STABILIZATION OF LATERITIC GRAVEL USING PRECIPITATED CALCIUM CARBONATE FOR THE USE OF SUBBASE CONSTRUCTION FOR LOW VOLUME ROADS: A CASE STUDY OF BATU TOWN

MSc. THESIS

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A THESIS SUBMITTED TO FACULTY OF CIVIL ENGINEERING AND BUILT ENVIRONMENT, HAWASSA INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES

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This is to certify that the thesis "Stabilization of lateritic gravel with precipitated calcium carbonate for the use of subbase construction for low volume roads: A case study of Batu town (East Shoa Zone, Ethiopia)." submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Road and Transport Engineering, the Graduate Program of the Department of Civil Engineering and has been carried out by FEYYISA GOBENA KUMBI Id. No GPRoTr/011/11, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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DECLARATION

I hereby declare that this M.Sc. thesis entitled "Stabilization of lateritic gravel using precipitated calcium carbonate for the use of subbase construction for low volume roads: A case study of Batu Town" is my original work under the supervision of Prof. Emer Tucay Quezon submitted to the School of Graduate Studies of Hawassa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Civil Engineering, Road and Transport Engineering. I further declare that this work has not been submitted to any other institutions for the award of any degree or diploma and all sources of materials used for the thesis have fully acknowledged.

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This M.Sc. thesis entitled "Stabilization of lateritic gravel using precipitated calcium carbonate for the use of subbase construction for low volume roads: A case study of Batu Town" has been submitted for examination with my approval as thesis advisor.

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Place and date of submission: Hawassa University, 19/10/2020

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LIST OF ABBREVIATIONS

AASHTO…………. American association state of highway and transportation organization

CBR…………….……..California Bearing Ratio

CSA……………….. Crushed Stone Aggregate

ERA………………...Ethiopian Road Authority

GRAS……………..…...Generally Recognized As Safe

LAA……………….. Los Angeles Abrasion

LL…………………..….Liquid Limit

LG ………………….Lateritic Gravel

MBS……………..…..Mesken Borrow site

MLRA……………... Multiple linear regression Analysis

PCC……………….... Precipitated Calcium Carbonate

PI…………………....Plasticity Index

SL…………………...Shrinkage Limit

TFV………………… Ten Per cent Fines Value

US…………………...United state

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DEDICATION

This thesis work is dedicated to the luminary young man of my community the late Dr. Gurraachaa Gobena and the king of Oromo music of resistance the late Artist Hacaaluu Hundeessaa.

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ABSTRACT

Lateritic gravel materials do not satisfy the gradation requirement for subbase course as it is mostly composed of larger grain sized particles lacking of fine materials. The two most important factors likely to affect the engineering behavior of lateritic gravel materials were the gradation and the strength of the gravel particles which not satisfied by materials they are using at the moment. This thesis study has been done to check the use of blended precipitated calcium carbonate with lateritic gravel as subbase material for the construction of low volume roads in Batu town based on Ethiopia Roads Authority standard requirements for subbase materials. In the beginning engineering properties of both materials were studied by doing some laboratory tests on each materials differently and later the mechanical stabilization of lateritic gavel was carried out in blending of lateritic gravel with different proportion of Precipitated calcium carbonate. The optimum amount of precipitated calcium carbonate required for stabilization is obtained after the compaction test, as a result the maximum dry density attained was found to be 2.1g/cc after the blending of 30 percent precipitated calcium carbonate with 70 percent lateritic gravel. As the test result revealed the California bearing ratio values of blended materials were 42% which is more than Ethiopia Roads Authority specification requirement for low volume roads subbase. In addition to the improvement of California bearing ratio values the blending of precipitated calcium carbonate with lateritic gravel results in fulfill the Ethiopia Roads Authority specification requirement for gradation as it constitutes fine particles. The correlation of soaked California bearing ratio value and other independent variables like maximum dry density and optimum moisture content developed using Minitab statistical software to be Soaked California bearing ratio = -7.86 + 29.24 maximum dry density – 0.17 optimum moisture content. In conclusion the test results favors the use of blended Precipitated calcium carbonate and lateritic gravel as subbase material for low volume roads that can results in reduced cost road construction, reduced environmental problem caused by Precipitated calcium carbonate on children, improved California bearing ratio value and urban land use.

Key words: Stabilization, Lateritic gravel, Precipitated calcium carbonate, California bearing ratio, Gradation

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1 INTRODUCTION

1.1 Background

For good and efficient transportation road construction is a major concern. Road is important for economic growth and the development of any community or state as it promotes quick and easy movement of the people between origin and destination. In addition, it promotes market integration, thereby providing an avenue for the reduction of price volatility and the reallocation of resources in line with another comparative advantages (Athira, et al., 2017).

Readily available, cheaper and materials with some deficiencies can be improved aiming high qualities in terms of strength and workability to be used for construction at minimum construction costs. Lateritic gravel is composed of large sized granular materials that does not satisfy the gradation requirement of ERA specification manual of 2011. In addition to this the precipitated calcium carbonate stockpile in the middle of town is finer in nature and may be used as the finer materials required to fit gradation envelope of ERA standard specification 2013. The properties of Lateritic gravel may be improved by additions of binders; usually cement hydrated lime or bitumen. The blending of lateritic gravel with precipitated calcium carbonate can alter the gradation property which may improve the gradation (Szendefy, 2002).

Lateritic gravels, especially those containing small percentage fines, are possibly difficult to compact and this tends to cause it to be unstable. If these gravels are selected to be used as road subbase construction materials, a low-cost method of improving the mechanical behavior and strength of lateritic gravel is desirable. For use in road works, lateritic soils may fall short to satisfy specification requirements, especially subbase or base material specification (Qian, et al., 2017).

The long term performance of any construction project depends on the stability of the underlying soils. Engineers are often faced with the problem of constructing road bed on or with soils which do not possess sufficient strength to support wheel load imposed upon them either in construction or during the service life of the pavement. It is at time necessary to treat these soils to provide a stable sub grade or a working platform for the construction of the pavement. These treatments are generally classified into two processes; soil modification

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or soil stabilization. Treatment of marginal soils increases their use as construction materials (Sahoo & Mohanty, 2016).

The addition of fines improves the strength and density of the compacted lateritic gravels. The road examination confirmed that the action of traffic produces the same breakdown effect in gravel roads as was observed in the laboratory compaction tests. Since the precipitated calcium carbonate which found at Batu town is rejected for being fine in the production of lime and discarded; it may meets the requirement for finer materials in road construction using lateritic gravel (Dauda, 2019).

In addition to being finer material, precipitated calcium carbonate possess strong rocks of carbon family which grinded to pass sieve size of 20mm. higher percentage of calcium in precipitated calcium carbonate owes it the strength required for road construction materials in terms of bearing capacity.

The improvement in the strength and durability of red ash soil in recent times has become imperative, which has encouraged researchers to use stabilizing materials that can be sourced locally at a very low cost.

1.2 Statement of the Problem

Lateritic gravel in its natural state generally has a low bearing capacity and low strength due to its 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 breakdown, limits their usefulness as pavement materials due to lack of fine particles to fill the gap between the coarser material. Untreated lateritic materials have presented many problems in road construction and maintenance. Consequently, for the past three decades stabilization of lateritic materials by admixtures has been practiced and studied in Africa (Amu, et al., 2011).

Lateritic gravel is a widespread material in tropical and subtropical African countries. It appears to be a kind of building material for pavement engineering because of its low cost, environmental friendly aspects, and limited sources of quality aggregates. But its use is justified only when the appropriate technologies for treatment are utilized. Otherwise, the road sections built with raw lateritic gravel will become the subject of deterioration, which is mainly caused by rain erosion and traffic intensification (Gidigasu, 2010).

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The use of locally available stabilizer is of good economic values as it reduces both the hauling cost and time of construction which are the crucial components in the construction projects. The factory have earlier discarded the precipitated calcium carbonate as it cannot be used for the production of calcium oxide. Hence finding ways through which it could be used as lateritic gravel stabilizer for the road projects is seemed to be valuable.

In addition to the stabilizing the red ash soil, the removal of the calcium carbonate stock pile at midblock in the town helps the municipality to get use of extra free land and environmentally reduces the ill effects of calcium carbonate emitting in the form of fine dust during the dry season which carried by wind. So the use of this calcium carbonate in stabilizing lateritic gravel may result in triple advantages as it gives municipality to get free land, Local contractors experience the process of blending different soils in improving soil strength characteristics and residents around the factory will be relieved from the dusty soil affecting their health.

The aim of the proposed thesis is to examine if lateritic gravel materials of low volume road construction could be found suitable for subbase course construction for road projects after precipitated calcium carbonate treatment.

1.3 Objective of the Thesis Study

1.3.1 General objective

The general objective of the study is to evaluate stabilization of Lateritic gravel using precipitated calcium carbonate for the use as subbase course for low volume road projects.

1.3.2 Specific objectives

- To assess the engineering properties of lateritic gravel and precipitated calcium carbonate.
- To determine the optimum calcium carbonate required for lateritic gravel stabilizer and evaluate the economic cost benefits of using precipitated calcium carbonate.
- To establish correlation between the soaked CBR and the index properties of the stabilized subbase layer.

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1.4 Research Questions

The research study tries to address the following research questions;

1. What are the engineering properties the red ash soil and precipitated calcium carbonate for use in subbase course layer?
2. What is the optimum calcium carbonate required for lateritic gravel stabilizer meeting the strength requirements for sub-base course per Standard Specifications and how much its cost benefits can be derived from using calcium carbonate as the red ash stabilizer?
3. Is there any strong relationship between the soaked CBR and the index properties when stabilized with precipitated calcium carbonate for subbase layer?

1.5 Significance of the Study

Lateritic gravel present at Butajira is being used for the construction of a low volume cobblestone road and gravel roads at Batu and another nearby towns. However, in this study will be conducting various tests to determine if the same soil will be suitable for road subbase course works, if its properties can be varied by precipitated calcium carbonate stabilization. So, the finding of this study is expected to contribute to help;

- The client to find the way to get use of what is discarded as waste for the road construction in the town which may reduce the cost of hauling red ash from far location.
- Contractors will get the experience in making use stabilized soils with easy and simple stabilization methods.
- Improves the roads defects arising in early service years due to problematic lateritic soils which in turn reduces road maintenance cost.
- Helps the municipality by delivering the land covered by the stock calcium carbonate to be used for another purpose for the municipal use.

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1.6 Scope of the study

The study was mainly concerned on checking whether the blended materials of finer precipitated calcium carbonate and coarser lateritic gravel can be used for road subbase construction of low volume roads by comparing the laboratory test results of blended materials with that of recommended test values asper the ERA manual of low volume roads part, 2011. Engineering properties for both materials before blending is also done to check the compliance of the materials' laboratory test result with that of recommended values for each tests.

1.7 Limitation

Even though the test results were done as per the ERA standard specification requirement, the number of tests done to accomplish the maximum number tests required to develop the correlation between dependent variable which is soaked CBR and independent variables like MDD, OMC, PCC proportion and swell characteristics were limited due to shortage of budget to undertake as many tests as required for developing the best fitted model using all independent variables. Hence the correlation between variables were developed by using three different variables. In addition the soaked CBR test for different proportion of blended samples by itself needs long time as it's done after soaking the samples in water bath for 4 days.

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2 LITERATURE REVIEW

2.1 Introduction

The importance of roads in the development of any nation can hardly be overemphasized, as they play an important role in the transportation of goods and services. This is commonly achieved in Ethiopia through a vast network of roads that connect rural and urban centers. Efforts at achieving the construction of more roads are hindered by the high cost of their construction which is attributed to the non-availability of suitable road building materials within the vicinity of most road projects. Lateritic gravel which is locally called Red ash, an igneous rock deposit arising from the weathering of rocks, is one of the most common and readily available road building materials that can be sourced locally in Great Rift Valley. The importance of road construction for economic development leads to the substantive study on locally available materials for construction. Lateritic gravel or Red Cinder gravel offers significant potential as a low-cost, naturally occurring material in low-volume rural road construction and rehabilitation. However, the variability in its engineering parameters, particularly its grading, density, porosity and strength, have meant that the material often fails to meet standard specifications for road construction (Hearn, et al., 2019).

In African countries where economic development is based primarily on agriculture, a network of major highways, secondary roads, and low-cost feeder roads is of utmost importance. Economy requires that local materials be used in the construction of these roads. Yet, untreated lateritic materials have presented many problems in road construction and maintenance. Consequently, for the past three decades stabilization of lateritic materials by admixtures has been practiced and studied in Africa. Understanding the importance of roads for economic development, construction of roads with cost effective materials are required after modifying the properties of marginal materials (Amu, et al., 2011).

These soils are formed under weathering conditions productive of the process of laterization, the most important characteristic of which is the decomposition of ferro-alumino silicate materials and the permanent processes that produce Lateritic gravel. When Lateritic gravel consists of high plastic clay, the plasticity of the soil may cause cracks and damage to pavements, roadways, building foundations or any other civil engineering projects. Investigation of the engineering properties like atterberg limits helps to minimize the crack

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occurrence by providing remedial measures to overcome the problems associated with them (Reema & Kalita, 2014).

Most laterites are encountered in an already hardened state. In some areas of the world, natural laterite deposits that have not been exposed to drying are soft with a clayey texture and mottled coloring, which may include red, yellow, brown, purple, and white. When the laterite is exposed to air or dried out by lowering the ground water Table, irreversible hardening often occurs, producing a material suitable for use as a building or road stone. Frequently, laterite is gravel-sized, ranging from pea sized gravel to 7.62cm minus (passing 7.62cm), although larger cemented masses are possible. The laterites which are being used for subbase construction at Batu town exhibit the softness property when it is obtained from the borrow site (Zelalem, 2005).

The geotechnical behavior of lateritic soil altered up on drying due to alteration of clay minerals on dehydration and / or aggregation of fine particles to form larger particles. Important factor contributing to the close spacing of particles is the development of capillary stresses of significant magnitude. These capillary stresses lead to particle aggregation and reduce the available surface for interaction with water which is reflected in the reduction in plasticity characteristics. Hence, index properties and engineering properties should be tested by simulating the actual condition (Pandan, et al., 2013).

2.2 Definition of Laterites

The term laterite may be correctly applied to clays, sands, and gravels in various combinations while. The type of laterite found at Butajira is red in colour and larger nodular gravel mixed with sand sized aggregates (Lambe and Whitman, 2011).

The lateritic gravels behave more like fine grained sands, gravels, and soft rocks of uniform aggregate size. It 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 laterite rock or laterite gravel (Thagesen, 2001).

Laterites and lateritic soils are the products of intensive defined weathering which is called laterization under sub-tropical and tropical climatic conditions. Laterites can be defined based on the ability of a soft red material to harden on exposure to air. Laterite soils as

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profiles in which a laterite horizon is found, and lateritic soils as profiles in which immature horizons are found which develop under ‘appropriate’ conditions (Pandal, 2015).

Under conditions favorable to tropical weathering, the weathering processes may be so intense and may continue so long that even the clay minerals, which are primarily hydrous aluminum silicates, are destroyed; in the continued weathering the silica is leached and the remainder consists merely of aluminum oxide such as gibbsite, or of hydrous iron oxide such as limonite or goethite derived from the iron. This process is known as laterization. The extent to which a residual soil has been laterized may be measured by the ratio of silica, SiO_2, remaining in the soil to the amount of Fe_20_3 and Al_20_3 that has accumulated (Bogale, 2013)

The important reasons for the confusion regarding the correct identification of laterites is the large area of the tropical and subtropical zones involved and the different degrees of laterization encountered in the various parts (Mohanty, 2016).

Table 2. 1 Silica-sesquioxide ratio as a classification criterion

Soil Type	$Si0_2 /R_2O_3$
True laterites	1. 33 or less
Lateritic soil	1.33 - 2.00
Non-lateritic soil	2. 00 and over

(Source: Charman, 1988)

Silica has got a chemical formula of SiO_2 and Sesquioxide is a combination of Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3), designated as R_2O_3.

2.3 Regional Distribution

Laterite is a very widespread soil group. They cover extensive areas in tropical countries with intermittently moist climate. The six main regions of the world in which laterites occur are Africa, India, South-East Asia, Australia, Central and South America (Nikolaides, 2015).

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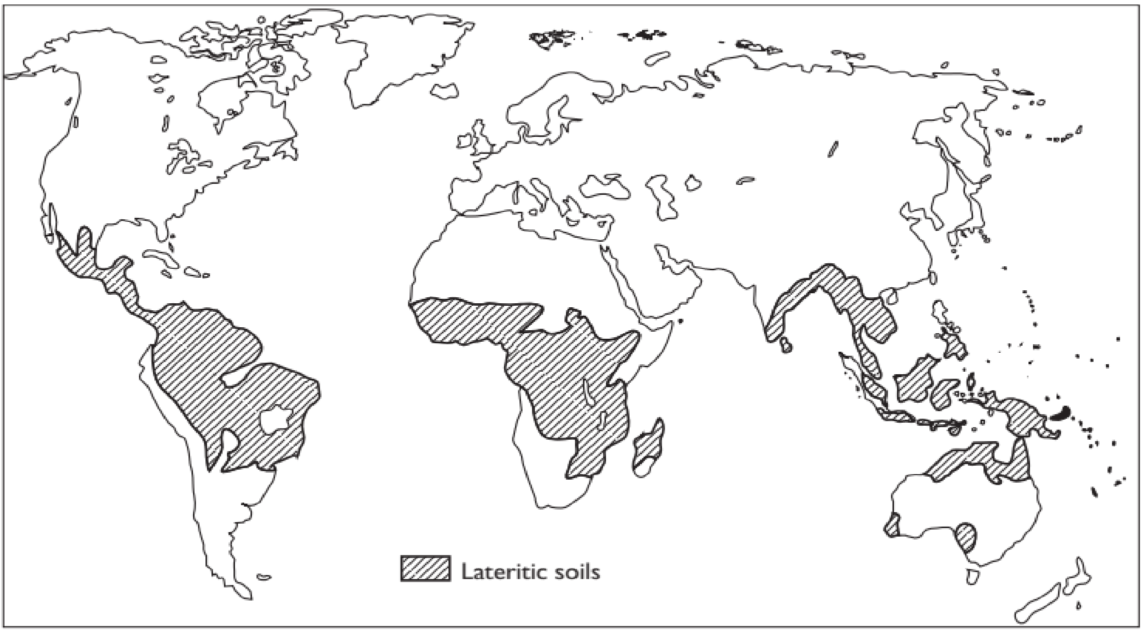

Figure 2. 1 Schematics of the study Distribution of Laterites (Source: Charman, 1988)

2.4 Classification of lateritic soils

Experience with soils in stable temperate zones has revealed that particle-size distribution exerts great influence on the engineering properties of soils. It is also one of the most important properties by which soils can be easily identified and classified on the basis of simple field and laboratory tests. Depending on the granular size the lateritic soils can be classified as the following.

Lateritic clays <0.002mm

Lateritic silts = 0.002-0.06mm

Lateritic sands = 0.06-2mm

Lateritic gravel = 2-60mm

Lateritic stones/Cuirasse > 60mm

Due to the presence of iron oxides lateritic gravel are mostly red in color ranging from light through bright to brown shades (Nikolades, et al, 2017).

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2.5 Lateritic gravel as construction materials

Most soils used for road construction are not completely granular (i.e. cohesionless); they usually contain varying percentages of fines content. Soil with particle size smaller than 75 μm, is referred to as fines according to the Unified Soil Classification System (ASTM, 2000) and American Association of State Highway and Transportation Officials (AASHTO, 2000) classification systems. The level of fines content in any soil has been found to affect important properties of the soil including soil composition, particle friction, compaction, moisture and type of soil. These properties in turn affect the performance of the soil when used as a sub-base material although the actual effects vary from soil sample to sample (Falde & Ogendengbe, 2000).

Concretionary laterites are valuable road pavement materials, widely used in the tropics as sub-base, base material and for gravel roads. The term laterite, however, has tended to be indiscriminately applied in tropical highway engineering to any red soil, and as a result the usefulness of laterites for road construction has been underestimated. Laterites are a good material for embankment construction (CIRIA, 1995).

Laterized soils work well in pavement construction particularly when their special characteristics are carefully recognized. Lateritic soil has also been successfully used in the construction of slopes, embankments, foundations, reinforced retaining walls and dams in both tropical and sub-tropical regions. They are used as sub base and bases for low cost roads and these carry low to medium traffic. But, their performance after construction will changed in short service years because of the problems associated with the required strength by the standards of the country for specific use of the material causing much discomfort as there will be consecutive bumps caused by sinking of cobblestones forming wave like surface on the road (TRL, 2012).

Laboratory testing to check the suitability of concretionary laterites to be used as road pavement materials should take into account how these, materials are affected by the testing procedures. Some lateritic soils are sensitive to pretreatment and testing procedures. So laboratory testing should be simulated to site condition (Morin & Todor, 1977).

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Main characteristics of lateritic gravels and gravely soils are the high content of fines. Consequently, such materials do not fit into the existing temperate zone classification systems for coarse grained soils. In addition, laterites undergo property changes during construction. The most sensitive property is gradation as the nodules tend to crush under heavy compaction (Lyon, 1971).

According to Millard (1993), Laterites of use to the road and embankment construction material are generally thin strata occurring at shallow depth. So a great care should be taken during material investigation and excavation for construction material production. The deposit is likely to vary in thickness, depth and quality both along-slope and down-slope Hence, care should be taken to prevent contamination of laterite while removing overburden and stockpiling the laterite.

According to Lyon Associates (1971), some deposits of lateritic gravel are immature and exhibit self-hardening properties when drying. This tendency may indicate that traditional requirements governing the selection of road materials can be relaxed. Thus, gravel that is normally considered mechanically unstable and too plastic may give acceptable performance as a pavement material. The hardening of laterite pavements is actually due to a combination of causes. Compaction is improved by traffic and the construction process, since weak, coarse particles tend to fracture. This somewhat alleviates the gap-grading and improves the stability.

According to CIRIA (1995) some laterites are gap-graded with a depleted sand-size fraction, to contain variable percentage of fines, and to have coarse particles of variable strength which may break down in performance, limits their usefulness as pavement materials on highly trafficked roads. Such laterites need to be improved by appropriate stabilization measures. Lime and cement treatments are common in tropics.

Studies have been trying to find practical results for the appropriate utilization of these locally available lateritic soils. In the recent past, some investigations have also been made on lateritic soils in order to utilize this local material in the building industry and highway construction. Authors with similar studies have worked on the geotechnical properties of lateritic soils. Jackson (1980) reported that lateritic soils have been used successfully as base

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and sub-base materials in road construction. Vallerge et al. (1969) worked on laterite soil in connection with construction of road, highways and airfields. The engineering problems associated with lateritic soil were evaluated by Lyons et al. (1971). Balogun (1984) reported that the addition of lime to the soil increases its optimum moisture content, liquid limit, California Bearing Ratio (CBR) etc. Alao (1983) studied the engineering properties of some soil samples from Ilorin area and discovered that they could be stabilized by compaction and that the samples could yield maximum strength if they are compacted on the dry side of their optimum moisture content (omc). Ogunsanwo (1989) evaluated CBR and shear strength of some compacted lateritic soils from southwestern part of Nigeria. He reported CBR of 27% in un-soaked and 14% for soaked sample for laterite soils derived from Amphibolites.

2.6 Stabilization of Lateritic Gravels

Stabilization improves the properties of the deficient soils. Soil stabilization is the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. Stabilization, in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. Soil stabilization also refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties. One may achieve stabilization by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture or by adding stabilizing material to an undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids (Bailey, et al., 1999).

Lateritic gravel is a widespread material in tropical and subtropical African countries. It appears to be a kind of building material for pavement engineering because of its low cost, environmental friendly aspects, and limited sources of quality aggregates. But its use is justified only when the appropriate technologies such as cement stabilization are utilized. Otherwise, the road sections built with raw lateritic gravel will become the subject of deterioration, which is mainly caused by rain erosion and traffic intensification (Gidigasu, et al., 2010)

As for the geotechnical properties of the lateritic gravel, they were generally determined by known tests: particle size distribution, Atterberg limits, and references of the Proctor

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modified ratio and Californian bearing ratio (CBR). The use of the CBR test for evaluating the strength of lateritic gravel was due to the wide use of the test for pavement design in tropical areas (Akinmusuru, et al.,2019)

The aim of stabilizing soil is to alter its physical properties, increase its strength and durability and thus provide a satisfactory foundation material. The admixtures most commonly used today in road construction throughout the world are cement, lime asphalt and sand. Cement appears to be the most common additive used in Africa; its use has been reported in Ghana, Gambia, Sierra Leone, Ivory Coast, Nigeria, Kenya, Uganda, Tanzania, Zambia, Southern Rhodesia and South Africa. The use of lime has been reported in Uganda, Kenya, Zambia, Nigeria, Basutoland and South Africa. The use of asphalt in Africa has been limited to lateritic soils, of a sandy nature. Stabilization by ad mixture of sand has been investigated and used in Nigeria, but because of the limited availability of sand in Africa has not been widely used (Dauda, et al., 2019).

To evaluate the use of lime, cement, asphalt and sand as stabilizers for lateritic materials from Africa, a series of studies was carried out. A total of 20 representative soil materials were selected for this purpose, nine from Ghana, two from the Congo, and one each from Ivory Coast, Kenya, Uganda, Dahomey and Niger. The materials from Sierra Leone were tested at Fourah Bay College. Four samples, one from Niger and Dahomey and two from the Congo, were sent to the Asphalt Institute Laboratories in College Park, Maryland for asphalt stabilization testing. The materials from Ghana, Congo and Sierra Leone were stabilized both with lime and with cement, whereas the soils from Ivory Coast, Kenya, Uganda and Dahomey were stabilized with lime only. The material from Niger was stabilized with cement only. One clayey gravel from Ghana was stabilized with sand (Adeboje, et al. , 2017).

2.7 Material requirements for sub-base according to ERA manual for low volume roads

2.7.1 Strength requirements

Soil chosen for a particular road work must be suitable for the environment and must have enough strength to bear the load the road is intended for. The strength of the soil used for road work is measured in terms of the California bearing ratio (CBR) of the soil and the

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bearing capacity (determined from the shear strength of the soil). The Atterberg limits of the soil are also considered along with the strength parameters (Hicks, 2002).

According to ERA 2011 manual for low volume roads a minimum CBR of 30% is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum of 95% (preferably 97% where practicable) AASHTO T180 compaction. Under conditions of good drainage and when the water table is not near the ground surface, the field moisture content under a sealed pavement will be equal to or less than the optimum moisture content in the AASHTO T180 compaction test. In such conditions, the sub-base material should be tested in the laboratory in an unsaturated state. If the road base allows water to drain into the lower layers, as may occur with unsealed shoulders and under conditions of poor surface maintenance where the road base is pervious, saturation of the subbase is likely. In these circumstances the bearing capacity should be determined on samples soaked in water for a period of four days. The test should be conducted on samples prepared at the density and moisture content likely to be achieved in the field.

The soaked CBR is usually obtained for a sub-base material in the laboratory, by soaking the compacted soil sample in water for four days. A shorter soaking period is permissible for A-1-a and A-3 soils if tests show that a shorter period does not affect the test results, but in no case shall the soaking period be less than 24 hours. Surcharge weights, in the form of annular discs with a mass of 2 kg are placed on top of the soil test sample before the sample is soaked. Each 2 kg disc is roughly equivalent to 75 mm of surcharge material. The surcharge weights allow for the increase in strength due to road construction material placed above the subgrade or the sub-base. The plunger penetrates through a hole in the disc to reach the soil (Ayodele, et al., 2000).

2.7.2 Particle size distribution and plasticity requirements

In order to achieve the required bearing capacity, and for uniform support to be provided to the upper pavement, limits on soil plasticity and particle size distribution may be required. Materials which meet the recommendations of Tables 2.1 and 2.2 will usually be found to have adequate bearing capacity (ERA manual for low volume roads part B).

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Table 2. 2 Typical particle size distribution for sub-bases

Sieve size (mm)	Percent by mass of total aggregate passing test sieve
50	100
37.5	80 – 100
20	60 – 80
5	30 – 100
1.18	17 – 75
0.3	9 – 50
0.075	5 – 25

Source: Design manual for low volume roads part B, 2011

Table 2. 3 plasticity characteristics for granular sub-bases

Climate	**Liquid Limit**	**Plasticity Index**	**Linear Shrinkage**
Moist tropical and wet tropical (N<4)	< 35	< 6	< 3
Seasonally wet tropical (N<4)	< 45	< 12	<6
Arid and semi-arid (N>4)	<55	< 20	<10

Source: Design manual for low volume roads part B, Final Draft, 2011

2.8 Mechanical Stabilization of Lateritic Gravel using Calcium carbonate

Soil stabilization is any treatment (including compaction) applied to a soil to improve its strength and reduce its vulnerability to water. If the treated soil is able to withstand the stresses imposed on it by traffic under all weather conditions without excessive deformation, then it is generally regarded as stable (Negi, et al., 2013)

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Mechanical Stabilization is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material (OGE, 2008).

Mechanical stabilization of a material is usually achieved by adding a different material in order to improve the grading or decrease the plasticity of the original material. The physical properties of the original material will be changed, but no chemical reaction is involved. For example, a material rich in fines could be added to a material deficient in fines in order to produce a material nearer to an ideal particle size distribution curve. This will allow the level of density achieved by compaction to be increased and hence improve the stability of the material under traffic. The proportion of material added is usually from 10 to 50 percent. During blending the proper percentage of materials to be blended is chosen by using this proportion developed by Philippines department of road (DFID, 2000).

Mechanical stabilization is accomplished by mixing/ blending soils of two or more classifications or gradations to obtain a material meeting required specifications. The blending may occur at the construction site, a central plant, or a borrow area. The blended material is then spread and compacted by conventional means to meet requirements. Mechanical stabilization of subbase material improves substandard materials, load carrying capacity, stress distribution characteristics and reduction of pumping (Hyoumbi, et al., 2017)

The utilization of industrially manufactured soil improving additives has kept the cost of construction of stabilized roads high. This has continued to deter developing and underdeveloped nations of the world from providing accessible roads to their rural dwellers who often constitute the majority of the population and are mainly dependent on agriculture. To improve the properties of the lateritic gravel using manufactured additives will increase cost of the road construction (Siddharth, et al., 2013).

Studies on the use of laterite gravels as flexible pavement materials through mechanical and chemical stabilization by Crushed Stone Aggregate (CSA) and lime, respectively on the three samples collected from western part of Ethiopia, Gedo-Nekemte and Gedo-Fincha-Lemlem Berha road project routes in the National Regional State of Oromia. Compaction and CBR testes were carried out on trial mixes prepared by blending 10 to 15 % fine soils

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by mass with natural cinder gravel samples to determine the optimum amount of fine soils required to mechanically stabilize cinder gravel samples. This helps the compaction of coarser material by filling the gap between coarser materials (Berhanu, 2009).

Mechanical stabilization was carried out at 20%, 40% and 60% CSA by volume of blended laterite and the chemical stabilization was investigated with addition of 4%, 8%, 12% and 16% lime by dry weight of blended laterite. The test results indicated that the laterite gravel fulfilled the CBR, Los Angeles Abrasion (LAA) and TFV(Ten Per cent Fines Value) requirement of ERA(Ethiopian Road Authority) when blended it with 40% and 60% Crushed Stone Aggregate for base course and 20% Crushed Stone Aggregate for subbase, regardless of having out values beyond the specification. The plasticity of laterite was reduced with the addition of lime as a result of increase in plastic limit and a slight decrease in liquid limit. The addition of lime has resulted in an increase in optimum moisture content and reduction of maximum dry density for the same compaction effort (Qian, et al., 2017).

The laterite stabilized with 12% lime fulfilled all of the requirements set for sub base materials. It was found out that the natural laterite gravel can be used for base course construction by stabilizing it with a combination of 40% Crushed Stone Aggregate+8% lime and 60% Crushed Stone Aggregate+8% lime for CB2 and CB1(Road note 31 base course strength requirements),respectively. Lowest PI values 4.3 and 5.1% were recorded at a combination of 40% CSA+12% lime and 60% CSA+8% lime, respectively. These mixtures are also satisfying both the strength and durability requirements for flexible pavement materials. The author concluded that CSA and lime as effective stabilizing agents for improvement of laterite gravel for use as flexible pavement materials (Deboch, 2019).

Precipitated Calcium Carbonate also known as purified, refined or synthetic calcium carbonate. It has the same chemical formula as other types of calcium carbonate, such as limestone, marble and chalk: Ca_2CO_3. The calcium, carbon and oxygen atoms can arrange themselves in three different ways, to form three different calcium carbonate minerals. The most common arrangement for both precipitated and ground calcium carbonates is the hexagonal form known as calcite. A number of different calcite crystal forms are possible: scalenohedral, rhombohedral and prismatic. Less common is aragonite, which has a discrete

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or clustered needle orthorhombic crystal structure. Rare and generally unstable is the laterite calcium carbonate mineral (Ohba, 2014).

Calcium carbonates, including PCC, are considered to be non-toxic. In the U.S., the Food and Drug Administration has Affirmed calcium carbonate to be GRAS (Generally Recognized as Safe). As long as the PCC meets certain purity requirements, it can be used as a direct food additive, as a pharmaceutical or as an indirect additive in paper products that come in contact with food. Similar acceptances and approvals exist around the world where PCCs are widely used in these applications. PCC is generally made from a high purity calcium carbonate rock called limestone. This limestone deposit is the result of a very thick layer of prehistoric sea animal shells and skeletons being laid down on the ocean floor. These shells and skeletons were largely composed of calcium carbonate. Over a period of five hundred million years this deposit was under high temperature and high pressure, and the deposit changed to a coarsely crystallized limestone. All of the organic matter that was in the deposit was removed by oxidation, a process called diagenesis (Davies, et al., 2017).

If this kind of geological process continues a very long time, the crystals become very small, forming marble, an extremely hard form of calcium carbonate. If the time, temperature and/or pressures are not great, the seabed only partially metamorphoses, and the result is very soft chalk, such as that forming the White Cliffs of Dover in England. In chalks, remnants of animal shells and skeletons are often still seen (Bonsor, et al., 2014).

2.9 Sampling Techniques

Depending on the distance between borrow site and laboratory, in many cases, only one or two three-bag samples could be taken from each soil types under study. The high variability in observed material properties, therefore, presented significant problems for representative sampling according to the study done by (Morin & Todor, 2012).

Disturbed soil samples were collected from four corners of the borrow site and PCC were collected from a single place as the stock of it has the same chemical composition and physical properties according to the report from the chemistry department head of the factory.

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The samples on the northern part were obtained from the freshly dozed stoke pile to be used for the subbase construction of Cobblestone roads and gravels roads in the surrounding towns including Batu.

2.10 Blending of Aggregates

Aggregates that are used in unbound, hydraulically bound and bituminous layers almost always consist of an admixture of two or more aggregate fractions or fine aggregate, medium and coarse aggregate and perhaps extra filler. These materials are proportioned in the mixture in such a way that the final gradation is within the specification limits. The procedure to determine the optimum proportions is known as aggregate composition (Maize,et al., 2018).

To do the blending the lateritic gravel which represented the coarser problematic construction material is obtained from Jijo site on the road from Butajira to Worabe which is dozed for the sell by the youth organized at there and the precipitated calcium carbonate which represents the fine soil is obtained from Batu PCC land stock located in the caustic soda factory of Batu town.

The aggregate composition can be carried out by trial-and-error, mathematical (linear equation or least squares) or graphical methods. The following three methods are practiced for blending materials for road construction.

2.10.1 Trial-and-error method

The trial-and-error method is used only by experienced engineers. This method is based on estimation of the approximate optimum proportions and verification of the estimation. In the case that the original estimation does not give a gradation within the limits specified, the process is repeated with different values. This method will be even simpler if the aggregates to be blended are from only two sources (Nikolaides, 2015)..

Compaction and CBR testes were carried out on trial mixes prepared by blending 10 to 15 % fine soils by mass with natural cinder gravel samples to determine the optimum amount of fine soils required to mechanically stabilize cinder gravel samples (Berhanu, 2009).

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2.10.2 Mathematical methods

2.10.2.1 Linear equation method

The linear equation method is the most common method used to blend two or more aggregates. It is based on linear equations of the form

$$a \times PAi + b \times PBi = PX, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where a, b are percentage proportions of individual aggregates A, B, C, D and so on, used in the composition; PAi and PBi are the percentage of material passing through a given sieve (i) for the individual aggregate A, B; and PX is the percentage of combined aggregates passing through a given sieve; initially, this percentage is equal to the mid value determined from the range of limiting values given in the specification (Vinod.B.R, 2008).

2.10.2.2 Least squares method

The equations derived in the example above can be solved by the least squares method. To solve the system of linear equations with the least squares method, the reader is referred to a suitable handbook. However, this method is nowadays included in most computer software readily available (Microsoft Excel, etc.). It should be stated that the advantage of using the least squares method is the fact that one and only one solution; the optimum one; is obtained.

2.10.3 Graphical method

The graphical method of aggregate composition was used in the past by some engineers as it was considered simple and did not require solving mathematical equations. It was easy to combine two aggregates and a bit more complicated for three or more. Nowadays, the graphical method has been phased out (Nikolaides, 2015).

2.11 Correlation of Physical and Engineering Properties

Correlations of engineering soil parameters such as CBR is essential for rapid determination from soil parameters for a proper design of soil road. The physical and engineering properties of the tropical soils have been similarly analyzed by means of regression analyses to establish the existence of useful relationships to assist the engineer in the selection of materials for highway construction on the basis of routine classification tests (Rakaraddi, 2015).

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According ERA manual 2011 for LVR Soaked California bearing ratio (CBR) value (in %) is considered as strength parameter in design of sub-base layer in addition to grading. Hence, soaked CBR can be taken as the dependent variable and the other parameters like Gradation, PI, MDD, and natural moisture content can be categorized under independent variables. Because of the low quantity of fines in cinder gravels (including blended materials), plasticity index alone is not a good measure of the potential influence of plasticity; it is recommended to use plasticity modulus. The recommended maximum plasticity moduli (based on maximum plasticity index for sub-base and maximum percentage passing the 425µm sieve for the sub-base envelope) for sub-bases are therefore 360 in wet tropical, 720 in seasonally wet tropical, 1200 in arid and semi-arid.

2.12 Techniques Adopted for CBR Correlations

The soils have high bearing capacity with little or no volume change and therefore can be used as construction materials in engineering works. Soaked California bearing ratio (CBR) value (%) is considered as strength parameter in design of sub-base layer. The soaked CBR test requires large quantity of soil sample and the soil is remolded to its maximum dry density (MDD) and time consuming. Therefore it is very difficult to carry out to entire stretch of road in a short duration and leads to serious delay in the project and increases its cost. To overcome this problem a simple and less time consuming method is necessary by correlating soaked CBR value with easily determining soil parameters (Paper, 2014).

Soaked CBR value is correlated with aggregate strength for the granular materials, liquid limit and gradation characteristics of soil. The developed correlation to predict CBR of stone dust mixed poor soil. Correlation should be developed for lateritic gravel stabilized with PCC to quantify the value of dependent variables based on independent variables (Vinod, 2008)

Both simple linear and multiple linear regression were used for correlating soaked CBR value in terms of classification and compaction properties. To establish relation between soaked CBR and different soil properties, graphs are plotted with CBR against different soil parameters and suitable trend line is drawn with higher correlation coefficient. Correlation quantifies the degree to which dependent and independent variables are related. Linear regression quantifies goodness of fit with R^2 value. R^2 value provides a measure of how well

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future outcomes are likely to be predicted by the model. Any correlation with R^2 value more than 0.80 will be viewed as a best fit. Multivariate linear regression (MLR) analysis is carried out to identify simultaneously two or more independent variables that explain variations of a dependent variable. Soaked CBR value are considered dependent variable which are denoted by X, while liquid limit, plastic limit, plasticity index, linear shrinkage, maximum dry density and optimum moisture content are considered as the independent variables (Paper, 2014).

$X = \alpha + \beta 1Y1 + \beta 2Y2 + \ldots \beta nYn + e$ …………………………………...…………….(2.2)

Where X = dependent variable

α = X-intercept

β = slopes associated with X

Y = values of independent variables

e = error

CBRs = - 808 - 3233 PL + 3232 LL - 3236 PI - 0.12 LS + 407 MDD + 14.0 OMC……. (2.3)

Multiple Linear Regression Analysis (MLRA) has been carried out by considering soaked CBR value as the independent variable and the rest of soil properties as dependent variables. MLRA can be carried out using standard statistical software like data analysis tool bar of Microsoft Excel in order to derive the relationship statistically (Sunkara Yashwant, 2015b).

A correlation between the CBR value of the soil and soil properties like LL, PL, PI, OMC, MDD, a multiple regression model is developed using the data analysis tool pack of Microsoft excel. The mathematical equation developed is as follows:-

CBR = -0.258 - (0.014*LL) - (0.015*PI) + (0.011*OMC) + (2.100*MDD) --------------- (2.3)

The coefficient of correlation (R^2) for the above equation was found to be 0.970. Hence the equation holds good in correlating the CBR value with other soil properties (Korde & Yadav, 2015).

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2.13 Cost Analysis

As per ERA Guideline (2018) for use of cinder gravels the cost of the materials used to build roads is a major component of the costs of road provision. The materials available in many rural areas do not meet the strict specifications for their use in road construction projects. Consequently, road provision in these areas is often constrained by the cost of sourcing more conventional road-building materials from long haul distances.

Currently many natural materials can be stabilized to make them suitable for road pavements provided that the cost of overcoming a deficiency in the locally available material does not exceed the cost of importing another material which is good without stabilization. The stabilization techniques are used to increase the ability to distribute the load over a greater area, to reduce the required thickness of the pavement layers, and to eliminate the excavation and exporting of unsuitable material and importing new materials. as we can understand from this statement the ability to distribute the load over a greater area depends on the bearing capacity and stabilizing may increase the CBR value which in turn reduces the pavement thickness (Diaz, et al., 2017).

In a developing country like Ethiopia, the materials used for construction should be cost effective. Hence a cost comparison is required for recommending any new material. Before recommending stabilizing agent for practical purpose for stabilizing, a cost comparison was to be done to ascertain whether it proves cost effective on the longer run. Any new material or method will be accepted only if it is cost effective. It is observed that, with the optimum cement content as the percentage of aggregates increases, the cost of soil per unit volume increases. Hence, soil treated with 10% of aggregates in addition to optimum cement content is preferred. The addition of optimum amount of PCC reduces the amount of lateritic gravel to be used in construction which in turn reduces the construction cost as PCC can be afforded by lower price than that of lateritic gravel measured in Truck full loaded materials (Yashwant, 2015b).

The findings of blending finer materials with Lateritic gravel was resulted in increased CBR, dry density, increased the use of solid waste in construction industries and reduced environmental impacts of solid waste. In case of this research, the cost analysis is analyzed based on the financial cost comparing for untreated and PCC treated lateritic gravel.

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3 MATERIALS AND METHODS.

3.1 Description of the Study Area

This research study area is located at Batu /Ziway town, which is 160 Km away from the capital of Ethiopia along the road connecting Addis Ababa to Nairobi in the East Shewa Zone of the Oromia Region of Ethiopia. Batu has a latitude and longitude of 7°56′N 38°43′E with an elevation of 1643 meters above sea level. Batu is a town and separate woreda in central Ethiopia. But, the town geographically lies within Adami Tulu Jido Kombolcha distririct.

Adami Tulu Jido Kombolcha district has semi-arid and arid agro-climatic Zones. It receives an average annual precipitation of 759.7 mm. The annual rainfall varies from a low of 513.92 mm in 1979 to a high of 1096.1 mm in 1976. About 41.49% of the annual rainfall is recorded during the period from June to September. The driest months are November and December; only 0.58% of the annual rainfall is recorded during this period. The mean annual temperature is 19.98°C at Batu station while it is 20.04°C at Adami-Tullu station. The mean monthly temperature varies from 18.5°C to 21.6°C. May is the hottest month with mean maximum temperature of 28°C. The coolest month is December with minimum temperature of 10.7°C. The average air relative humidity is 72.75%, varying from 68% (November) to 78% (July and September) on the monthly average (Gashaw, 2009).

The area where the sample was taken is located in Southern Ethiopia, in the South Nations, Nationalities and peoples National Regional State, Gurage Zone, Mesken district. Sample was collected from Mesken borrow site stock pile which is 40.7km from Batu town having Latitude 8^o6’01’’N & Longitude 38^o22’31”E. The red ash from this site has being used for gravel road construction and as the subbase layer for the low volume roads located in short distance from the source. In this thesis the use of Red Ash/ Lateritic gravel as subbase construction material of low volume roads after blending with precipitated calcium carbonate were assessed by using recommended laboratory tests to characterize subbase materials according to ERA manual for low volume roads part B of 2011.

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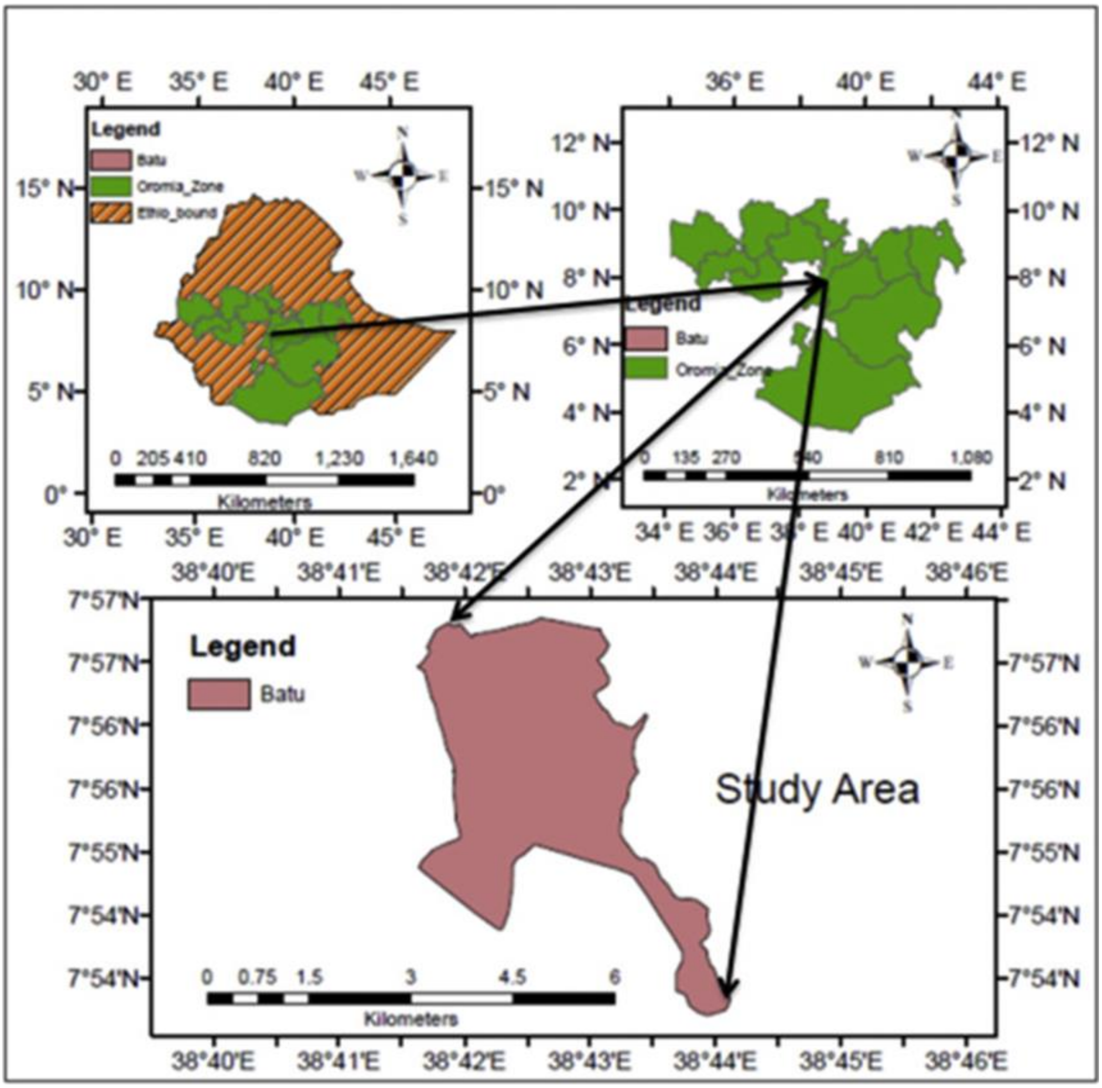

Figure 3. 1 Map of Batu Town

Source: Batu municipality land administration bureau

3.2 Research Design

Each of the sample materials are subjected to engineering property tests including particle size distribution and Atterberg limits (i.e. Liquid and plastic limits), modified proctor compaction test to obtain the maximum dry density and the optimum moisture content of both samples, water absorption test, specific gravity , California bearing ratio (CBR) test for soaked conditions and los angles abrasion test. The testing procedures followed were in general conformance with those recommended in the ERA standard specification for low volume roads.

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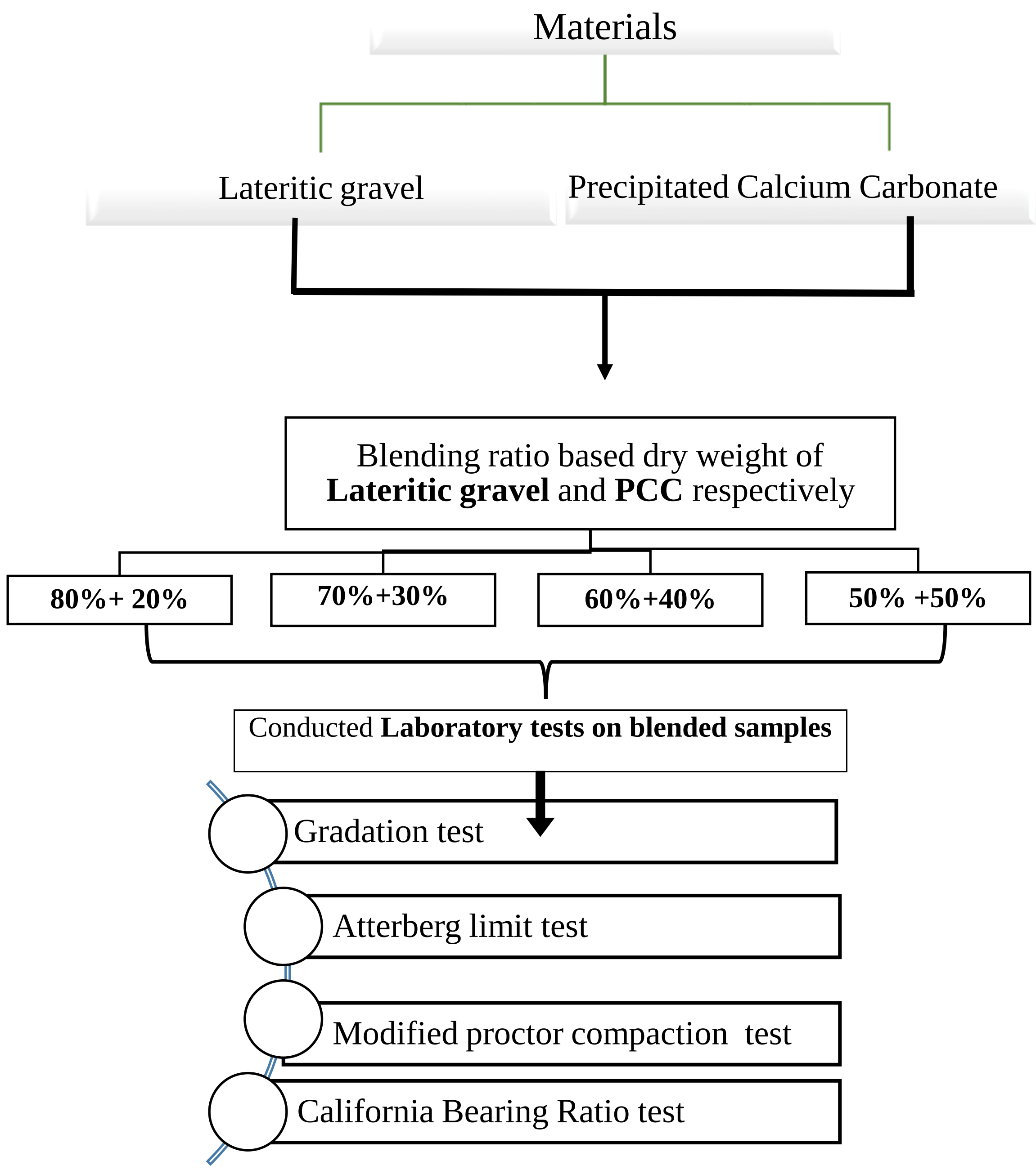

Figure 3. 2 Schematics of the study

3.2.1 Methods of Data Collection.

3.2.1.1 Sources of Data

Data used for this proposal is primary data (by making important site visits of precipitated calcium carbonate site and Red ash brought from Butajira for road subbase construction in Batu town for cobblestone road construction) and secondary data (i.e. by browsing different

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scholars those well discussed about stabilization of Lateritic soil for different uses in road construction.

3.2.1.2 Procedure of Data Collection

The data required for the study to meet the specific objectives and research questions are obtained both from the locations of the materials under study. The general framework of collecting data can be listed as follows:-

- Making general reconnaissance survey of the location of both precipitated calcium carbonate and lateritic gravel.
- Collecting the sufficient samples from both borrow site and calcium carbonate stock. The size of the samples depends on the requirements of the samples for the tests intended to be done to assure the stabilization of lateritic gravel using precipitated calcium carbonate for strength and consistency tests. Gradation test will be carried out for the lateritic gravel.
- Engineering problem of Lateritic gravel will be reviewed from different sources as well as my investigation under specifications for lateritic gravel properties will be identified and the proper percentage of Calcium carbonate will be decided for stabilizing the gravels from Butajira borrow site.

3.2.2 Laboratory tests procedure

Various laboratory tests are available to identify and study the properties of soils. There are different tests to study the engineering properties of natural gravel and treated gravel. Before testing, materials were prepared in accordance with AASHTO T 87-86. After sample of lateritic gravel are brought from the borrow site and waste disposal site for PCC at Batu town Caustic Soda factory the materials preparation for the tests or quartering is done after properly mixing the materials to constitute available size distribution at DAEWOO E & C aggregates and soil laboratory center under consultancy of Kyongdong Kunhwa Engineering and Consulting in collaboration with Ethioinfra and Core consulting. These methods involves air drying of samples by spreading the material out on sacks in the laboratory center compound and leaving it open in the air for 4 days as seen on the photos found below. The laboratory test of this research focused on three sections. In the first section, the engineering

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properties of the laterite gravel material (sample SW & NW) was investigated using the following laboratory tests. Lateritic gravel collected from SNNPR around Butajira town at 1.50m depth for SW sample and 2.20m for NW sample is used for the study of engineering properties of them differently. The lateritic gravel sample was sealed in the air tight plastic bags and transported to the Ethiopian Geological survey Institute of Mekanisa branch laboratory for complete silicate analysis testing prior to undertaking engineering property tests. After collecting the soil is dried for 7 days. The index properties of the samples including Grain Size Analysis Specific Gravity, Water Absorption, Atterberg Limits, Modified Proctor's Compaction, California Bearing Ratio (soaked) and Los Angeles Abrasion were determined in accordance with AASHTO test procedures.

Figure 3.3 A) Samples of LG and PCC

Figure 3.3B) Air drying lateritic gravel

Figure 3.3 C) Modified proctor test

Figure 3.3D) Washed samples of lateritic gravel

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Figure 3. 3 Sample of lateritic gravel for tests and compaction test, air drying

Table 3. 1 Laboratory tests on Lateritic gravel only

No	Test	Method
1	Grain Size Analysis	AASHTO T-27
2	Specific Gravity	AASHTO T-84
3	Water Absorption	AASHTO T-84
4	Atterberg Limits	AASHTO T-89 & T-90
5	Modified Proctor‘s Compaction	AASHTO T 180-01 Method B
6	California Bearing Ratio (soaked and unsoaked)	AASHTO T-193
7	Los Angeles Abrasion	AASHTO T-96

In the second section the properties of PCC sample was investigated using the following tests.

Table 3. 2 Laboratory tests on PCC only

No	Test	Method
1	Grain Size Analysis	AASHTO T-27
2	Water Absorption	AASHTO T-84
3	Atterberg Limits	AASHTO T-89 & T-90
4	Modified Proctor‘s Compaction	AASHTO T 180-01 Method B
6	California Bearing Ratio (soaked and unsoaked)	AASHTO T-193

In the third section the properties of PCC sample blended with lateritic gravel in different trial proportion starting from 20 to 50 percent by dry weight was investigated using the following tests listed in table 3.3 as per ERA specification manual 2013. The trial blending proportion is taken from DFID report on mechanical stabilization of road sub bases for highly trafficked roads in Philippines which is 10 to 50 percent by dry weight.

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Table 3. 3 Laboratory tests on blended PCC and Lateritic gravel

No	Test	Method
1	Grain Size Analysis	AASHTO T-27
2	Atterberg Limits	AASHTO T-89 & T-90
3	Modified Proctor‘s Compaction	AASHTO T 180-01 Method B
4	California Bearing Ratio (soaked and unsoaked)	AASHTO T-193

3.3 Study Period

The time required for the study of blended materials of both lateritic gravel and precipitated calcium carbonate suitability for subbase road construction of low volume roads extends from January to September, 2020 GC including time for reviewing related literatures, laboratory Experiment time, analysis and interpreting the laboratory results, concluding and recommending the best practices in using the mechanical stabilization of LG using PCC. The laboratory session undertaken for one and half month at Daewoo camp between Abosa and Meki town.

3.4 Materials

3.4.1 Lateritic gravel

The gravel used in this investigation is obtained locally from nearby borrow sites and known as a red ash soil. Disturbed samples of lateritic gravel will be collected from Butajira borrow site near Butajira Town, South Nations, Nationalities and peoples State, Ethiopia (latitude 8.136°N and longitude 38.439°E) as the process of sampling will be simpler in case than undisturbed soil sampling.

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Figure 3. 4 sampling lateritic gravel

3.4.2 Precipitated calcium carbonate

PCC to be used as lateritic gravel stabilizer for this study will be collected from Batu caustic soda factory compound which is stored on a 39,741m^2 as it is measured from google map in November 4, 2019. The store is prepared by excavating the soil to a depth of 8m on the north part and reduced to the ground level on the south direction. Taking the average depth of 6 meter the volume of the PPC will be 238,446m^3.

Figure 3. 5 Extracting sample of PCC

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3.5 Sample Population

The sample population is taken to be the closer borrow site to the study area. Currently the contractors around Batu town are using the lateritic gravel from borrow site around Butajira town. The representative sample was collected from three mountains at Jijo. The one on the Worabe Exit named as SW sample while the borrow site around Mesken was named as NE. The sample on the little hilly area between worabe exit and Mesken akebeby borrow site was named as MBS for research to easily identify the where sample was obtained from. The three borrow site were considered to be the population while the representative sample was obtained based on requirement of the sample for the tests undertaken for the engineering property study of Lateritic gravel. PCC used as the stabilizer was taken from a single source in the town. But the soils with similar properties and chemical composition are available in large quantity at nearby locations to Batu Town.

3.6 Sampling Technique and Sample Size

The sampling technique employed for this particular research is none probability sampling as the location of the materials for the intended study is selected by the will of the researcher depending on the selection of the municipality to use materials from those sources as a road subbase construction material. To get the representative sample for the location in vicinity to Batu town three borrow sites for lateritic gravel were chosen and complete silicate analysis has done for samples from two sources at Ethiopia geological survey institute as the cost testing is high to undertake for all. Development of a sampling strategy that allows representative sampling of the range of lateritic gravels potentially usable in road construction round area under study is based on the source currently being harnessed by the localities to meet their need for subbase material for low volume road construction. The required sample is obtained by referring the amount of materials required for tests and the total of 9 sacks of Lateritic gravel and 6 sacks of PCC based ERA specs of 2013. Two more sacks of lateritic gravel sample was added in order to do additional tests for blended materials during the requirement of additional inputs for correlation analysis of study variables.

3.7 Methods of Samples Collection

According to ERA site investigation manual 2013 laterite horizon than can be used for road construction can be investigated by trial pits. The spacing of the pits depends on the extent

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of the horizon and it is advisable to first start with a few pits and decrease the spacing later. Careful attention should be given to sampling and with the samples clearly defining the potentially useful horizon. Sufficient and representative material should be taken to allow for compaction and CBR testing in addition to classification tests and natural moisture content. The samples collected are obtained the excavated pile prepared for sale fully represent the materials of lateritic gravel.

The samples were obtained by digging out the materials using shovel for PCC and lateritic gravel is obtained from the excavated stock of red ash at the sites using excavator and prepared to be loaded for sale. It is important to select materials from below the weathered zone, which can extend to a depth of 2 meters as stated by research on weathered rocks by TRL. Therefore both samples are of disturbed sample type.

3.8 Study Variables

The variables under study can be further divided into dependent variables and independent variables for the development of correlations between the variables.

In this research paper multilinear regression analysis is conducted to determine the correlation of dependent variables and independent variables. To develop the good fitted multilinear model, the soaked CBR correlation with different independent variables are used after careful testing undertaken to identify their respective values. Accordingly the independent considered for this specific study are, maximum dry density, optimum moisture content, natural moisture content, plasticity index, grain size distribution and specific gravity. The dependent variable is the soaked CBR value of the blended sub-base material for the construction of low volume roads. The model used all independent variables to develop the Correlation, but it checks first the significance of all variables on response factor by using Minitab 19 statistical software.

3.9 Method of Data Processing and Analysis

This thesis study has done to check the use of blended precipitated calcium carbonate with lateritic gravel as subbase material for the construction of low volume roads in Batu and nearby towns based ERA standard requirements for subbase materials. The laboratory test

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is done on the samples of precipitated calcium carbonate collected from caustic soda factory and lateritic gravel from Butajira area.

The recommended engineering properties tests for subbase materials for low volume roads was done according to laboratory test procedures on the samples of precipitated calcium carbonate, Lateritic gravel and blended materials. The interpretation of laboratory results were done according to the obtained results following the specification ERA manual 2011 on each type of tests done on the representative samples.

The aggregates are tested to find out their conformability to the ERA standard specifications based on the required characteristics to be chosen as construction material or rejected. The results from these tests were compared with the standard specifications of ERA. Excel spreadsheet and descriptive methods of statistical analysis in the form of table, charts, and graph were used to aid further interpretation of the data.

After deciding the proportion of precipitated calcium carbonate, the economic analysis was done comparing the material initial purchasing cost of blended materials over lateritic gravel which being used as subbase material for low volume roads construction in Batu town.

Multiple linear regression (MLR) analysis is carried out to identify simultaneously two or more independent variables that explain variations of a dependent variable. MLR analysis was carried out to determine the relationship between 6 independent variables related to both the soaked and unsoaked CBR values. MINITAB 19 was used in the multiple regression analysis where independent variables are first identify that is affecting the dependent variable.

The correlation analysis is an advanced method of data visualization and analyze that allows to look at relationships between two or more variables. In analyze might be interested in knowing what factors most impacts the response factor. In this study the correlation between the Soaked CBR and different factors like content of PCC, Atterberg limits, Moisture content, and MDD are considered. Based on the Laboratories performed data, CBR is dependent variable and MDD, OMC, PI and NMC are taken as independent variables. But the minimum number of tests required to develop good fitted model for soaked CBR using five different independent variable is not accomplished. Minitab software have been used to

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analyze the data and to differentiate the relationship between the response factor and independent variables.

3.10 Multiple Linear Regression Verification Criteria

Methods to determine validity of regression models include comparison of model predictions and theory, collection of new data to check model predictions. Comparison of results with theoretical model calculations, and data splitting or cross validation in which the portion of the data is used to estimate the model coefficients, and the remainder of the data is used to measure the prediction accuracy of the model. Multiple linear regression requires at least two independent variables which is assumed to have linear relationship. The linearity of the assumption can be tested with scatter plots. Variance inflation factor higher than 10 indicate that the multicollinearity between independent variables are highly correlated with each other. A rule of thumb for the sample size is that regression analysis requires at least 5 cases per independent variable in the analysis.

3.11 Data Quality Assurance

This research paper is the product of both the quantitative data regarding the sample sizes, number test repetition and qualitative data obtained from the results. The collected samples fully represent the actual materials existing on the sites as they were obtained directly from the source and laboratory tests were performed on the same material brought to the testing center. As the testing is undertaken at material testing center owned by ERA for the Meki-Batu stretch expressway construction the test undertaken are of good quality and can fully express the materials under study. The Data's presented for the research study under my title is assured by the laboratory hosting company as solely work of myself by writing the letter of approval of the tests undertaken by me at their material laboratory center.

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4 RESULTS AND DISCUSSION

4.1 Introduction

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

The Lateritic sample collected was disturbed sample type. Precipitated calcium carbonate which is considered to be waste as it is not serving for the purpose they stocked it is located in the compound of Batu Calcium Oxide factory. The sample of PCC is obtained by digging that stockpile with shovel. The chemical and mineralogical analysis done for the sample depicts as the sample can fully represent the stockpile at this place and disturbed soil type is collected and tested for the suitability of it to be used as lateritic gravel stabilizer.

From the field survey observation during the construction road subbase layer at Batu Town the absence of the fine materials which is the important factor affecting the engineering properties of lateritic gravel like gradation is apparent. The two most important factors likely to affect the engineering behavior of lateritic gravel materials were the gradation and the strength of the gravel particles. As far it is used as subbase material for low volume roads the recommended tests for subbase materials according to the ERA specification 2011, are undertake to comprehend the compliance of it as the subbase materials before blending with PCC and after blending with PCC by different proportions of blending.

Both Lateritic gravel and PCC samples were prepared for test by air drying for seven days and sieving to the required size. Grain size analysis was determined according to AASHTO T-27. Index properties of soils were determined using Atterberg limit test, according to AASHTO T-89 & T-90. Soil classification was made according to the AASHTO classification system (AASHTO, 2006).

The tenacity of this study is to investigate the suitability of a stabilized lateritic gravel using PCC for the construction of subbase layer of low volume roads.

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4.1.1 Mineralogical and Chemical Tests of lateritic gravel and PCC

The mineralogical composition is considered to be more important in explaining the physical properties of lateritic gravel. The mineralogical constituents can be divided in to major elements, which are essential to laterization, and minor elements, which do not affect the laterization process. The major constituents are oxides and hydroxides of aluminum and iron, with clay minerals and, to a lesser extent, manganese, titanium and silica. The minor constituents are residual remainants. The result showed that major elements Al_2O_3 and Fe_2O_3 constitute 40% of total mineralogical elements.

Table 4. 1 Complete silicate analysis or chemical composition report for Lateritic gravel samples

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
NE	52.26	17.73	9.64	7.92	5.34	2.96	0.22	0.14	0.50	0.77	0.14	1.19
SW	53.70	14.12	9.70	8	7.56	2.82	0.72	0.10	0.37	0.78	1	0.19

Silica to sesquioxide ratio was developed by charman in 1988 was being used to classify materials as lateritic or non-lateritic. The ratio of Silica (52.26) to Sesquioxide (Al_2O_3 + Fe_2O_3 = 27.37) of sample from Mesken borrow site labelled as NE is 1.91 fall in the margin of $1.33 < R < 2$ that shows as the soil material is lateritic.

As the R value of silica (53.70) to Sesquioxide (Al_2O_3 + Fe_2O_3 = 23.82) of sample from Worabe Mewcha or SW is 2.25 which greater than 2.0 the soil falls under the classification of non-laterites. During laterization process, the soil materials undergo the complete dehydration (sometimes involving hardening) of the Sesquioxide rich materials and secondary minerals which tends to create the weathered soils. Accordingly the gravel at Worabe Mewcha is classified under tropical weathered soil.

Table 4. 2 Complete silicate analysis or chemical composition report for PCC

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
M-Z/02	4.9	1.04	0.60	50.90	0.64	0.68	<0.01	0.10	<0.10	0.07	2.3	39.71

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The complete silicate analysis for PCC shows that it is non-laterite. As the major content of PCC is calcium oxide it can be used as a good road construction material.

4.2 Laboratory Test Results

4.2.1 Unstabilized Lateritic Gravel

4.2.1.1 Grain Size Distribution

Grain size distribution/ analysis is an attempt to determine the relative sizes of different grain particles. Limits on particle size distribution may be vital to achieve the required bearing capacity to support both the upper pavement layers and the traffic loading expected on the road during the roads' service life of the.

Grain size distribution is used to determine the grading of materials proposed for use as construction materials based on the specification requirements. The results are used to determine compliance with applicable specification requirements for the use of it for the specific goal to be achieved.

Materials which meet the recommendations of ERA specifications for the use as subbase usually be found to have adequate bearing capacity expected from it.

Table 4. 3 Gradation results of Mesken Borrow Site samples

Sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	Mesken BS 1	Mesken BS 2	Mesken BS 3	Mesken BS 4	ERA Specs
50	100	100	100	100	100
37.5	100	100	100	99	80-100
20	92.29	88.64	90.28	87	60-80
5	44.56	46	52	48	30-100
1.18	26.12	28	29.68	32	17-75
0.3	2.04	2.68	3.2	2.94	9-50
0.075	2.93	2.45	3.2	2.88	5-25

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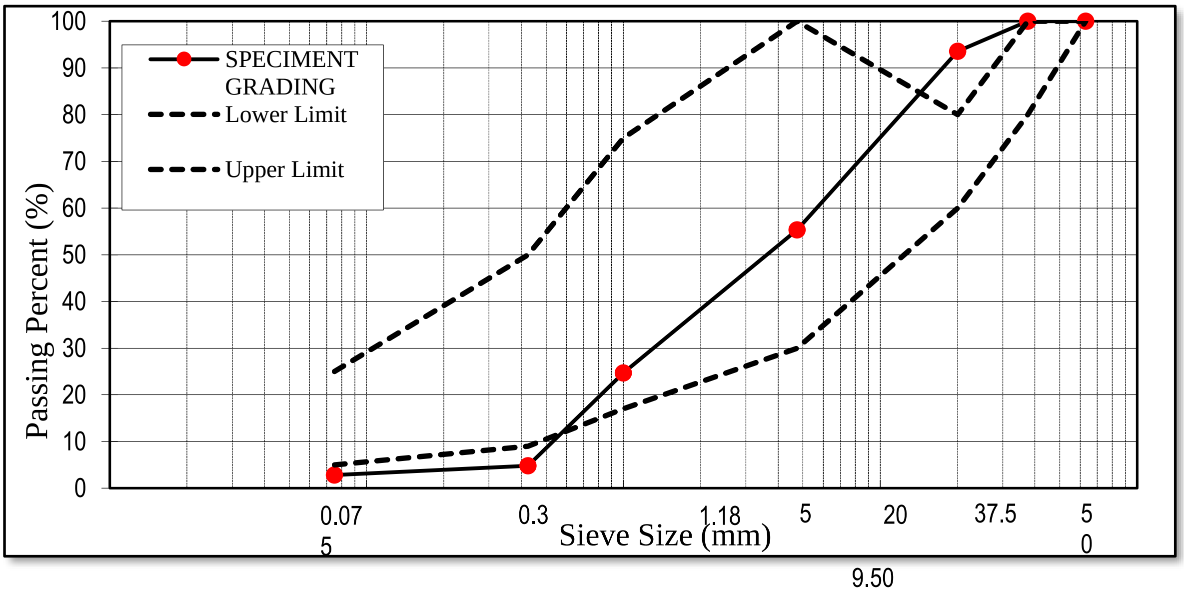

Figure 4. 1 Sieve Analysis result of Lateritic gravel from MBS 1

The above gradation analysis results from both table 4.3 and figure 4.1 shows that the material currently being used for subbase construction at Batu Town is violating the specification given by ERA 2013 by three different sieve sizes. But this material do not satisfy the gradation requirement for subbase materials on three sieve sizes of 20, 0.3 and 0.075mm size. The gradation curve for samples listed in the table can referred on appendix 4(A).

Table 4. 4 Gradation results of Worabe mewcha Borrow Site samples

Sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	Worabe BS 1	Worabe BS 2	Worabe BS 3	Worabe BS 4	ERA Specs
50	100	100	100	100	100
37.5	98.16	98	100	100	80-100
20	95.36	83.24	85	90.12	60-80
5	40.03	56	49.36	54	30-100
1.18	31.42	33.58	38	44.32	17-75
0.3	2.94	4.78	7.8	8.84	9-50
0.075	0.9	0.21	0.19	0.95	5-25

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The sample from this site is coarser than that of Mesken borrow site. The gradation result shows as the materials from this site do not meet the required gradation for low volume roads subbase by three different sieve sizes including 20, 0.3 and 0.075mm.

Table 4. 5 Gradation results of Jijo Borrow Site samples

Sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	Jijo BS 1	Jijo BS 2	Jijo BS 3	Jijo BS 4	ERA Specs
50	100	100	100	100	100
37.5	100	100	100	100	80-100
20	98.10	94	90.48	91.37	60-80
5	66.29	58.12	51	64	30-100
1.18	40.03	46	55	37	17-75
0.3	5.46	5.2	3.88	7.4	9-50
0.075	0.899	0.59	0.48	0.94	5-25

The sample from Jijo borrow site is similar to that of worabe mawcha site in gradation characteristics as both of them don't conform to ERA specification for subbase materials sieve sizes 20, 0.3 and 0.075mm.

4.2.1.2 Atterberg Limits

Since the lateritic gravel samples seems non plastic the test is undertaken after soaking in water for almost 24 hours, The Atterberg limits are used in estimating other engineering properties of a soil and in soil classification. Because these limit values are easily determined and simple to use, they have been used for basic soil classification or for predicting soil behavior such as strength, volume change, hydraulic, and thermal conductivity, or use for correlation of these values to other complicated soil parameters, such as tensile strength, CBR, compression index, coefficient of consolidation, cohesion, and internal friction angle (Fang & Daniels, 2006).

Following AASHTO T-89 & T-90 standards, Laboratory test results showed that both lateritic gravel and weathered tropical soils around Butajira area are non-plastic materials. They tends to crumble immediately when they were being rolled in to thread of 3mm

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diameter. This result satisfies the requirement of ERA technical specification in which the plasticity index shall be less than 20 for Arid and semi-arid climate at Batu town and nearby towns located around it.

4.2.1.3 Water Absorption and Specific Gravity

Water absorption of an aggregate is accepted as measure of its porosity. The lateritic gravel is porous in nature and the water filled pores during immersion does not fully reside inside the aggregate. Water absorption indicates the amount water absorbed by the material or water holding the material's capacity after immersion of it in water for 24 hours.

Water absorption provided an idea of strength of aggregate materials. More water absorption is more porous in nature. It is generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness based on tests conducted for the specific property.

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregates having low specific gravity are generally weaker than those with higher specific gravity values. The specific gravity test helps in the identification of aggregate.

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. It is the measure of strength or quality of the specific material. Aggregates having low specific gravity are generally weaker than those with higher specific gravity values.

Accordingly, laboratory test results revealed that the absorption & specific gravity of the lateritic gravels are 10.62 % and 2.46, respectively. Consequently, the lateritic gavel samples has high water absorption capacity because of its high porosity.

4.2.1.4 Modified Proctor's Compaction

The compaction of the soil material is directly related to the moisture content during compaction. Unless the moisture content is at its optimum value during compaction, maximum density cannot be achieved. The proctor compaction test defines the relationship between soil density and moisture content to determine the maximum density at a certain

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moisture content, known as the optimum moisture content. Since ERA specification recommends AASHTO T 180 for the subbase of low volume roads the determination of MDD and OMC are determined after the curve is drawn for the values of both density and water content. AASHTO T-180 is done in similar procedure and apparatus as that AASHTO T-99. Apparatus used during compaction test are cylindrical mold, detachable collar, base plate, rammer, Balance, moisture can, oven, straightedge and sieves mixing tool. But they differ by mass of rammer, number of layers, rammer drop height and number of blows per layer.

Prior to doing the laboratory test modified proctor compaction required mass of representative sample was obtained and thoroughly mixed with sufficient amount of water. Then compaction is done on the sample by varying the amount water to be added until the maximum weight of wet soil is reached and begin to reduce with further addition of water.

Figure 4. 2 Moisture Density Relationship for lateritic gravel only

no. layers	5	Rammer weight	4.5kg
Mold diameter, mm	152	Blows per layer	56
Volume of mold (cm^3)	2123		

Weight of wet soil + mold	(gm)	9985.0	10215.0	10335.0	10185.0
Weight of mold	(gm)	6202.0			
Weight of wet soil	(gm)	3783.0	4013.0	4133.0	3983.0
Wet density	(gm/cm^3)	1.782	1.890	1.947	1.876
Woisture content : container no.		H-4	H-86	H-67	H-50
Weight of wet soil + container	(gm)	450.0	475.0	580.0	470.0
Weight of dry soil + container	(gm)	440.0	460.0	550.0	440.0
Weight of container	(gm)	175.0	190.0	175.0	175.0
Weight of moisture	(gm)	10.0	15.0	30.0	30.0
Weight of dry soil	(gm)	265.0	270.0	375.0	265.0
Moisture content	(%)	3.8	5.6	8.0	11.3
Dry density	(gm/cm^3)	1.717	1.791	1.803	1.685

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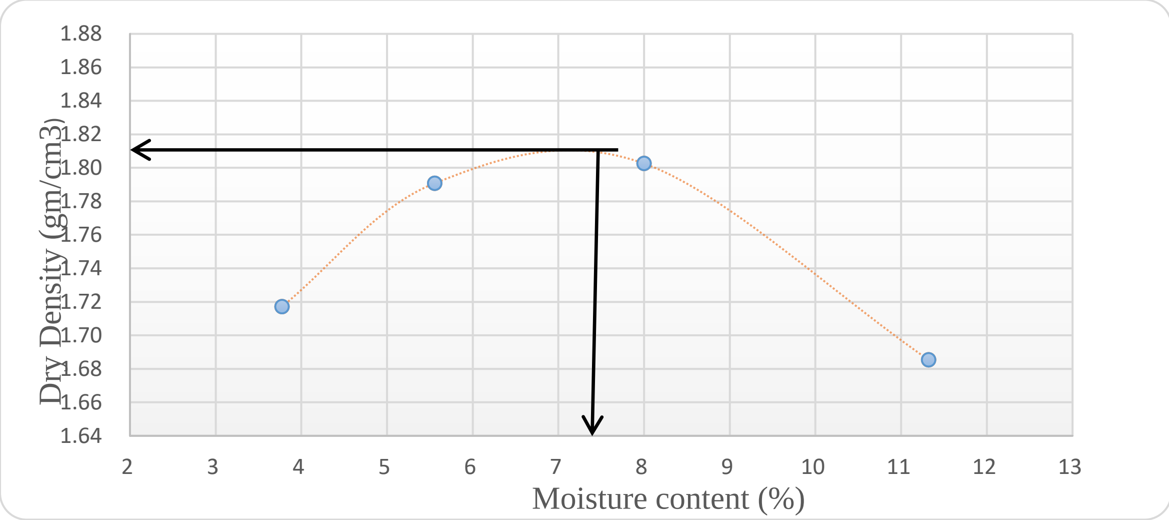

Figure 4. 3 Modified Proctor's Compaction

Accordingly, the test was carried out which produced that the maximum dry density (MDD) of the Mesken area borrow site lateritic gravel is 1.713g/cc at the optimum moisture content (OMC) of 7.7% after reading the graph drawn with density versus moisture content.

4.2.1.5 California Bearing Ratio

The California bearing ratio (CBR) is one of method used to express the bearing capacity or the strength of the soil material over which the pavement is going to be constructed. CBR can be defined as the ratio of the load required to cause a certain penetration of the plunger into the soil material to the load required to obtain the same penetration on a specimen of standard material.

The CBR for the lateritic gravels samples was done considering area's environmental, climatic condition of the area under study. Basically Batu Area is classified under semi-arid climatic condition. But most of the low volume roads in the town is constructed using Cobblestone which cannot fully restricts water drain towards road subbase materials due to the gap or openings between successive cobbles. Therefore the soaked CBR can simulate the subbase material's actual bearing capacity under the leaky upper layers of the low volume roads as the area gains rain for almost one full season in the year.

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The specimen's compaction is carried out in five approximately equal layers of compacted thicknesses to carry out the CBR test. Each layer receives a certain number of blows. This number of blows, which is the same for each layer, is determined in such a way that the density reached per specimen is either a little lower or a little higher than the maximum density, determined by the modified proctor method. In my cases 10, 30 and 65 blows are used for three different CBR determinations.

According to ERA manual for low volume roads (2013) minimum CBR of 30% is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum of 95% (preferably 97% where practicable) AASHTO T180 compaction. During this test the MDD is taken from the laboratory compaction test on lateritic gravel.

Table 4. 6 Dry density of lateritic gravel before and after soaking.

Number of Blows	Before soaking		After soaking	
	DD(g/cc)	Moisture (%)	DD(g/cc)	Moisture (%)
10	1.67	9	1.57	9.3
30	1.74	8.84	1.68	9.1
65	1.81	7.4	1.76	7.7

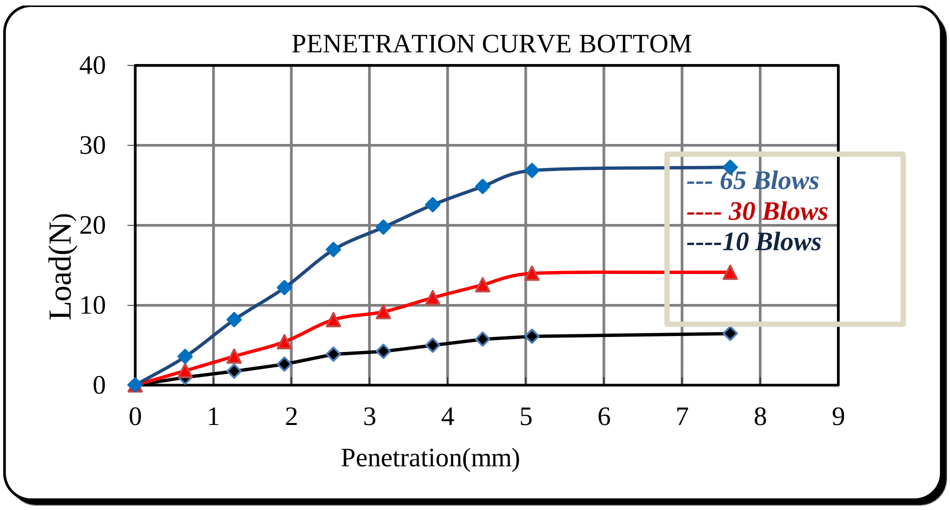

Figure 4. 4 California Bearing Ratio test

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4.2.1.6 Los Angeles Abrasion

Los Angeles Abrasion test is used to determine the wear on aggregates under the influence of crushing and abrasion forces. The forces are developed during rotation of the aggregate and steel spheres in an apparatus known as the Los Angeles machine consisting rotating drum with steel balls inside. During the rotation of the drum lateritic gravel samples the aggregates in contacting with aggregates undergoes attrition forces while the aggregates in contact with steel balls are under abrasive force. Along with the 5Kg dry aggregate, steel spheres 45 to 49 mm in diameter and mass between 400 and 445g each are added and the drum is then sealed and is rotated for 500 revolutions.

The test was carried out accordingly, and Los Angeles Abrasion Value (LAAV) has been found to be 43.39%, which is less than 45% based on the standard specification meets the standard technical specification requirement.

Figure 4. 5 Los Angeles Abrasion test results

Trial No.	1	2	3
Number of Revolution	500	500	500
Total Weight of Sample Tested (g)	5,000	5,000	5,000
Weight of Tested Sample Retained on No.12 Sieve (g)	2,810	2,895	2786
Percent Loss (%)	43.8%	42.1%	44.28%
Average	43.39%		

4.2.2 Laboratory Test Results for Precipitated Calcium Carbonate

4.2.2.1 Grain Size Analysis

The PPC at Batu Caustic Soda Factory stockpile is of the size passing sieve 19.5mm during the period of damping onsite as waste. But sodium oxide reacts with carbon dioxide in the long process of oxidation reaction and changed into sodium carbonate which results in agglomerated aggregate sodium. According to the ERA specification sieve size arrangement for the low volume roads subbase materials the PCC fully passes the three sieve sizes including 50, 37.5 and 20mm. This indicates as the PCC at Batu cannot be used as road

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Subbase materials before blending it with other granular materials as its will be finer than the ERA requirement for grading.

Table 4. 7 Gradation results of representative PCC samples from four directions

Sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	PCC-E-01	PCC-W-02	PCC-N-03	PCC-S-04	ERA Specs
50	100	100	100	100	100
37.5	100	100	100	100	80-100
20	100	100	100	100	60-80
5	85.81	89.97	88.44	87.03	30-100
1.18	58.11	70.49	66.18	59.29	17-75
0.3	24.53	42.60	37.99	26.95	9-50
0.075	12.95	26.17	18.52	13.61	5-25

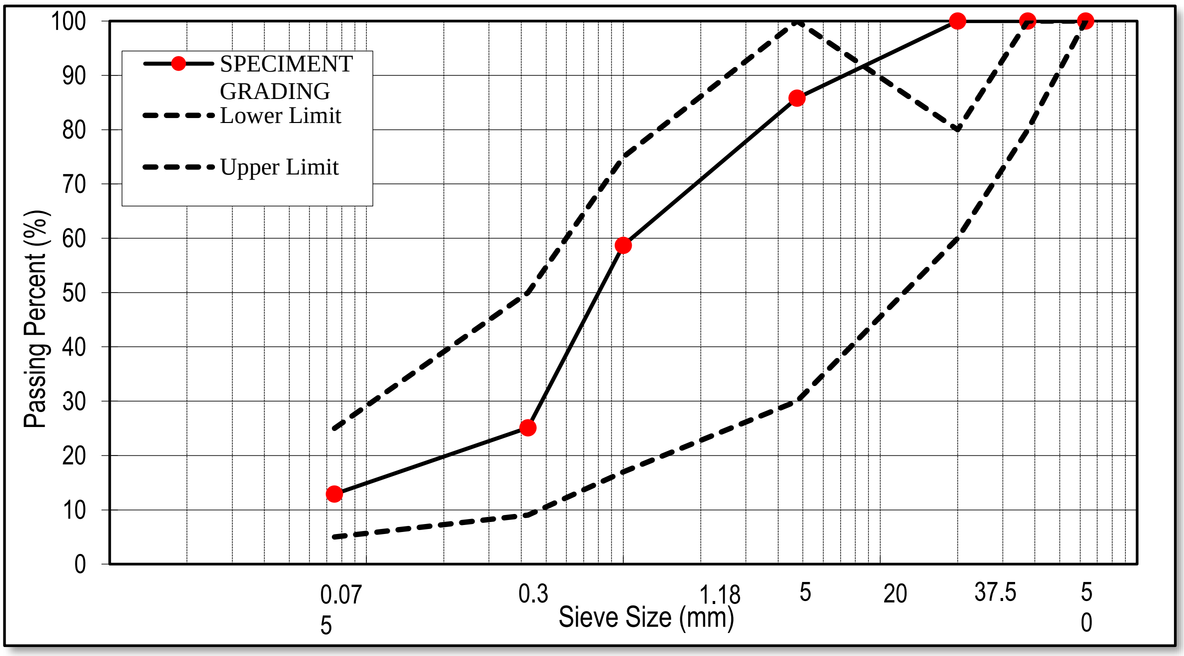

Figure 4. 6 Gradation curve of PCC –E-01

As we can see from figure 4.6, gradation test result in the table 4.7 and gradation curve, PCC material fails to meet ERA requirement of gradation for expected bearing capacity based on

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the defined sieve analysis for test sieve sizes of 50, 37.5 and 20mm respectively. Hence it cannot be used as the subbase construction material for low volume roads.

4.2.2.2 Water Absorption and Specific Gravity

Since more than 85.81% of the PCC passes sieve size 5mm; the standard method that is followed for determining the specific gravity and absorption AASHTO T-84 using Pycnometer.

The test results indicates that the water absorption and specific gravity of the PCC are 8.5% and 1.68 respectively.

4.2.2.3 Atterberg Limit

PCC at stockpile have different oxides in its nature as a grinded calcined rocks. Due to the fear of sodium oxide fumigation during dry season the natural expansive soil of the area is dispersed on the top of the PCC stockpile in the directions related to the nearby residents. The liquid limit test for PCC alone was carried out in which it was observed that the groove of it on the Casagrande brass cup closed in less than eight blows for five trials and it was also observed to crumble before reaching a thickness of 3mm when rolled to check its plastic limit. Based on the observations made during the trials to check LL and PL of PCC alone it was observed as PCC by itself is considered as Non-Plastic material.

Depending on the test results from the PCC mixed with nearby Expansive soil the property of it was altered with the mixing of PCC and the Expansive soil. The percentage composition of the PCC and the soil differs from samples location. After LL and PL are determined for the samples for PCC content of from southern, Eastern, northern and western direction of the stockpile PI was identified to be 5.4, 6.78, 7.45 and 8.01 respectively.

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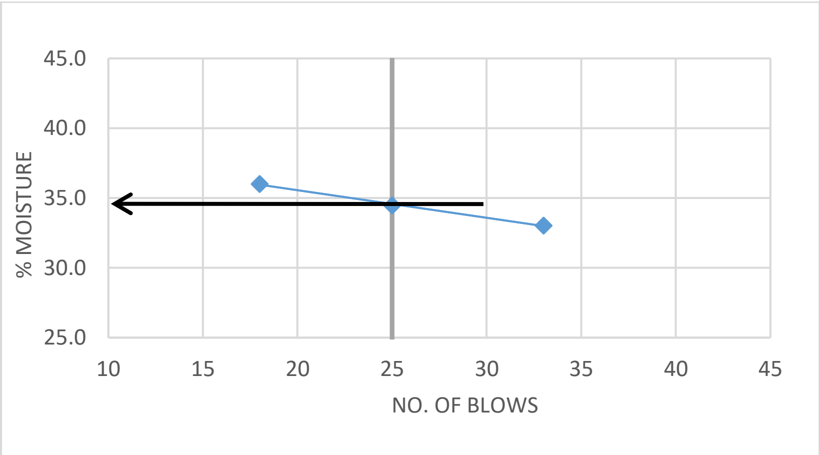
Table 4. 8 Liquid limit and plastic limit test

	Liquid Limit Test			Plastic Limit Test	
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2
No. of Shocks N	33	25	18	-------	-------
Mass of Container M_c	56.44	54.55	59.08	54.83	55.26
Mass of Sample + Container M_1	75.73	73.23	73.85	63.40	64.29
Mass of Moist Sample $M_m=M_1-M_c$	19.29	18.68	14.77	8.57	9.03
Mass of Dried Sample + Container M_2	70.94	68.44	69.94	61.55	62.33
Mass of Dried Sample $M_d=M_2-M_c$	14.50	13.89	10.86	6.72	7.07
% Moisture $w = (M_m-M_d) / M_d \times 100$	33.0	34.5	36.0	27.5	27.7



4.2.2.4 Modified Proctor's Compaction

The compaction characteristics of PCC was analyzed using modified proctor test based the ERA specification manual for the compaction analysis of road subbase materials.

Accordingly, the test was carried out which produced that the maximum dry density (MDD) of the PCC is 1.70g/cc at the optimum moisture content (OMC) of 14.15% as indicated in figure 4.7.

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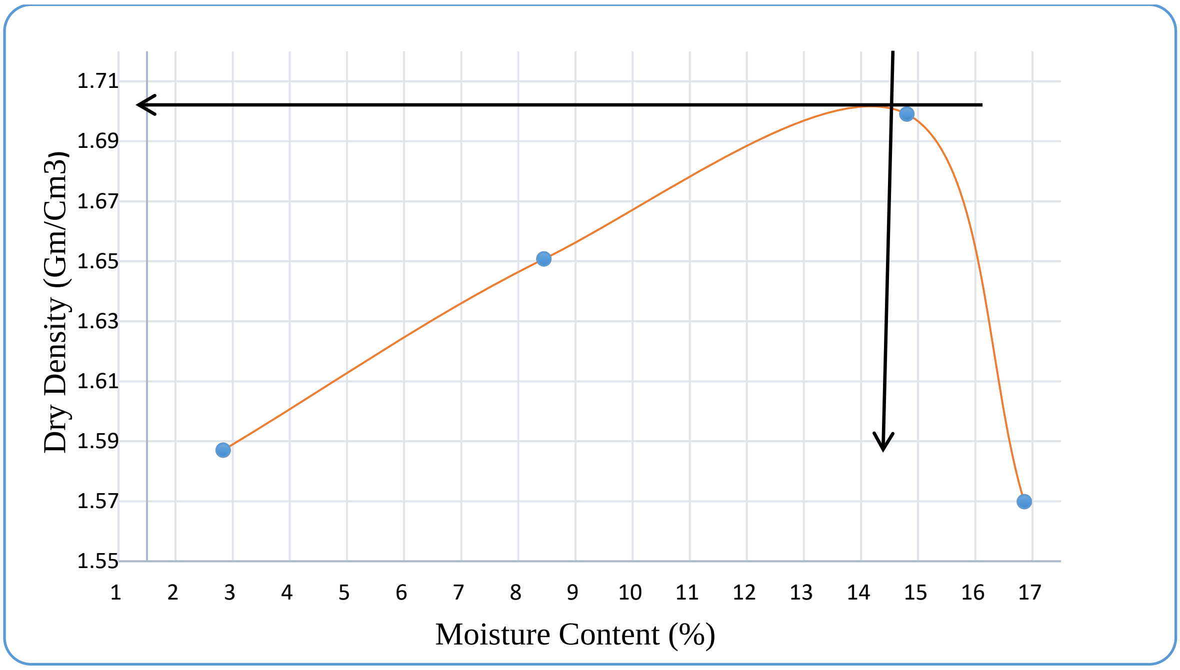

Figure 4. 7 Moisture density curve

4.2.2.5 California Bearing Ratio

The compaction of specimen is carried out in five approximately equal layers compacted thicknesses to carry out the CBR test for PCC. Each layer receives 10, 30 and 65 number of blows. This number of blows, which is the same for each layer, is determined so that the density reached per specimen is either a little lower or a little higher than the maximum density, determined by the modified proctor method. In cases of this study 10, 30 and 65 blows are used for three different CBR determinations. The obtained soaked CBR of PCC was 32.2% where ERA specification requirement subbase material is 30%.

Table 4. 9 Dry density of PCC before and after soaking.

Number of Blows	Before soaking		After soaking	
	DD(g/cc)	Moisture (%)	DD(g/cc)	Moisture (%)
10	1.88	13	1.61	14.2
30	2.01	11.65	1.72	12
65	2.3	9.3	1.1.96	10.44

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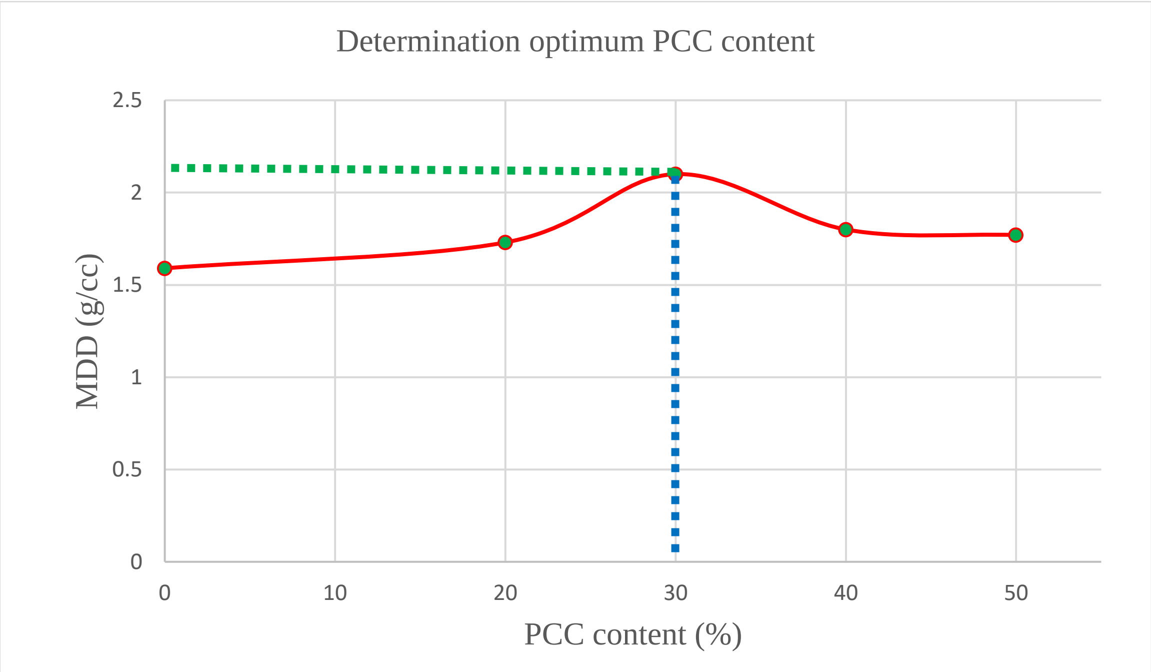
4.3 Laboratory Test Results of Lateritic Gravel Blended with PCC.

4.3.1 Determination of the Optimum Proportion of PCC and Evaluating economic benefits of using precipitated calcium carbonate blended with lateritic gravel

The proportion of precipitated calcium carbonate which results with maximum density is regarded as the optimum amount precipitated calcium carbonate needed to be determined. To achieve this objective, the compaction was carried out by blending lateritic gravels with precipitated calcium carbonate at various proportions starting with 20%, 30%, 40% and 50% by weight of the lateritic gravel. The method of compaction that was followed in this regard was AASHTO-T180 method D (Modified Proctor Test).

Table 4. 10 Determination of the Optimum Proportion of PCC

PCC content (%)	MDD (g/cc)	OMC (%)
0	1.76	8
20	1.78	9.5
30	2.1	9.8
40	1.88	10.3
50	1.86	11.1



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As shown both on the above table and graph the optimum amount of precipitated calcium carbonate that results in maximum dry density of 2.1g/cc reached is 30%.

The cost comparison of using lateritic gravel by itself as the subbase material or blending it with optimum amount of precipitated calcium carbonate as obtained from maximum dry density is evaluated based the cost analysis of construction materials required for decided road segment. Subbase materials are placed on well compacted subgrade soils to a desired depth that is 15 to 30cm depth as per municipality specification for low volume roads in the town and other road construction costs starting from site clearance to final paving above subbase course is taken to be equal.

Lateritic gravel may be ripped by loader or manpower, loaded by loader, transported by the Truck, spread by the grader and compacted or grid-rolled with a roller to produce a levelled and sealed running subbase course for low volume roads construction in Batu Town. The subbase layer construction from blended precipitated calcium carbonate and lateritic gravel can be done in the same approach except the requirement of additional water needed satisfy the optimum moisture content identified during MDD test. Initial Costs of lateritic gravel subbase and blended materials used in this thesis can be summarized based on the costs incurred on both materials with the current existing market price to accomplish certain task. The use PCC for subbase materials for low volume roads is abandoned since it does not satisfy gradation requirement of ERA specification for subbase materials.

Table 4. 11 Initial purchasing cost of PCC and LG

Materials	Purchasing cost of 14m^3 (ETB)	Quantity required for 500x10m road segment(m^3)	Total Initial purchasing cost
Lateritic Gravel	2,700	1,008	194,400
PCC	1,400	1,008	100,800
30% PCC and 70% Lateritic Gravel	2,240	1,008	165,800
Difference in materials purchase cost per 500m length			28,600

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To demonstrate cost benefits from using precipitated calcium carbonate as lateritic gravel stabilizer for subbase construction of low volume roads, initial materials purchasing cost comparison is performed. The same subgrade condition and thickness of the subbase materials assumed for the representative test sections under analysis. After all the use of 30% PCC blended with Lateritic gravel as a subbase material for low volume roads in the case of Batu town and surrounding towns and villages will result in the following benefits

- Reducing the demands on lateritic gravel which indirectly reduces road construction costs and construction period
- Reducing Environmental problems caused by dispersion of fine PCC containing sodium oxide specially on children
- Reducing the landfill area being used as PCC stockpile in the town
- Harnessing the materials considered to be waste by the factory for construction

4.3.2 Correlation between the soaked CBR and the index properties

The correlation between soaked CBR and other index properties of blended PCC and Lateritic gravel is analyzed using Minitab 19 statistical software for Engineers. Soaked CBR is a function of many independent variables like MDD, OMC, Proportion of PCC and average swelling of the sample after soaking for four days. Since the number of independent variables are more than one, multilinear regression analysis establishes the correlation between dependent variable which is soaked CBR and independent variables. Input data were the test results tabulated below and the regression equation derived by the software after analysis of data is:

Soaked CBR = -7.86 + 29.24 MDD - 0.166 OMC…………………………………..……. (4.1)

Table 4. 12 Coefficients of Regression Equation

Term	Coefficient	SE coefficient	T-value	P-value	VIF
Constant	-7.86	8.13	-0.97	0.366	
MDD	29.24	5.33	5.48	0.001	1.46
OMC	-0.166	0.713	-0.23	0.822	1.46

The software output value of variance inflation factor smaller than 10 which approves the absence collinearity among independent variables. Hence the developed correlation is acceptable.

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Table 4. 13 Model Summary

S	R-sq	R-sq adjusted	R-sq predicted
1.69	85.72%	81.64%	71.64%

An alternative measure of the strength of the regression model is adjusted for degrees of freedom by using adjusted mean of squares which is used as a measure of model fit. Since the value of adjusted mean square from software output is 81.64% the developed model fits the regression requirement. Again P –Value which allows to decide which variable is significantly related to the response variable the lower value of 0.001 for MDD depicts as soaked CBR is highly related to MDD.

Table 4. 14 Data Inputs for correlation analysis

Soaked CBR from test result	MDD	OMC	Predicted Soaked CBR
41.3	1.76	8	42.27
43.4	1.78	9.5	42.61
51.6	2.10	9.8	51.92
43.5	1.88	10.3	44.8
43.2	1.86	11.1	44.6
40.7	1.74	8.2	41.66
40	1.70	8.8	4.39
42	1.72	9.3	40.90
41.5	1.70	9	40.40
50.2	1.94	10.1	49.36

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Scatterplot of Soaked CBR vs MDD and OMC

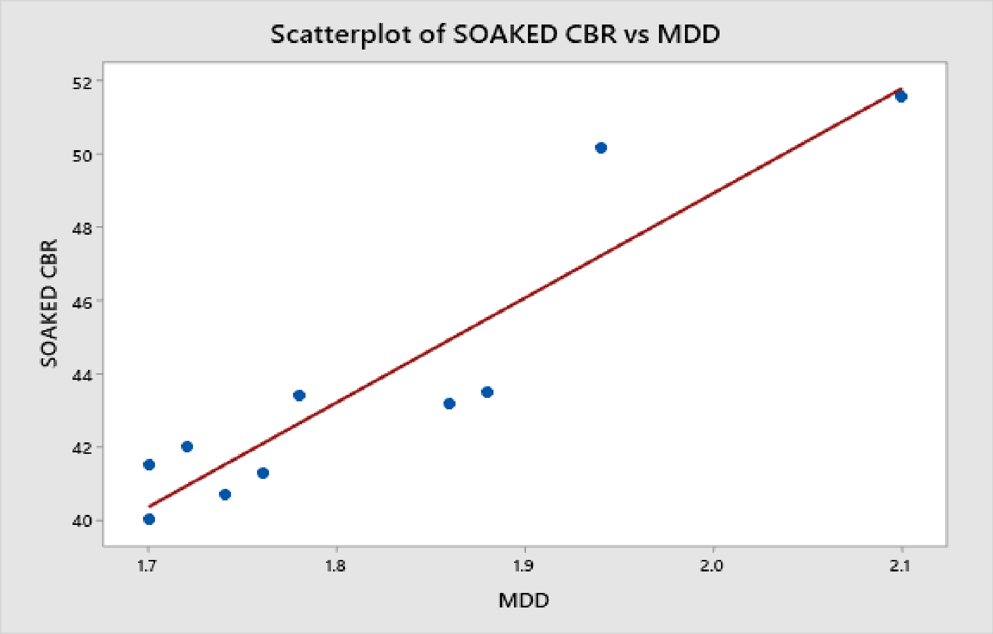

Figure 4. 8 Scatterplot of soaked CBR versus Maximum dry density

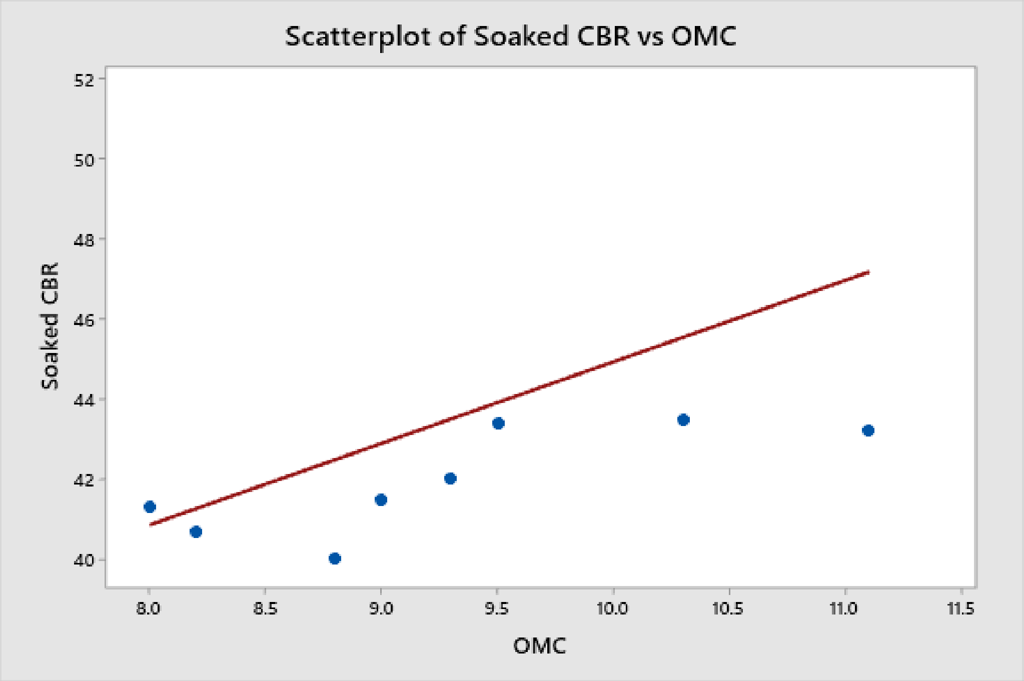

Figure 4. 9 Scatterplot of soaked CBR versus optimum moisture content

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A Pareto chart is a basic quality tool that helps you identify the most frequent response you can categorize. The chart visually depicts which factors are more significant in affecting the response factor. The Soaked CBR value of blended Precipitated calcium carbonate and lateritic gravel is highly affected by maximum dry density of the material as seen from the pareto chart as well as P-value.

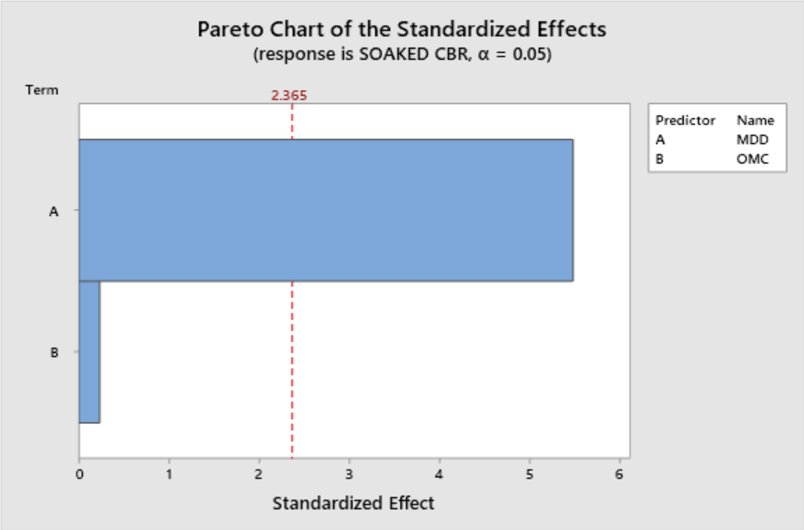

Figure 4. 10 Pareto chart of the standardized Effects

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5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This thesis study has tried to check whether Lateritic gravel of Butajira area could be used as a subbase course construction material of low volume roads after stabilized with precipitated calcium carbonate of Batu Caustic Soda factory. To do so I did laboratory tests on blended materials as well as differently on materials as per ERA specification for subbase materials of low volume roads.

From the laboratory work on blended materials for this thesis study, I came up with the following conclusions.

- Both lateritic gravel and precipitated calcium carbonate before blending do not fulfill the gradation requirements for subbase materials of low volume roads. PCC stockpile is finer as all samples drawn from the site passes 20mm and above sieve sizes while the lateritic gravels lacks fine materials.
- As it is seen from Atterberg limit test results both Precipitated calcium carbonate and lateritic gravel are non-plastic.
- The optimum amount of precipitated calcium carbonate blended and resulted in maximum dry density of 2.10 is 30%.
- Gradation curve of the materials for subbase roads improved and it lies within the range of lower and higher sieve size curve boundary asper ERA specification requirement for low volume roads subbase.
- The CBR value of lateritic gravel has increased after blending with precipitated calcium carbonate in different proportion. Comparing the CBR values of different proportion of precipitated calcium carbonate blending 30% of precipitated calcium carbonate and 70% lateritic gravel by weight resulted in maximum CBR value of 51.8 after soaking in water for four days.
- Stabilization of lateritic gravel with precipitated calcium carbonate improves Gradation, Californian Bearing Ratio and Maximum Density.

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5.2 Recommendations

The precipitated calcium carbonate stockpile in the midblock of Batu town is considered to be waste as it does not fit the requirement of calcium oxide production for being too fine and being taken by air in the form of carbon dioxide during burning in the kiln. Using this material as stabilizer is of good worth. Being fine helps to fulfill the gradation requirement of lateritic gravel.

After investigation of using precipitated calcium carbonate as lateritic gravel stabilizer the following recommendations can be made.

- Since gradation of lateritic gravel do not fall within the gradation envelope required by ERA specification for low volume roads subbase construction because of its coarser size the addition finer material to fill the gap is desirable.
- The tests on blended materials make certain the use of precipitated calcium carbonate as lateritic gravel stabilizer for subbase construction for low volume roads. However, the field performance of this blended materials ought to be investigated on a representative road segment constructed from blended materials.
- The municipality of Batu and Adami Tullu district may find use the blended materials for road construction as it reduces subbase construction cost of purchasing materials.
- Further study should be done on the use of precipitated calcium carbonate for use of as road construction works as the quantity of the stockpile is huge.

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Appendices

Appendix 1 Chemical composition of Lateritic Gravels

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -23/03/2020

Customer Name: -Feyisa Gobena Kumbi.

Request No:- GLD/RQ/228/20

Report No:- GLD/RN/222/20

Sample type:- Soil

Sample Preparation: - 200 Mesh

Date Submitted: - 27/02/2020

Number of Sample:- Two (2)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
NE	52.26	17.73	9.64	7.92	5.34	2.96	0.22	0.14	0.50	0.77	0.14	1.19
SW	53.70	14.12	9.70	8.00	7.56	2.82	0.72	0.10	0.37	0.78	1.00	0.19

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Yirgalem Abriham
Tizita Zemene
Nigist Fikadu

Checked By
Yohannes Getachew

Approved By
Gosa Haile

Quality Control
Negash Worku

Appendix 2 Chemical composition of Precipitated Calcium Carbonate

	GE(LOGICAL SURVEY OF ETHIOPI	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	**Complete Silicate Analysis Report**	Effective date:	May, 2017

Issue Date: - 09/03/2018

Report No: GLD/TR/0094/18

Sample Preparation: - 200 Mesh

Number of Sample: One (1)

Name of Customer:- Daewoo E&C

Sample type: - Rock

Date Submitted: - 29/01/2018

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: LiBO2 FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	MnO	P2O5	TiO2	H2O	LOI
M-Z/02	4.94	1.04	0.60	50.90	0.64	0.68	<0.01	0.10	<0.01	0.07	2.30	39.71

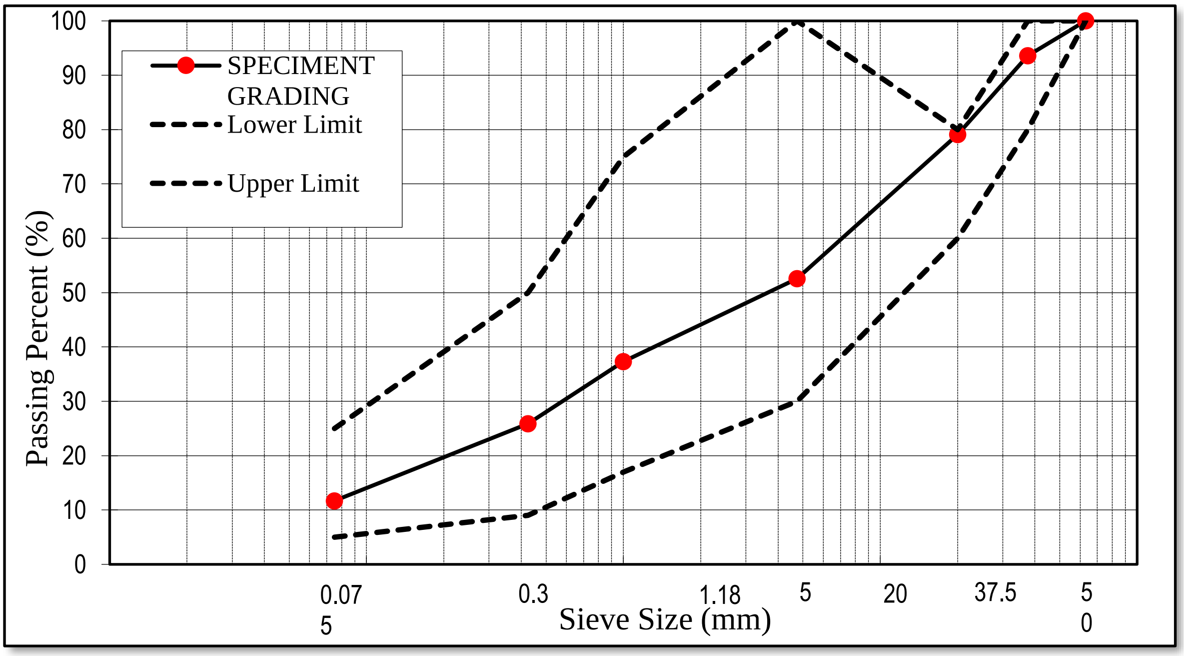
Analysts	Checked By	Approved By	Quality Control
Tizita Zemene Dessie Abebe Tihitna Beletkachew Yohannes Getachew Nigist Fikadu	Tamiru Siraye	for Gosa Haile	Awash Yirga

Appendix 3 Details of the LG's Blended with PCC Laboratory Test Results

A. Sieve Analysis

1. 80% LG and 20% PCC

SIEVE TEST	Total	4860	Gradation			Cumulative Retained
Material Size (mm) Sieve Size (mm)	Mass Retain	% Retain	% Passing	Specification (Classification A)		
50.0	0.0	0.0	100.0	100	100	0.0
37.5	320.0	6.5	93.5	70.0	100.0	6.5
20.0	725.0	14.92	78.58	60.0	80.0	21.42
5.00	1324	27.2	51.38	30.0	100.0	48.62
1.18	765.0	17.4	33.98	17.0	75.0	66.02
0.3	568.0	11.7	22.28	11.0	50.0	77.72
0.075	712	15	7.28	5.0	25.0	92.72



$$\text{Grading Modulus (GM)} = \frac{\text{Cumulative Retained \% } 1.18\text{mm} + 0.3\text{mm} + 0.075\text{mm}}{100}$$

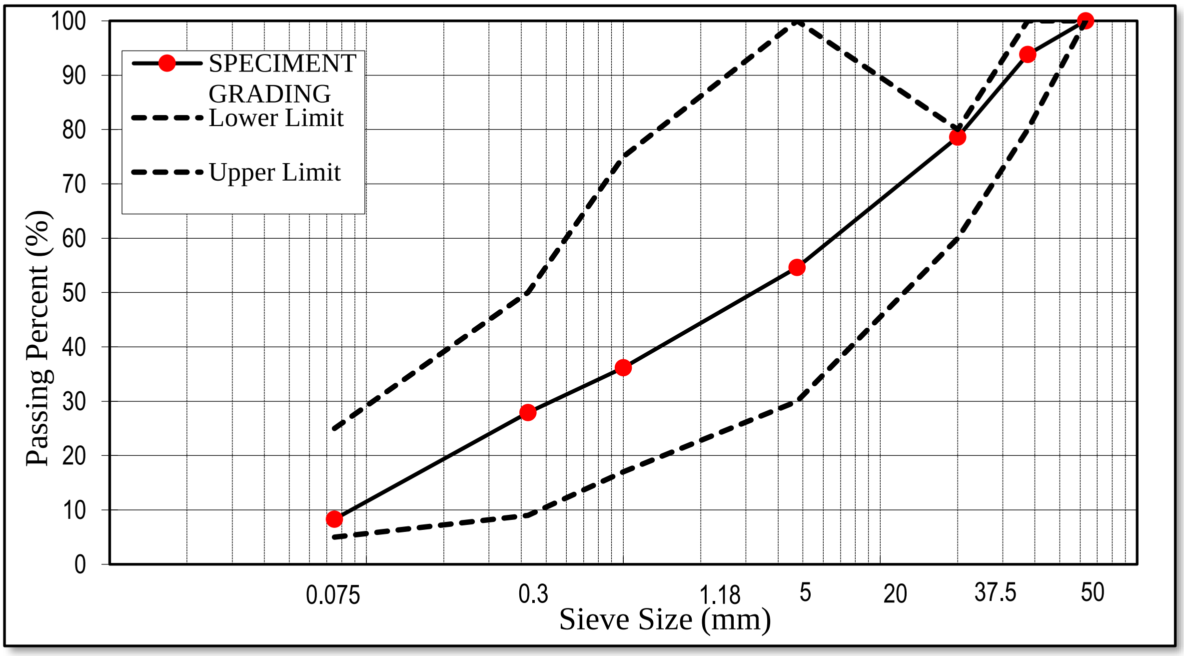
$$\text{Grading Modulus (GM)} = \frac{66.02 + 77.72 + 92.72}{100}$$

$$\text{Grading Modulus (GM)} = 2.36$$

`

2. 70% LG and 30% PCC

SIEVE TEST	Total	5000	Gradation			Cumulative Retained
Material Size (mm)	Mass Retain	% Retain	% Passing	Specification (Classification A)		
Sieve Size (mm)						
50.0	0.0	0.0	100.0	100	100	0.0
37.5	312.0	6.2	93.8	70.0	100.0	6.2
20.0	760.0	15.2	78.6	60.0	80.0	21.4
5.00	1200.0	24.0	54.6	30.0	100.0	45.4
1.18	921.0	18.4	36.2	17.0	75.0	63.8
0.3	414.0	8.3	27.9	11.0	50.0	72.1
0.075	980.0	19.6	8.3	5.0	25.0	91.7



$$\text{Grading Modulus (GM)} = \frac{\text{Cumulative Retained \% 1mm} + 0.425\text{mm} + 0.075\text{mm}}{100}$$

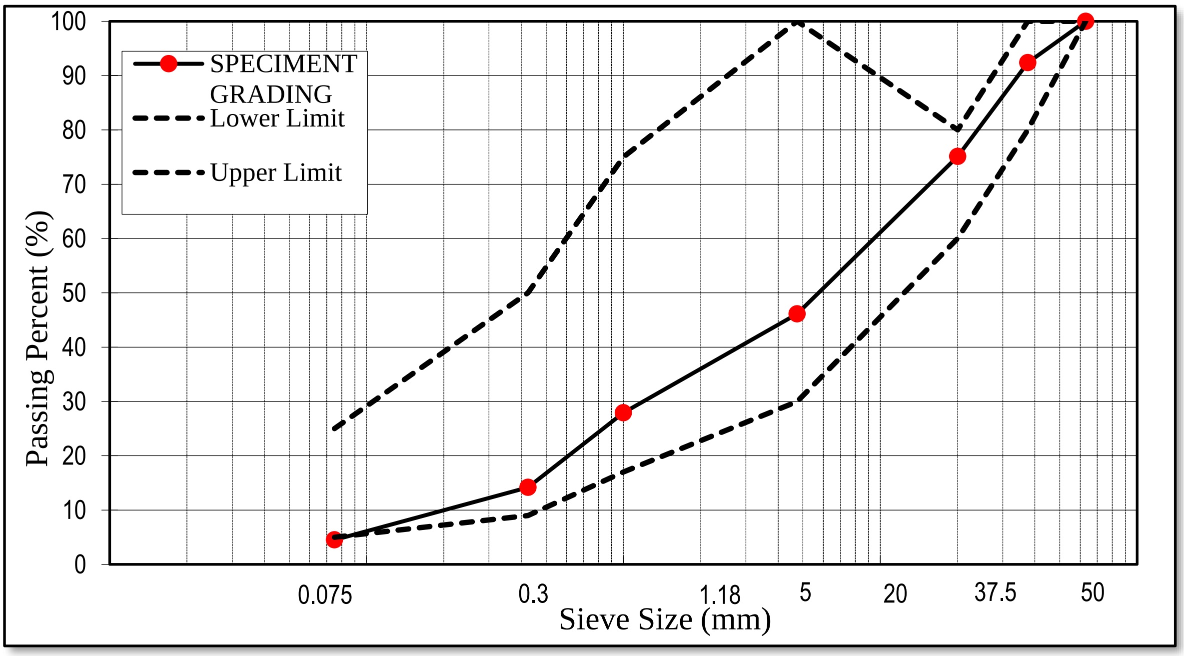
$$\text{Grading Modulus (GM)} = \frac{63.8 + 72.1 + 91.7}{100}$$

$$\text{Grading Modulus (GM)} = 2.3$$

`

3. 60% LG and 40% PCC

SIEVE TEST	Total	5140	Gradation			Cumulative Retained
Material Size (mm)	Mass Retain	% Retain	% Passing	Specification (Classification A)		
Sieve Size (mm)						
50.0	0.0	0.0	100.0	100	100	0.0
37.5	378.0	7.4	92.6	70.0	100.0	7.6
20.0	864	16.8	78.58	60.0	80.0	24.9
5.00	1448	28.17	51.38	30.0	100.0	53.9
1.18	912	17.74	33.98	17.0	75.0	72.1
0.3	687	13.36	22.28	11.0	50.0	95.8
0.075	487	9.7	4.5	5.0	25.0	95.5



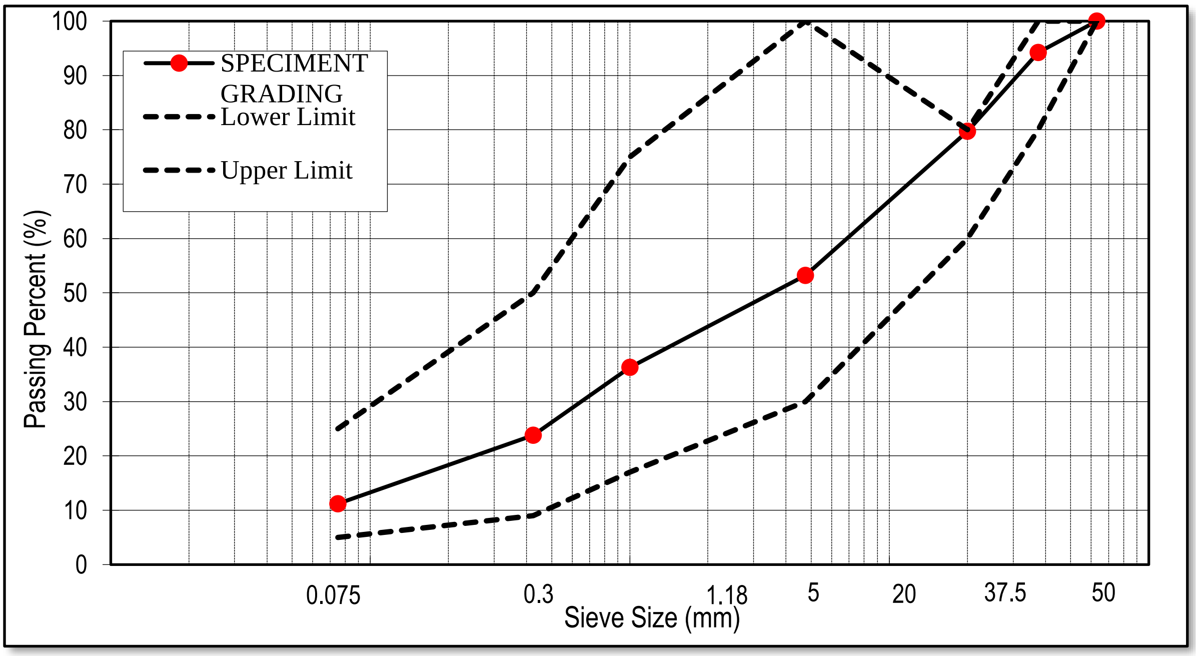
$$\text{Grading Modulus (GM)} = \frac{\text{Cumulative Retained \% 1mm} + 0.425\text{mm} + 0.075\text{mm}}{100}$$

$$\text{Grading Modulus (GM)} = \frac{70.12 + 83.48 + 97.52}{100}$$

$$\text{Grading Modulus (GM)} = 2.51$$

4. 50% LG and 50% PCC

SIEVE TEST	Total	4600	Gradation			Cumulative Retained
Material Size (mm)	Mass Retain	% Retain	% Passing	Specification		
Sieve Size (mm)						
50.0	0.0	0.0	100.0	100	100	0.0
37.5	290.0	6.3	93.7	70.0	100.0	6.3
20.0	725.0	15.17	78.58	60.0	80.0	21.47
5.00	1324	24.08	51.38	30.0	100.0	45.55
1.18	844	18.35	33.98	17.0	75.0	63.9
0.3	623	13.54	22.28	11.0	50.0	77.44
0.075	688	14.96	7.28	5.0	25.0	92.4



$$\text{Grading Modulus (GM)} = \frac{\text{Cumulative Retained \% 1mm} + 0.425\text{mm} + 0.075\text{mm}}{100}$$

$$\text{Grading Modulus (GM)} = \frac{63.9 + 77.44 + 92.4}{100}$$

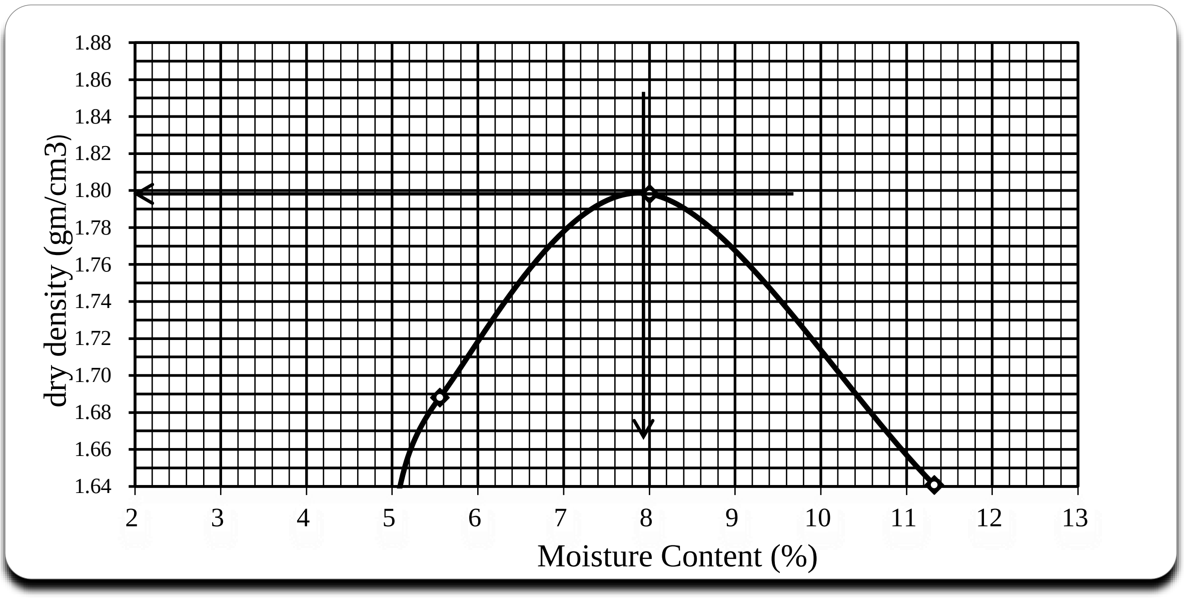
$$\text{Grading Modulus (GM)} = 2.34$$

`

B. Moisture Density test

1. 80% LG and 20% PCC

Weight of Wet Soil + Mold	(gm)	9785.0	9985.0	10325.0	10080.0
Weight of Mold	(gm)	6202.0			
Weight of Wet Soil	(gm)	3583.0	3783.0	4123.0	3878.0
Wet Density	(gm/c^3)	1.688	1.782	1.942	1.827
Moisture Content : Container No.		H-4	H-86	H-67	H-50
Weight of Wet Soil + Container	(gm)	290.2	475.0	580.0	470.0
Weight of Dry Soil + Container	(gm)	284.8	460.0	550.0	440.0
Weight of Container	(gm)	175.0	190.0	175.0	175.0
Weight of Moisture	(gm)	5.4	15.0	30.0	30.0
Weight of Dry Soil	(gm)	109.8	270.0	375.0	265.0
Moisture Content	(%)	4.9	5.6	8.0	11.3
Dry Density	(gm/cm^3)	1.609	1.688	1.798	1.641



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2. 70% LG and 30% PCC

Weight of Wet Soil + Mold	(gm)	9845.0	9995.0	10488.0	10195.0
Weight of Mold	(gm)	6202.02			
Weight of Wet Soil	(gm)	3640.0	3911.0	4423.0	3994.0
Wet Density	(gm/c^3)	1.715	1.842	2.083	1.881
Moisture Content : Container No.		T-14	M-03	T-22	T-10
Weight of Wet Soil + Container	(gm)	450.0	475.0	580.0	470.0
Weight of Dry Soil + Container	(gm)	441.0	464.0	564.0	441.0
Weight of Container	(gm)	175.0	190.0	175.0	175.0
Weight of Moisture	(gm)	9.0	11.0	16.0	29.0
Weight of Dry Soil	(gm)	266.0	274.0	389.0	266.0
Moisture Content	(%)	3.4	4.0	4.1	10.9
Dry Density	(gm/cm^3)	1.658	1.771	2.001	1.696

3. 60% LG and 40% PCC

Weight of Wet Soil + Mold	(gm)	9785.0	9985.0	10325.0	10080.0
Weight of Mold	(gm)	6202.0			
Weight of Wet Soil	(gm)	3586.0	3845.0	4235.0	3885.0
Wet Density	(gm/c^3)	1.689	1.811	1.995	1.830
Moisture Content : Container No.		M-19	M-41	M-15	M-21
Weight of Wet Soil + Container	(gm)	468.0	487.0	604.0	470.0
Weight of Dry Soil + Container	(gm)	441.0	464.0	564.0	441.0
Weight of Container	(gm)	171.0	184.0	125.0	172.0
Weight of Moisture	(gm)	27.0	23.0	40.0	29.0
Weight of Dry Soil	(gm)	270.0	280.0	439.0	269.0
Moisture Content	(%)	10.0	8.2	9.1	10.8
Dry Density	(gm/cm^3)	1.536	1.674	1.881	1.652

`

C. CBR Test for blended materials

70% Lateritic gravel and 30% Precipitated Calcium Carbonate

Density Determination						
Soaking condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
Mold number	M21		M50		D10	
weight of soil + mold, g	11140	11580	11430	11815	11850	12120
weight of mold, g	7930		7880		7260	
weight of soil , g	3210	3650	3550	3935	4590	4860
volume of mold, g/cm^3	2105		2105		2105	
wet density of soil, g/cm^3	1.525	1.734	1.686	1.869	2.181	2.309
dry density of soil, g/cm^3	1.404	1.602	1.563	1.760	2.032	2.102

Moisture Determination									
Soaking Condition	10 Blows			30 Blows			65 Blows		
	Before		After	Before		After	Before		After
container number	H-9	A-38	M-90	H-140	M-90	H-48	H70	Q20	H9
wet soil + container, g	391.2	389.5	439.6	380.6	356.6	450.3	441.6	363.6	438.0
dry soil + container, g	376	372.0	419.2	369.0	341.0	435.0	425.0	350.1	415.0
weight of container, g	181.4	187.3	171.1	194.8	171.2	189.7	171.5	182.9	181.2
weight of water , g	15.2	17.5	20.4	11.6	15.6	15.3	16.6	13.5	23.0
weight of dry soil, g	194.6	184.7	248.1	174.2	169.8	245.3	253.5	167.2	233.8
moisture content %	7.8	9.5	8.2	6.7	9.2	6.2	6.5	8.1	9.8
	8.6			7.9			7.3		

`

Penetration bottom test									
Penetration date	7/4/2020								
Penetration (mm)	10 Blows			30 Blows			65 Blows		
	Dial Reading	Load (KN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)
0	0.0	0.0		0.0	0.0		0.0	0.0	
0.64	1800	1.8		2250	2.3		365	0.4	
1.27	2750	2.8		2555	2.6		1175	1.2	
1.91	3500	3.5		3005	3.0		2745	2.7	
2.54	4100	4.1	30.5	5105	5.1	38.0	4880	4.9	36.3
3.18	4950	5.0		6925	6.9		7890	7.9	
3.81	5605	5.6		7675	7.7		8995	9.0	
4.45	6000	6.0		8535	8.5		9575	9.6	
5.08	6455	6.5	32.4	9430	9.4	47.4	10275	10.3	51.6
7.62	6755	6.8		10120	10.1		27260	27.3	
10.16	6900	6.9		15420	15.4		28410	28.4	

Swell			
Soaking Date	4-Feb-2020		
Time	Afternoon Time		
Mold Number	10	30	65
Initial reading (mm)	0	0	0
Final reading (mm)	0.49	0.40	0.30
Percent Swell (%)	0.42	0.34	0.26
Average	0.34		

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80% Lateritic gravel and 20% Precipitated Calcium Carbonate

Density Determination						
soaking condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
mold number	U19		R9		M19	
weight of soil + mold, g	11220	11710	11515	11885	11630	11940
weight of mold, g	7975		7985		7890	
weight of soil , g	3245	3735	3530	3900	3740	4050
volume of mold, g/cm^3	2105		2105		2105	
wet density of soil, g/cm^3	1.542	1.774	1.677	1.853	1.777	1.924
dry density of soil, g/cm^3	1.400	1.646	1.544	1.697	1.660	1.757

Moisture Determination									
soaking condition	10 Blows			30 Blows			65 Blows		
	Before		After	Before		After	Before		After
container number	H37	H19	T19	H30	H11	H13	H29	H23	H7
wet soil + container, g	440	415.0	360.0	440.0	420.0	400.0	410.0	350.0	355.0
dry soil + container, g	418	391.0	346.5	419.8	399.5	381.0	394.0	339.0	339.0
weight of container, g	175	175.0	172.9	170.3	175.0	174.2	175.0	175.0	170.9
weight of water , g	22	24.0	13.5	20.2	20.5	19.0	16.0	11.0	16.0
weight of dry soil, g	243	216.0	173.6	249.5	224.5	206.8	219.0	164.0	168.1
moisture content %	9.1	11.1	7.8	8.1	9.1	9.2	7.3	6.7	9.5
	10.1			8.6			7.0		

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Penetration Bottom Test									
Penetration date	28/03/2020								
Penetration (mm)	10 Blows			30 Blows			65 Blows		
	Dial Reading	Load (KN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)
0	0	0.0		0	0.0		0	0.0	
0.64	1750	1.8		2005	2.0		2520	2.5	
1.27	2400	2.4		2700	2.7		2985	3.0	
1.91	3150	3.2		3005	3.0		3255	3.3	
2.54	3550	3.6	26.4	4050	4.1	30.1	4750	4.8	35.3
3.18	3850	3.9		4950	5.0		5005	5.0	
3.81	5160	5.2		5300	5.3		6985	7.0	
4.45	5390	5.4		5985	6.0		7355	7.4	
5.08	6410	6.4	32.2	7895	7.9	39.7	8650	8.7	43.4
7.62	6515	6.5		8205	8.2		9005	9.0	
10.16	6785	6.8		9100	9.1		9650	9.7	

Swell			
Soaking Date	24/03/2020		
Time	Afternoon Time		
Mold Number	10	30	65
Initial reading (mm)	0	0	0
Final reading (mm)	0.42	0.37	0.30
Percent Swell (%)	0.36	0.32	0.26
Average	0.31		

`

60% Lateritic gravel and 40% Precipitated Calcium Carbonate

Density Determination						
Soaking condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
Mold number	A19		D21		M48	
Weight of soil + mold, g	11425	11860	11695	12040	12010	12260
Weight of mold, g	7925		7955		7950	
Weight of soil , g	3500	3935	3740	4085	4060	4310
Volume of mold, g/cm^3	2105		2105		2105	
Wet density of soil, g/cm^3	1.663	1.869	1.777	1.941	1.929	2.048
Dry density of soil, g/cm^3	1.531	1.719	1.631	1.795	1.771	1.856

Moisture Determination									
Soaking condition	10 Blows			30 Blows			65 Blows		
	Before		After	Before		After	Before		After
Container number	D08	H19	H29	K52	T50	H06	Q52	A35	H35
Wet soil + container, g	440	415.0	360.0	440.0	420.0	400.0	410.0	350.0	355.0
Dry soil + container, g	412	394.0	345.0	412.0	386.0	383.0	382.0	335.0	338.0
Weight of container, g	50	173.7	173.1	45.0	52.5	173.1	54.4	173.0	173.1
Weight of water , g	28	21.0	15.0	28.0	34.0	17.0	28.0	15.0	17.0
Weight of dry soil, g	362	220.3	171.9	367.0	333.5	209.9	327.6	162.0	164.9
Moisture content %	7.7	9.5	8.7	7.6	10.2	8.1	8.5	9.3	10.3
	8.6			8.9			8.9		

`

Penetration Bottom Test									
Penetration date	29/03/2020								
penetration (mm)	10 Blows			30 Blows			65 Blows		
	Dial Reading	Load (KN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)
0	0	0.0		0	0.0		0	0.0	
0.64	1680	1.7		1995	2.0		2425	2.4	
1.27	2350	2.4		2685	2.7		2895	2.9	
1.91	3005	3.0		2995	3.0		3195	3.2	
2.54	3450	3.5	25.7	4005	4.0	29.8	4605	4.6	34.3
3.18	3785	3.8		4895	4.9		4895	4.9	
3.81	4965	5.0		5255	5.3		6795	6.8	
4.45	5295	5.3		5895	5.9		7195	7.2	
5.08	6355	6.4	31.9	7785	7.8	39.1	8665	8.7	43.5
7.62	6445	6.4		8125	8.1		8985	9.0	
10.16	6695	6.7		8995	9.0		9555	9.6	

Swell			
Soaking Date	25/03//2020		
Time	Afternoon Time		
Mold Number	10	30	65
Initial reading (mm)	0	0	0
Final reading (mm)	0.78	0.52	0.28
Percent Swell (%)	0.67	0.45	0.24
Average	0.45		

`

50% Lateritic gravel and 50% Precipitated Calcium Carbonate

Density Determination						
Soaking condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
Mold number	M28		A30		M20	
Weight of soil + mold, g	11530	11955	11710	12035	11860	12155
Weight of mold, g	8000		7910		7881	
Weight of soil , g	3530	3955	3800	4125	3979	4274
Volume of mold, g/cm^3	2105		2105		2105	
Wet density of soil, g/cm^3	1.677	1.879	1.805	1.960	1.890	2.030
Dry density of soil, g/cm^3	1.567	1.725	1.656	1.813	1.770	1.828

Moisture Determination									
Soaking condition	10 Blows			30 Blows			65 Blows		
	Before		After	Before		After	Before		After
Container number	A29	T04	H08	E29	N8	H2	K30	T25	H23
Wet soil + container, g	440	415.0	360.0	440.0	420.0	400.0	410.0	350.0	355.0
Dry soil + container, g	412	394.0	345.0	412.0	386.0	383.0	382.0	335.0	337.0
Weight of container, g	56.1	50.9	177.4	53.5	52.1	172.9	47.0	50.9	174.6
Weight of water , g	28	21.0	15.0	28.0	34.0	17.0	28.0	15.0	18.0
Weight of dry soil, g	355.9	343.1	167.6	358.5	333.9	210.1	335.0	284.1	162.4
Moisture content %	7.9	6.1	8.9	7.8	10.2	8.1	8.4	5.3	11.1
	7.0			9.0			6.8		

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Penetration Bottom Test									
penetration date	30/03/2020								
penetration (mm)	10 Blows			30 Blows			65 Blows		
	Dial Reading	Load (KN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)
0	0	0.0		0	0.0		0	0.0	
0.64	1705	1.7		2000	2.0		2300	2.3	
1.27	2095	2.1		2705	2.7		2790	2.8	
1.91	2925	2.9		2885	2.9		3205	3.2	
2.54	3405	3.4	25.3	3945	3.9	29.4	4565	4.6	34.0
3.18	3805	3.8		4785	4.8		4785	4.8	
3.81	4895	4.9		5105	5.1		6605	6.6	
4.45	5425	5.4		5855	5.9		7050	7.1	
5.08	6495	6.5	32.6	7655	7.7	38.4	8595	8.6	43.2
7.62	6425	6.4		8105	8.1		9025	9.0	
10.16	7005	7.0		8895	8.9		9755	9.8	

Swell			
Soaking Date	26/03//2020		
Time	Afternoon Time		
Mold Number	10	30	65
Initial reading (mm)	0	0	0
Final reading (mm)	0.83	0.58	0.42
Percent Swell (%)	0.71	0.50	0.36
Average	0.52		

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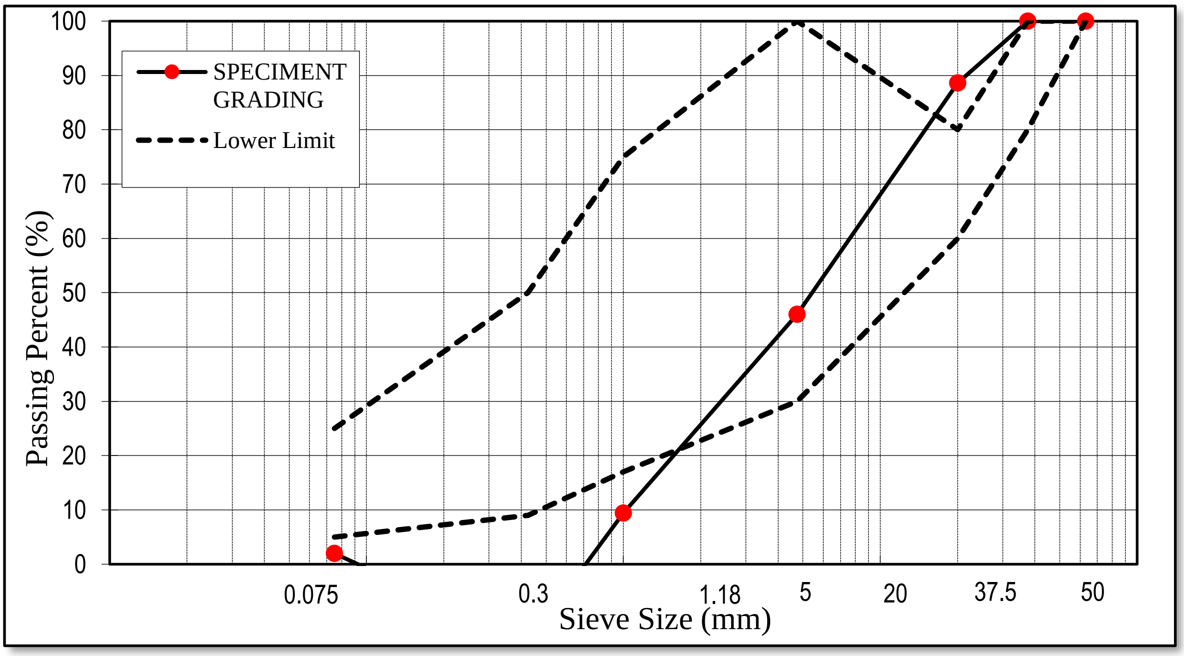
Appendix 4 Details of the PCC Laboratory Test Results Lateritic Gravel

A. Gradation analysis of lateritic gravel

Sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	Mesken BS 1	Mesken BS 2	Mesken BS 3	Mesken BS 4	ERA Specs
50	100	100	100	100	100
37.5	100	100	100	99	80-100
20	92.29	88.64	90.28	87	60-80
5	44.56	46	52	48	30-100
1.18	26.12	28	29.68	32	17-75
0.3	2.04	2.68	3.6	2.94	9-50
0.075	2.93	2.45	2.8	2.88	5-25

Mesken borrow site 1 gradation curve



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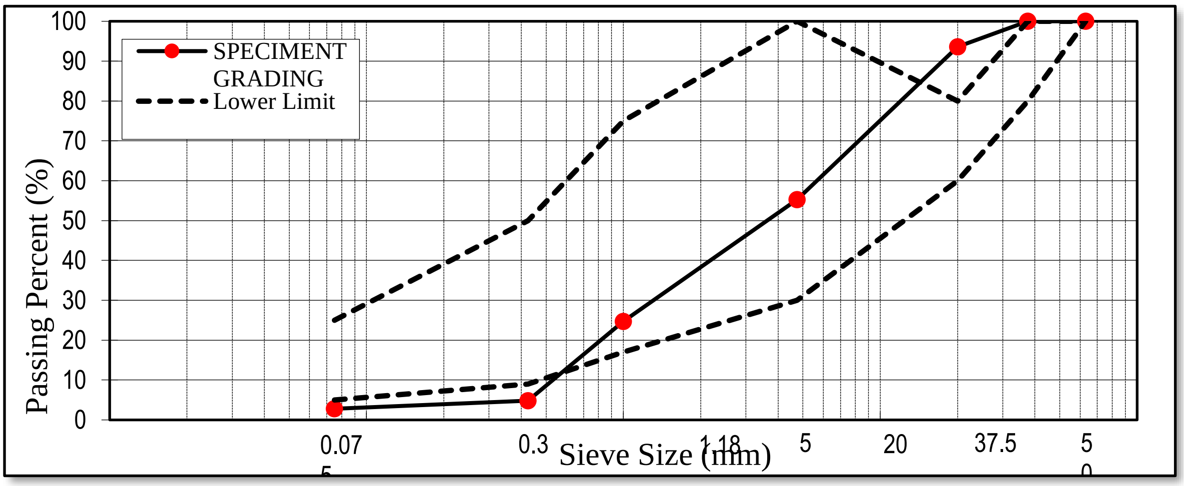
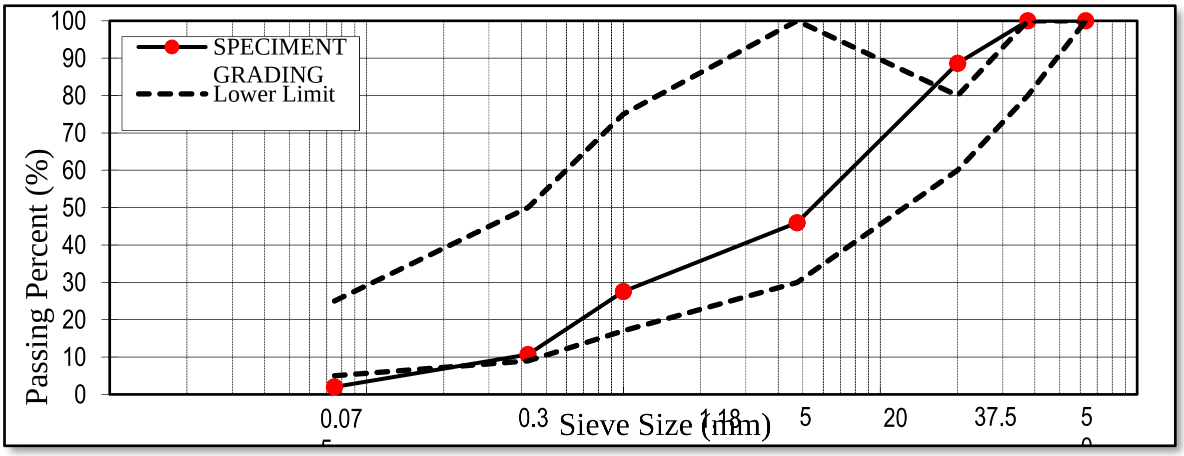
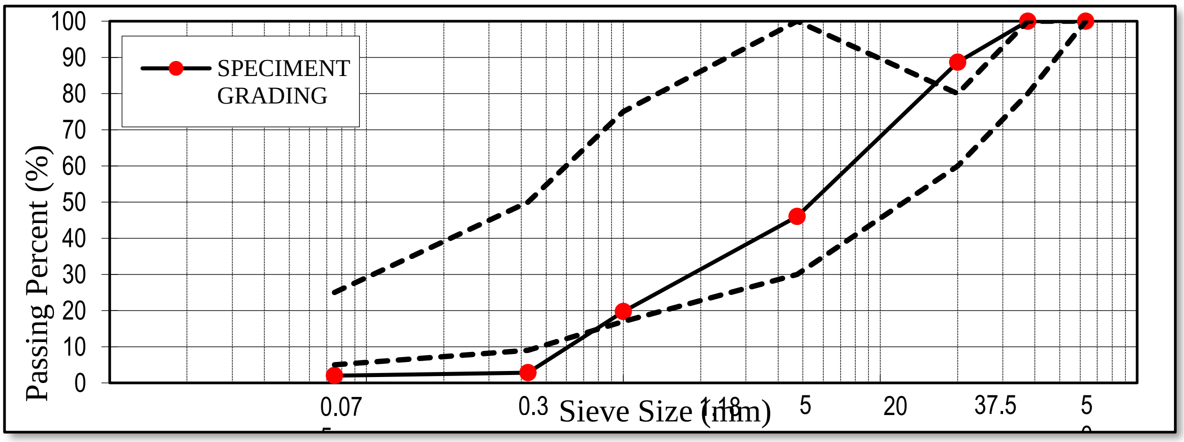
Mesken Borrow site 2 Gradation curve.



Mesken Borrow site 3 gradation curve



Mesken Borrow site 4 gradation curve



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B. Soaked CBR

Density Determination						
Soaking condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
Mold number	M5		R9		M48	
Weight of soil + mold, g	11039	11480	11835	11860	11550	11995
Weight of mold, g	7925		7990		7985	
Weight of soil , g	3114	3555	3845	3870	3565	4010
Volume of mold, g/cm^3	2105		2105		2105	
Wet density of soil, g/cm^3	1.479	1.689	1.827	1.838	1.694	1.905
Dry density of soil, g/cm^3	1.353	1.569	1.675	1.718	1.573	1.765

Moisture Determination									
Soaking condition	10 Blows			30 Blows			65 Blows		
	Before		After	Before		After	Before		After
Container number	H29	H36	Q52	H3	H06	T25	T19	H23	T04
Wet soil + container, g	451.4	505.9	439.4	466.4	515.1	465.1	473.2	513.4	490.4
Dry soil + container, g	425	482.0	412.0	446.0	483.0	438.0	452.0	489.0	458.0
Weight of container, g	173.1	189.5	54.2	183.8	173.3	51.1	173.4	174.8	50.8
Weight of water , g	26.4	23.9	27.4	20.4	32.1	27.1	21.2	24.4	32.4
Weight of dry soil, g	251.9	292.5	357.8	262.2	309.7	386.9	278.6	314.2	407.2
Moisture content %	10.5	8.2	7.7	7.8	10.4	7.0	7.6	7.8	8.0
	9.3			9.1			7.7		

`

Penetration Bottom Test									
Penetration date	30/03/2020								
Penetration (mm)	10 Blows			30 Blows			65 Blows		
	Dial Reading	Load (KN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)	Dial Reading	Load (kN)	C.B.R (%)
0	0	0.0		0	0.0		0	0.0	
0.64	1655	1.7		1985	2.0		2155	2.2	
1.27	1985	2.0		2685	2.7		2685	2.7	
1.91	2895	2.9		2775	2.8		3125	3.1	
2.54	3345	3.3	24.9	3885	3.9	28.9	4485	4.5	33.4
3.18	3755	3.8		4655	4.7		4605	4.6	
3.81	4785	4.8		5085	5.1		6495	6.5	
4.45	5375	5.4		5685	5.7		6985	7.0	
5.08	6385	6.4	32.1	7455	7.5	37.4	8215	8.2	41.3
7.62	6400	6.4		7955	8.0		8875	8.9	
10.16	6855	6.9		8755	8.8		8845	8.8	

Swell			
Soaking Date	26/03//2020		
Time	Afternoon Time		
Mold Number	10	30	65
Initial reading (mm)	0	0	0
Final reading (mm)	0.3	0.23	0.16
Percent Swell (%)	0.26	0.20	0.14
Average	0.20		

`

C. Specific gravity and water Absorption of Mesken site Lateritic gravel

Trial no	1	2	3
Pycnometer no	P1	P2	P3
Mass of saturated surface dry test sample in air, (A)(gr)	500	500	500
Mass of pycnometer + soil + water (M2)(gr)	1605	1589	1583
Mass of pycnometer + water (M1)(g)	1302	1294	1292
Mass of oven dry test sample in air (B)(gr)	473	467	452
Absorption (%)= (A-B)/B	0.057	0.071	0.106
Average Absorption (%)	0.0816		
Specific gravity at 23 ^{O}C = A/(M1+A-M2)	2.54	2.44	2.39
Average specific gravity at 23 ^{o}C	2.46		

Specific gravity and water Absorption of Worabe Mawcha borrow site LG

Trial no	1	2	3
Pycnometer no	P1	P2	P3
Mass of saturated surface dry test sample in air, (A)(gr)	500	500	500
Mass of pycnometer + soil + water (M2)(gr)	1560	1571	1555
Mass of pycnometer + water (M1)(g)	1270.5	1268	1277
Mass of oven dry test sample in air (B)(gr)	452	458	439.5
Absorption (%)= (A-B)/B	0.106	0.092	0.138
Average Absorption (%)	0.1678		
Specific gravity at 23 ^{O}C= A/(M1+A-M2)	2.38	2.54	2.25
Average specific gravity at 23 ^{o} C	2.39		

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Appendix 5 Details of the PCC Laboratory Test Results

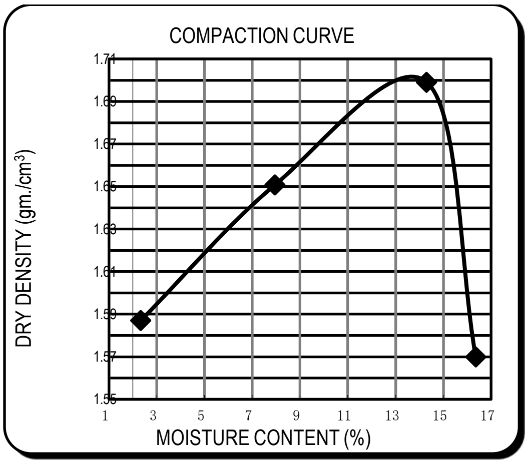
A. Modified Proctor Test (AASHTO T-181, Method *D*)

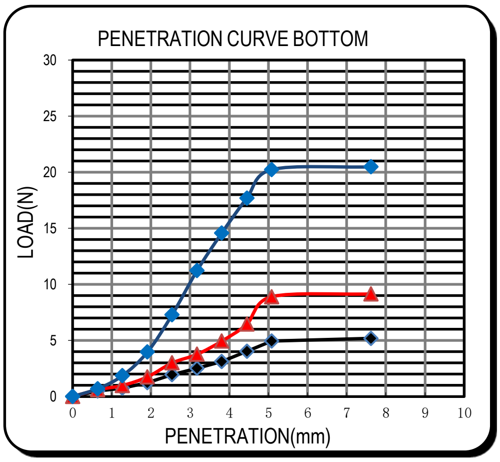
Weight of wet soil + mold	(gm)	9650.0	9985.0	10325.0	10080.0
Weight of mold	(gm)	6202.0			
Weight of wet soil	(gm)	3448.0	3783.0	4123.0	3878.0
Wet density	(gm/cm^3)	1.624	1.782	1.942	1.827
Moisture container no.		H-68	H-107	H-4	H-95
Weight of wet soil + container	(gm)	290.2	381.6	298.6	371.5
Weight of dry soil + container	(gm)	284.8	356.8	267.7	326.8
Weight of container	(gm)	53.5	44.7	51.6	53.5
Weight of moisture	(gm)	5.4	24.8	30.9	44.7
Weight of dry soil	(gm)	231.3	312.1	216.1	273.3
Moisture content	(%)	2.3	7.9	14.3	16.4
Dry density	(gm/cm^3)	1.587	1.651	1.699	1.570

MDD (gm/cm^3)	OMC (%)	Number of blows	% Moisture before soak	Dry Density	CBR (%)	% Moisture after 96 hours	Swell (%)	Swell (%)	Standard Load (kN)	
									2.54mm	5.08mm
1.621	13.85	10	20.4	1.420	24.8	34.5	1.12	0.69	13.44	19.91
		30	18.9	1.482	44.7	29.7	0.60		13.44	19.91
		65	14.0	1.621	51	27.3	0.36		13.44	19.91

95% M.D.D = 0.95*1.621 = 1.54

CBR Value = 51.0%





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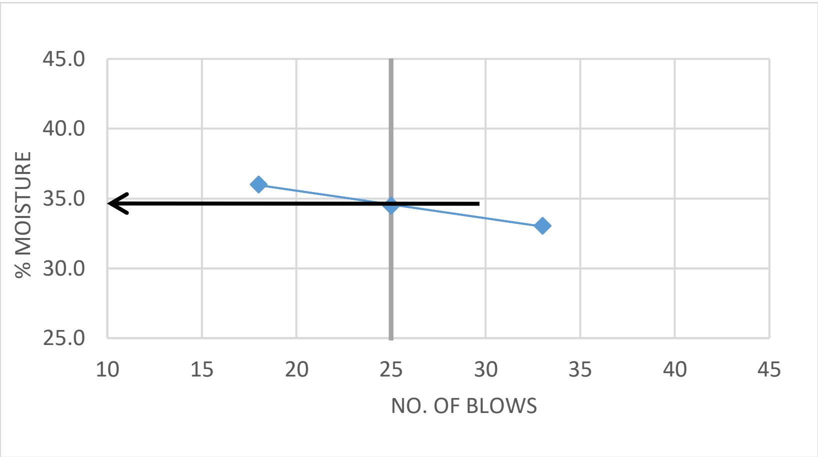
B. Atterberg Limit Tests

PCC on south direction with soil covering it

	Liquid Limit Test			Plastic Limit Test	
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2
No. of Shocks N	33	25	18	-------	-------
Mass of Container M_c	56.44	54.55	59.08	54.83	55.26
Mass of Sample + Container M_1	75.73	73.23	73.85	63.40	64.29
Mass of Moist Sample $M_m=M_1-M_c$	19.29	18.68	14.77	8.57	9.03
Mass of Dried Sample + Container M_2	70.94	68.44	69.94	61.55	62.33
Mass of Dried Sample $M_d=M_2-M_c$	14.50	13.89	10.86	6.72	7.07
% Moisture $w = (M_m-M_d) / M_d \times 100$	33.0	34.5	36.0	27.5	27.7



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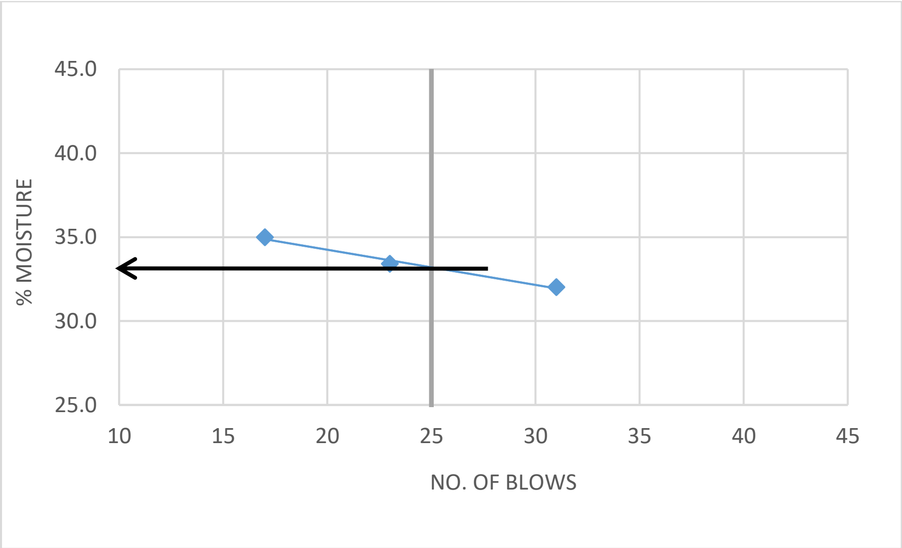
PCC on west boarder direction with mix of local expansive soil

		Liquid Limit Test			Plastic Limit Test	
		Trial 1	Trial 2	Trial 3	Trial 1	Trial 2
No. of Shocks	N	31	23	17	-------	-------
Mass of Container	M_c	57.35	53.95	56.19	56.22	57.36
Mass of Sample + Container	M_1	76.56	70.40	76.02	66.18	67.01
Mass of Moist Sample	$M_m=M_1-M_c$	19.21	16.45	19.83	9.96	9.65
Mass of Dried Sample + Container	M_2	71.90	66.28	70.88	64.11	65.03
Mass of Dried Sample	$M_d=M_2-M_c$	14.55	12.33	14.69	7.89	7.67
% Moisture	$w = (M_m-M_d) / M_d \times 100$	32.0	33.4	35.0	26.2	25.8



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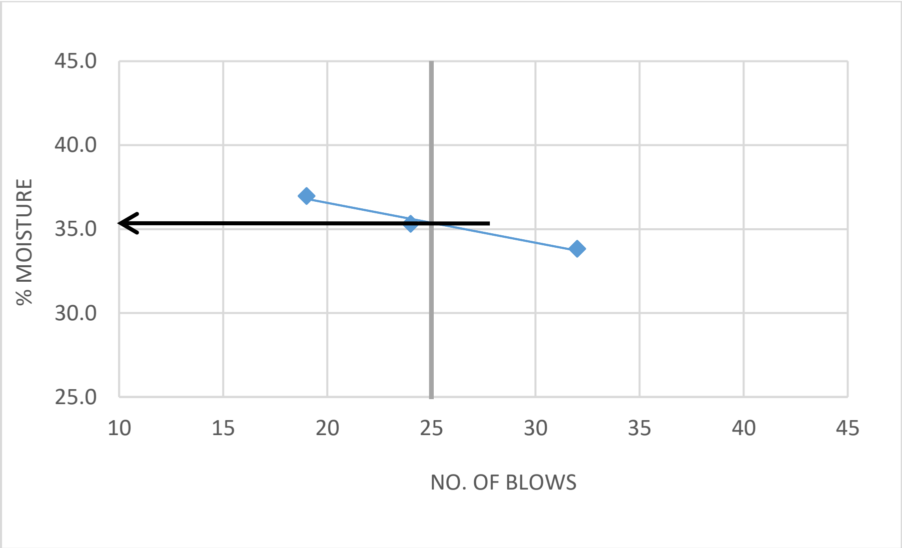
PCC on the north direction covered with soil

		Liquid Limit Test			Plastic Limit Test	
		Trial 1	Trial 2	Trial 3	Trial 1	Trial 2
No. of Shocks	N	32	24	19	-------	-------
Mass of Container	M_c	55.17	55.07	56.12	54.40	53.66
Mass of Sample + Container	M_1	69.73	74.34	74.16	62.67	61.82
Mass of Moist Sample	M_m=M_1-M_c	14.56	19.27	18.04	8.27	8.16
Mass of Dried Sample + Container	M_2	66.05	69.31	69.29	60.88	60.06
Mass of Dried Sample	M_d=M_2-M_c	10.88	14.24	13.17	6.48	6.40
% Moisture	w = (M_m-M_d) / M_d x 100	33.8	35.3	37.0	27.6	27.5



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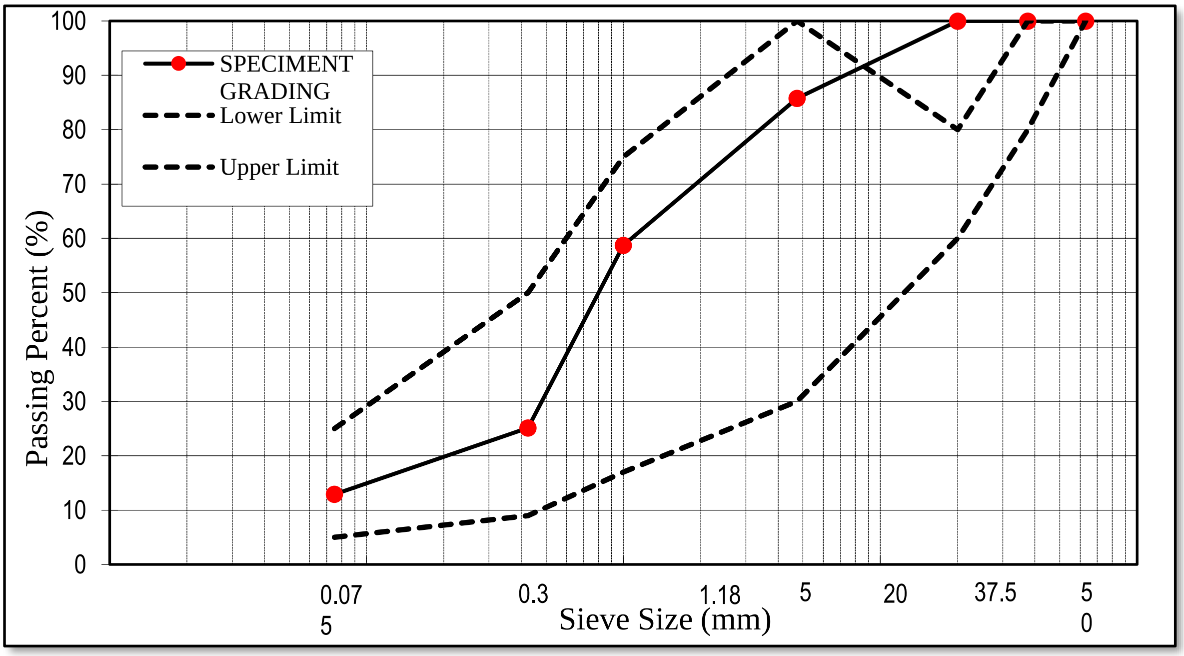
C. Sieve Analysis

Sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	PCC-E-01	PCC-W-02	PCC-N-03	PCC-S-04	ERA Specs
50	100	100	100	100	100
37.5	100	100	100	100	80-100
20	100	100	100	100	60-80
5	85.81	89.97	88.44	87.03	30-100
1.18	58.11	70.49	66.18	59.29	17-75
0.3	24.53	42.60	37.99	26.95	9-50
0.075	12.95	26.17	18.52	13.61	5-25

Gradation of curve PCC -E-01



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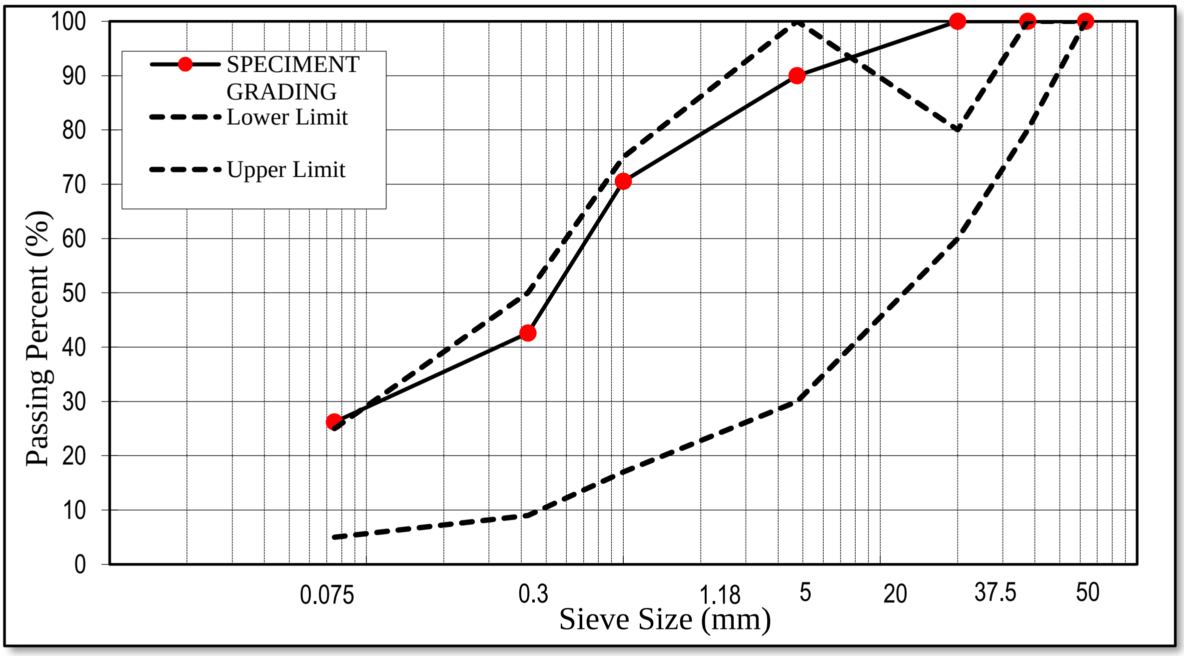
Gradation of curve PCC -W-02



Gradation of curve PCC -N-03