JIMMA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

EVALUATION OF THE SUITABILITY OF LATERITIC SOIL OF JIMMA ZONE AS ROAD CONSTRUCTION MATERIALS

BY

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APRIL, 2016

JIMMA , ETHIOPIA

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE DEGREE OF MASTER OF SCIENCE IN GEOTECHNICAL ENGINEERING.

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APRIL, 2016

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DECLARATION

This thesis is my original work and has not been presented for degree in any other university

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This thesis has been submitted for examination with my approval with university supervisors

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ACKNOWLEDGEMENTS

First and for most I would like to give my glory and praise to the almighty God for giving me all the strength and hope to accomplish my research paper.

I am greatly indebted to my advisor, Dr. Fikadu Fufa, for his invaluable comments, encouragements and guidance for the preparation of this thesis. Besides, I would like to extend my gratitude to Murad Muhammed (MSc) for his cooperation and constructive comment for the accomplishment of this paper.

My Special thanks and deepest gratitude also go to all of my families for their encouragement, especially for my mother & dad for her all spiritual support Aki, even if I lost you at this moment, by the help of God your dream becomes real.

The financial support received from the Ethiopian Road Authority fund is appreciated.

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ACRONYMS

AASHTO	American Associate State Highway and Transportation Official
AD	Air Dried
AR	As Received / at natural moisture content /
ARTBA	American Road & Transportation Builders Association
ASL	Above Sea Level
ASTM	American Society for Testing Material
CBR	California Bearing Ratio
EBCS	Ethiopian Building Code of Standard
ERA	Ethiopian Road Authority
GI	Group Index
GSE	Geological Survey of Ethiopian
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
OD	Oven Dried
PI	Plastic Index
PL	Plastic Limit
S	Soaking
USCS	Unified Soil Classifications System
X-RD	X-Ray Diffraction

ABSTRACT

Lateritic soils are highly weathered and altered residual soils reach in secondary oxides of iron, aluminum, or both formed by the in-situ weathering and decomposition of parent rocks under tropical and sub tropical regions with hot, humid climatic conditions. Their formation process involves the leaching out free silica and base and accumulation of oxides of iron, aluminum oxide or both. Due to the presence of iron oxides lateritic soils are red in color.

Geotechnical investigation is one of the effective means of detecting and solving pre and post construction problems. The Geotechnical properties of lateritic soils and their suitability for road construction have been evaluated for selected site in Jimma zone, Oromiya, Ethiopia. The principal purpose of this investigation is to obtained the geotechnical properties of lateritic soil of Jimma zone with aim of providing a valuable data base for emerging road construction which hasten the development of the country in order to support poverty reduction measure that have been taking place in the country, a total of twenty seven (27) samples at depth of 1.0 to 3.0 m after removing overburden soil at different pre-treatment condition were collected from nine(9) different locations in the zone namely Agaro, Jimma ,Serbo, Limu, Sokoru, Babu, Yebu, Seka and Dedo.

All the analysis were carried out in accordance with the standard given by ASTM testing procedures The soil specimens were tested at different sample preparation prior to testing. The research will be conducted by using both descriptive and analytical methods the test carried out on the soil sample includes geochemical test which are X-Ray Diffraction chemical tests as well as engineering property test which include moisture content, specific gravity, grain size analysis, Atterberg limit test, compaction and California Bearing ratio.

Lateritic soil sample of Sokoru have been poor to fair in their properties and satisfy the criteria for sub grade only; Samples from Agaro, Seka & Dedo are fair in their properties and used for sub grade and lateritic soil samples from Jimma, Serbo, Limu ,Babu & Yebu are good in their general properties and used for base & sub base according to Bowls and using Ethiopian Road Authority Design Manual the lateritic soil samples of Agaro ,Sokoru and Seka satisfy the condition for poor value as sub grade ; lateritic soil samples of Serbo, Limu, Babu & Limu satisfy *good as sub grade materials & lateritic soil sample of Jimma only satisfy good to excellent as sub grade materials as sub grade materials from the calculated value.*

In order to use the lateritic which are widely distributed in Ethiopia as materials in road construction proper selection criteria should be used .The use of lateritic soil for road construction has been done using the in appropriate specifications, i.e. those developed for the climate conditions of Europe and North America .It is clear that in order to reduce the wastage of a valuable resource many countries has been prepared their own specification. Therefore it is suggested that a detailed investigation to be carried out and the specifications (selection criteria) adapted for lateritic soil of Jimma zone as road construction materials.

Key word: Evaluation, lateritic, suitability, road construction.

CHAPTER ONE: INTRODUCTION

1.1. Background of the Study

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of parent rock s under tropical and sub tropical climatic conditions. Their formation process involves the leaching out free silica and base and accumulation of oxides of iron, aluminum oxide or both. Due to the presence of iron oxides lateritic soils are red in color. Lateritic soils are the product of intensive weathering that occurs in accumulation of hydrated iron and aluminum oxides (Alexander and Candy, 1962; Gidigasu, 1972).

Lateritic soils are reddish tropical soils that have gained a wide range of utilization as construction materials in roads, houses, airfield pavement and landfill for foundation. Pathogenic factors also known as soil forming factors such as climate, drainage, vegetation, chemical and mineralogical composition and degree of weathering control engineering properties of lateritic soils Since lateritic and lateritic soils have no reasonable constant properties i.e. they are variable and erratic in nature (Mesida, 1985).

The properties of lateritic soils are influenced by geology, climate and the degree of weathering. It has been found that the geotechnical properties of these soils in different countries are also different. Lateritic soils formed on the same parent rock in the same tropical country, but under different climatic conditions have different geotechnical properties (Umarany, and Williams, 1990). Lateritic and lateritic soils are found almost everywhere in the tropics and non tropics with wide applications (B.S.Badmus, 2010).

Lateritics have been widely used for foundations and other construction purposes in subtropical and tropical regions, where they are deposited abundantly. For any soil to be utilized for civil engineering works there is need for its investigation to enable the engineers to use the soil economically, to predict their engineering properties and their performance under field conditions, with a fairly good degree of accuracy(Blight,1997).

Lacroix (1913) classified lateritic into true lateritic, silicate lateritic and lateritie clays, on the basis of the hydroxides content, and this was developed further by (Martin and Doyne,1930) with the application of a silica-alumina ratio, the definition has been based on the ratios of silica (SiO_2) . Alexander and Cady (1962) reintroduced the concept of hardening and its relationship to the crystallization of iron oxides and dehydration. The classification has been based on the ratio of silica (SiO_2) to Sesquioxides (Fe_2O_3, Al_2O_3) with the ratio between 1.33 and 2 was therefore proposed for lateritic soils. Values greater than 2.0 are indicative or non-lateritic soil (Bell, 1993, Blight, 1997).

The study of engineering properties of Africa soils began before some decades , few engineers has shown interest in this study; hence, there is a paucity of geotechnical data .The few studies have been carried out in our country .Several researchers have worked on the geotechnical properties of lateritic soils. Jackson(1980) reported that lateritic soils have been used successfully as base and sub-base materials in the construction of roads, highways, airfields, and earth dams and as the foundation of structures (Blight,1997).

In many countries of Africa there is a growing realization of the cost effectiveness of up grading and new constricting road projects. This has challenged road authorities to make optimum use of naturally occurring materials which are often rejected by specifications for use in road construction materials. One such naturally occurring material is lateritic soil which is a type of residual soil that occurs extensively in the tropical and sub-tropical zones of the world, including much of central, southern and western Africa. Fortunately, research carried out in the late 1960s in a number of countries, notably in Angola, Mozambique, Brazil,Australia and Nigeria indicates that the performance of lateritic has often been better than expected on the basis of their specifications. However, if successful use is to be made of this material, the conditions under which it can be successfully used must be carefully specified (Dr.Frank Netter berg, 2014).

The lateritic soils are used as pavement construction when their special characteristics are carefully recognized. Because of their structural strength can be very suitable as Sub-grade, sub- base and surfacing materials. Some of them are even suitable for good quality airfield pavements. Although lateritics are resistant to the effects of moisture, there is a need for good drainage to prevent softening and breakdown of the structure under repeated loadings. Lateritic can provide a suitable low-grade wearing course (Olugbenga ;Oluwole ; and Iyiola ; 1986).In the Niger Delta, exploration and exploitation for oil and gas has been going on for over five decades. This has resulted in massive construction of roads in the region. Lateritic soils in the region have been the major Construction material for these roads (Ugbe, 2011).

The index properties of red, highly weathered lateritic soils of Jimma zone are presented in this study. Chemical and mineralogical properties are the criteria for distinguishing between lateritic materials and those only partially laterite.

This thesis work provides some basic engineering properties of lateritic soil of Jimma zone.

1.2. Statement of the Problem

There is no previously done research on lateritic soil of Jimma zone, thus paper gives us better understanding about the behavior of the lateritic soil of the zone. Identifying the soil characteristic is essential to determine the type of test and test procedure that is applied during sampling, sample preparation and testing.

A common error is to be assumed that because the soil are from the same region their Engineering properties will be the same, However, Adeyemi and Wahab (2008) have established that there could be significant variability in geotechnical properties of lateritic soils within quite short distances (Ugbe, 2011).The engineering properties of such soils have not been studied well and due to this reason roads constructed around this area face a shortage of construction materials (Braja M., 2002).

Several studies at deferent time have been reported on the geotechnical characteristics of lateritic soil; through numerous conflicting viewpoints which are appropriate to confuse most engineers. Available data on geotechnical characteristic of lateritic soil show that these soils range in performance from excellent to poor for engineering purposes (Gidigashu, 1976).As mentioned by Ethiopian Road Authority design manual (ERA, 2001).Lateritic soil is a widely available material in Ethiopia and now a day's most infrastructures of the country have been constructed in the area where lateritic soils are widely available (ERA pavement Design Manual, 2002).As Jimma Zone Road Authority 2005 & 2006 report, in some project of the zone the scarcity and non availability of construction materials occurs and become a major worry to the federal and regional road authority and cause unexpected increment of project costs, but by determining the Engineering properties of Lateritic soils of the zone such problem is solved and substitute with lateritic soil which its properties fit with the given specifications, there has been an urgent need for an up to date review of geotechnical characteristics of lateritic soils.

The principal purpose of this investigation is to obtained the geotechnical properties of lateritic soil of Jimma zone with aim of providing a valuable data base for emerging road construction which hasten the development of the country in order to support poverty reduction measure that have been taking place in the country,

1.3. Objectives

1.3.1. General Objective

The general objective of this study is to evaluate the engineering properties of lateritie soil of Jimma zone for the road construction materials.

1.3.2 Specific Objectives

1. To characterize mineralogical and chemical composition of lateritic soil of Jimma zone.
2. To determine the degree of laterization of Jimma zone lateritic soil.
3. To determine the geotechnical properties of lateritic soil of Jimma zone.
4. To evaluate the conformance of lateritic soil of Jimma zone with the standard specifications.

1.4. Research Question

The research questions that the researcher had sought to be answered were as follows:

1. Ho to characterize mineralogical and chemical composition of lateritic soil of Jimma zone?
2. What is the degree of laterization of Jimma zone lateritic soil?
3. Is there any conformance of lateritic soil of Jimma zone with the standard specifications?

1.5. Experimental Program

A mineralogical analysis was performed on air-dried random powdered samples using a Philips X-ray diffractometer, Chemical analyses was also carried out in accordance with Fields and (Perrott ;1966).Tests were performed to check for the presence of Secondary minerals. The Specimens are all obtained from disturbed bag samples.

Classification testing was performed in accordance with ASTM, AASHTO, and USCS and mineralogical composition of the soils. Sieve analyses, hydrometer testing and specific gravity determinations were carried out, together with Atterberg Limit testing, which was performed on fractions of the total samples finer than 0.425 mm.

The Atterberg Limit tests were made for three cases on specimens that had been at their natural moisture content, AD for 5 minutes; and on specimens that were OD at 105°C. The specimens were cured overnight at water content close to their plastic limit. Liquid limit testing was carried out using the Casagrande apparatus. The mixing time after adding increments of water was for 5 min and 25min to evaluate the effect of mixing time. Each test was repeated for All soil samples recovered from different depths of the area.

1.6. Scope of the research

A total of twenty seven (27) samples were taken from nine (9) test pits namely, Seka 20 km in Southeast, Dedo 20 km in South, Yebu 22 km and Agaro 45 km in Northeast and Serbo 18 km and Sokoru 75 km in Northwest, Babu 22.km and Limu 75 km North of Jimma town and Jimma town itself. The laboratory investigation were carried out in accordance with the procedure given in ASTM , at different pre treatment conditions at received, air dried and oven dried at 50^{o}c and 105^{o}c.

The research is limited to the geochemical test & index properties on samples taken from different location of Jimma Zone. Due to unavailability of equipments in the country, it was not possible to conduct scanning electro microscope test to asses in the qualitative explanations of the observed macro structure behavior of the soil in terms of its microstructure.

1.7. Significance of the Study

Ever increasing material costs are squeezing county and state transportation budgets and causing real reductions in the actual amount of construction work put in place, according to a new American Road & Transportation Builders Association ARTBA economic report. With the continuing escalation of global fuel prices, localized materials shortage in many countries are beginning to experience potentially unprecedented construction cost increases and recently, our country is carrying different infrastructures development. Among these road construction is one. Therefore the findings of this study will provide the engineering properties of soils of the study area. Thus, Ethiopian Road Construction Authority and Oromia Rural Road Construction and Rehabilitation Authority can easily indentify soils that are suitable for road construction to hasten the development of the country in order to support poverty reduction measures that have been taking place in the country.

1.8. Limitation of the Study

The research has encountered the following limitations:

1. Due to the budget constraints the test were conducted on small number of samples and hence the results are indicative rather than definitive.
2. Due to lack of sufficient laboratory equipment and personnel at GSE laboratory the laboratory test has taken longer period more than seven month and obliged to undertake small number of tests.
3. Transportation problem for sampling infrastructure problem.

1.9. Structure of the Thesis

This thesis has six chapters and their contents are outlined below each covering a specific topic of the research work. The introductory chapter, which includes background of the study, problem statement, and objective methodology of the thesis work, research question scope of the study, significant of the study, limitation and structure of the thesis are presented. The second chapter presents brief literature review which comprises a description of previous works it includes mineralogy and identification of lateritic soil, characteristic of lateritic soil, discusses about the occurrences of lateritic soil, classification and its engineering properties. Sampling area in detail including location, climate, and geology, the types of laboratory tests conducted and sample description as detail more over in situ properties with sample description deals with chapter three. Chapter four devoted to the types of test conducted with the interpretations of result ,analysis and discussion. The test results compared with previously done lateritic soils and laboratory test results discussion are presented also in chapter five. Chapter six presents conclusions made out of the present work & the recommendations drawn from the research.

CHAPTER TWO: LITERATURE REVIEW

2.1. General Characteristics of Lateritic Soils

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of parent rock s under tropical and sub tropical climatic conditions. Their formation process involves the leaching out free silica and base and accumulation of oxides of iron, aluminum oxide or both. Due to the presence of iron oxides lateritic soils are red in color.

Lateritic is the product of a tropical weathering process which has the following effects: the parent rock is chemically changed by enrichment with iron and aluminum oxides; the clay mineral component becomes largely Kaolinitic; and the Silica content is reduced. This process usually produces yellow, ochre, red or purple materials; red is often the predominant color. Even if tropical weathering in oxidizing conditions generally leads to reddening, it does not always produce a lateritic material (Charman, 1995).

Despite its wide spread occurrence and use in many African countries and, indeed , in many other tropical country of the world , much confusion still exist concerning the general characteristics of what is often referred to loosely as ‘lateritic”. However, the numerous attempts made at definition and classification, to enable engineering behavior to be predicated, have been unsatisfactory because the term has been so loosely applied without a detail soil description to the formation of the materials.

Lateritic soils contribute the general economy of the tropical and sub tropical regions where they are in abidance because, because they are widely utilize in civil engineering works as constriction materials. As road construction materials, they form the sub-grade of most tropical road , and can also be used as sub –base and base course .Lateritic soils are economically covenant in road constriction , in the sense that they are cheaper than the other materials that can be achieve comparable strength with them and they are more available than those materials .Adequate information on its geotechnical properties is important because the durability and strength of the road depends on (IJSCE,2015).

Lateritic soils have been used successfully as base, sub-base and surfacing materials in road construction (Jackson, 1980). But because of its heterogeneous nature there is the need to study the geotechnical characteristics of lateritic soils whether they could be useful as construction materials or not (Little, 1971).

The physical properties of lateritic soils, commonly known as index properties, varies from region to region due to heterogeneous nature and highly variable degree of weathering controlling by region climatic and topographic conditions and the nature of bed rock,(Nndi,1988). It also varies with depth of the soil and can be determined by sample laboratory tests.

2.2. Review of Past Work

Lateritic soils result from an intense process of in situ weathering of igneous, sedimentary, and metamorphic rocks commonly found under unsaturated conditions (Rahardjo, et al, 2004). The disintegration of these underlying rocks occurs as the water washes out the soil minerals such as sodium, potassium, calcium, magnesium, nickel and other metals, and they are rich in minerals such as aluminum, phyllosilicates, aluminum oxides, iron (III) oxides, and hydroxides (Brainy Encyclopedia 2005).The particular presence of iron oxides lateritic soils are red in color ranging from light through bright to brown shades and most of the time it doesn't support plant life or vegetation well because they dry hard and compact, and lack organic matter.

Since its discovery by Buchanan (1807) in Malabar, India lateritic has been defined and described by a number of researchers in several different ways. Ola (1978) used local terminology in defining lateritic soils as all product of tropical weathering with reddish, brown color with or without nodules or concretion but not exclusively found below hardened ferruginous crust of hardpan. Osula (1984) defined lateritic as a highly weathered tropical soil; rich in secondary oxides of combination of iron, aluminum and manganese.

Lateritic (also known as "red soils") is used to cover all tropically weathered soil that has been involved in the accumulation of oxides of iron, aluminum or silica (Malomo, 1977). In other words, red soil is a highly weathered material rich in secondary oxides of iron, aluminum, or both. According to Alexander and Candy (1962) it is nearly devoid of bases and primary silicate, but it may contain large amount of quartz and kaolite. It is either hard or capable of hardening on exposure to wetting and drying (Agbede, 1992).

The term lateritic may be correctly applied to clays, sands, and gravels in various combinations while "lateritic soils" refers to materials with lower concentrations of oxides.Bridges (1970) states that the correct usage of the term lateritic is for "a massive vesicular or concretionary iron-stone formation nearly always associated with uplifted peneplains originally associated with areas of low relief and high groundwater".

Fookes (1997) named lateritics based on hardening, such as "ferric" for iron-rich cemented crusts, "alcrete" or bauxite for aluminum-rich cemented crusts, "calcrete" for calcium carbonate-rich crusts, and "silcrete" for silica rich cemented crusts . Other definitions have been based on the ratios of silica to sesquioxides. In lateritics the ratios are less than 1.33. Those between 1.33 and 2.0 are indicative of lateritic soils, and those greater than 2.0 are indicative of non-lateritic soils (Bell, 1993).Most lateritics are encountered in an already hardened state. When the lateritic is exposed to air or dried out by lowering the groundwater table, irreversible hardening occurs, producing a material suitable for use as a building or road stone. The lateritic soils behave more like fine grained sands, gravels, and soft rocks. The lateritic typically has a porous or vesicular appearance which may be self-hardening when exposed to drying; or if they are not self hardening, they may contain appreciable amounts of hardened lateritic rock or lateritic gravel.

The behavior of lateritics in pavement structures has been found to depend on various properties like particle size characteristics, nature, strength of gravel particles, degree to which the soil has been compacted, The traffic volume, climate and, hydrological regime of the engineering site and the topography of the area. Thagessen, (1996) when the grading of lateritic ;gravel is close to a mechanically stable particle size distribution, the material performs satisfactorily both as un-stabilized base and/or sub base in light trafficked gravel roads. Arulanandan, 1969) Stated that the situation may be worsened by water due to its softening effect on the soil and to the strength reduction it causes. This leads to pavement distress and partially to failure. Lateritic soils are-formed in hot, wet tropical regions with an annual rainfall between 750mm to 300mm, (usually in areas with a significant dry season) on a variety of different types of rocks with high iron content.

The behavior of lateritic soils in pavement structure has been found to depend mainly on their particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions (Gidigasu, 1976). Well-graded lateritic gravels perform satisfactorily as unbound road foundations. However, their tendency to be gap-graded with depleted sand-fraction, to contain a variable quantity of fines, and to have coarse particles of variable strength which may break down, limits their usefulness as pavement materials on roads with heavy traffic (Thagesen, 1996).

Another definition categorize lateritic soils in to lateritic , lateritic and non-lateritic soils , depending the silica to sesquoxide ratio less than 1.33 are indicative for lateritics , those between 1.33 to 2.00 shows true lateritic and those greater than 2.00 of non lateritic types(Bell,1993). This definition is not convenient from an engineering point of view especially where there is lack of adequate laboratory facility.

The definition of lateritic which had wide acceptance among authors stat that "lateritic is a highly weathered materials reach in secondary oxides of aluminum and iron or both .it is nearly void or void of bases primary silicate, but it may contain large amounts of quartz and kalonite"(Alexander and Candy ,1962).

In the present study different literature source were used. This includes maps and reports, books journals and materials available on the internet .Previous studies conducted in Ethiopia that of similar nature to the present research were sassed & include as part of literature review.

Gidigasu (1972) worked extensively on lateritic soils of Ghana and concluded that lateritic was derived from chemical and mechanical disintegration of the parent materials resulting in to concentration of iron and aluminum oxide.

Lateritic soils are story of the various soil types that occur in the tropics and sub-tropics, The chemical composition and morphological characteristics of these products are influenced by the degree of weathering to which the original material has been subjected .In 1889 Russel the U.S. Geological Survey, In his discussion of the aerial decay of rocks and the origin of the red color of certain formation in the United States, was probably the first to emphasize that in the warm moist temperature and tropical climates the water percolating through rock has a strong solvent power and that weathering is more rapid in warm than in cold regions and greater in humid than in air climates. In (1903) Holland also suggested that during the weathering of aluminous silicates in the tropics, the silica, alkali and alkaline earths are removed in solution, while the alumina and ferric oxide become dehydrated and remain behind. Various definitions of ''lateritics" have been Suggested (Gidigasu, 1976).

The lateritic of the various soil types that occur in the tropics and sub-tropics, lateritics are of special interest in conjunction with building construction. They are found abundantly in the tropics and sub tropics, where they generally occur just below the surface of wide grasslands or forest clearings in regions which high rainfall. . The colures can vary from ochre through red, brown, violet to black, depending largely on the concentration of iron oxides.

The special characteristics of lateritics, by which they differ from other soils, are as follows soft occurrences tend to harden on exposure to air, which is why blocks have traditionally (e.g. in India) been cut in situ, allowed to harden and then used for masonry wall construction (hence the name was derived from "later", the latin word for "brick").The darker the lateritic, the harder, heavier and more resistant to moisture it is, some lateritics are found to have a pozzolanic reaction when mixed with lime (which can be explained by the high clay content), producing hard and durable building materials (eg stabilized blocks).

2.2.1. Definition Based on Hardening Property

The term lateritic was first introduced by Buchanan (1807) to describe a ferruginous, vesicular, un stratified and porous materials in Malabar, India .The freshly dug materials was soft enough to be readily cut in to regular sized blocks with an iron instrument but up on exposure to air it gradually hardens and was remarkable resistance to the weathering effect of climate .This material was locally used for masonry building as brick and the name was derived from " lateritic" , the Latin word for brick. All later attempts to replace the word "lateritic" with others failed and by the end of the 19th century lateritic were recognized as tropical and subtropical weathering products of various crystalline igneous rocks, sediments, detritus deposits and volcanic ash; and it was morphologically identified as surface or near-surface occurrences in various tropical and subtropical region of the world. Attempts to restrict the term lateritic to the in-situ hardened and soft materials that harden on exposure also failed when Branford, 1859 and Harrison, 1910 respectively reported the hardening of lithormage and red sesquioxide poor materials. The problem become further complicated when it appeared that the reliance on the criterion of hardening alone could lead to such terms as "ferruginous'', "Siliceous'' and "Calcareous'' lateritic to describe various forms of the material(Gidigasu,1976).

2.2.2. Chemical Alteration

Mallet, 1883 was perhaps the first to introduce the chemical concept by establishing the ferruginous and aluminous nature of lateritic soils. Bauer, 1898 also established the relatively insignificant content of silica and high content of aluminums in an hydroxide form comparable to the composition of bauxite. Warth and Warth, 1903 established that some Indian lateritics contained small amount of alumina, but were rich in iron oxides; while others contained large amounts of aluminum oxide but were relatively poor iron. The great interest developed in lateritic as a possible source of aluminums ore intensified research on the material. Former; 1911 abandoned the criterion of physical hardness of the lateritic in its natural state or on exposure, and developed a comprehensive system of nomenclature of lateritic soils on the basis of their chemical composition. He defined various forms of lateritic on the bases of the relative contents of the so-called lateritic constituents (Fe, Al, Ti and Mn) in relation to silica . A similar and more comprehensive chemical classification system was proposed by Lacroxi, 1913, who divided lateritic in to True lateritic Silicate lateritic clays; depending on the relative contents of hydroxides.

A narrow approach to the chemical classification was proposed by Martin and Doyne; 1927 & 1930, who defined three grades of lateritic soils on the bases of the silica alumina ratio Ratios less than 1.33 have been considered as indicative of true lateritic, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of non lateritic tropically weathered rock.

Winterkorn et.al; 1951 questioned the use of a silica-alumina ratio since the original definition of lateritic by Buchaman; 1807 attached special importance to the role iron oxides play in the lateritic rock. Moreover, the hardening process in lateritic soil seams to consists mainly of the crystallization of the amorphous iron in lateritic soils is also considered the most important factor influencing their engineering properties (Winterkorn et, 1951).The use of silica sesquioxide ratio ($SiO_2/Al_2O_3+Fe_2O_3$) after Joachin and Kandiah; 1941 with the same limiting value as those proposed Martin and Dayne were adopted. The chemical definition later gives way to morphological definitions.

2.2.3. Morphological Definitions

Meanwhile, Walther; 1915, 1916 proposed the morphological definitions to cover all red-colored, brick –liked alluvial and tropical red earths. He was followed by Harrassowitz;1926 who proposed a typical lateritic profile which agrees with the description of Fox;1939 and Laeroix ; 1913.Pendelton ; 1936 also emphasized that although the silica aluminum or the silica – sesquioxide ratios are useful parameters, they do not conclusively defined lateritics. Consequently, Pendelton and Sharasuvana; 1946 defined ‘‘lateritic’’ soils as profiles in which a lateritic horizon is found and ‘’lateritic soils’’ as profiles in which there is an immature literite horizon from which a true lateritic horizon will develop if appropriate conditions prevail long enough. A certain combining both the chemical and physical concepts was proposed by Kellog;1949 who classified lateritic in to four principal forms of sesquioxides - rich materials that are either hard in situ or capable of hardening on exposure to air. The morphological, physical and chemical concepts proposed by various researchers have been summarized by Alexander and Cady; 1962 as follows; lateritic is a highly weathered materials, reach in secondary oxides of iron, aluminum, or both. It is nearly void of bases and primary silicates, but it may contain large amount of Quartz and kalonite .It is either hard or capable of hardening on exposure to wetting and drying. This is short review of the proposed definitions of “lateritic’’ revels how complex lateritic soils are, apparently defying any satisfactory geological, chemical or ecological definition (Gidigasu, 1976).

2.3. Mineralogy of Lateritic Soil

Mallet (1883) was perhaps the first to introduce the chemical concept for establishing the ferruginous and aluminum nature of lateritic soils. Fermor (1911) defined various forms of lateritic soils on the basis of the relative contents of the so-called lateritic constituents (Iron, Aluminium, Titanium and Manganese in relation to silica. Also Lacroix (1913) divided lateritic into:-true lateritic, silicate lateritic, and lateritic clays depending on the relative contents of the hydroxides. There are other several attempts by the researchers to classify lateritic in terms of their chemical compositions, but Fox (1936) has demonstrated that such classifications are inadequate, other than in relations to deposits that may be exploited for their minerals content, classification based on chemical composition cannot be used to distinguish between indurate and softer formations.

The high content of the sesquioxides of iron or aluminum relative to other components is a feature of lateritic. These essential components are mixed in variable proportions. Some lateritic may contain more than 80% of Fe_2O_3 and little of Fe_2O_3; while others may contain up to 60% of Fe_2O_3 and only a little of Fe_2O_3. Although alkali and alkaline bases are almost entirely absent in most cases, this is not an absolute criterion. In particular, some ferruginous tropical soils may contain significant amounts of alkali and alkaline bases.

Combined silica content is low in Sesquioxides .This combined silica is predominantly in the form of Kaolinite, the characteristic clay mineral of most tropical formation. It was on this basis that D'hoore (1954) made a theoretical calculation of free Fe_2O_3 content from combined silica content employing the formula:

Free Fe_2O_3 = Total Fe_2O_3 — (SiO_2 x 0.849)

The use of this formula leads to the statement that alumina was present principally in combined form in lateritic of Buchanan's type. Although alumina is sometimes the main constituent, the sesquioxides of iron are most common and the most frequent.

The degree of laterization of the soil samples will be evaluated based on Silica to sesquioxides ratio. The sesquioxide, designated as R2O3, is the combination of aluminum oxide (Fe_2O_3) and Iron oxide (Fe_2O_3). The chemical formula SiO2 designates the silica.

Accordingly soils having an sesquioxides ratio greater than 2 are non lateritic tropically weathered soils, soils sesquioxides ratio lies between 1.33 and 2 indication for lateritic and soils sesquioxides ratio is less than 1.33 for those of true lateritic.

Mineralogy controls the sizes, shape, and surface characteristic of the particles in the soil. Physical and engineering properties of soils are also being controlled by mineralogy. These features along with interaction with the fluid phase determine plasticity, swelling, compression strength and hydraulic conductivity behavior. Thus mineralogical composition is an important factor that is fundamental to the understanding of geotechnical engineering characteristics of residual soils.

Furthermore good understandings of the basement soil on which highways, dam and other transportation facilities are constructed are very important. Salter (1988) said the performance of a highway pavement is influenced to a very considerable extent by the sub-grade material. Furthermore, Oglesby and Hicks, 1992) said that before 1920, attention was focused largely on the pavement surface, and little notice was given to the sub-grade and base materials or to the manner in which they were placed or compacted. Later, increased vehicle speeds brought demands for higher design that resulted in deeper cuts and higher fills. In many instances, subsidence or even total failure of the roadway resulted. Study of these failures indicated that faults lay in the sub-grade and not the pavement. This led to investigation of the properties of sub-grade materials and basement materials. In order to fully appreciate the usefulness of lateritic soil, determining the engineering properties of lateritic is able to identified the imposed problems (in both field and laboratory) and useful solutions applied by properties of the soil.

Concretionary lateritics are valuable road pavement materials, widely used in tropics as a sub-base, base material and for gravel roads. The term lateritic, however, has tended to be indiscriminately applied in tropical red soils. As a result the usefulness of lateritics for road construction has been underestimated. The sensitivity of these materials to test procedures has to be assessed and the laboratory testing has to simulate the site condition (Hicks, 1992).

Lateritic soils, like any other group of soils, present certain challenges as foundation materials, though there is no specific stability of deformation problems associated particularly with the process of laterization. The cementing action of iron oxide tends to improve the strength and deformation characteristics of lateritic formation.

A literature review has revealed that the geo-technical characteristics and engineering behavior of lateritic soils depend mainly on the genesis and degree of weathering (i.e. decomposition, laterisation, desiccation and hardening). Morphological characteristics as well as the type and content of secondary minerals are other genetic characteristic (Agbede, 1992).

2.4. Engineering Properties of Lateritic Soil

The engineering properties of soils are governed by many factors, such as the geology of the parent rock, topography, and climate, which differ significantly from one region to another. This is particularly true of lateritic materials and the classification of lateritic materials is complicated by the fact that they are the product of a complex weathering process, and soils in a particular area may be at varying levels of lateralization. Lateritic materials have been studied extensively over the past forty years, and specifications have been developed for pavement construction in tropical Africa. However, it is important for these specifications not to be blindly adopted for materials with differing engineering properties and performance characteristics (Lyon, 1971).

It is important in many respects to recognize the differences between lateritic and non- lateritic soils and further to recognize the various types of lateritics the fact remains that the true consideration for identification and evaluation of lateritic soil for engineering purpose is not, but what are its significant geotechnical characteristics and engineering behavior (Vallerga et al.,1969).

In different countries of Asia and Africa, lateritie soils are the traditional materials for road and airfield construction. Though a good deal of literature is available on lateritic soils and several excellent reviews have been prepared on lateritic soils (Lyon, 1971),

The available data on lateritic soils gives the impression that the red color seems to have been accepted by most authors as the most important property by which these soils could be identified. Other obviously significant basic physical properties such as texture, structure, consistency, etc., often were ignored .It is also noted that the lack of uniformity in pretreatment and testing procedures (resulting from association with different standards in different parts of Africa) makes it difficult to compare even textural data on the same soils. It is noted that three major factors influence the engineering properties and field performance of lateritic soils (Gidigashu, 1976).

Field performance and geotechnical characteristics and of lateritic and lateritic soil may be interoperated in the light of all or some of the following parameters:

a. Soil forming factors (parent materials, topography, climate vegetation, derange condition and period of time in which the weathering process have been operated).
b. Degree of weathering (degree of laterization), and texture of the soil , genetic soil type ,
c. Position in the topographic site , and
d. Depth of soil in the profile (Gidigashu, 1976).

2.5. Engineering Classification

Samples to be tasted shall be subjected to the following pre-treatment conditions in the following manner:

a. As received - at natural moisture content
b. Air dried - dried at constant weight under normal temperature
c. Oven dried - dried in an oven for 25 hour at temperature of 50^oC & 105^oC respectively.
d. Socked - immersed in water for 24 hours

Studies on the relation between the natural moisture content and the liquid limit and plastic limit have shown that generally the natural moisture content is less than the plastic limit in normal. Lateritic soil However, the lateritic soils from high rain fall areas may have moisture contents as high as plasticity limit (Hirashima, 1948).

2.6. Lateritic as Construction Materials

Lateritic soils are soils usually encounter during road construction project and may vary from highly expansive to non expansive in nature. Therefore these soils should be adequately investigated since the stability and performance of the pavement are generally influenced by the nature of sub grade and sub base materials of the pavement (Chen, 1988).

Some lateritic soils are valuable road pavement materials, widely used in the tropics and non tropical area as sub base, base material and for gravel wearing roads. The term lateritic, however, has tended to be indiscriminately applied in tropical highway engineering to any red soil, and as a result the usefulness of lateritics for road construction has been under-estimated (Charman, 1995).

Lateritic soils are widely used as construction materials for various construction works in most tropical and non tropical countries (Gidigashu, 1976).

The classification of soils in to sub-grade, sub base and surfacing materials based on fractions passing No 200 sieve. According to Little and Nair (2009), a soil can be considered as a sub –

grade if 25 % or more passing through the No.200 sieve ,otherwise it may be classified as a base materials. The properties of the lateritic soils depend on its mineralogical constituents.

Some lateritics are valuable road pavement materials, widely used in the tropics as sub base, base and for gravel wearing roads, However, laboratory tests to check the suitability of lateritics as road pavement materials, should take into account the engineering properties (Charman, 1995; Zelalem, 2005).

CHAPTER THERE: MATERIALS AND METHOD

3.1. Study Area Description

The sampling area, Jimma zone is one of the thirteen (13) zones of Oromia region regional state which geographically located in the south western part of Ethiopia. Jimma town is the capital of the zone that is 345 km far away from capital city of Ethiopia Addis Ababa. It covers a total surface area of 19,305.5 km2. According to the 2007 population and housing census of Ethiopia, the total population of Jimma zone was 2,486,155 from the total population in the zone, 2,204,225 (88.66%) is the rural population which directly depends on agricultural activities for domestic use and exchange of commodities with urban residents. The zone is one of the major coffee growing areas of Oromia region well endowed with natural resources contributing significantly to the national economy of the country. The zone bordered in Northwest by Illubabor in East by Wellega and in West by Shewa zones as well as in south by Southern Nations and Nationalities People's Regional state. The zone is divided into 17 districts and 22 urban centres (Figure 1) (Dechassa, 2000).

In general topographical features elevation varies from 1000 to 3360 m ASL with average minimum and maximum temperatures in range of 7°C up to 12°C and 25°C up to 30°C respectively. Annual rainfall of the zone is one of the highest in the country reaching up to 120 mm - 2800 mm per annual (Yonas Seifu,2002).

The research ware conducted in nine (9) Weredas of Jimma zone namely, Seka 20 km in Southeast, Dedo 20 km in South, Yebu 22 km and Agaro 45 km in Northeast and Serbo 18 km and Sokoru 75 km in Northwest, Babu 22.km and Limu 75 km North of Jimma Town and Jimma town itself.

3.1.1. Climate Conditions

In terms of climate Jimma Zone enjoys different types of climate conditions, moist Dega covers area of 21.67" ha, moist kolla covers area of 73,445.047 ha, moist weinadega covers area of 125,216.83 ha, wet dega covers area of 233,401.823 ha, wet kola covers area of 99,268.614 ha, wet weinadega covers area of 1,280,822.049 ha and wet " wurch " covrs area of 438.173 ha. The larger part of Jimma zone land lies under weinadega category (Ephrem, 2013).

3.1.2. Temperature

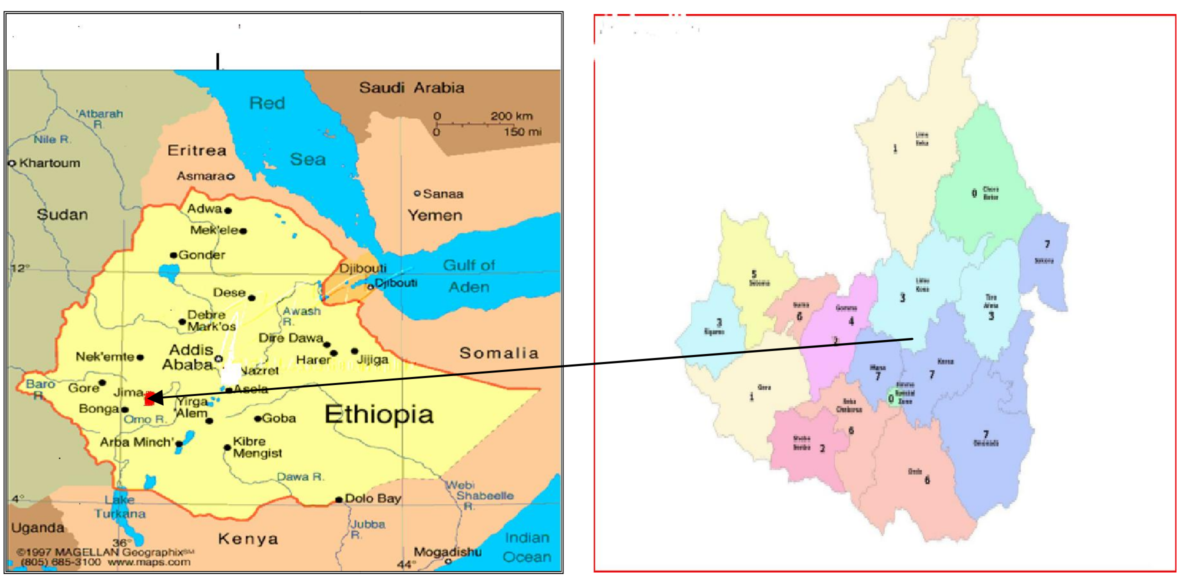
Latitude, altitude, winds and humidity, have significant impacts on temperature condition in Ethiopia .The maximum and minimum temperatures of Jimma zone range 25°C - 30°C and 7°C - 12°C, respectively.

3.1.3. Rain Falls

Jimma Zone reliably receives good rains, ranging from 1,200 – 2,800 mm per annual More than 90% of the annual rainfall is received between February and October that brings an average 11 to 24 rainy days (Dechass, 2000).

3.1.4. Topography

Topographically Jimma zone lies on low hill on the left side of the wide alluvial plain of the river Gibe, an affluent of the Omo River which subsequently joins the Gibe. The minimum and maximum altitude of the zone ranges between 880 m to 3360 m above ASL.



`Fig 3.1 Map of Jimma Zone

3.2. Geochemical Test

Geotechnical test are conducted under the present study include X-Ray diffraction test and chemical test the test were performed at the mineralogical and petrography laboratory department of Ethiopian Geological Survey by powder diffraction method after grinding the bulk sample without separating of clay fraction.

3.3. Index Property Test

The index property test conducted under present study incorporated natural moisture content, specific gravity, atterberg limit, grain size analysis, compaction and California bearing ratio.

Table3.1. Testing procedure

Parameters	Standard
Natural moisture content	AASHTO T262 - 93
Specific gravity	AASHTO T100 – 03 , T85-91
Grain sieve analysis	AASHTO T88 - 86
Atterberg limit test	AASHTO T89 – 02 , T-90-00
Compaction test	AASHTO T 180
Soil classification	AASHTO M-145
CBR test	AASHTOT193

3.4. Sample Collection

The soil specimens for this thesis work were collected from nine (9) Werdas of the Zone namely Agaro (AG) ,Jimma (JI), Serbo (SE), Limu (LI), Sokoru (SO), Babu (BA), Yebu (YA), Seka (SA) and Dedo (DE) twenty seven (27) representative samples three (3) samples from each depth were collected at depth of 1.0 to 3.2 m after removing the overburden soil at different pre-treatment condition .Prior before sampling visual site investigations were made and accordingly nine test pits were chosen as shown on Table 3.2 based on visual description the sub surface geotechnical layers are outlines two layers (The first layer & the second layers). The choice of these sites and soil is justified by the main & co adviser also the fact that these site is a borrow pit from where various construction companies get their material for road construction the sampling has been carried out from July 2013 to middle of December, 2013 in connection with the detailed investigation.

Table 3.2 Sample designation & depth of sampling.

Sample Location	Designation	Depth (m) after removing the overburden Soil
Agaro	AG	1.00
		3.00
Jimma	JI	1.30
		3.20
Serbo	SE	1.10
		3.20
Limu	LI	1.00
		3.00
Sokoru	SO	1.20
		3.00
Babu	BA	1.00
		3.00
Yebu	YA	1.10
		2.90
Seka	SA	1.00
		3.00
Dedo	DE	1.10
		3.10

Fig 3.2 Test pit excavation at Agaro

Fig 3 .3 Samples from Serbo

Fig 3.4.Samples collected from different places at the laboratory

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Geochemical Test

4.1.1. General

Geotechnical test are carried out to know quantitatively and qualitatively main oxides of the soil materials. All soils contain almost the same amount of colloid oxides and hydroxides. The oxides and hydroxides of iron, aluminum and silicon are of greatest interest (Mitchell, 1979).

4.1.2. X-Ray Diffraction Test Result

Using X- Ray diffraction method the major constituent minerals of the soil samples are determined.

Table 4 .1 Mineralogical Composition

Location	Mineral constituent								
	Quartz (%)	Kalinite (%)	Albite (%)	Ferrosilite (%)	Goethite (%)	Lindgrenite (%)	Ferrinatrite	Pyrophyllite	Hematite
Agaro	47.40							43.80	8.80
Jimma	32.60		32.60	34.90					
Seka	66.30				15.10	18.60			
Serbo		29.40			70.60				
Limuu		40.40					59.60		

As shown on Table 4.1 the test result showed that the lateritic soil sample of Agaro ware composed of Quartz, Pyrophyllite & Hematites; the lateritic soil sample of Jimma ware composed of Quartiz, Albite & Ferrosilite; the lateritic soil sample of Seka ware composed of Quartiz, Goethite & Lindgrenite; the lateritic soil sample of Serbo ware composed of Kaolinite & Goethite and finally the lateritic soil sample of Limu ware composed of Kaolinite & Ferrosilite.

4.1.3. Chemical Test Result

The degree of laterization of the soil samples can be evaluated based on ratio of Silica to Sesqui-oxides as detailed in literature review section 2.2.If the Silica to Sesquioxides ratio is less than 1.33 the samples have been considered as true lateritics, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of non lateritic soils.

Table 4.2 Chemical test of the soil sample

Loca-tion.	Elements determined and their chemical contents (%)												
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	Lol	S-S
Agaro	40.72	28.56	12.12	0.16	0.66	0.70	0.94	0.22	0.10	1.27	0.07	13.05	1.00
Jimma	47.02	22.44	13.67	0.26	1.19	0.84	0.87	0.32	0.13	1.14	0.85	11.27	1.30
Serbo	44.35	19.75	15.75	0.11	0.31	0.62	0.61	0.21	0.02	2.85	1.52	13.87	1.25
Limu	36.06	26.44	20.36	0.06	1.14	0.52	0.72	0.24	0.14	5.37	0.22	10.19	0.77
Dado	60.16	18.93	11.36	0.14	0.24	0.36	0.40	0.06	< 0.01	0.93	0.21	7.64	1.59

Table 4.2 indicate that the lateritic soil samples at Agaro, Jimma, Limu and Serbo having high S-S ratio. The degree of laterization of, silica to S-S ratio is less than 1.33 this indicates that the soil samples are true lateritic and lateritic soil sample of Dedo is between 1.33 and 2.00 and the soil is lateritic.

4.2 Index Property

4.2.1 General

Index properties have wide applications in civil engineering practice and a number of index properties which are easily recognized in soil mechanics (Blight G.E, 1997).

The physical properties of residual soils, commonly known as the index properties vary from region to region due to the heterogynous nature and highly variable degree of weathering controlled by regional climatic and topographic conditions, and nature of bed rock,(Nnadi,1988).

The physical properties of soil which are not primary interest to the geotechnical engineers but indicative of the engineering properties of soils are index properties (Blight G.E., 1997). The properties of soil which serve mainly for identification and classification purpose are known as index properties which can determined by laboratory tests.

4.2.2 Effect of Mixing Water

Water might be chemically reacting with the oxides of lateritic soils during testing. The tests vary insignificantly up on changing of testing water type (Hanna; 2008) Hence; distilled water ware used for the soil testing for this research work.

4.3. Moisture Content Test Result

At different pretreatment conditions the moisture content were calculated using the normal calculation.

Oven temperature 110ºc for water content determination is too high for clay and some of tropical soils. These soils contain loosely bound water of hydration or molecular water which can be lost at high temperature, resulting in a change of the soil characteristics (Bowles, 1978). This effect was checked by calculating moisture content at different pre treatment conditions.

Two set of samples were dried to constant weight using drying oven at temperature of 105ºc, 50 ºc and a maximum relative humidity (RH) of 30%.

Table 4.3 Natural moisture content comparison at different temperature

Sample Location	Depth of Sampling after removing overburden soil	Natural moisture content at		Deference
		50 ^{O}C	105 ^{O}C	
Agaro	1.00	24.05	28.29	4.24
	3.00	22.00	27.65	5.65
Jimma	1.30	13.91	18.85	4.94
	3.20	15.34	20.14	4.80
Serbo	1.10	15.02	19.65	4.63
	3.20	18.65	23.65	5.00
Limu	1.00	15.65	20.14	4.49
	3.00	19.57	23.65	4.08
Seka	1.00	24.74	30.25	5.51
	3.00	24.65	29.47	4.82
Dedo	1.20	23.21	26.41	3.20
	3.00	21.92	24.40	2.48

As can be notice from Table 4.3 for the lateritic soil of Jimma zone natural moisture content results of oven dried at 50 ºc ± 5 ºc and at 105 ºc ± 5 ºc should between 4 % and 6 % or more this indicates that soils under investigation contain loosely bound water of hydration , there is definite structural water or amorphous clay minerals found and dehydration of S-S does significantly affect the index properties of lateritic soils of this area hence, these thesis work can be done using different pre treatment conditions as received, air dried & oven drying at temperature of 105 ºc ± 5 ºc.

Table 4.4 .Natural moisture content of the soil samples at different pre treatment conditions

Sample Location	Depth of Sampling after removing over-burden soil	Natural Moisture (%) content at		
		AR	AD	105 ^{O}C
Agaro	1.00	20.68	24.78	28.29
	3.00	21.37	25.35	27.65
Jimma	1.30	12.36	16.62	18.85
	3.20	14.56	19.65	20.14
Serbo	1.10	17.13	18.65	19.65
	3.20	21.50	22.84	23.65
Limu	1.00	15.78	18.66	20.14
	3.00	19.36	22.61	23.65
Sokoru	1.20	15.47	20.68	23.36
	3.00	18.74	20.89	24.62
Babu	1.00	20.38	22.17	25.14
	3.00	18.65	19.00	20.14
Yebu	1.10	20.97	22.69	24.12
	2.90	25.12	27.41	29.00
Seka	1.00	25.98	27.52	30.25
	3.00	27.03	28.12	29.47
Dedo	1.10	20.40	22.85	26.41
	3.10	20.31	23.64	24.40

As can be noted from table 4.4 at received pre treatment condition the natural moisture content of the lateritic soil samples varied between 12.36 % and 27.03 %, at air dried condition between 16.62 % and 28.12 %, and for oven dried at temperature of 105 ^{o}C lies between 18.85 and 30.25 %.

4.4. Specific Gravity

Specific gravity of a soil is defined as the ratio of the weight of the soil to an equal volume of distilled water at stated temperature. Specific gravity value is used for competition of particle size in hydrometer, phase relation such as void ratio, degree of saturation unit weight etc, compression index in consolidation test, for computation of density corresponding to full saturation (zero void air curve) in compaction test.

A decrease in specific gravity is due to aggregation of clay particles on drying and an increased valve in test result indicates the presence of minerals constituting iron, which recognized through chemical analysis (Table 4.2).Specific gravities vary not only with the soil textural but also within different fractions. The specific gravity has been used as a measure of the degree of laterization. Lateritic soils have been found to have very high specific gravities values between 2.6 to 3.4 (Lyon, 1971).

Table 4.5 Specific gravity of the soil samples at different pre treatment conditions

Sample Location	Depth of sampling after removing the overburden soil (m)	Specific gravity at		
		As Received	Air Dried	Oven Dried
Agaro	1.00	3.14	3.00	2.98
	3.00	3.02	2.95	2.93
Jimma	1.50	2.82	2.78	2.76
	3.20	2.89	2.75	2.73
Serbo	1.60	2.85	2.76	2.73
	3.20	2.82	2.72	2.71
Limu	1.50	2.89	2.80	2.78
	3.10	2.82	2.75	2.73
Sokoru	1.70	3.23	3.18	3.16
	3.00	3.15	3.10	3.08
Babu	1.20	2.84	2.78	2.76
	3.00	2.81	2.77	2.75
Yebu	1.00	2.87	2.73	2.71
	3.00	2.84	2.72	2.70
Seka	1.00	3.32	3.11	3.10
	3.00	3.14	3.10	3.00
Dedo	1.10	3.25	3.12	3.11
	2.90	3.15	3.10	3.00

The specific gravity has been used as a measure of the degree of laterization, Table 4.5 show that the lateritic soil of Jimma zone is highly literized. This agree with the value of specific gravity for similar soil according to Lyon, lateritic soils have been found to have very high specific gravities value between 2.6 and 3.4 , the contributing factor for rise specific gravity is due to high amount of iron oxide. The range of specific gravity from 2.65 to 2.67 suggests the presence of clay or silt which actually can be of advantage at the sub-grade and sub-base levels of road construction (Barja;1978).

The test results summary is shown in Table 4.5 from the test results one can see that air dried and as received pretreatment conditions give nearly similar and large values. This is shows that the oven drying temperature affects the value of the specific gravity. The specific gravity values of oven dry sample are less than the above two. Hence specific gravity significantly changes upon drying prior to testing and oven drying temperature. The detected specific gravity for the samples ranged between 2.81 and 3.32 for as received pre treatment conditions, between 2.72 and 3.18 for air dried conditions and between 2.70 and 3.12 for oven dried preretirement conditions. Thus, lower specific gravity value indicates a course soil, while higher values indicate a fine grained soil.

Laboratory test results on lateritic soils of Jimma zone (Table 4.4) show, increased temperature from as received condition to oven drying temperature decreases specific gravity by an average of 4.75 %.

4.5 Grain Size Analysis

4.5.1General

The soil sample brought from test pit was first air dried and then pulverized before it was screened through the nest of sieves. Some of the soil particles passing the No. 10 sieve is oven dried at 105 ºC for 24 hours for oven dried sample and air dried sample is also taken. Both samples were subjected to hydrometer analysis and the results were expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale (Accordance to AASHTO T87-86).

4.5.2 Grain Size Analysis Test Result

The grain size analysis test results for all soil samples under investigation at different pre treatment conditions are summarized in Table 4.5.The corresponding grain size distribution curves are shown in Fig 4.1 to Fig 4.9.The values obtained from gradation test were analyzed with respect to the effect of pre treatment, soil variation along laterally and depth wise .

The grain size distributions of some lateritic soils change as a result of hydration reaction when dried especially at high temperature .The test result for dry preparation of sample expected to result in decreased percentage of finer fraction (clay & silt). On the other hand, test result on sample carried out wet preparation (air dried) is expected the reverse as compared to effect of drying that is increased percentage of finer fraction .But the test results of the grain size analysis of the samples under investigation for this thesis work resulted in negligible deference following different sample preretirement procedure.

Table 4.6 Grain size analysis test results of the samples at as air dried and oven dried

Site Location	Depth after removing the overburden soils (m)	Particle size			
		Air dried		Oven dried	
		Clay	Silt	Clay	Silt
Agaro	1.00	66.44	17.33	62.68	14.84
	3.00	67.65	17.14	61.99	11.24
Jimma	1.30	28.62	19.49	27.88	15.33
	3.20	26.67	17.35	25.11	14.65
Sokoru	1.20	37.70	25.15	36.54	23.65
	3.20	32.40	30.87	31.60	22.80
Serbo	1.10	19.00	14.87	18.91	13.06
	3.20	17.50	14.33	16.89	12.20

Air drying soils of the area were observed to result in an increase of clay and silt fractions. Table 4.6 shows the impact of increased temperature on clay and silt fraction. Air drying decreases clay and silt fraction by an average of 12.68 % respectively. Drying was observed to hardly affect the percentage by silt size.

Table 4.7 Grain size analysis test results of the samples

Site location	Depth after removing the overburden (m)	Sample condition	Percentage amount of passing (%)			
			Clay	Silt	Sand	Gravel
Agaro	1.00	OD2	57.67	12.61	19.6	10.12
		AD1	62.68	14.84	13.23	9.25
	3.00	OD2	54.18	10.96	25.45	9.40
		AD2	61.99	11.24	17.53	9.24
Jimma	1.30	OD1	24.34	13.22	18.64	43.80
		AD1	27.88	15.33	17.39	39.40
	3.20	OD2	23.34	11.89	18.65	46.10
		AD2	25.11	14.65	23.18	37.06
Sokoru	1.20	OD2	32.86	21.11	34.45	11.58
		AD2	36.54	23.65	29.4	10.41
	3.00	OD1	30.25	20.15	32.87	16.71
		AD1	32.40	22.80	30.13	14.67
Serbo	1.10	OD2	16.63	11.10	6.00	66.27
		AD2	18.91	13.06	5.52	62.51
	3.20	OD1	12.25	9.60	6.09	72.04
		AD1	16.89	12.20	7.24	63.67
Limu	1.00	OD2	18.65	10.65	19.15	51.52
		AD2	19.75	13.20	19.25	47.80
	3.00	OD1	16.62	7.65	13.03	62.70
		AD1	17.36	10.60	14.70	57.34
Babu	1.00	OD1	11.40	15.25	20.79	52.56
		AD1	12.02	17.11	18.52	52.35
	3.00	OD2	8.58	13.28	23.01	55.13
		AD2	10.65	12.98	20.32	54.36

Yebu	1.10	OD1	26.68	14.36	7.40	51.56
		AD1	30.18	17.25	9.31	43.26
	2.90	OD2	21.00	13.67	13.47	51.86
		AD2	26.60	15.96	9.75	47.69
Seka	1.00	OD2	38.50	23.00	29.30	9.20
		AD2	39.65	26.67	23.58	10.10
	3.00	OD1	24.65	22.14	34.21	18.93
		AD1	35.68	24.65	27.26	12.41
Dedo	1.10	OD1	43.65	19.30	30.00	7.05
		AD1	56.35	13.45	21.20	9.00
	3.10	OD2	41.02	14.84	35.00	9.12
		AD2	48.65	11.25	32.85	7.24

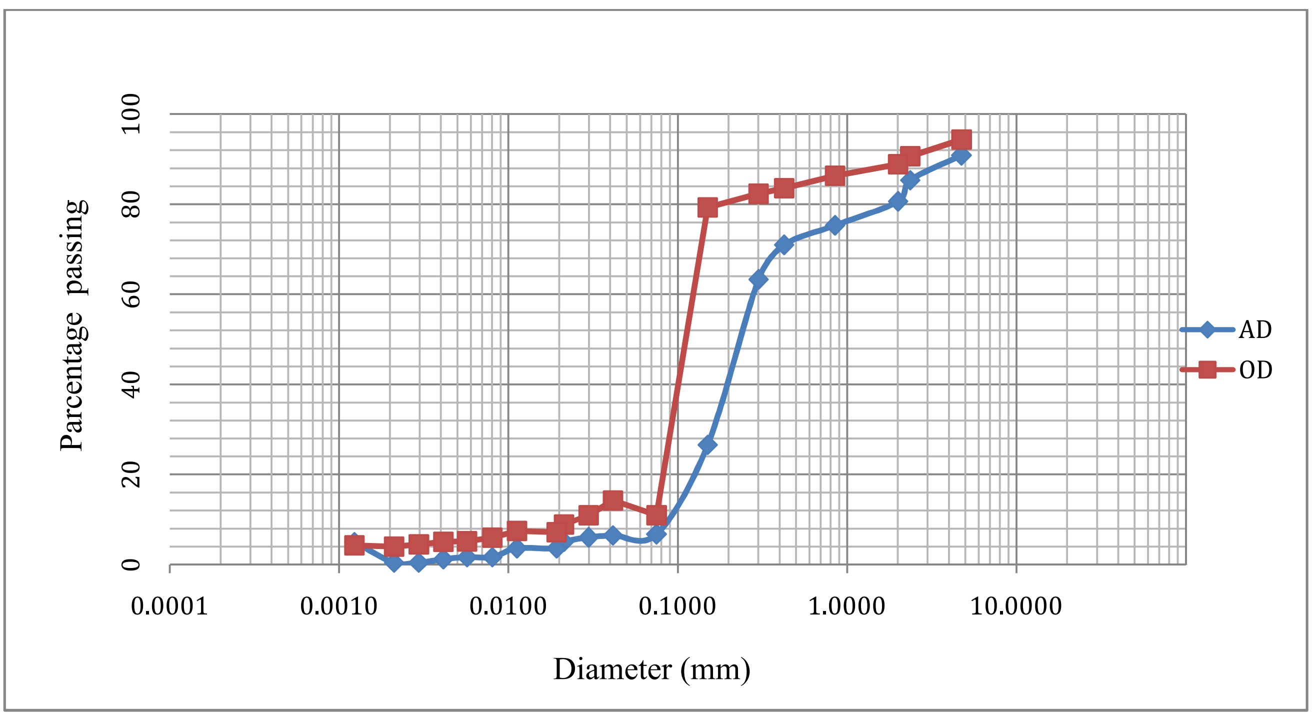


Fig 4.1 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Agaro

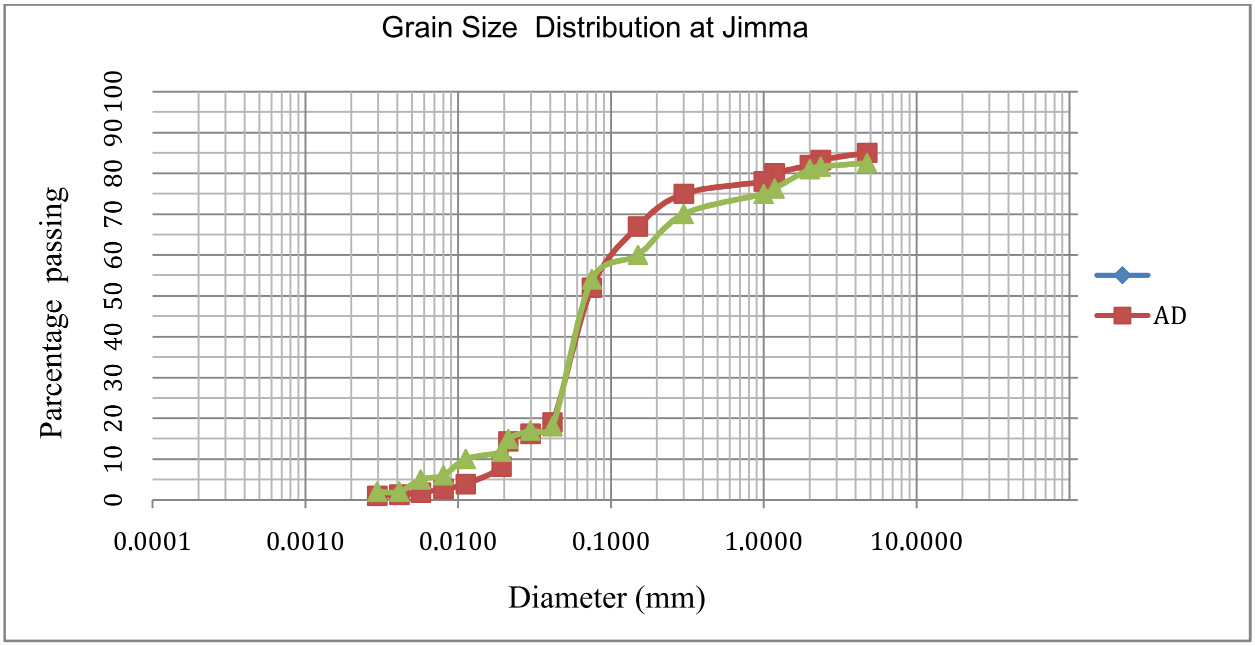


Fig 4.2 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Jimma

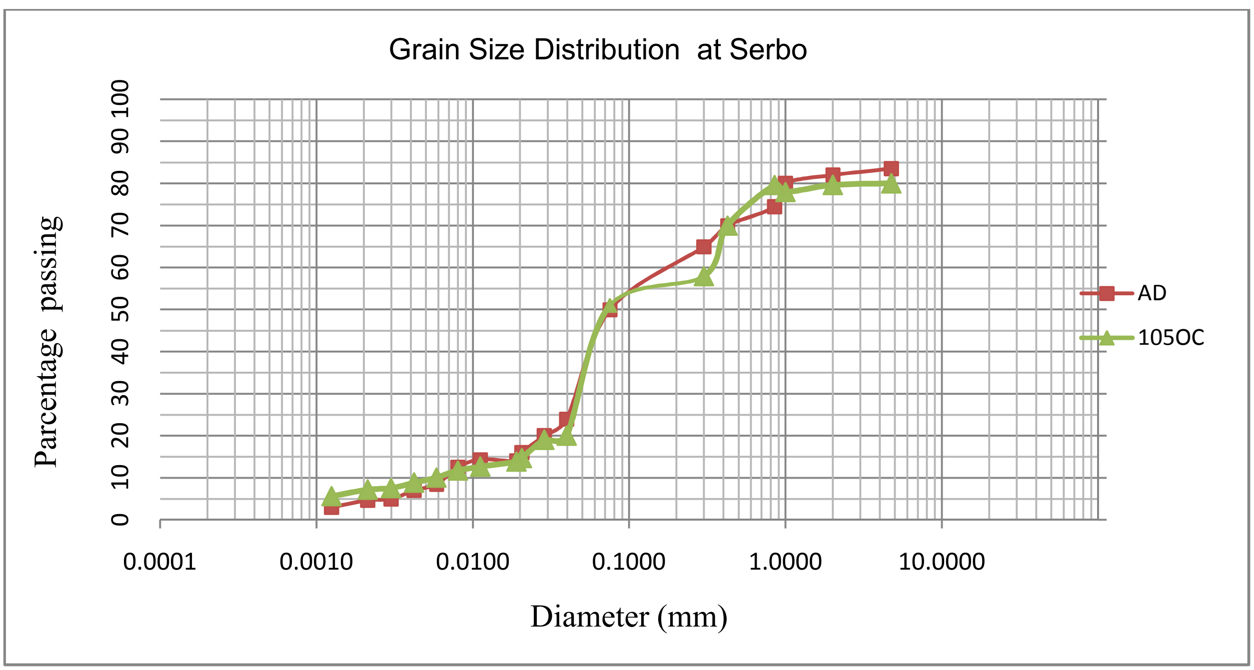


Fig 4.3 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Serbo

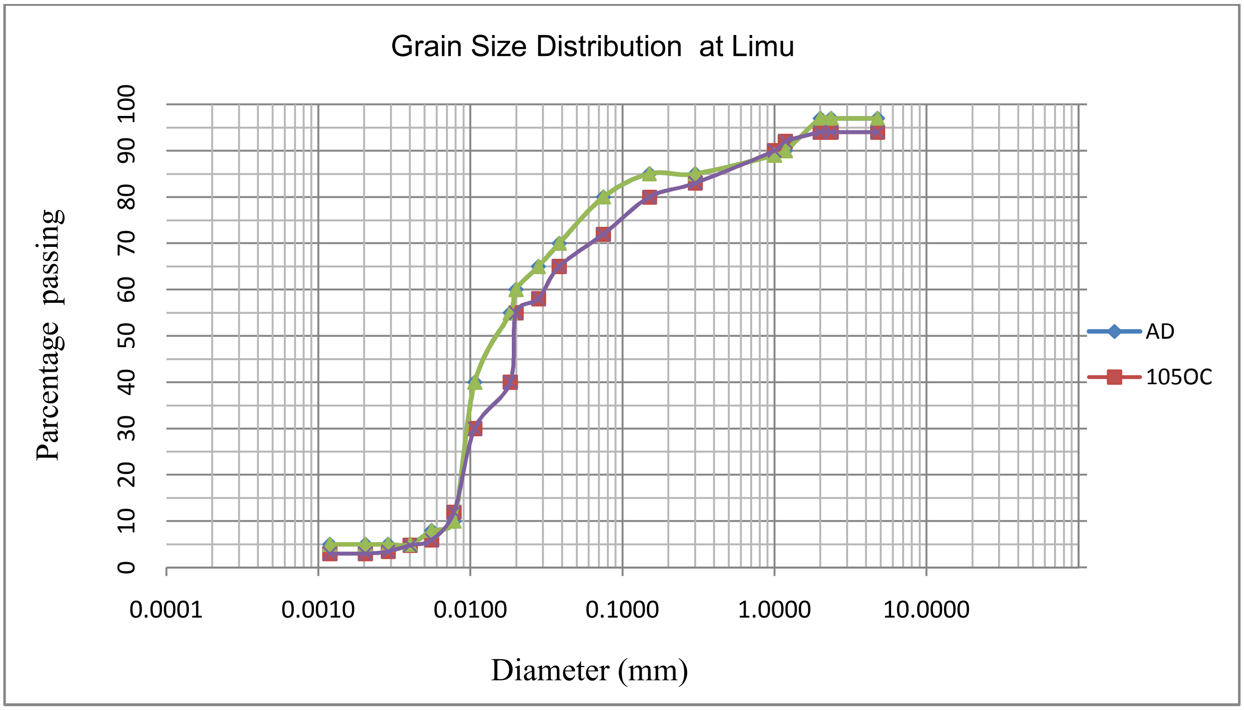


Fig 4.4 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Limu

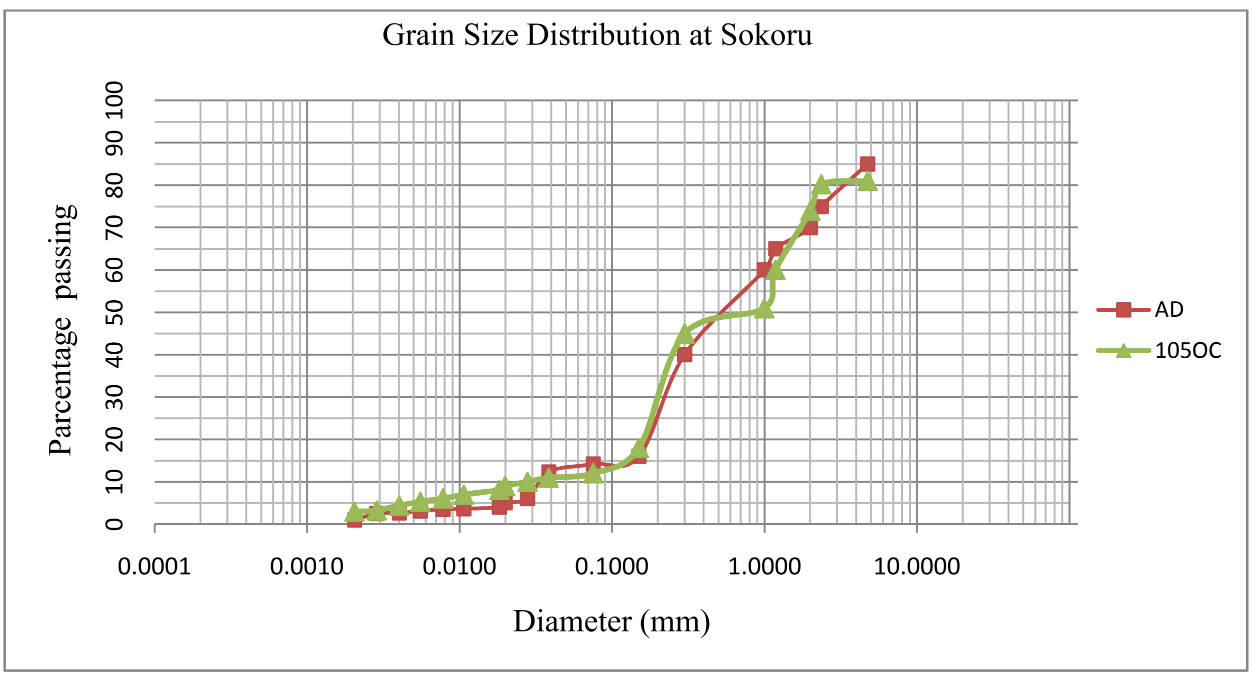


Fig 4.5 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Sokoru

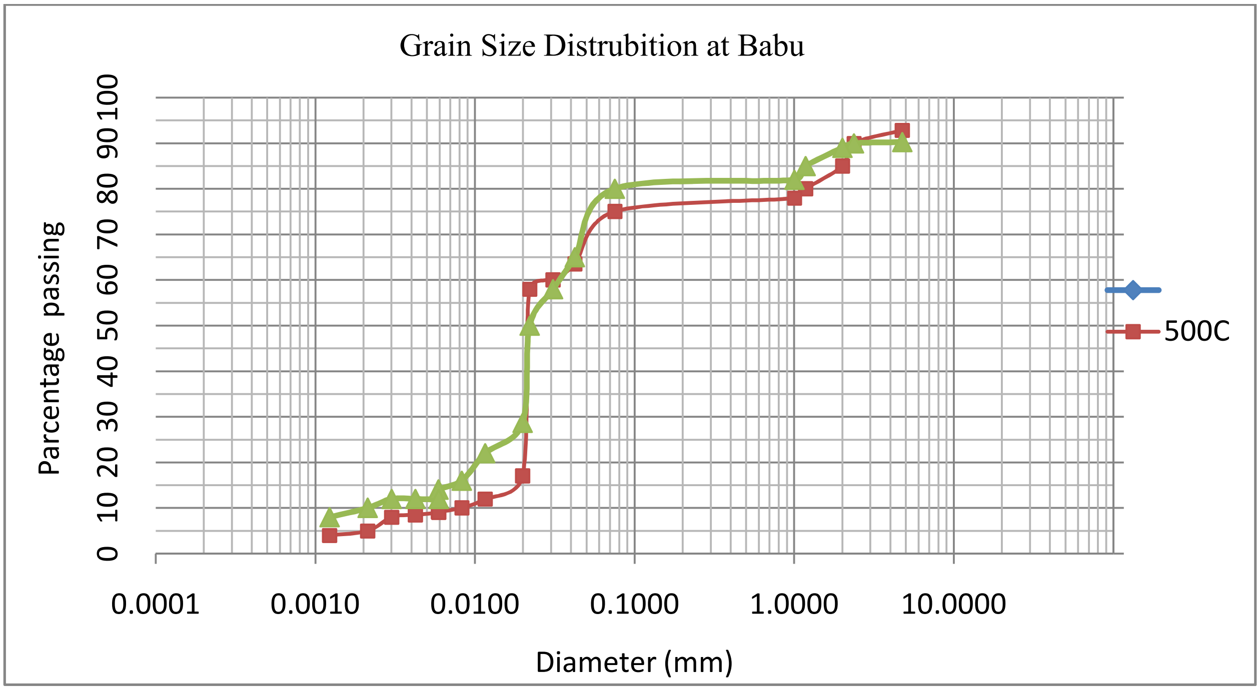


Fig 4.6 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Babu

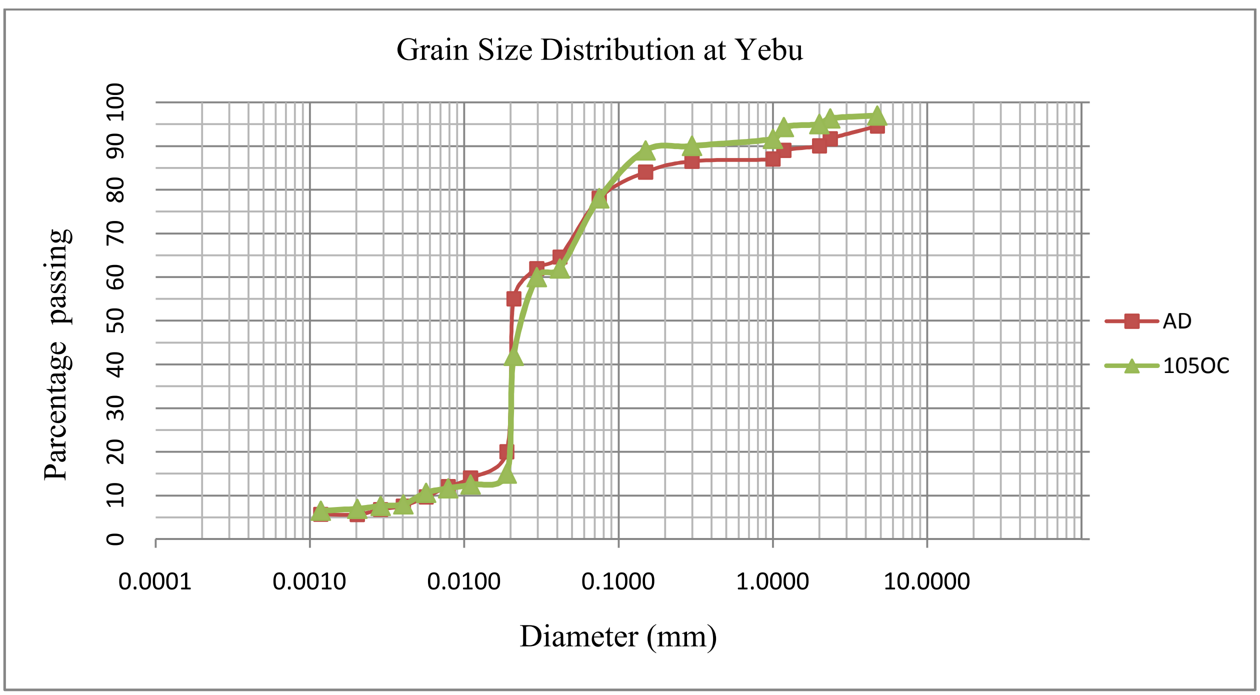


Fig 4.7 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Yebu

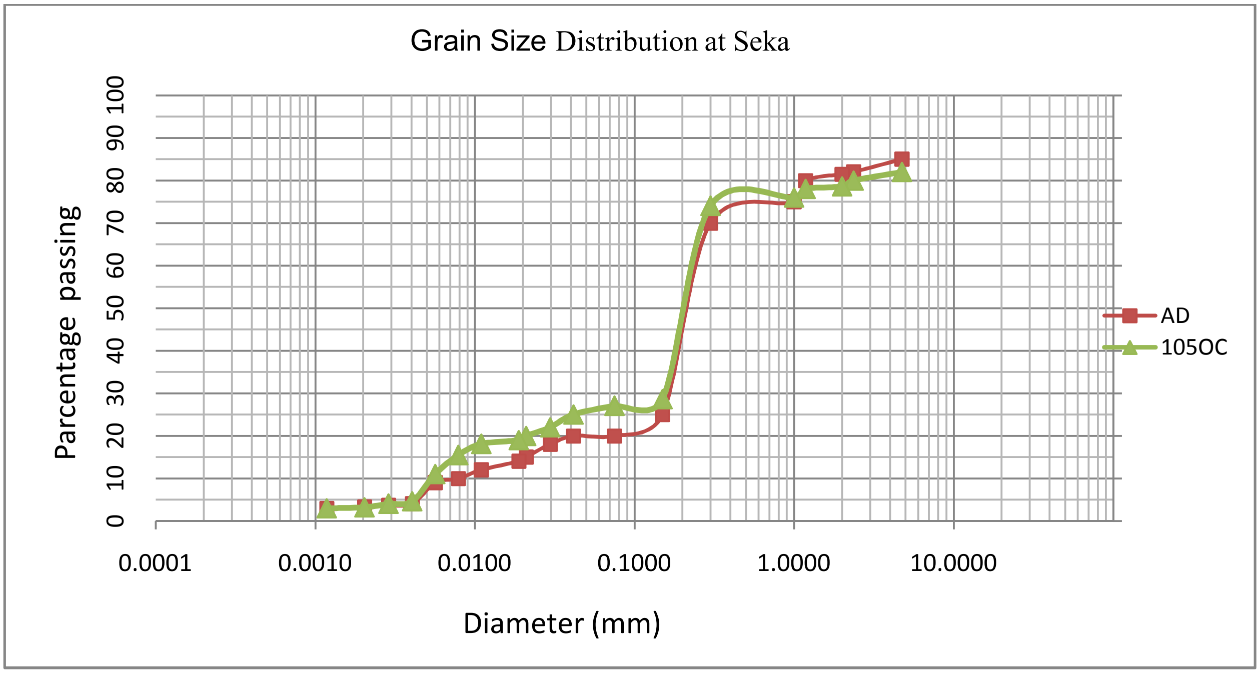


Fig 4.8 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Seka

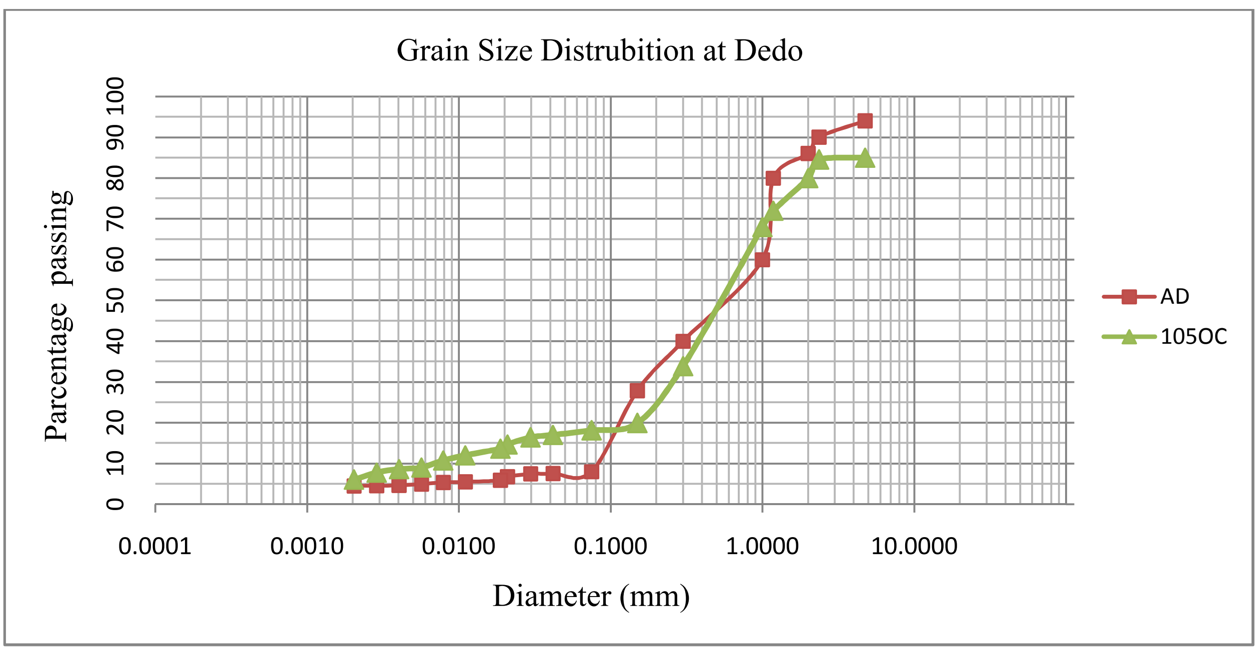


Fig 4.9 Typical grain size distribution curves of soil samples as air dried and oven dried condition - Dedo

Lateritic soil has higher content of fines and quantity of the clay fraction reduces with depth which is in the fact that degree of weathering decrease with depth (Gidigasu, 1976). From the curve and the table one can absorb that the quantity of clay fraction reduce with depth which is in agreement with the fact that the degree of withering decrees with depth. The test results show great deference for almost all soils under investigations, when these soils are dried, the fine particles come together and reduce the available surface for contact with water to reduce the plasticity characteristics. The drying of soil samples leads the soil particles come together due to cementation by Sesquioxides (Hanna, 2005). The soil under investigation is shown on Table 4.7.

The grain size analysis test results for lateritic soil samples under investigation at oven dried and air dried sample conditions and classification system are presented in Table 4.7 and Fig 4.1 up to Fig 4.10.The result of the grain size distribution from the grading curves is presented in Table 4.6 above ,The table shows that at oven drayed condition the lateritic soil samples have gravel range between 7.05 % and 72.04 %, course , medium and fine sand content between 6.00 % and 35.00 % and fine content between 21.85 % and 70.28 % and from this between 7.65 % and 23.00 % silt and between 8.58 % and 62.68 % clay , air drayed condition the lateritic soil samples have gravel range between 7.24 % and 63.67 %, course , medium and fine sand content between 5.52 % and 32.85 % and fine content between 23.63 % and 77.52 % and from this between 10.65 % and 68.68 % silt and between 10.65 % and 62.68 % clay.

4.6 Atterberg Limit Test Result

Atteberg limit tests are carried out to determine the consistency of clay & silt grained soils .The test for lateritic soils normally give large range of results (Rossiter D.G., 2004).When liquid limit test are carried out on lateritic samples the increase in cementation due to the aggregation of fine particles will be brake down values. To reduce these effects the mixing time was kept to a minimum, generally about 5 minutes for each limit point (Lyon, 1971).

Atterberg Limits were determined for air dried, oven dried and as received or at the natural moisture content. The air- drying samples were prepared by spreading the specimen in the laboratory for about 10 days at the room temperature was about 20-22ºc. The oven drying samples were prepared by putting the sample in an oven for 24 hours at a temperature of 110 ºc + 5º. The portions of the soil samples passing the No. 40 sieve were used for the preparation of the sample. At as received pre treatment condition samples are difficult to be sieved at natural moisture content hence, wet preparation was used. In this procedure, to reduce disaggregation, the soil should be broken down by soaking in distilled water. The soil should be immersed in distilled water to form slurry, which is then washed through a 425 µm sieves until the water runs clear. The material passing the sieve is collected and air dried until it is wet without any free water used for Atterberg Limit test.

Table 4.8 Atterberg limit test result of lateritic soils of Jimma zone as received, air dried and oven dried pre- treatment conditions.

Location	Depth after removing the overburden (m)	Liquid Limit (%)			Plastic Limit (%)			Plastic Index (%)		
		AR	AD	OD	AR	AD	OD	AR	AD	OD
Agaro	1.00	65.00	68.50	70.20	27.14	25.00	30.00	37.86	43.50	40.20
	3.00	68.50	69.00	71.75	34.00	22.48	24.60	28.35	46.52	47.15
Jimma	1.30	44.50	46.50	49.25	23.60	26.45	29.25	20.90	20.05	20.00
	3.20	39.50	45.50	48.00	18.50	13.50	26.00	21.00	32.00	22.00
Serbo	1.10	27.50	29.15	29.50	4.90	5.12	4.75	22.60	24.03	24.75
	3.20	24.00	25.50	30.00	2.20	3.50	9.50	21.80	22.00	20.50
Limu	1.00	49.00	47.50	49.00	22.65	25.87	30.47	22.35	21.63	18.53
	3.00	46.00	46.80	50.00	24.00	27.15	2950	22.00	19.65	20.50
Sokoru	1.20	75.62	77.15	80.00	29.00	38.40	45.00	46.60	38.75	35.00
	3.00	74.00	76.20	81.65	34.00	38.00	39.24	40.00	38.20	42.41
Yebuu	1.10	30.00	33.50	40.10	9.95	11.90	20.02	20.05	21.60	20.08
	3.00	30.50	33.00	37.50	6.55	9.51	10.10	23.95	23.49	27.40
Babu	1.10	39.00	42.25	47.25	14.40	18.65	22.82	24.60	23.60	24.43
	2.90	38.50	40.00	43.00	12.50	15.00	16.91	26.00	25.00	26.09
Seka	1.00	73.00	76.50	79.65	48.91	54.20	58.81	24.09	22.30	20.84
	3.00	75.70	76.00	81.00	52.00	52.14	59.86	23.70	23.86	21.14
Dedo	1.10	79.50	80.50	85.50	22.07	25.55	27.25	57.43	54.95	58.25
	3.10	82.50	83.00	84.50	24.33	28.45	31.25	58.17	54.55	52.75

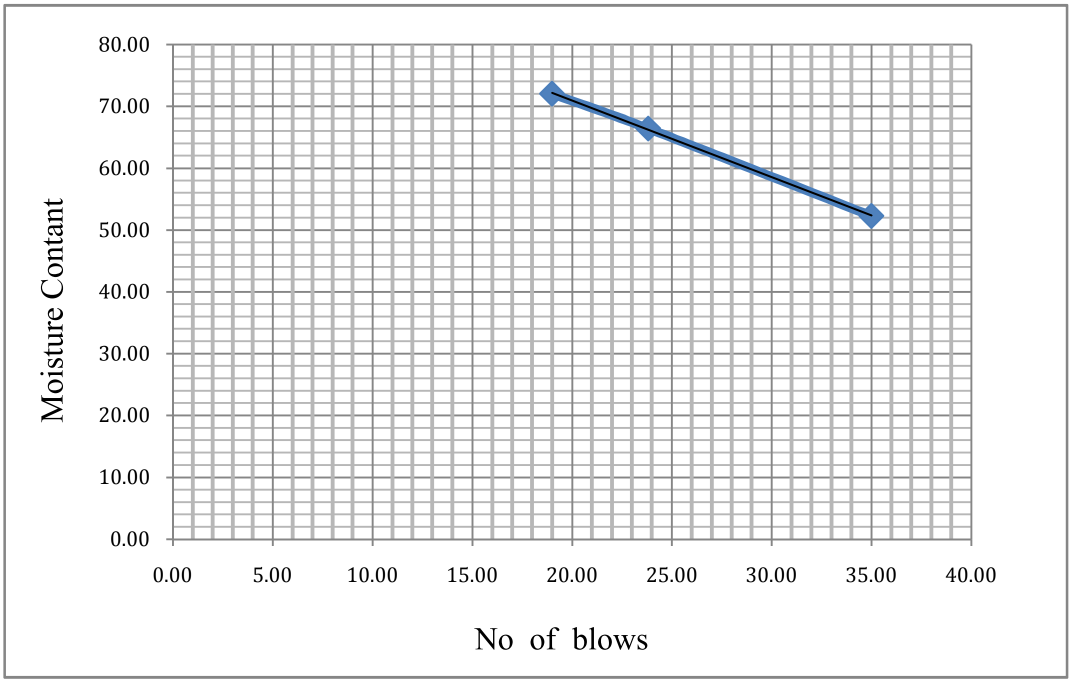


Fig: 4.10 Liquid limit chart at received condition –Agaro

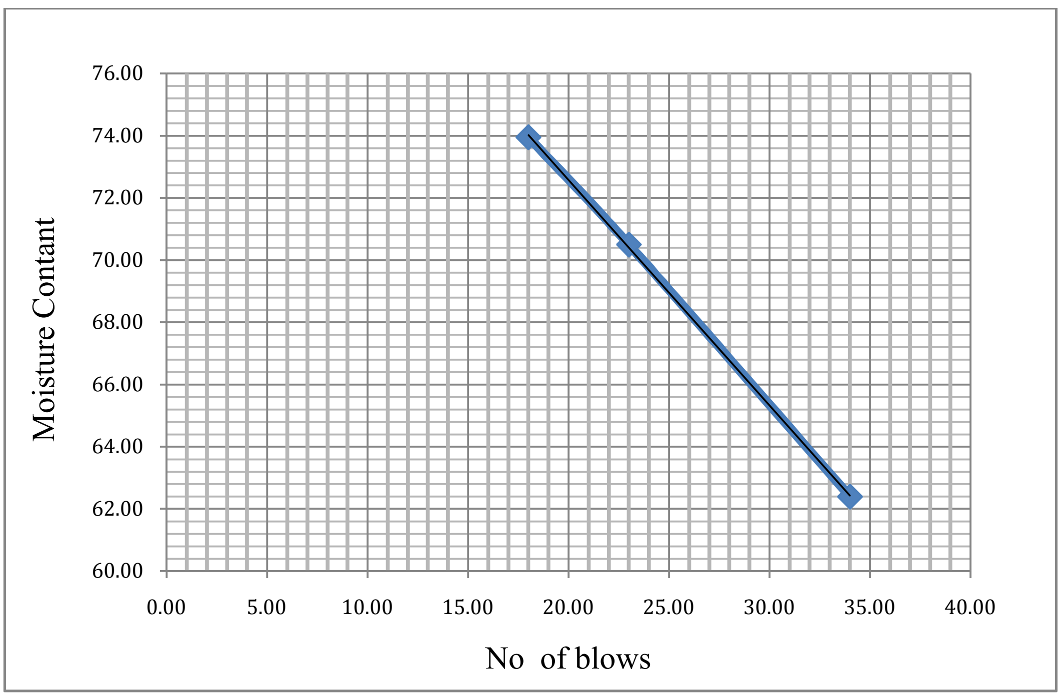


Fig 4.11 Liquid limit chart at air dried preretirement condition-Agaro

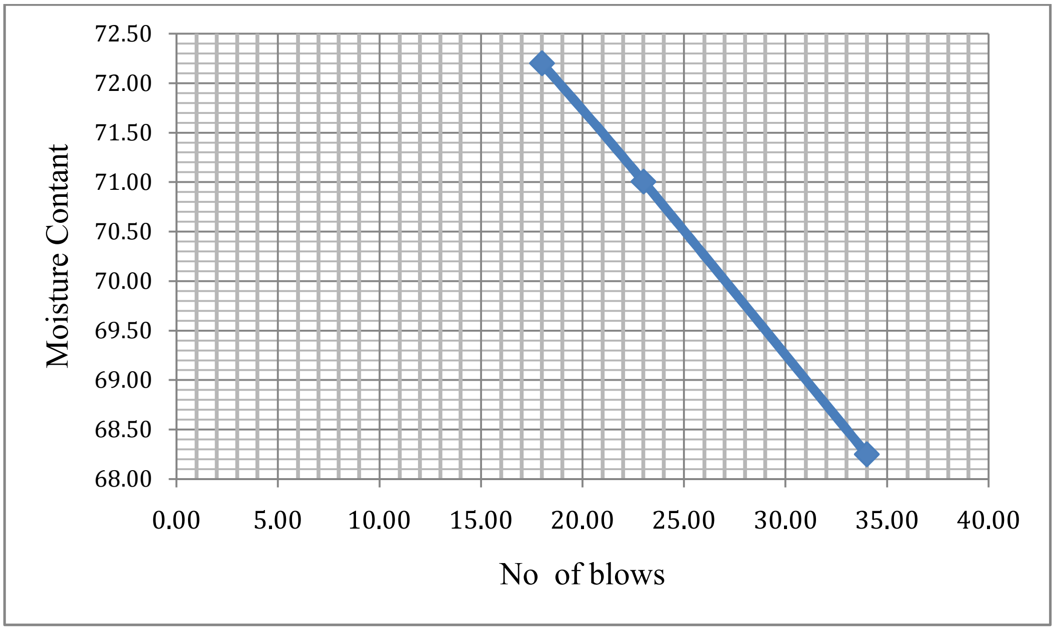


Fig 4.12 Liquid limit chart at oven dried preretirement condition-Agaro

The Atterberg limits test on the sample shows that the liquid limit, plastic limit and plastic index of lateritic soil sample varied between 42.80 % – 82.83 %, 21.00 – 52.00 % and 20.05 % - 58.17 as received condition , Between 46.00 % – 82.97 % 22.48 % – 54.20 % and 19.65 – 54.95 % as air dried , between 46.50 % – 85.37 % ,24.00 – 59.86 % and 18.53 % – 58.25 % as oven dried at 105 + /- 5 ^{o} c respectively as shown in table 4.7 Soil with liquid limit less than 30 % are considered to be low plasticity , those with liquid limit between 30 % and 50 % exhibit medium plasticity and those with liquid limit greater than 50 % exhibit high plasticity .

The soils are of low to medium plasticity (LL<50) which indicate the probable absence of expendable fine materials. As shown in Table 4.8 Lateritic soil samples of Serbo exhibit low plasticity, soil samples of Jimma, Limu, Babu & Yebu exhibit medium plasticity and samples from Agaro, Sokoru, Seka & Dedo exhibit high plasticity. This plasticity index of the soil (PI. 8 - 22 %).

The ERA manual states that the liquid limit of sub-grade materials should not exceed 80% and the plasticity index of sub-grade materials should not exceed 55%. This shows that except soil samples at Sokoru and Dedo the soils satisfy the requirements for sub-grade materials.

4.7 Soil Classification System

Wesley classifies residual soils on the basis of minerals and (Lyon, 1971) and also pedological classification classifies on the basis of climate, drainage, topography and parent material. The AASHTO classification system is convenient as a basis for classifying tropically weathered soils. Some road construction stake holders' uses conventional soil classification system using the grain size distribution and the Atterberg limit values. The soils under investigation have been classified according to AASHTO M-145 and UCSC method is also shown in Table 4.9.

Table 4.9 Soil classification according to AASHTO and USCS

Site location	Depth after re-moving the over-burden (m)	Sample condition	G I	Classification According to	
				AASHTO	USCS
Agaro	1.00	OD2	26.00	A-7-5	CH
		AD1	33.00	A-7-6	CH
	3.00	OD2	33.00	A-7-6	CH
		AD2	38.00	A-7-6	CH
Jimma	1.30	OD1	3.00	A-7-6	GM
		AD1	4.00	A-7-6	GM
	3.20	OD2	4.00	A-7-6	GM
		AD2	8.00	A-7-6	GM
Sokoru	1.20	OD2	15.00	A-7-5	MH
		AD2	19.00	A-7-5	MH
	3.00	OD1	20.00	A-7-5	CH
		AD1	22.00	A-7-5	MH

Serbo	1.10	OD2	0.00	A-2-6	GC
		AD2	1.00	A-2-6	GC
	3.20	OD1	0.00	A-2-6	GC
		AD1	1.00	A-2-6	GC
Limu	1.00	OD2	0.00	A-7-5	GM
		AD2	0.00	A-7-6	GM
	3.00	OD1	0.00	A-2-6	GM
		AD1	1.00	A-2-6	GM
Babu	1.00	OD1	0.00	A-2-7	GC
		AD1	1.00	A-2-7	GC
	3.00	OD2	0.00	A-2-7	GC
		AD2	0.00	A-2-7	GC
Yebu	1.10	OD1	4.00	A-7-6	GC
		AD1	6.00	A-7-6	GC
	2.90	OD2	3.00	A-7-6	GC
		AD2	5.00	A-7-6	GC
Seka	1.00	OD2	11.00	A-7-5	MH
		AD2	15.00	A-7-5	MH
	3.00	OD1	16.00	A-7-5	MH
		AD1	19.00	A-7-5	MH

Dedo	1.10	OD1	35.00	A-7-6	CH
		AD1	39.00	A-7-6	CH
	3.10	OD2	28.00	A-7-5	CH
		AD2	40.00	A-7-6	CH

4.8 Compaction

4.8.1General

Samples that were crushed to pass through 4.76mm sieve aperture of about 3kg were used. The sample is examined as air dried and oven dried pre-treatment conditions. Oven drying of samples were carried out at temperature of 105^{o}c.The samples was mixed with suitable amount of water of 5 % at initial stage and increased to 7 %, 9%, and 13% on subsequent test. Maximum dry density and optimum moisture content were determined from the graph of dry density against moisture content.

The compaction criteria commonly used for constriction of clay liners generally includes two parts namely, a minimum dry density and range of acceptable water contents (Wallace, K.B., 1973).

4.8.2 Test Result

The value of maximum dry densities and optimum moisture contents of the soil samples at different preretirement conditions has been summarized in Table 4.10 and samples plot of maximum dry densities versus optimum moisture content shown in Fig 4.13 and Fig 4.14. are presented in from the test results one can observe that the maximum dry densities and optimum moisture content results show that oven drying samples always gives the highest maximum dry densities and lowest optimum moisture content while samples at natural moisture content give the lowest maximum dry densities and highest optimum moisture contents.

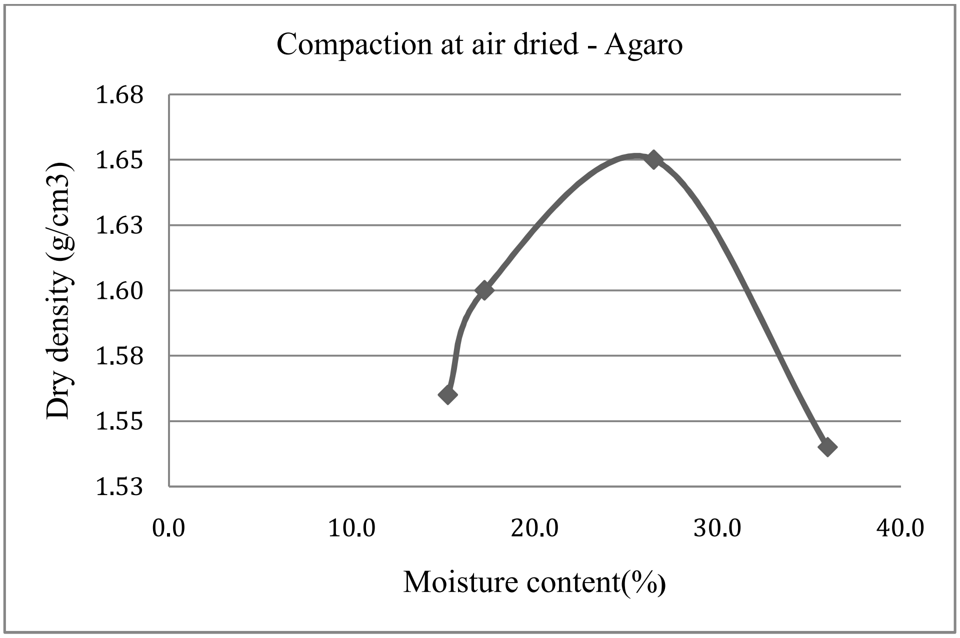


Fig 4.13 Maximum dry density versus maximum moisture content at air dried condition – Agaro

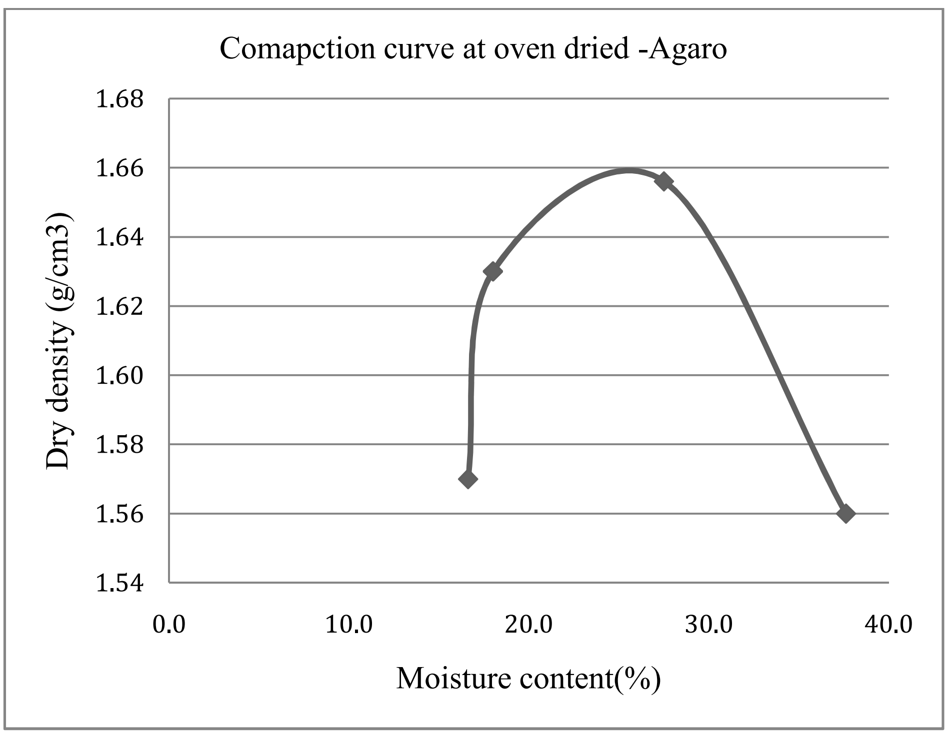


Fig 4.14 Maximum dry density versus maximum moisture content at Jimma air dried condition – Agaro

Table 4.10 Summary of compaction test at deferent pre treatment condition, method of testing and testing procedure

Location	Testing procedure	MDD (g/cm3)		OMC (%)	
		AD	OD	AD	OD
Agaro	Fresh	1.65	1.69	25.62	23.65
Jimma	Fresh	1.93	1.96	13.21	12.60
Serbo	Fresh	1.84	1.87	12.60	10.50
Limu	Fresh	1.90	1.92	11.85	10.10
Sokoru	Fresh	1.35	1.41	19.35	17.65
Babu	Fresh	1.96	1.99	16.52	15.25
Yabu	Fresh	1.85	1.87	27.40	25.32
Seka	Fresh	1.37	1.39	30.14	29.80
Dado	Fresh	1.25	1.44	26.14	25.65

The value of maximum dry density and optimum moisture content for the soils exposed to different drying conditions has been summarized in Table 4.10 and figure 4.13 and 4.14 one can see that oven dried sample gives the highest maximum dry densities and lowest optimum moisture contents while samples at natural moisture content give the lowest maximum dry densities and highest optimum moisture contents.

The lateritic soil of Jimma zone has the lowest OMC and MDD value of 10.10 % and 1.39 g $/cm^3$ and highest OMC value of 29.80 % and MDD value of 1.99 g $/cm^3$ at oven dried pre-treatment conditions and has the lowest OMC and MDD value of 11.85 % and 1.25 g $/cm^3$ and has higher OMC value of 30.14 % and MDD value of 1.96 g $/cm^3$ at air dried pre -treatment conditions.

The minimum values of MDD for sub grade material are supposed to be 1.5gm/cc (Mytsebri Shire, 2009). Hence, taking this in to account, the soils from Jimma, Serbo, Limu, Babu and Ye-bu are suitable sub grade materials.

4.9. California Bearing Ratio Test Result

The CBR values are used by road material engineers to design the thickness of pavement that will be laid on top of the sub grade. The design of pavement is very much dependent on the CBR value of sub grade. The strength of the sub grade is the main factor in determining the thickness of the pavement. Sub grade strength is expressed in terms of its California Bearing Ratio Value. The California Bring Ratio test is generally carried out in the laboratory. The sample must be compacted at the equilibrium moisture content to dry density likely to apply after the road has been constructed. The CBR test is acceptable internationally as reliable method of pavement design and it is also used in soil classification of road base materials for highway design and construction. Thus it becomes necessary to determine the CBR of the literate soil. The study herein presented the minimum California Bearing Ratio which serve as the most important factor during road pavement constructions.

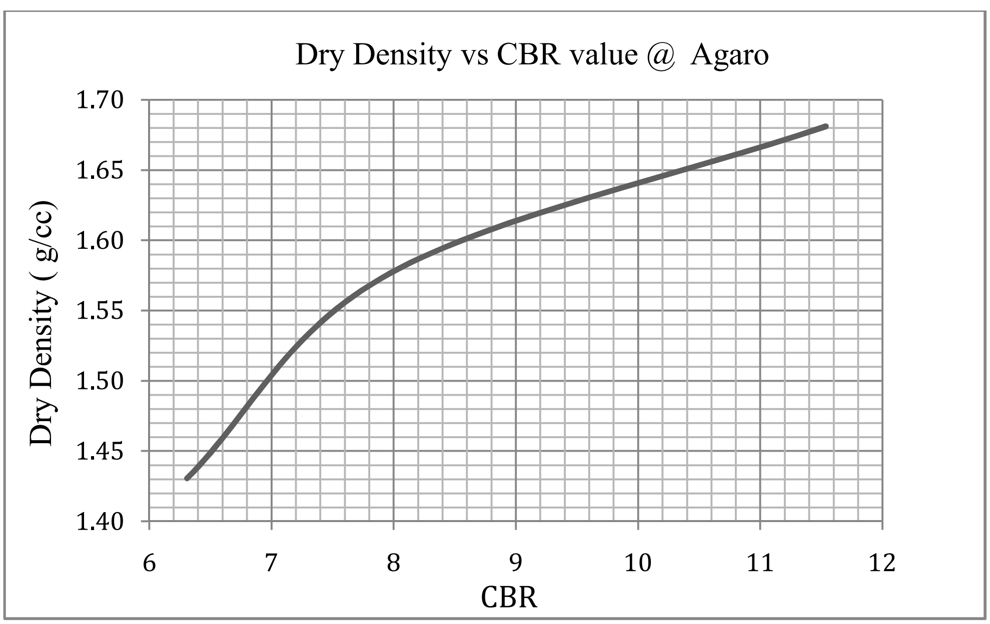


Fig 4.15 Dry Density vs. CBR value at Agaro

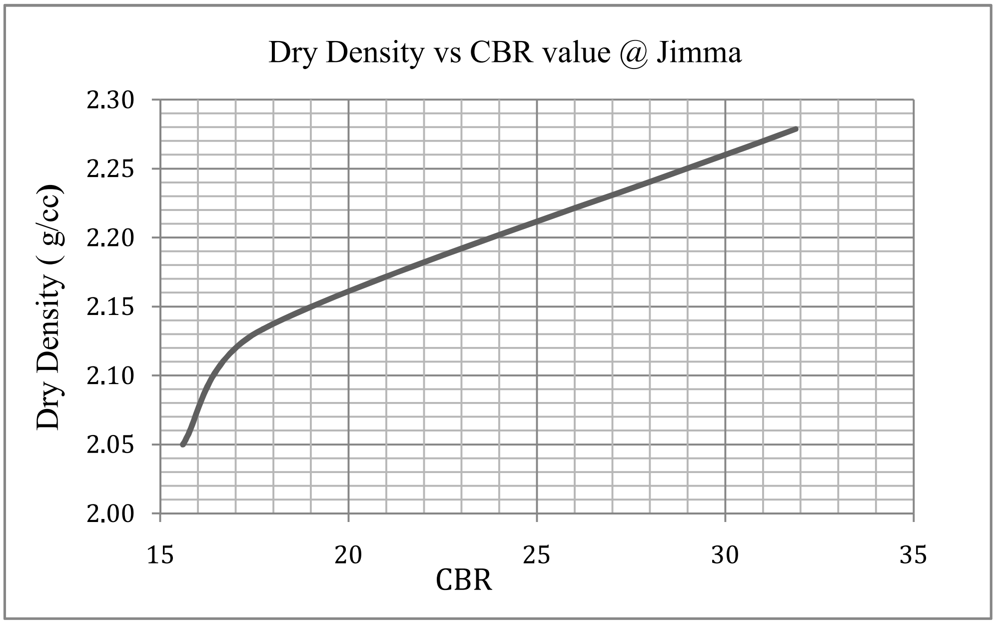


Fig 4.16 Dry Density vs. CBR value at Jimma

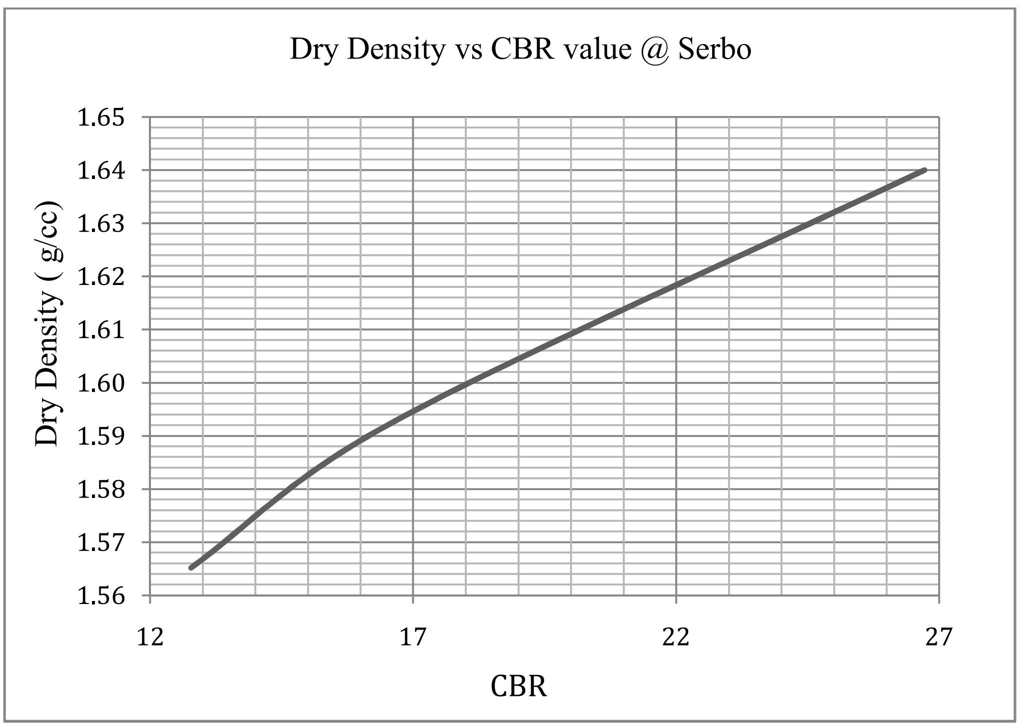


Fig 4.17 Dry Density vs. CBR value at Serbo

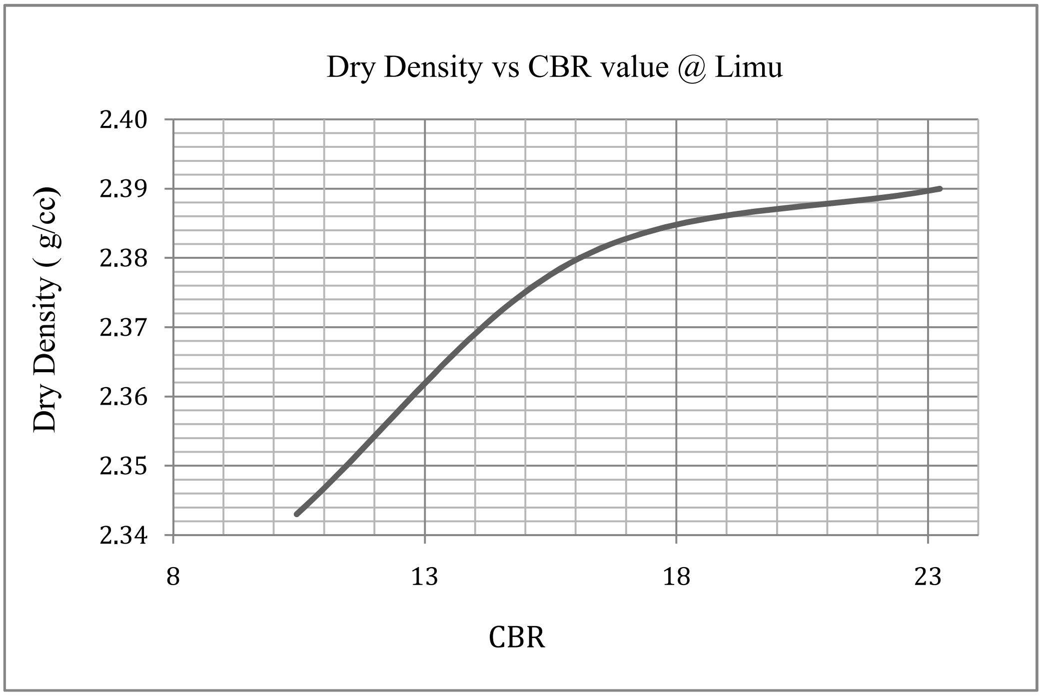


Fig 4.18 Dry Density vs. CBR value at Limu

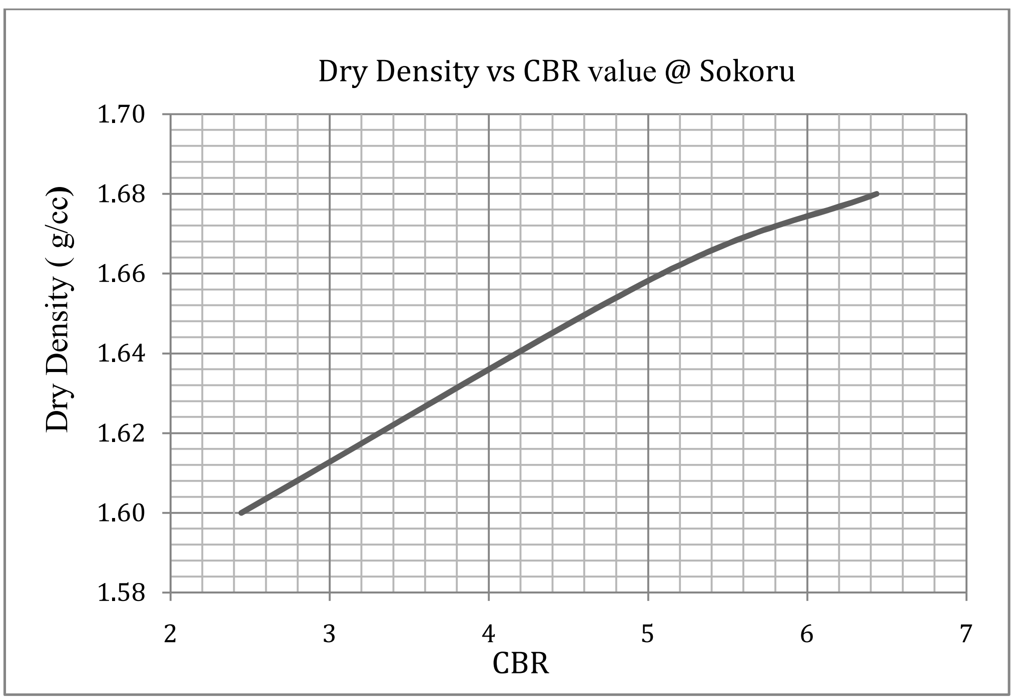


Fig 4.19 Dry Density vs. CBR value at Sokoru

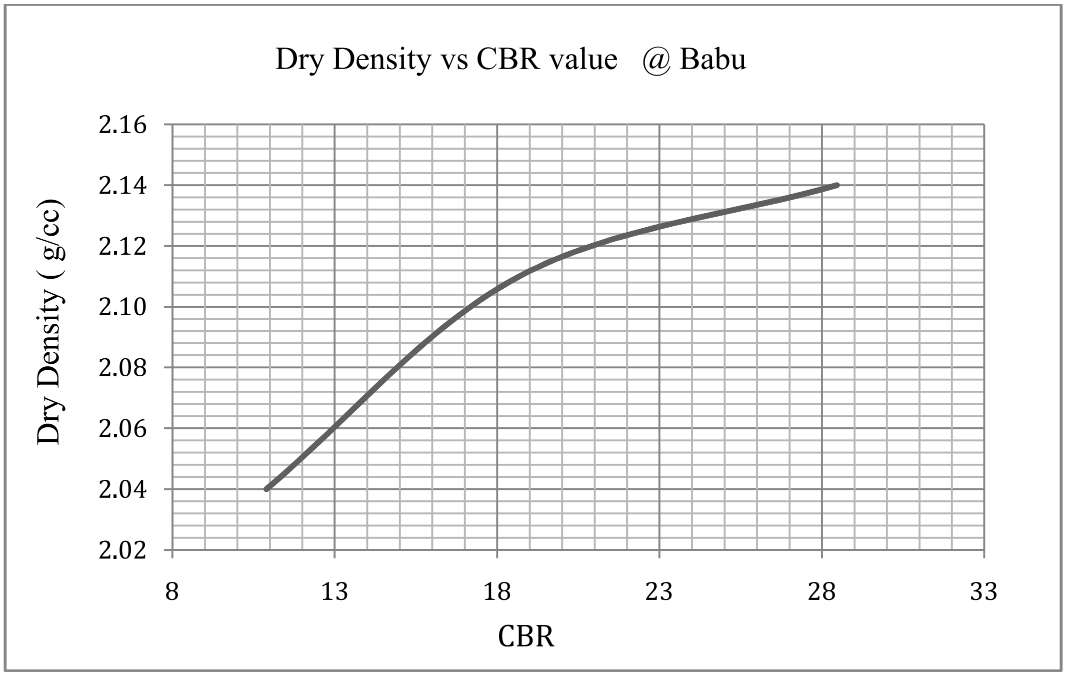


Fig 4.20 Dry Density vs. CBR value at Babu

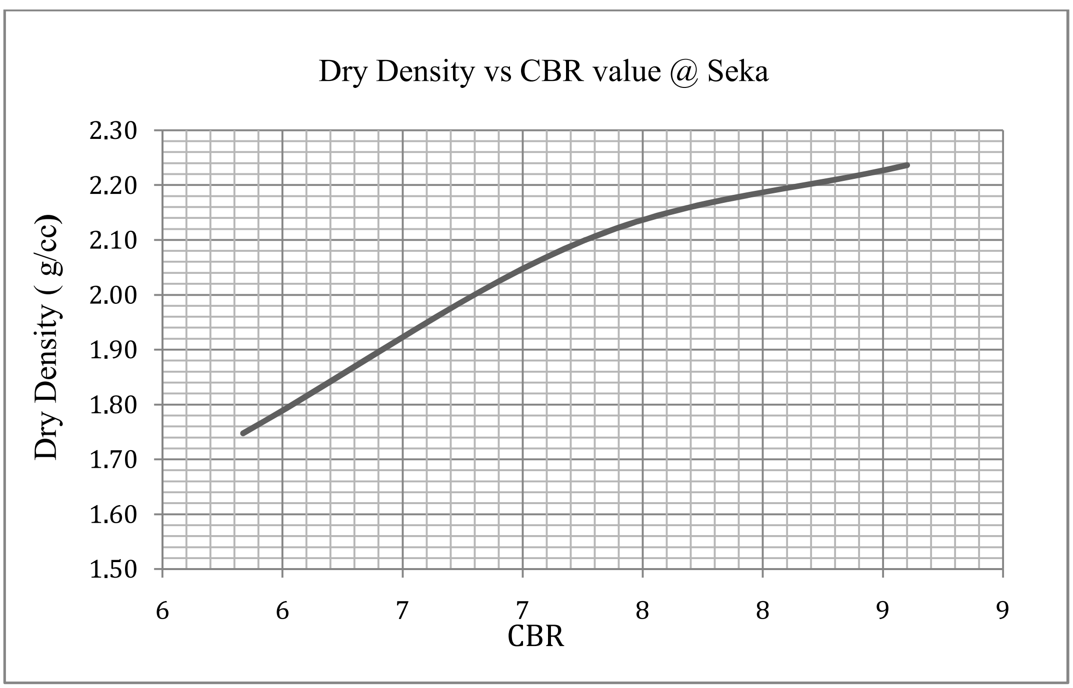


Fig 4.21 Dry Density vs. CBR value at Seka

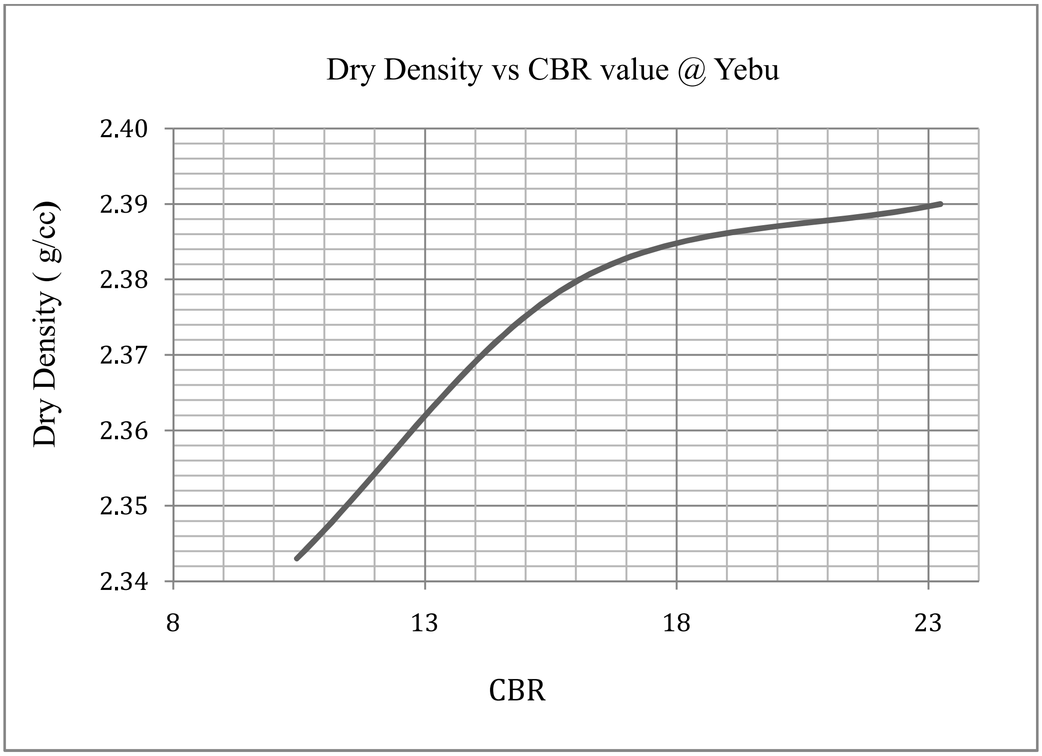


Fig 4.22 Dry Density vs. CBR value at Yebu

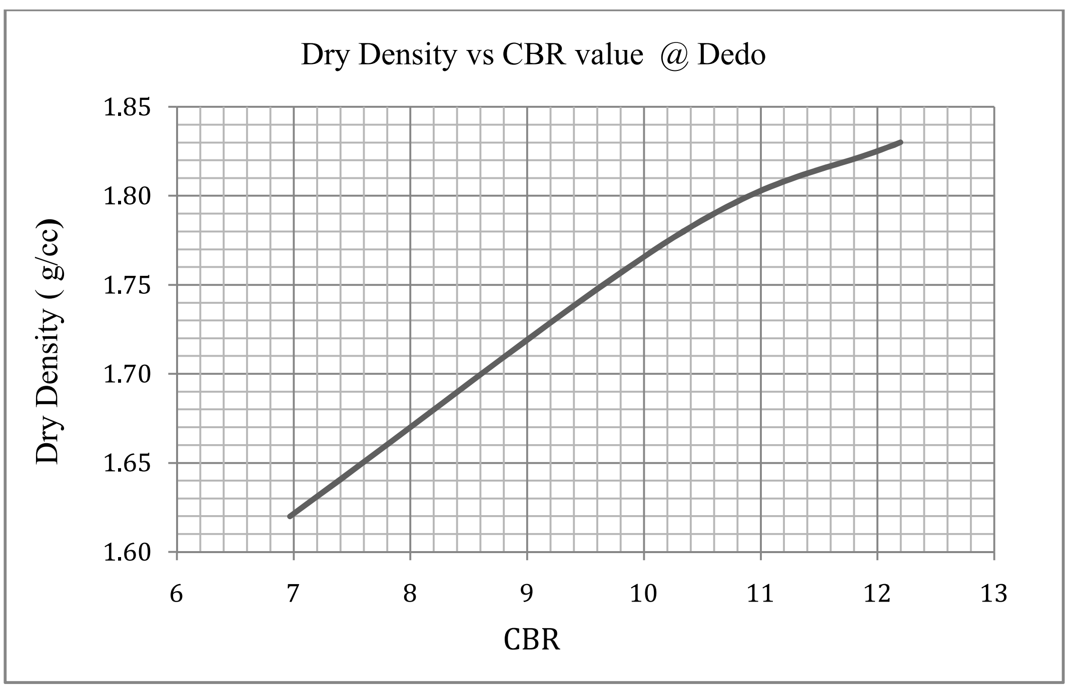


Fig 4.23 Dry Density vs. CBR value at Dedo

Table 4.11 CBR values and samples general properties

Location	OMC	MDD (g/cc)	CBR	Bowls		ERA
				General properties	Use	Value as sub grade
Agaro	24.86	1.61	10.14	Fair	Sub grade	Poor
Jimma	13.98	2.28	43.48	Good	Base , sub base	Good to excellent
Serbo	12.63	1.68	33.37	Good	Base , sub base	Good
Limu	11.48	2.39	29.36	Good	Base , sub base	Good
Sokoru	19.58	1.68	7.59	Poor - Fair	Sub grade	Poor
Babu	16.19	2.14	36.85	Good	Base , sub base	Good
Yabu	27.23	2.63	30.54	Good	Base , sub base	Good
Seka	27.83	2.24	9.78	Fair	Sub grade	Poor
Dado	24.34	1.85	13.79	Fair	Sub grade	Poor to fair

The values of CBR have been shown in Table 4.11. It has soaked CBR value ranging from 7.59 % and 43.48 %, dry density ranges 1.61 g/ cc3 to 2.63 g/ cc3 and maximum dry density ranging from 11.48 % to 27.83 % for sample soil.

According to Ethiopian Road Authority Design Manual (ERA.2002) it can be seen that samples lateritic soil of Agaro , Sokoru and Seka satisfy the condition for poor value as sub grade ,Lateritic Serbo, Limu, Babu & Limu satisfay good as sub grade materials & lateritic soil sample of Jimma only satisfy good to excellent as sub grade materials as sub grade materials from the calculated value.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

Based on the values obtained from the various tests carried out on the sample, it could be concluded that

1. The test result reveals that the soil sample of Agaro ware composed of Quartiz, Pyrophyllite & Hematites; the soil sample of Jimma ware composed of Quartiz,Albite & Ferrosilite; the soil sample of Seka ware composed of Quartiz, Goethite & Lindgrenite; the soil sample of Serbo ware composed of Kaolinite & Goethite and finally the soil sample of Limu ware composed of Kaolinite & Ferrosilite.

2. The Geochemical test results show that soil samples at Agaro, Jimma, Limu and Serbo are true laterite ; soil sample of Dedo is lateritic .

3. For the lateritic soil of Jimma zone natural moisture content results of oven dried at 50oC ± 5oC and at 105o C ± 5o C should between 4 % and 6 % this indicate that there is definite structural water or amorphous clay minerals found dehydration of S-S does significantly affect the index properties of lateritic soils of this area.

4. It is observed that the lateritic soil of Jimma zone is highly laterzed and also the result show that the quantity of clay fraction reduce with depth which is in agreement with the fact that the degree of withering decrees with depth.

5. Soil samples of Serbo exhibit low plasticity , soil samples of Jimma ,Limu, Babu & Yebu exhibit medium plasticity and Soil samples from Agaro, Sokoru ,Seka & Dedo exhibit high plasticity.

6. The test results show that when these soils are dried, the fine particles come together and reduce its percent.

7. The result of the grain size distribution from the grading curves is presented in Table 4.6 above ,The table shows that at oven drayed condition the lateritic soil samples have gravel range between 7.05 % and 72.04 %, course , medium and fine sand content between 6.00 % and 35.00 % and fine content between 21.85 % and 70.28 % and from this between 7.65 % and 23.00 % silt and between 8.58 % and 62.68 % clay , air drayed condition the lateritic soil samples have gravel range between 7.24 % and 63.67 %, course , medium and fine sand content between 5.52 % and 32.85 % and fine content between 23.63 % and 77.52 % and from this between 10.65 % and 68.68 % silt and between 10.65 % and 62.68 % clay.

8. The Atterberg limits test on the sample shows that the liquid limit, plastic limit and plastic index of lateritic soil sample varied between 42.80 % – 82.83 %, 21.00 – 52.00 % and 20.05 % - 58.17 as received condition , Between 46.00 % – 82.97 % 22.48 % – 54.20 % and 19.65 – 54.95 % as air dried , between 46.50 % – 85.37 % ,24.00 – 59.86 % and 18.53 % – 58.25 % as oven dried at 105 + /- 5 ^{o} c respectively accordingly Lateritic soil samples of Serbo exhibit low plasticity, soil samples of Jimma , Limu, Babu & Yebu exhibit medium plasticity and samples from Agaro, Sokoru ,Seka & Dedo exhibit high plasticity.

9. The lateritic soil of Jimma zone has the lowest OMC and MDD value of 10.10 % and 1.39 g /cm^3 and highest OMC value of 29.80 % and MDD value of 1.99 g /cm^3 at oven dried pre-treatment conditions and has the lowest OMC and MDD value of 11.85 % and 1.25 g /cm^3 and has higher OMC value of 30.14 % and MDD value of 1.96 g /cm^3 at air dried pre -treatment conditions, the soils from Jimma, Serbo, Limu, Babu and Yebu are suitable sub grade materials.

10. According to Ethiopian Road Authority Design Manual (ERA.2002). it can be seen that samples lateritic soil of Agaro , Sokoru and Seka satisfy the condition for poor value as sub grade ,Lateritic Serbo, Limu, Babu & Limu satisfay good as sub grade materials & lateritic soil sample of Jimma only satisfy good to excellent as sub grade materials as sub grade materials from the calculated value.

5.2 Recommendations

1. The results and findings of the present study are on small number of samples and on small area of the zone further studies would be mandatory before implementation of results from the present study.

2. In order to use the lateritic which are widely distributed in Ethiopia as materials in road construction proper selection criteria should be used .The use of lateritic soil for road construction has been done using the in appropriate specifications, i.e. those developed for the climate conditions of Europe and North America . It is clear that in order to reduce the wastage of a valuable resource many countries has been prepared their own specification. Therefore it is suggested that a detailed investigation to be carried out and the specifications (selection criteria) adapted for lateritic soil of Jimma zone as road construction materials.

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