5.9 shows a sketch of typical CBR value.

5.7.1 Calculation of California bearing ratio (CBR) of blended cinder and natural gravel (3:2)

Penetrations of 2.5mm and 5.08mm may be used for calculating the CBR value. However, the CBR at 2.5mm penetration is generally used for assessing the quality of the material.

i. Record the plunger force value at 2.5 mm penetration from the (corrected) force-penetration curve for each of the three specimens.

ii. Calculate the corresponding CBR values from the equation:

CBR value (in %) = P x100/13.2

Where p is the plunger force in (KN) at 2.5mm penetration

iii. Record the plunger force values at 5mm penetration from the (corrected) force-penetration curves.

iv. Calculate the corresponding CBR values from the equation:

CBR value (in %) = P x100/20

Where p is the plunger force in (kN) at 5mm penetration.

Table .5.9 Comparison between CBR value of 1:1, 2:1 and 3:2 respectively

Test results	ERA desirable limit	One cinder : One natural gravel	Two natural gravel :One cinder gravel	Three natural : Two cinder
Grading modulus	Minimum 1.5	2.63	2.6	2.46
OMC	-	12%	21%	13%
MDD	-	1.955gm/cm^3	1.835gm/cm^3	1.935gm/cm^3
CBR	>40%	150	75	79
AASHTO soil		A-1-a(0)	A-1-a(0)	A-2-4(0)

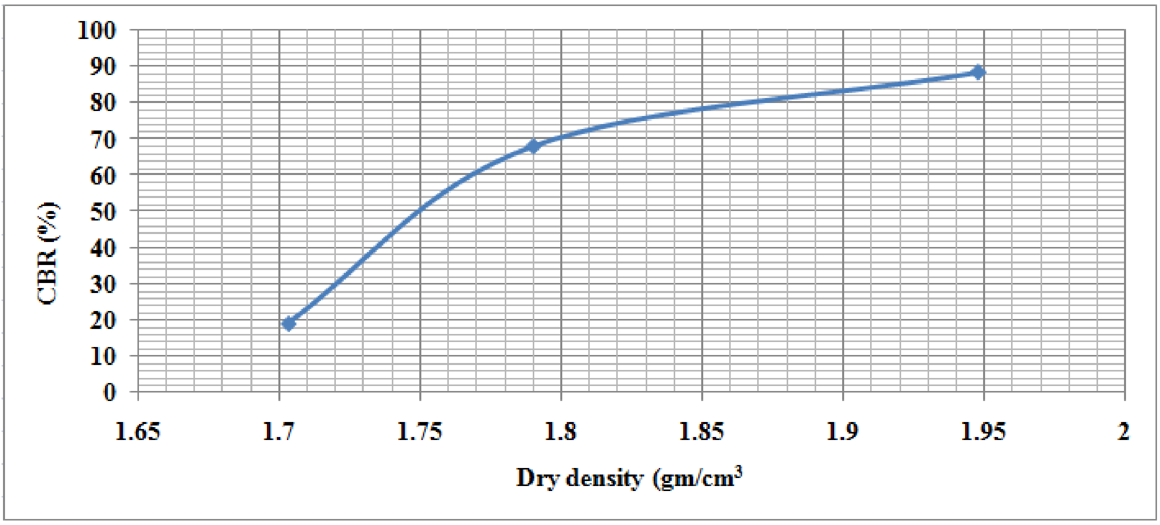


Fig.5.10 % of CBR- Dry Density relation ship

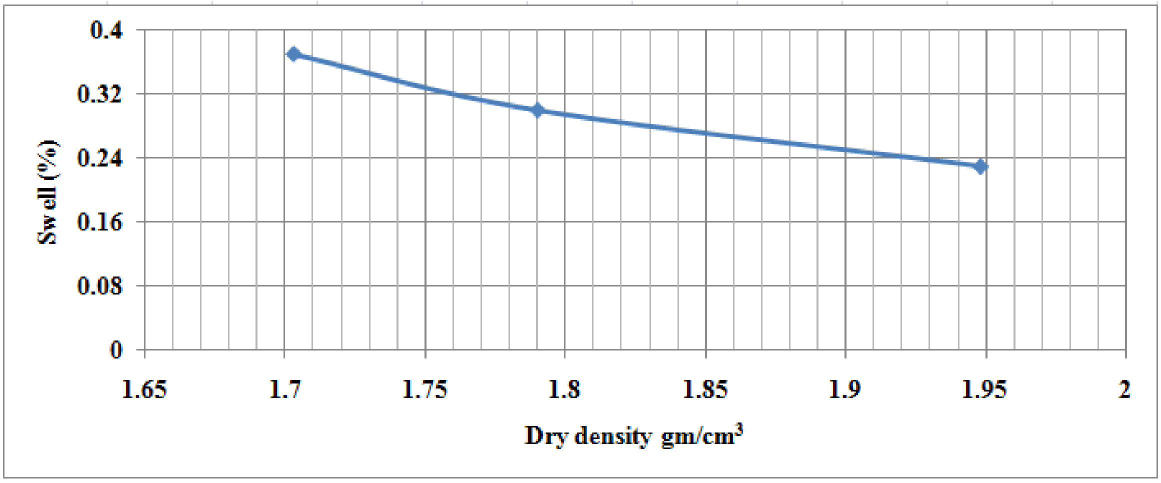


Fig.5.11 %swell and dry density

Table.5.10. Determination of CBR & Swell (%)

BLOWS	LOAD IN kN		CBR,%		SWELL%
	2.54mm	5.08mm	2.54mm	5.08mm	
10	2.53	3.67	19	18	0.37
30	8.96	12.86	68	64	0.30

From table5.9 clearly shows that, the CBR ,density and moisture content value of cinder is higher before blending while the grading modulus decrease and the soil group changes from A-1-a(0) to A-2-4(0). Similarly the swelling potential of blended cinder decreased as the dry density increase.

5.8 Loss Angeles Abrasion Test of blended cinder and natural gravel (3:2)

(AASHTO,1993 is a standard test method which measure degradation of mineral aggregates resulting from slow destruction, impact and grinding in a rotating drum containing a specified of steel spheres.

Loss Angeles Abrasion is used to determine the hardness, résistance of a given cinder & natural gravel during compaction. The Ethiopia Road Authority Manual (ERA,2002) Specification recommends that the Los Angeles Abrasion value shall not exceed 51% when determined in accordance with the requirements of AASHTO T-96.
A 5000 gram of volcanic cinder and natural gravel sample was placed in a drum with steel balls. The drum was rotated and the bolls grind down the aggregate particles. Soft Aggregates are quickly ground to dust, while hard aggregates lose little mass (SANRA, 2011).

Abrasion resistance applies only to coarse aggregates. Aggregates vary in their resistance to fracturing under impact (toughness) and breaking down into smaller pieces from abrasive action (hardness). The acceptable limits are set by the Los Angeles Abrasion Test AASHTO T-96. The limits vary from 30.0 to 50%, depending on the classification of the aggregate. The percentage is a measure of the degradation or loss of material as a result of impact and abrasive action.

For this reason a given amounts of blended volcanic cinder gravel have been sieved with 19 mm sieve size and the materials which were coarser than 19 mm sieve was discarded. Finally materials passing 12.5 mm sieve size and retained on 9.5 mm sieve was washed and placed in an oven for 24 hours. Lastly the Loss Angeles Abrasion value is calculated as follow:-

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

Table 5.11 shows loss Angeles abrasion value

Designation	Blended cinder with natural gravel(3:2)
No. of revolutions	5000
Total Wt.of Sample tested(gm)	5000
Wt.of tested Sample retained on 1.7mm sieve	3749
Weight loss	1251
Percent Loss (%)	25

Table 5.11 shows the abrasion test result of 5000gm of blended cinder (3:2) after linear Abrasion test at a rate of 1000RPM/1000 gm of sample. Finally the final% lost of blended cinder material is found 25% losses which satisfy the required standards.

5.9 Linear shrinkage of blended cinder and natural gravel (LS)

Shrinkage due to drying is significant in clays, but less so in silts and sands. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to the converse condition of expansion due to wetting.

Linear shrinkage is found by determining the change in length of semi-cylindrical bar sample of soil when it dries out, starting from near the liquid limit. The linear shrinkage value is a way of quantifying the amount of shrinkage likely to be experienced by clayey or other cementing material (ERA, 2002).

$$LS = \frac{\text{Length of wet soil bar} - \text{length of the dry soil bar}}{\text{Length of wet soil bar}} \times 100$$

Where: LW = length of the wet soil bar, mm LD = length of the dry soil bar, mm.

LS = 100(140mm -136mm)/140mm =2.8mm

5.10 Summery

A result obtained from index test indicates that blending of two volcanic cinders with three weathered natural gravel generally improves its engineering quality. Based on gradation analysis the final blending trial proportion is fully within the upper and lower limit of grading envelope. However, from grading modulus calculation even if the final mix satisfy the grading envelope still the material is dominated by coarse grained.

From Attereberg limit test the blended cinder gravel gradually improves from non plastic to plastic characteristics with plastic index value of 10. Similarly, from CBR test result the material have better bearing capacity than those specified for sub-base material by ERA.

Finally additional tests such as LAA and LS have been carried out on blended cinder (3:2) in order to measure degradation or loss of material as a result of impact, abrasive actions and quantifying how much the material will shrink or swell due to the presence of clayey stuff. Accordingly, the material was found with 25% of LAA and 2.8 of LS value and satisfies the ERA specification for sub-base construction.

CHAPTER SIX

CONCLUSION and RECOMMENDATIONS

This research was attempted to investigate blending proportion of volcanic cinder with natural gravel to be used as road sub-base material. For this purpose three volcanic cinders from the same source but different location and weathered natural gravel from Dukem have been collected during the research.

Accordingly, gradation were and sieve analysis were carried out on three volcanic cinder samples which obtained from the same source, but different location and depth before blending. Cinder gravels which has better grain size distribution have been selected for blending with natural gravel at 1:1, 2:1 and 3:2, respectively. Finally, all quality tests which are necessary for sub-base road construction have been performed to fulfill the ERA standards.

6.1 Conclusion

i. Volcanic cinders are pyroclastic materials which are mainly found within the main Ethiopian rift valley associated with recent volcanic activities. Rarely support any vegetation than grasses. This indirectly implies the weathering depth of the source material is not as such deep. It is also relatively easy to dig without heavy machinery except, a wheel loader to open the fence of the source.

ii. During the research two volcanic cinder gravel from the same source, depth (>2m) and one volcanic cinder from the same source but different location and depth (<2m) have been collected for gradation and sieve analysis. Based on AASHTO T-27 sieve and gradation analysis cinders have generally deficiency of fine grain material. However, the amount or % of fine grained soil material that passes sieve no.200 (0.075mm) still varies from source to source and depth.

iii. Cinder gravel which are found at relatively depper depth have higher amount of coarse grain material than shallow one. This might be due to several reasons such as, Degree of physical weathering, chemical alteration and the presence of tiny bedded volcanic ash deposit. Generally the amount of fine grained material that passes sieve no.200 (0.075mm) of C1, C2 and C3 were found 1.7%, 9.1% and 1.8% respectively.

iv. Even thought volcanic cinder gravel before blending satisfies the Ethiopian Road Authority grading specification yet the material is non plastic.

v. Results obtained from Atterburg limit or AASHTO T89-T91 standard test indicates cinder materials are none plastic. Indirectly the amount of fine grain or clay or any other cementing materials that have plasticity property is inadequate. This clearly indicates that cinders gravel have grain to grain contact with large amount of void space occupied either by water or air. This reduces density and makes compaction trial difficult.

vi. Results of sieve analyses that were performed after blending of cinder with natural gravel clearly show the fine grain deficiency of cinder material is improved either from the weak nature of cinder under compaction or from natural gravel. This enhance the amount of fine grain soil within a given soil sample.

vii. Comparison of dry density and CBR value where carried out between 60% of natural gravel and volcanic cinders only. As a result blending of 60% of natural gravel improves its dry density from 1.573gm/cm^3 to 1.935gm/cm^3 but CBR value reduces from 125% to 79% but it satisfy the ERA bearing capacity requirement for sub-base material.

viii. During three-point CBR testing investigation the cinder gravels 'were not affected by changes in moisture and even complete immersion in water only reduced their strength slightly and this will enhance the advantage of using cinders in wet climatic region where the ground water level is near and can adversely affect the pavement sub-base.

xi. The addition of locally available weathered natural gravel to make up for the deficiency of fine material in the grading improved the stability of cinder gravels and indicated that this could be a useful construction practice.

x. Blending of 50% volcanic cinder with 50% of natural gravel and 67% of natural gravel with 33% of volcanic cinder has no plasticity characteristic and its plastic product is zero.

xx. Blending of 40% of volcanic cinder with 60% 0f natural gravel improves its index properties and readily can be used for sub-base road construction as far as it satisfy ERA sub-base materials requirements. Additionally this can play significant role in project cost minimization, time, and man power and preserving selected source materials to be used for other major mega project.

6.2 Recommendation

The current research and previous study carried out so far indicates that, cinder gravels should make useful road construction materials especially for gravel roads.

Previous research on volcanic cinder gravels basically deals with mechanical stabilization of cinder with fine grained soil and cement for base and sub-base road construction. However, since fine grained soil by itself is hard to obtain everywhere in the construction project blending of volcanic cinder with weathered natural gravel should be practiced.

Caution should be exercised in interpreting, using of scoria and cinder gravels for different pavement section. This is because since scoria and cinder gravel have their own grain size randomly using those material may affect their grading properties.

The grading analyses of cinder gravels are mostly out of standard specification. However, as far as volcanic cinders are different from source to source in terms of degree of weathering (Chemical or physical) and grain size distribution, mixing of two different cinder gravel should be practiced in order to improve their deficiency of fine grained soil.

Mixing of volcanic cinder gravel with local available earth material should be done on stockpile than roadmix.This prevents further breakdown of volcanic cinder which can affect its strength and makes it to easily wash away by erosion under water and sometimes by wind.

Finally further work, however, is necessary to examine a range of cinder gravels' under known conditions of traffic and climate in bituminous surfaced roads as well as in gravel roads before limits can be recommended for their various uses.

REFERENCES

AACRA (Addis Ababa City Roads Authority), (2003). Pavement Design and Rehabilitation Manual. Unpublished technical report, AACRA, Addis Ababa, Ethiopia, 32 pp.

Bekele Abebe., Acocella, V., Tesfaye korma., Derege Ayalew. (2007). Quaternary faulting and volcanism in Addis Ababa, Ethiopia, 150 pp.

AASHTO (American Association of State Highway and Transportation Officials), (1993). Guide for Design of Pavement Structures. Washington D.C.

American Association of State Highway and Transportation Officials (1993). AASHTO Guide for Design of Pavement Structures. Washington D.C.

Annual Book of ASTM (American Society for Testing and Materials) Standards (1988), Soil Mechanics and Foundation, 11th edn. A Saurabh and Co. publication.

Biraj Gautam,(2010) Optimum Use of Local Material for Roadway Base and Marino Engineering Associates, Inc.

Casey, M., Ebinger, C., Keir, D., Gloaguen, R., Mohamed, F. (2006). Strain accommodation in transitional rifts: extension by magma intrusion and faulting in Ethiopian rift magmatic segments. In: Yirgu, G., Ebinger, C., Maguire, P. (Eds.), the Afar Volcanic Province within the East African Rift System. Special Publication of the Geological Society, London, pp. 143–164. Ethiopia (Scale 1:2,000,000), 2nd edition. EIGS. Bull No. 3.

Collins RJ and Ciesielski SK. (1994). Recycling and use of waste materials and by-products in highway construction. Synthesis of Highway Practice199, National Cooperative Research Program (NCHRP), Transportation Research Board, Washington, DC.

ERA (Ethiopian Road Authority), (2002).Pavement design manual. Unpublished technical report, ERA, Addis Ababa, Ethiopia, 8pp.

Fisher, R.V. (1961). Proposed classification of volcanoclastic sediments and rocks. Geological Society of America Bulletin **72**:1409–1414.

FAO (1984e), Provisional Soil Map of Ethiopia. Land Use Planning Project. Addis Ababa, Ethiopia.

GSE (Geological Survey of Ethiopia), (2010).Geology of the Akaki-Beseka area (NC3-14) Ministry of Mines,E.I.G.S,Unpublished Report,GSE,Addis Ababa,Ethiopia,80pp.

Girma Birhanu. (2009). Stabilizing Cinder Gravels for Heavily Trafficked Base Course. Journal of EEA. **26**: 24-29.

Jennings, J.E.and Brink, A.B.A. (1961). A guide to profiling for civil engineering purposes in South Africa.Trans.S.Afr.Instn.Civil Engs.pp.145-151.

Lawrance, C.J. (1975). The use of punched cards in the storage and retrieval of engineering information. ERA/TRRL (UK) Joint Road Research Project JRRP Report No 2 Addis Ababa, Ethiopian.

Mohr, P.A, (1967a), The Ethiopian rift system. Bulletin of the Geophysical Observatory 3 (1), 33-62.

Mohr, P.A. (1967b), Major volcano-tectonic lineament in the Ethiopian rift system. Nature 213 (5077), 664–665.

MoA (Ministry of Agriculture), (2000). Agroecological Zonations of Ethiopia. Addis Ababa, Ethiopia.

Newil, D., Robinson, R. and Kassaye Aklilu. (1987).Experimental Use of Cinder Gravels on Roads in Ethiopia. In: Proceedings of the 9th Regional Conference for Africa on Soil Mechanics and Foundation Engineering. Crowthorne, Lagos, pp. 467-488.

Newill, D, and Kassaye Aklilu, (1980). The location and engineering properties of volcanic cinder gravels in Ethiopia, In: Seventh Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Rotterdam, Accra, Ghana pp.21-32.

Osburn, J.C. (1982). Scoria exploration and utilization in New México. Pages 57–59 in Industrial Rocks and Minerals of the Southwest. Circular 182. Compiled by G.S. Austin. Socorro: New Mexico Bureau of Mines and Mineral Resources.

Peccerillo, A., Barberio, M.R., Yirgu, G., Ayalew, D., Barbieri, M., Wu, T.W. (2003). Relationships between mafic and peralkaline silicic magmatism in continental rift settings: a petrological, geochemical and isotopic study of the Gedemsa volcano, central Ethiopian rift. Journal of Petrology ***44*** (11), 2003–2032.

Schmid, R. (1981). Descriptive nomenclature and classification of pyroclastic deposits and fragments - recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks.Geology ***9***:41–43.

CSAE (Central Statistic Authority of Ethiopia), (1999). Ethiopia, Summary and Statistical Report of the Population and Housing Census,

Saltan and findik,(2007) Stabilization of sub-base layer materials with waste pumice in flexible pavement Mehmet Saltan_, F. Selcan Findik Engineering and Architectural

Faculty, Department of Civil Engineering, Suleyman Demirel University, West Campus, 32260 Isparta, Turkey

South African National Roads Agency (SANRA) (2011).Pavement design manual, Pretoria, Republic of South Africa, 2-11pp

Tamiru Alemayehu,(2006) Groundwater Occurrence in Ethiopia.

Tamiru Alemayehu, Tenalem Ayenew, Dagnachew Legese, Yirga Tadesse, Solomon Waltenigus and Nuri Mohamed (2006). *Ground water Vulnerability mapping of the Addis Ababa Water Supply Aquifers.* Addis Ababa University, Department of Geology & Geophysics (AAU) and Addis Ababa Water & Sewerage Authority (AAWSA),Addis Ababa, Ethiopia.

Tefera, Mengesha., Tesfaye, Chernet. and Haro. W. (1996). Exploration of the Geological Map of The main Ethiopian Rift. Journal of African Earth Sciences ***48*** (2–3), 115–124.

Tesfaye Chernet (1993). Hydrogeology of Ethiopia and Water resources Development. Ethiopian Institution of Geological Survey note p222.

Tyrone O. Rooney a,*, Ian D. Bastow b, Derek Keirc, (2010). Insights into extensional processes during magma assisted rifting: Evidence from aligned scoria cones. Journal of Volcanology and Geothermal Research 2-14

Williams, F.M., Williams, M.A.J., Aumento, F. (2004). Tensional fissures and crustal extension rates in the northern part of the Main Ethiopian Rift. Journal of African Earth Sciences ***38*** (2), 183–197.

Wood, C.A. (1980a), Morphmetric analysis of cinder cone degradation. Journal of Volcanology and Geothermal Research ***8***:137–160.

Wood, C.A. (1980b). Morphometric evolution of cinder cones. Journal of Volcanology and Geothermal Research **7**:387–413.

Yitayou Eshete. (2011). Blending of cinder with fine grained soil to be used as Sub-Base materials (The Case of Butajira-Gubre Road Project) unpublished Mater Thesis, Addis Abba University, Addis Ababa, Ethiopia, 36 pp

APPENDECIS

Appendix-A Monthly precipitation of Akakai area (2000-2013)

Table A-1 Monthly precipitation of Akakai area (2000-2013)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.0	0.0	29.1	93.0	64.9	100.1	188.9	210.0	124.1	17.2	23.4	3.8
2001	0.0	20.7	121.2	23.6	118.0	142.6	257.5	145.0	64.9	2.2	0.0	0.0
2002	31.1	10.5	87.8	53.9	76.6	108.0	167.1	166.3	52.3	0.0	0.0	17.7
2003	19.6	24.8	23.9	114.0	1.4	125.4	325.1	307.4	113.4	0.0	0.0	40.8
2004	15.6	15.8	61.4	154.5	15.4	95.2	150.3	189.1	80.9	4.8	3.4	0.7
2005	28.8	7.3	47.9	112.2	140.7	139.9	218.7	231.4	152.7	9.1	15.2	0.0
2006	2.6	44.2	56.3	79.7	22.0	84.3	276.4	262.6	148.1	38.0	0.0	3.2
2007	34.2	24.7	25.6	96.8	64.6	132.7	254.2	221.8	148.5	14.3	1.3	0.0
2008	0.0	0.0	0.6	34.2	62.4	140.2	253.5	252.3		7.2	64.8	0.0
2009	60.2	0.0	10.0	118.7	47.7	63.5	235.3	322.4	71.3	32.8	4.0	16.8
2010	0.0	63.8	126.2	170.0	95.2	164.8	334.4	169.8	154.1	5.2	14.8	7.8
2011	0.0	2.5	45.2	20.7	128.7	60.0	204.3	304.0	194.5	0.0	4.7	
2012	0.0	0.0		61.0		80.6	228.0	243.9	122.9	0.0	0.0	0.0

Table A-2 Maximum temperature of the Akaki area (2000-2013)

2000	26.2	27.1	27.7	0.0	27.1	0.0	24.6	23.8	24.7	25.2	25.7	25.8
2001	26.3	27.3	26.2	27.7	26.9	25.6	24.6	24.7	25.8	26.9	26.5	26.4
2002	26.0	27.6	27.5	27.9	28.5	26.9	25.8	24.7	26.1	27.0	26.5	26.2
2003	26.7	28.3	28.0	27.3	28.9	27.1	23.7	23.6	24.9	26.6	26.6	25.6
2004	27.4	27.5	27.8	26.5	28.6	26.3	24.7	24.3	25.7	25.9	26.6	26.7
2005	27.1	29.0	28.2	27.8	26.8	26.3	23.7	24.5	24.6	26.2	26.3	26.1
2006	26.5	27.9	27.9	27.3	28.6	26.0	24.3	23.8	24.9	26.4	25.8	25.6
2007	26.3	27.4	28.8	27.5	28.2	25.5	23.9	23.4	24.7	26.0	25.8	25.8
2008	27.2	27.0	29.3	29.0	29.0	25.6	24.0	23.3	24.9	26.4	25.2	26.2
2009	26.5	28.0		28.5	30.0	29.3	24.5	24.4	26.0	25.9		
2010	27.0	27.2	26.9	27.5	27.2	26.8	23.4	23.7	24.7	26.7	26.0	26.2
2011	26.6	28.1	27.6	29.5	28.7		25.3		25.2	26.6	26.2	25.7
2012	26.8	26.9		27.8	29.7	27.4	24.1	24.0	25.1	26.7	26.9	26.5
2013	27.0	0.0	29.1	28.9	28.2	26.7	24.5	23.6	25.9	26.0	26.1	25.1

Table A-3 Minimum monthly temperature of Akaki area (2000-2013)

2000	9.3	10.0	12.9	15.0	15.7	13.9	14.0	14.2	14.2	13.4	11.8	10.4
2001	10.1	11.5	13.4	15.3	15.5	14.0	13.9	14.7	13.6	13.1	14.4	15.2
2002	15.4	16.4	14.3	14.6	15.8	14.8	14.5	14.2	13.8	13.8	12.7	13.9
2003	11.8	13.2	14.2	15.1	15.0	15.1	14.2	14.1	15.0	14.9	14.9	12.8
2004	14.6	14.2	14.6	15.9	16.2	15.6	14.7	14.6	14.9	14.6	14.2	14.5
2005	13.6	15.2	16.5	16.2	16.1	15.4	15.8	15.5	15.6	16.0	14.6	13.6
2006	15.3	15.4	15.5	16.0	16.3	15.3	15.1	15.3	15.4	15.6	15.0	14.8
2007	15.0	15.1	15.6	16.2	16.5	15.3	16.6	16.7	17.3	17.4	17.1	16.5

2008	17.8	18.0			17.7	16.5	14.4	14.3	15.6	16.0	14.2	14.0
2009	14.3	16.1	17.0	17.2	17.9	18.2	15.3	15.7	16.3	15.7		
2010	13.6	14.6	15.3	16.3	16.5	14.2	13.2	13.2	12.7	9.4	7.8	7.4
2011	9.3	8.5	9.9	12.4	13.2		12.6	13.0	12.8	8.2	18.1	
2012						11.9	12.5	12.3	11.7	8.8	7.5	3.4
2013	4.1	5.0	8.5	8.7	8.3	8.1	8.8	8.4	7.2	7.7	8.8	6.7

Table A-4 Grain size analysis of volcanic cinder and natural grave before blending (01)

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
50	0	0	100
37.5	200.7	22.3	77.7
25	99.3	11	66.7
19	53.4	5.9	60.8
12.5	94.3	10.5	50.3
9.5	51.9	5.8	44.5
6.3	78.3	8.7	35.8
4.75	57.9	6.4	29.4
2.36	92.6	10.29	19.1
2	23.1	2.6	16.5
1.18	23.1	2.6	13.9
0.85	13.8	1.53	12.4
0.6	19.4	2.16	10.2
0.425	12.1	1.34	8.9
0.3	21.8	2.4	6.5
0.15	27.4	3	3.4
0.075	15.9	1.8	1.7
pan	**885**	**98.32**	

Weight before washing = 900gm, weight after washing= 885gm and loss =15gm

Table A-5 Grain size analysis of volcanic cinder and natural grave before blending (02)

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
75	0	0	100
63	201.4	13.5	82.4
50	0	0	69.2
37.5	60	4	49.73
25	32.7	2.19	42.73
19	92.4	6.2	33.03
12.5	131.6	8.8	28.03
9.5	63.1	4.2	19.43
6.3	104.7	7	16.93
4.75	87.3	5.9	14.43
2.36	182	12.23	12.49

2	59.6	4	9.49
1.18	59.5	3.99	7.8
0.85	42.7	3.98	4.16
0.6	59.4	3.97	2.81
0.425	30.9	0.2	2.43
0.3	51.4	3.45	3.56
0.15	62	4.16	4.1
0.075	30.8	2	2
pan	**1352**	89.77	

Weight before washing =1488, weight after washing =1352gm and loss 136gm

TableA-6 Grain size analysis of volcanic cinder and natural grave before blending (03)

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
37.5	0	0	100
25	233.4	17.6	82.4
19	175.6	13.2	69.2
12.5	257.8	19.47	49.73
9.5	94.7	7	42.73
6.3	127.9	9.7	33.03
4.75	68.6	5	28.03
2.36	114.2	8.6	19.43
2	33.4	2.5	16.93
1.18	33.3	2.5	14.43
0.85	25.7	1.94	12.49
0.6	42	3	9.49
0.425	22.5	1.69	7.8
0.3	48.2	3.64	4.16
0.15	17.9	1.35	2.81
0.075	5	0.38	2.43
pan	**1300**	**97.57**	**0**

Weight before washing =1324gm and Weight after washing =1300gm
Total weight loss =24gm

Table A-7 Grain size analysis of volcanic cinder and natural grave before blending (04)

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
70	0	0	100
63	498.4	21.1	82.4
50	318.3	0	69.2
37.5	211.1	4	49.73
25	150	2.19	42.73
19	230.6	6.2	33.03
12.5	179.6	8.8	28.03
9.5	84.2	4.2	19.43
6.3	107	7	16.93
4.75	62	5.9	14.43
2.36	81.7	12.23	12.49

2	23.1	4	9.49
1.18	23	3.99	7.8
0.85	13.2	3.98	4.16
0.6	16.4	3.97	2.81
0.425	10.7	02	2.43
0.3	16.9	3.45	3.56
0.15	29.2	4.16	4.1
0.075	17.8	2	2
pan	**2073**	**98.17**	

Weight before washing 2357gm and weight after washing 2073gm = 284gm loss

Appendices -B

Atterbereg limit test result of volcanic cinder (02) and natural gravel (04)

Table B-1 Atterbereg limit test result natural gravel (04)

	LIQUID LIMIT				PLASTIC LIMIT	
	1	2	3	4	1	2
N0. Of blows	36	26	15			
Tare	E46	A16	A51		A31	A71
Wt.Tare +wet soil g	37.88	32.87	35.76		24.14	24.98
Wt.Tare + dry soil g	30.95	26.65	28.68		22.53	23.07
Wt.water g	6.93	6.22	7.08		1.91	1.61
Wt.of Tare g	17.57	14.68	15.16		16.66	16.09
Wt. of dry soil g	13.38	11.97	13.52		5.87	6.98
No. of blows N	36	26	15		Average plastic limit	
Moisture content %	51.79	51.96	52.37		27.43	27.36
					LL	52
					PL	27
					PI	25
Passing sieve%				2mm	0.425mm	0.075mm
				17	15	12
AASHTO SOIL CLASIFICATION	A-2-7 (0)					

Table B-2 Atterbereg limit test result of volcanic cinder (02)

	LIQUID LIMIT				PLASTIC LIMIT	
	1	2	3	4	1	2
N0. Of blows						
Tare						
Wt.Tare +wet soil g						NP
Wt.Tare + dry soil g		NP				
Wt.water g						
Wt.of Tare g						
Wt. of dry soil g						
No. of blows N					Average plastic limit	
Moisture content %						
					LL	

					PL	
					PI	
Passing sieve%				2mm	0.425mm	0.075mm
				17	15	12
AASHTO SOIL CLASIFICATION A-2-7 (0)						

Appendices -C

Atterbereg limit and gradation of blended cinder gravel (1:1), (2:1) and (3:2)

Table C-1 Atterbereg limit and gradation of blended cinder gravel (1:1)

	LIQUID LIMIT				PLASTIC LIMIT	
	1	2	3	4	1	2
N0. Of blows						
Tare						
Wt.Tare +wet soil g						NP
Wt.Tare + dry soil g		NP				
Wt.water g						
Wt.of Tare g						
Wt. of dry soil g						
No. of blows N					Average plastic limit	
Moisture content %						
					LL	
					PL	
					PI	
Passing sieve%				2mm	0.425mm	0.075mm
				18	12	7
Aashto soil classification A-1-a (0)						

Table C-2 Sieve analysis

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
50	0	0	100
37.5	52.1	1.59	98.4
25	255.6	7.8	90.6
19	536.8	16.39	74.2
12.5	661.2	20.19	54
9.5	398.8	12.18	41.8
6.3	302.4	9.23	32.8
4.75	160.9	4.9	27.7
2.36	252.7	7.7	20
2	69.7	2.12	17.8
1.18	69.7	2.1	15.7
0.85	41.2	1.25	14.4
0.6	50.2	1.5	12.9
0.425	38.7	1.18	11.7
0.3	44.5	1.36	10.4
0.15	78	2.38	8
0.075	43.6	1.33	6.7
pan	**3056**	**98.9**	

Table C-3 Atterbereg limit and gradation of blended cinder gravel (2:1)

	LIQUID LIMIT				PLASTIC LIMIT	
	1	2	3	4	1	2
N0. Of blows						
Tare						
Wt.Tare +wet soil g						NP
Wt.Tare + dry soil g		NP				
Wt.water g						
Wt.of Tare g						
Wt. of dry soil g						
No. of blows N					Average plastic limit	
Moisture content %						
					LL	
					PL	
					PI	
Passing sieve%				2mm	0.425mm	0.075mm
				17	12	9
Aashto soil classification	A-1-a (0)					

Table C-4 sieve analysis of blended cinder (2:1)

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
63	0	0	100
50	230.7	7.6	92.4
37.5	219.3	7.2	85.1
25	575.2	19	66.1
19	398.8	13.17	53
12.5	361.9	11.95	41
9.5	186.4	6.15	34.8
6.3	205.1	6.8	28.1
4.75	109.5	3.6	24.4
2.36	186.8	6.17	18.3
2	50.5	1.7	16.6
1.18	50.4	1.7	14.9
0.85	31.8	1	13.9
0.6	34.6	1.14	12.8
0.425	24.2	0.8	12
0.3	29.5	0.97	11
0.15	39.1	1.29	9.7
0.075	19.8	0.65	9
pan	**2753.6**	**96.8**	

Weight before washing 3027gm and weight after washing 2753.6 =273.4gm weight loss

Table C-5 Atterbereg limit and gradation of blended cinder gravel (3:2)

	LIQUID LIMIT				PLASTIC LIMIT	
	1	2	3	4	1	2
N0. Of blows	36	26	15			
Tare	E46	A16	A51		A31	A71
Wt.Tare +wet soil g	37.88	32.87	35.76		24.14	24.98
Wt.Tare + dry soil g	30.95	26.65	28.68		22.53	23.07
Wt.water g	6.93	6.22	7.08		1.91	1.61
Wt.of Tare g	17.57	14.68	15.16		16.66	16.09
Wt. of dry soil g	13.38	11.97	13.52		5.87	6.98
No. of blows N	36	26	15		Average plastic limit	
Moisture content %	51.79	51.96	52.37		27.43	27.36
					LL	52
					PL	27
					PI	25
Passing sieve%				2mm	0.425mm	0.075mm
				17	15	12
Aashto soil classification	A-2-4 (0)					

Table C-6 sieve analysis of blended cinder (3:2)

Sieve size in mm	Wt.Retained	% Retained	Cum.% passing
50	0	0	100
37.5	185	1.59	95.6
25	582.9	7.8	81.5
19	356.8	16.39	73
12.5	618.7	20.19	58.1
9.5	346.8	12.18	49.8
6.3	375.6	9.23	40.7
4.75	210.3	4.9	35.7
2.36	364.1	7.7	26.9
2	102.8	2.12	24.4
1.18	102.8	2.1	22
0.85	64.4	1.25	20.4
0.6	74.5	1.5	18.6
0.425	56.8	1.18	17.3
0.3	58	1.36	15.9
0.15	100	2.38	13.5
0.075	49.7	1.33	12.3
pan	**3649**		

Weight before washing 4160gm and weight after washing3649gm = 511gm

APPENDICS D

Standard ,Index Tests and photos taken during sampling as well as ground verification

Table D-1 Standards used during index test

Symbols	Used
AASHTO T89-T91	Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soil
AASHTO T-193	Standard method for measuring bearing capacity
AASHTO T-27	Test Method for Sieve Analysis of Fine and Coarse Aggregates
AASHTO T-92	Standard Methods for linear shrinkage
AASHTO T 96-77	Standard methods for Los Angeles Abrasion

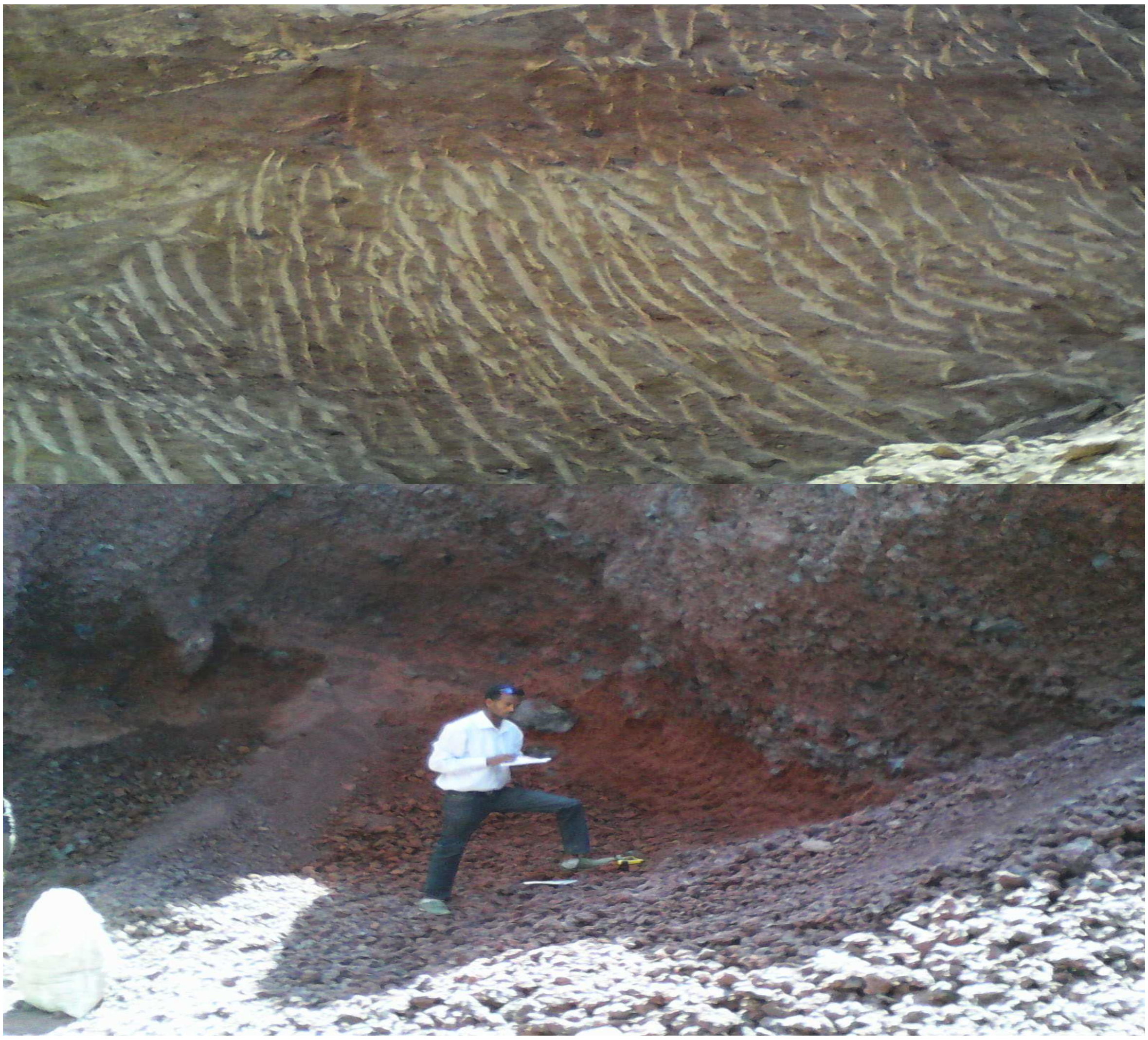


Plate .D-2 Photo taken during sampling and visual assessment of the source material.

Fig.D-3 Finished sub-base layer of the road.

Fig.D-4 Photo during petrographic analysis

Declaration

I hereby declare that the thesis entitled “Blending of Volcanic cinder for sub-base road construction” (a Case study of Gelan Asphalt Road project), Addis Ababa, Ethiopia has been carried out by me under the supervision of Tirufat Hailemariam (PhD), and Gezhagne Yirgu (Prof.), Department of Geology, Addis Ababa University, Addis Ababa during the year 2015 as partial fulfillment of MSc Degree program in Engineering Geology. I further declare that this work has not been submitted to any other university or institution for the award of any degree or diploma, and also that all source of materials used the thesis work has been properly acknowledged

…………………………………… ….…………………...

Gebretsadik Mesfin (Candidate) Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and it has been submitted for examination with my approval as a university advisor.

………………………………. …………………………

Tirufat Hailemariam (Main Advisor) Date

……………………………….. ……………………………

Gezhagne Yirgu (Co Advisor) Date