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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HIGHWAY ENGINEERING

INVESTIGATION OF ASPHALT PAVEMENT FAILURE DUE TO SUB-BASE AND SUBGRADE SOIL PROPERTIES: A CASE STUDY OF KEMMISE – DESSIE ROAD

By

SIRAJ HUSSEN

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Highway)

October, 2016

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Adviser: Dr.-Ing Esayas Alemayehu (PhD)

Co. Adviser: Mr. Fekadu Kitessa (MSc)

October, 2016

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr.-Ing Esayas Alemayehu (PhD) and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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Abstract

In this study an attempt was made to investigate the causes of failure due to sub base and subgrade soil properties and remedial measures of damaged pavement. The study focused on performing laboratory tests, taking representative pavement material samples (i.e sub-base and selected fill) from different portions of the road and making the necessary laboratory tests on the collected samples. Additional natural subgrade samples from left and right hand side of the road were also taken for laboratory testing.

The case study road pavement was damaged in different stations were seen during field observation. From field investigation in the study area was observed several type of pavement damaged such as; Raveled, transverse cracked, patched, differential settlement/depression, rutting, shoved/corrugation, and potholes/debonding layers of damaged.

To find out the real cause of pavement damaged related to soil pavement layer properties was conduct different laboratory test. Such as; sieve analysis (Wet method) to check the soil layer grain size distribution, Atterberg limit (LL and PL test) to find out the plasticity index of their soil, Compaction test (Modified) to get Maximum Dry Density and Optimum Moisture Content of the soil and finally California Bearing Ratio test to check the soil strength and stability.

The laboratory results showed that the soil materials used along the road have high percentage clayey material for half of the natural subgrade soil sample (rated as fair to poor materials for road use) and low percentages of clayey and silt/gravel/sand materials of sub-base and selected fill soil samples. The OMC are almost high for all the soil samples the exception of few samples. The MDD values were ranged from 1.33 kg/m³ to 2.25 kg/m³ for the soil materials. The Plasticity Indices and Liquid limits are very high for all Sub-base, selected fill and natural subgrade soil samples with the exception of few samples. Most of CBR values for the selected fill soil materials almost meet specification requirements while that of Sub-base and natural Subgrade soil - materials almost did not meet the specification requirements with the exception of few samples. Conclusively, the pavement failure may necessarily be due to weak/ poor soil pavement layer performance in the different failed location. Finally, a different remedial measure (i.e Patching, Sealing, Digging out and replace good soil and structural or non-structural overlay) was made with respect to their different type of pavement damaged in the study road.

Key Words: ***Pavement damage, laboratory test and pavement materials***

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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ASTM	American Society of Testing Method
CBR	California Bearing Ratio
DelDOT	Delaware's department of transportation
ERA	Ethiopian Road Authority
FMWH	Federal Ministry of Works and Housing
Km	Kilo meter
MDD	Maximum Dry Density
mm	millimetre
OMC	Optimum Moisture Content
RSDP	Road Sector Development Program
USCS	Unified Soil Classification System
˚c	Degree Celsius
˚F	Degree Fahrenheit

CHAPTER ONE

INTRODUCTION

1.1 Background

The understanding of soil behaviour in solving engineering and environmental issues as swelling soil especially expansive soils that can cause significant damage to road construction and other engineering application is the sole aim of geotechnical engineering. One of the major causes of road accident is bad road which is usually caused by wrong application of constructional materials especially expansive soil as selected fill and sub-base material by construction companies. And also roads built on weaker subgrade material resulting in poor performance and cause losses in both serviceability and economy. For a material to be used as either a selected fill or sub-base course depends on its strength in transmitting the axle-load to the sub-soil and or sub-grade (the mechanical interlock). The characteristics and durability of any constructional material is a function of its efficiency in response to the load applied on it (Amadi et al, 2015). Geotechnical soils and material characterization is important components for the design and construction of road projects. During characterization visual descriptions, sampling and testing of natural sub-grade soil, fill material and sub- base material along the project route are carried out. In the process of characterization, different techniques and procedures are applied for interpretation of soil condition. These interpretation techniques are often site specific and are influenced by geological, topographic, and climatic conditions. The data collected in the field, soil samples tested in the laboratory and results obtained determine the design of pavement structure as well as the cause of pavement failure. Some road pavements in the country were poorly constructed and were largely founded on problematic soils such as expansive clay soils leading to pavement failure. Rehabilitation/reconstruction of such failed road network has become a huge financial burden to the Government. Billions of birr is spent annually on reconstruction and rehabilitation of road across the country.

1.2 Current situation of Ethiopian roads

Ethiopia's economic growth is highly dependent on the agricultural sector. Therefore, development efforts to change the existing socio-economic condition of the nation would also be dependent on the efficiency of this sector for the foreseeable future. However, a better performance of the agricultural sector in particular, and the sustainable economic growth of the country at large would be achieved through an improvement of the basic infrastructure. Consequently, the road network has been identified as a serious bottleneck for the economic development of the country (ERA, 1996).

The provision of adequate road transport services (in quality, coverage and organization) is essential for the economic and social development of Ethiopia. Road transport accommodates 95% of passenger/freight movements in the country, import/distribution of petroleum products, fertilizers, relief food and collection/export of coffee from rural areas (ERA, 1996).

Road density is currently 33.18 km per thousand square kilo meters for the entire classified road network and around 21.64-km/1000 km2 for roads in good or fair condition. This compares poorly with other sub - Saharan Africa (SSA) countries where average road density is more than 50 km/1000 km2. Ethiopia ranks among the last in the region and its road density is at 66% of the regional average (ERA, 1996).

As of the year 2004, almost 65% of the total classified road network (23,803km) is in good or fair condition, with network composition of 14% for main asphalt roads, 36% for main gravel roads, and 50% for regional roads. This represents quiet an improvement over the situation in 1997, when it was estimated that less than 50% of the road network was in good or fair condition (ERA, 1996).

1.3 Road Network Development

In 1951, when the Ethiopian Roads Authority was established, the total road network was 6,400 km. This network was built mainly during Italian invasion. By 1974 when the Derg assumed power, the road network had grown to 9,260 km, of which 3,360 km were paved. The network had increased to 19,017 km of classified roads by 1991 (when the current Government assumed power), of which 4,109 were paved. The increase over these years was mainly due to the expansion of the rural road network to facilitate relief operation activities to drought and famine affected areas in 1970s and 1980s. With the formation of Eritrea as new state in 1992 the road network was reduced to 18,081 km of which 3,542 km was paved (ERA, 1996).

In 2004 the total road network has reached 36,496 km, of which 4,635 km (13%) are paved and the remaining 31,861 km (87%) are unpaved. Of the present classified road network, about 18,540 km are considered as the main road network administered by the Federal Government (ERA). The remaining 17,956 km of "low level" roads, generally categorized as "rural roads" are under the Regional Rural Roads Authorities. The table below summarizes the scope of classified road network in 2004(ERA, 1996).

Table1.1: Classified road network (2004) (in km)

Class of Road	Paved	Unpaved	Total
Federal Roads	4,635	13,905	18,540
Regional Roads	-	15,956	15,956
Local/Community Roads	-	2,000	2,000
Total	4,635	31,861	36,496

All in all, during the years 1951-1973, 1974-1991and since 1992; the road network was increasing on the average by 2.1%, 6.2% and 8.5% per annum respectively. The table and graph below show the network development by type of road from the year 1951-2004.

Table1.2: Road Network Developments since ERA was established in 1951

Duration	Network increase (in Km)	Yearly Average Growth Rate (%)
1951-1973(22 years)	2760	2.05
1974-1991(17 years)	9757	6.2
1992-2004(12 years)	18415	8.49

1.4 RSDP performance: twelve years assessment

The twelve years of the RSDP has seen significant improvements in restoration and expansion of Ethiopia's road network. These physical achievements have been matched by significant improvements in the maintenance of the network, strengthening of the management capacity of the road agencies, and delivery on policy reform (ERA, 2009).

As a result of the RSDP investment, the total road network in Ethiopia has been increasing on the average by 6% each year, between 1997 and 2009. As of June 2009, the total road network in the country has increased to 46,812 km (excluding community roads), an increase of some 20262 km since the launch of the program. Within a total land area of 1.1 million sq. km, the current road density is 42.6 km per 1000 sq. km (ERA, 2009).

The proportion of the road network in good condition has also increased, from 22 per cent in 1997, to 54 percent in 2009. Improvements have been realized in the quality of regional roads and rural accessibility has improved through the construction of new link roads and rural roads, in addition to a significant number of new community roads (ERA, 2009).

Table1.3: Change in Selected Indicators

INDICATORS	1997	2009
Proportion of Asphalt roads in Good Condition	17 %	70 %
Proportion of Gravel roads in Good Condition	25 %	54 %
Proportion of Rural roads in Good Condition	21 %	50 %
Proportion of Total Road network in Good Condition	22 %	54 %
Road Density/ 1000 sq. km	24.1 Km	42.6 Km
Road Density/ 1000 Population	0.46 Km	0.57 Km
Road Density/ 1000 sq. km (including community roads)	24 Km	120.5 Km
Road Density/ 1000 Population (including community roads)	0.49 Km	1.62 Km
Proportion of area more than 5km from all weather road	79 %	65.3 %
Average distance to all weather road	21.4Km	11.8Km

1.5 Statement of the problem

Pavements are a conglomeration of materials. These materials, their associated properties, and their interactions determine the properties of the resultant pavement. Thus a good understanding of these materials, how they are characterized, and how they perform is fundamental to understanding pavement. The materials which are used in the construction of highway are of intense interest to the highway engineer. This requires not only a thorough understanding of the soil and aggregate properties which affect pavement stability and durability, but also the binding materials which may be added to improve these pavement features. Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation, which can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory. The desirable properties of pavement soil as a highway material are stability, incompressibility, permanency of strength, minimum change in volume and stability under adverse conditions of weather, good drainage and adequate compaction.

Soil is a primary engineering material for road construction and maintenance. Most road authorities successfully identify and manage the physical properties of soil when undertaking road construction and maintenance. However, identification and management of soil properties and soil landscape processes, and in particular, how they may influence road construction and maintenance now, and in the future, is highly variable.

Kemise to Dessie trunk road network of the design life span are 25 years. Nevertheless, the damages of the pavements occur earlier than expected. One of the recent issues related to road transportation from Kemise to Dessie are the lower strength of pavement soil layers and poor performance of natural subgrade. This resulted to damages of roads and the pavement soil materials are not aligned with the specified design lifespan of the road structure.

Currently condition of a road some part of Kemisse- Dessie road is failed by different types of failures such as; Raveled, transverse crack, patched, depression, shoved/corrugation, rutting, and potholes, so it’s not suitable for driving and for road users. Misunderstanding the nature of soils and their properties can lead to construction errors that are costly in effort and materials.

In the case study area of statement of the problem on asphalt pavement damaged according to different impact level such as;

- ✓ Globally: involving soil damage may affect many aspects of the environment. For example, development of a road could encourage bush fires and deforestation, which, in turn, could lead to erosion of bare slopes, re-channelling of rivers and streams, and possibly minor landslides.
- ✓ Nationally: higher amount of maintenance cost are funded from the Ethiopian road authority
- ✓ Locally: vehicles operating on unmaintained rural roads during harvest time suffer a staggered some percept of reduction in vehicle life, with a resulting sharp increase in depreciation and hence vehicle operation costs.

It is for this reason that this research study to undertake investigation of asphalt pavement failure due to sub-base and subgrade soil properties along Kemmsie- Dessie road.

1.6 Research Questions

The research questions that the study sought to answer are as follows:

1. What type of laboratory tests were conducted for the identification of pavement soil material properties (sub-base and subgrade soils) at failed road sections?
2. Are that failed roads are the cause of sub-base and subgrade soil materials poor performance?
3. How to maintain the pavement damages caused by poor soil material conditions?

1.7 Objective of the study

The present research is conducted based on literature review, field observations and testing of samples in laboratory for analysis, interpretations and evaluations of pavement failure. The research includes geological assessment, sub- base, fill material and sub grade soils investigations, identifying the physical properties and classifying soils for engineering use. Accordingly, general and specific objectives have been framed as;

1.7.1 General Objective

To evaluate asphalt pavement failure due to sub- base, fill material and natural subgrade soil properties.

1.7.2 Specific Objectives

- To conduct different laboratory tests such as; Gradation test, Atterberg limits (LL and PL), proctor test (MDD and OMC), and California Bearing Ratio (CBR) test to know the sub-base and subgrade soil properties.
- To justify sub-base and subgrade soil performance based on their laboratory test results compared with different standard specifications of pavement design manuals.
- To explore quantifiable remedies to be taken to solve asphalt pavement damages

1.8 Outcomes of the study

- ✓ To classify the individual three soil layers for each representative sample such as; sub- base, fill material and natural subgrade. Additionally to know their strength to compared with highway standard manual specifications for road projects.
- ✓ To specify the actual cause of pavement failure section either unsuitable soil material or other related problems.
- ✓ Removal and replacement, and mechanical stabilization are proposed for unsuitable portion of the failed road section.
- ✓ To reduce yearly maintenance cost and road accident due to road failed section.

1.9 Scope and limitation of the study

The scope of the research to investigate asphalt pavement failures due to sub- base, fill material and natural subgrade soil properties on a case study basis from Kemise to Dessie trunk road. The research is conducted based on data collected from sample 1 to sample 7 only. The data were collected at road failed section away from the paved road. In the present research, there were limitations on availability of literatures and previous works regarding the highway engineering on investigation of pavement failure aspect.

Further, every effort was made to perform the present study in a scientific and logical manner under the constraints of;

- ERA in kombolcha district had not laboratory facility. So some samples were goes to lalibela Airfield,land side work overlay and access road construction project were to be conducted laboratory facility. But the other samples were conducted in Awash- Kombolcha- Hara Gebeya Railway project at foreign contractor of Yapi Merkezi, so in this company there is no enough laboratory equipment.
- Frequent failure of oven dried machine

Some of these limitations have affected the completion time for materials testing and reporting the results. Therefore, it is strongly recommended that the results and the findings of the present study must be considered as an exhaustive only for investigation of failed roads.

1.10 Organization of the thesis

Chapter One: general background, current situation of Ethiopian roads, road network development. And also statement of the problem, the objectives, Research questions, scope and limitations of the thesis work are discussed.

Chapter Two: discuss about flexible pavement, pavement functions, and pavement design factor. And also discuss about pavement material specifically sub-base, selected fill and natural subgrade soil material, soil classification, distress condition of pavement and finally general situation of highway maintenance.

Chapter Three: deals with Research methodologies such as; study area, study period, study design, sample size and their procedures, data collection process, data analysis and ethical considerations are discussed.

Chapter Four: deals with assessments of test results which were gathered from laboratory tests, whether it complies with the requirements set in the design specification of the project. In addition, comparison was made between the quality requirements set for sub-base, selected fill and natural subgrade in the specification of the project to that of the requirements set for the same in the ERA's specification for the design of flexible pavement.

Chapter Five: Finally conclusion and recommendation are made

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The field of pavement design is dynamic - the concepts are changing with time as technology develops and new equipment emerges for site investigation, material testing and traffic data collection, and new data become available. In the early stage, pavement design was carried out by a rule-of-thumb procedure based on entirely past experience. Through the observation of performances of the already constructed roads, highway engineers became aware that pavement performance is dependent on the subgrade soils. Pavements constructed over plastic soils showed higher distress than those constructed over granular deposits. With the knowledge of soil mechanics, pavement design was made with soil classification (ERA, 2002).

With the increase in traffic and usage and development of heavy transport means, the deterioration of pavements due to heavy trucks and aircrafts necessitated a more rational approach of design. This led to full-scale and laboratory experiments in different countries at different capacities. The well-known research investigations are those conducted in the United States of America. The results of these and other full-scale and laboratory experiments conducted under varying soil, climatic, and loading conditions in different countries have given rise to our understanding and development of the existing design methods. Although principles of pavement design are common to all problems and localities, different highway agencies in different countries use different design manuals prepared to suite their local conditions and available materials of construction (ERA, 2002).

2.2 Flexible Pavement

A pavement structure is a layer structure which supports the vehicle load on its surface and transfers and spreads the load to the subgrade without exceeding either the strength of the subgrade or the internal strength of the pavement itself. A flexible pavement is one, which has low flexural strength, and the load is largely transmitted to the subgrade soil through the lateral distribution of stresses with increasing depth (ERA, 2002).

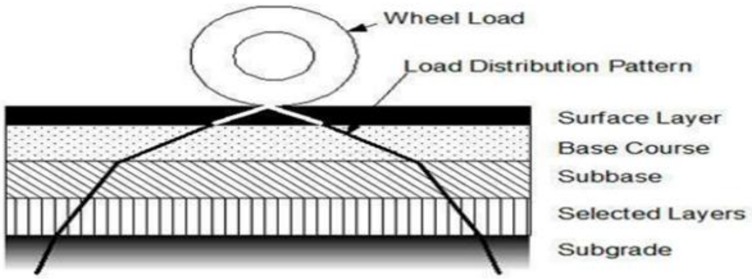

Figure2.1: Load distribution of flexible pavement (Source: Sharad & Gupta, India).

2.3 Pavement Functions

The primary functions of a pavement are to be: Providing a reasonably smooth riding surface: A smooth riding surface (Low Roughness) is essential for riding comfort, and over the years it has become the measure of how road users perceive a road. Roughness can arise from a number of causes, most often however it is from pavement distress due to structural deformation.

Provide adequate surface friction (skid resistance): In addition to a riding comfort, the other road user requirement is that of safety. Safety, especially during wet conditions can be linked to a loss of surface friction between the tyre and the pavement surface. A pavement must therefore provide sufficient surface friction and texture to ensure road user safety under all conditions (Sharad & Gupta).

Protect the subgrade: the supporting soil beneath the pavement is commonly referred to as the subgrade, should it be over-stressed by the applied axle loads it will deform and lose its ability to properly support these axle loads. Therefore, the pavement must have sufficient structural capacity (strength and thickness) to adequately reduce the actual stresses so that they do not exceed the strength of the subgrade. The requirements of a pavement can vary greatly depending on the combination of subgrade type and loading condition (magnitude and number of axle loads) (Sharad & Gupta).

Provide waterproofing: The pavement surfacing acts as waterproofing surfaces that prevent the under-laying support layers including the subgrade from becoming saturated through moisture ingress. When saturated, soil loses its ability to adequately support the applied axle loads, which will lead to premature failure of the pavement (Sharad & Gupta).

2.4 Pavement design factor

Pavement design methodology for both new pavements and rehabilitation of existing pavements consider several, if not all, of the following factors:

- Pavement design life: Each pavement design has a selected design life. Roadway cross section elements and other components of the project such as the pavement structure are expected to remain structurally sound for a designated period of time defined as design life. Although the roadway cross section may become operationally obsolete or the pavement distressed and in need of restoration or rehabilitation, they have not reached the end of their design life but rather have reach the end of a condition defined as service life. Not until they need complete replacement are they considered to have reached the end of their design life (DelDOT, 2011).
- Pavement Performance: The goal of a pavement design is to produce a pavement that when placed will perform functionally and structurally while maintaining its safety characteristics for at least the selected service life. Functional performance of a pavement identifies how well a pavement will serve the user. The characteristics identified are riding comfort and ride quality. This concept is called serviceability performance and provides a means to measure functional performance.
- Traffic: Traffic volumes using a facility, in particular the number and weight class of trucks is a major factor in determining how strong a pavement structure must be. In the design procedure, traffic data is reduced into axle loads, axle configuration, and number of applications of these loads. The result is a design number representing the damage done to the pavement caused by the effect a single axle carrying a load on the pavement over its design-life. For the design calculations, traffic data is converted into 18-kip [80kN] equivalent single axle loads or ESAL's. Since it is one of the more important design considerations, accurate traffic data will ensure that a pavement's design life will be attained and the pavement sections selected will not be over or under designed (DelDOT, 2011).
- Roadbed Soil: The pavement structure rests on a graded and compacted roadbed either of suitable natural material or on specified imported material. The roadbed soil has measurable material characteristics that are used in the

- Pavement design. One of the more difficult soils encountered on projects are those having a large organic content. These materials are extremely compressible, unstable and frequently non-uniform in properties and depth. These soils are the most complicated and expensive to deal with in order to provide an adequate roadbed. Small, shallow or localized deposits are most often excavated and replaced with suitable material. Deeper and more expansive areas involve more detailed geo-technical design, more complicated construction techniques and costs. Under-drains (a system of perforated pipes to collect and transmit the water to an outfall site) are recommended for use on all roadway projects to adequately address drainage and removing water from the roadbed.

  Another type of material encountered in constructing roadbeds is classified as cohesionless (sandy) soil and is much more difficult for the contractor to place and compact; it is readily displaced under the load of the equipment. To stabilize this type of soil it may be necessary to blend granular material or add a suitable admixture. Wet clay soils may also be encountered. Because of high moisture content this type of soil is unstable and cannot be compacted. Long periods of dry weather and exposure to the air are required to reduce the water content (DelDOT, 2011).
- Paving Material: Flexible pavements consist of a prepared roadbed with a sub-base of graded aggregate or bituminous concrete and a bituminous concrete base with a surface course. Properly preparing a uniform roadbed compacted to the prescribed density is especially important for providing the design support value necessary for flexible pavement to perform as designed.
- Temperature Change: Temperature changes affect (1) the creep properties of asphalt concrete, (2) thermal induce stresses in asphalt concrete, (3) contraction and expansion in Portland cement concrete, and (4) freezing and thawing of the roadbed soil. Temperature differences between the top and bottom of concrete slabs create uneven stresses on the slab and can be of concern. Temperature and a poorly drained pavement structure or subgrade, although normally not a concern in Delaware can combine to create freeze-thaw cycles that rapidly deteriorate the pavement.
- Drainage: Keeping the pavement subgrade and soil-bed dry is a major design

consideration. Excessive moisture combined with increasing traffic and load

- Applications will inevitably lead to premature pavement distress. Water can enter the pavement structure from many directions including a permeable pavement surface, unsealed or poorly sealed joints, surface cracks, high water tables, and even local springs. If water is trapped within the pavement structure, pavement performance will be affected through loss of support due to erosion of any granular material and loss of material strength (DelDOT, 2011).

2.5 Pavement Material

2.5.1 Subgrade Material Design

A. General Information

The subgrade is that portion of the pavement system that is the layer of natural soil upon which the pavement or sub-base is built. Subgrade soil provides support to the remainder of the pavement system. The quality of the subgrade will greatly influence the pavement design and the actual useful life of the pavement that is constructed. The importance of a good quality subgrade to the long term life of the pavement cannot be understated. As the pavement reaches design life, the subgrade will not have to be reconstructed in order to support the rehabilitated subgrade or the reconstructed pavement. In urban areas, subgrade basic engineering properties are required for design (Vernon & David, 2008).

B. Site Preparation

Site preparation is the first major activity in constructing pavements. This activity includes removing or stripping off the upper soil layer(s) from the natural ground. All organic materials, topsoil, and stones greater than 3 inches in size should be removed. Removal of surface soils containing organic matter is important not only for settlement, but also because these soils are often moisture-sensitive, they lose significant strength when wet and are easily disturbed under construction activities. Most construction projects will also require excavation or removal of in-situ soil to reach a design elevation or grade line (Vernon & David, 2008).

C. Design Consideration

Subgrade soil is part of the pavement support system. Subgrade performance generally depends on three basic characteristics:

Strength: The subgrade must be able to support loads transmitted from the pavement structure. This load-bearing capacity is often affected by degree of compaction, moisture content, and soil type. A subgrade having a California Bearing Ratio (CBR) of 10 or greater is considered essential and can support heavy loads and repetitious loading without excessive deformation (Vernon & David, 2008).

Moisture content: Moisture tends to affect a number of subgrade properties, including load-bearing capacity, shrinkage, and swelling. Moisture content can be influenced by a number of factors, such as drainage, groundwater table elevation, infiltration, or pavement porosity (which can be affected by cracks in the pavement). Generally, excessively wet subgrades will deform under load.

Shrinkage and/or swelling: Some soils shrink or swell, depending upon their moisture content. Additionally, soils with excessive fines content may be susceptible to frost heave in northern climates. Shrinkage, swelling, and frost heave will tend to deform and crack any pavement type constructed over them (Vernon & David, 2008).

D. General density- Moisture Content- Strength relationships of the subgrade

The strength of the subgrade is assessed in terms of CBR. The CBR depends on the nature of the soil, its density and its moisture content. The nature of the soil is dictated by the route location and the selected longitudinal profile for the road, and does not change except for the influence of the borrow materials and the movement of materials between cut and fill during earthworks operations. By contrast, the (dry) density of the subgrade soil will be modified from its original state at the time of the road construction, by compaction at subgrade level in cuts and by compaction of the excavated materials used in embankments. Similarly, the moisture content of the natural subgrade soil will be altered during construction, in order to approach the optimum (indicated by laboratory tests) which is conducive to a greater increase in density and in corresponding CBR strength. Upon completion of the construction operations, the natural soils will have been brought to a second state of moisture, density and strength. This second state is not the final state of the subgrade, however, and except in few particular cases, should not be used in design (ERA, 2002).

E. Characterization of subgrade soils based on their resistance to deformation

Subgrade materials are typically characterized by their resistance to deformation under load, which can be either a measure of their strength (the stress needed to break or rupture a material) or stiffness (the relationship between stress and strain in the elastic range or how well a material is able to return to its original shape and size after being stressed). The more resistant to deformation of a subgrade is the more loads it can support before reaching a critical deformation value (Awoke, 2006).

Three basic subgrade stiffness/ strength characteristics measurement commonly used are: California Bearing Ratio (CBR), Resistance Value (R-value) and elastic (resilient) modulus. The California Bearing Ratio (CBR) test is a simple strength test that compares the bearing capacity of a material with that of a well- graded crushed stone, thus a high quality crushed stone material should have a CBR value of 100%. It was primarily intended for evaluating the strength of cohesive materials having maximum particle sizes less than 19mm (0.75in).Originally it was developed by the California Division of Highways around 1930 and was subsequently adopted by numerous states, counties, US federal agencies and internationally (Awoke, 2006).

2.5.2 Unbound Pavement Materials

I. Sub-base Material

The sub-base is an important load spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the subgrade, it acts as a working platform for the construction of the upper pavement layers and it acts as a separation layer between subgrade and base course. Under special circumstances, it may also act as a filter or as a drainage layer. In wet climatic conditions, the most stringent requirements are dictated by the need to support construction traffic and paving equipment. In these circumstances, the sub-base material needs to be more tightly specified. In dry climatic conditions, in areas of good drainage, and where the road surface remains well sealed, unsaturated moisture conditions prevail and sub-base specifications may be relaxed. The selection of sub-base materials will therefore depend on the design function of the layer and the anticipated moisture regime, both in service and at construction (ERA, 2002).

II. Selected Subgrade Materials (Fill Materials)

These materials are often required to provide sufficient cover on weak subgrades.

They are used in the lower pavement layers as a substitute for a thick sub-base to reduce costs, and a cost comparison should be conducted to assess their cost effectiveness.

The requirements are less strict than for sub-bases. In estimating the likely soil moisture conditions, the designer should take into account the functions of the overlying sub-base layer and its expected moisture condition and the moisture conditions in the subgrade. If either of these layers is likely to be saturated during the life of the road, then the selected layer should also be assessed in this state. Recommended grading's or plasticity criteria are not given for these materials. However, it is desirable to select reasonably homogeneous materials since overall pavement behaviour is often enhanced by this. The selection of materials which show the least change in bearing capacity from dry to wet is also beneficial (ERA, 2002).

2.6 Engineering basic soil information

2.6.1 General information

The basic soil properties and definitions required for designing pavement foundations and embankment construction. Basic soil classification and moisture-density relationships for compacted cohesive and cohesionless soil materials are included. The standard for soil density is determined as follows (Vernon and David, 2008).

- ✓ Coarse-grained soil. The required minimum relative density and moisture range should be specified if it is a bulking soil.
- ✓ Fine-grained soil. The required minimum dry density should be specified; then the acceptable range of moisture content should be determined through which this density can be achieved.
- ✓ Inter-grade soils. The required minimum dry density or relative density should be specified, depending on the controlling test. Moisture range is determined by the controlling test.

2.6.2 Soil types

Soil: Soils are sediments or other unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter. Soil has distinct advantages as a construction material, including its relative availability, low cost, simple construction techniques, and material properties which can be modified by mixing, blending, and compaction.

However, there are distinct disadvantages to the use of soil as a construction material, including its non-homogeneity, variation in properties in space and time, changes in stress-strain response with loading, erodability, weathering, and difficulties in transitions between soil and rock (Vernon and David, 2008).

Prior to construction, engineers conduct site characterization, laboratory testing, and geotechnical analysis, design and engineering. During construction, engineers ensure that site conditions are as determined in the site characterization, provide quality control and quality assurance testing, and compare actual performance with predicted performance.

Engineering soil classification can be done based on soil particle size and by soil plasticity. Particle size is straightforward. Soil plasticity refers to the manner in which water interacts with the soil particles. Soils are generally classified into four groups using the Unified Soil Classification System, depending on the size of the majority of the soil particles (ASTM D 3282, AASHTO M 145).

(i) Gravel: Fraction passing the 3-inch sieves and retained on the No. 10 sieve.

(ii) Sand: Fraction passing No. 10 sieve and retained on the No. 200 sieve.

(iii) Silt and clay: Fraction passing the No. 200 sieves. To further distinguish between silt and clay, hydrometer analysis is required. Manually, clay feels slippery and sticky when moist, while silt feels slippery but not sticky.

2.6.3 Soil classification

Soils are classified to provide a common language and a general guide to their engineering behaviour, using either the Unified Soil Classification System (USCS) (ASTM D 3282) or the AASHTO Classification System (AASHTO M 145). Use of either system depends on the size of the majority of the soil particles to classify the soil.

1) USCS. In the USCS each soil can be classified as:
   Gravel (G),
   Sand (S),
   Silt (M) and
   Clay (C)

Table2.1: Unified Soil Classification System Soil Classification Chart

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		GRAVELS WITH FINES	GH	Silty gravels, gravel-sand-clay mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below).		
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures, see CL below).		
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.		
			SP	Poorly graded sands and gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below).		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures, see CL below).		
					Identification Procedure On Fraction Smaller Than No. 40 Sieve Size		
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	SILTS AND CLAYS Liquid limit greater than 50%		MH	Inorganic silts, micaeous or diatomaceous fine sands or silts, elastic silts.	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
			OH	Organic clays of medium to high plasticity.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils			PT	Peat, muck, and other highly organic soils.	Readily identified by color, odor, spongy feel, and frequently by fibrous texture.		

2) AASHTO

In the AASHTO system (see Table 2.2), the soil is classified into seven major groups: A-1 through A-7. To classify the soil, laboratory tests including sieve analysis, hydrometer analysis, and Atterberg limits are required. After performing these tests, the particle size distribution curve (particle size vs. percent passing) is generated, and the following procedure can be used to classify the soil (Schaefer and White, 2008).

Table2.2: Revised AASHTO System of Soil Classification

General Classification	General Materials (35% or less passing 0.075 mm)							Silt-clay materials (more than 35% passing 0.075 mm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
											A-7-5
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-6
Sieve Analysis % passing											
2.00 mm (No10)	50max										
0.425 mm (No40)	30max	50max	51min								
0.725 mm (No200)	15max	25max	10max	35max	35max	35max	35max	36min	36min	36min	36min
Characteristics of fraction passing											
Liquid limit				40max	41min	40max	41min	40max	41min	40max	40min
Plastic Index	6max		N.P	10max	10max	11min	11min	10max	10max	11min	11min
Usual types of significant	Stone fragment		Fine	Silty or clayey Gravel and sand				Silty soils		Clayey soils	
Constituent material	Gravel and sand		Sand								
General rating	Excellent to Good							Fair to poor			

2.7 Distress Condition of Pavement

2.7.1 Distress

Distress is an important factor of pavement design. In the empirical methods each failure criterion should be developed separately to take care of each specific distress. Unfortunately, most of the distresses are caused by the deficiencies in construction, materials and maintenance rather than design. However, knowledge of the various types of distress is important to pavement designers. It can help to identify the causes of the distress. If distress is due to improper design, improvement in the design method can be made. Furthermore, the evaluation of pavement distress is an important part of the pavement management system by which an effective strategy can be developed for maintenance and rehabilitation (Awoke, 2006).

2.7.2 Distresses in Flexible Pavements and Causes

2.7.2.1 Deformation

Deformation in pavement is defined as the change in the pavement surface profile and it can affect roughness condition and skid resistance when water ponding occurs. Deformations may also accelerate crack initiation. The common pavement deformations are corrugations, depressions, rutting, and shoving (Zahidul, 2006).

a. Corrugations

Corrugations in flexible pavements are identified as closely and regularly spaced transverse undulations, as shown in Figure 2.2. Corrugations are plastic movements of the pavement surface and usually occur where acceleration and deceleration take place such as, bus stop, bends, and intersections. Lack of stability in the surface or base course is the possible cause for corrugations.

Figure2.2: Corrugations in flexible pavements (Source: Zahidul, 2006).

b. Depressions

Depressions are localized bowl shaped settlement in the pavement caused by one or combination of the following: (i) settlement of service trenches, (ii) consolidation in the poorly compacted subgrade, and (iii) change of moisture in the subgrade. Water ponding in the depressions causes cracking and other pavement damages such as roughness and skidding problem (Zahidul, 2006).

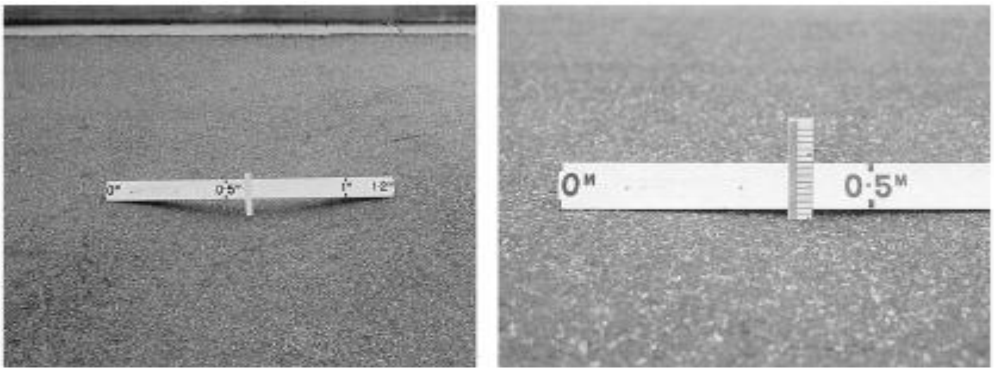

Figure2.3: Depressions in flexible pavements (Source: Zahidul, 2006).

c. Rutting

Rutting is the longitudinal depression that occurs in the wheel path due to inadequate surface thickness, and lack of compaction or stability in the surface or base course. Rutting in early pavement life may be due to poor compaction, high moisture content, or lack of lateral resistant. On the other hand, under-strength material and over loading are among the causes for rutting in the later part of pavement life. Untreated significant rutting may lead to further damage such as cracking and hydroplaning especially when water ponding occurs (Zahidul, 2006).

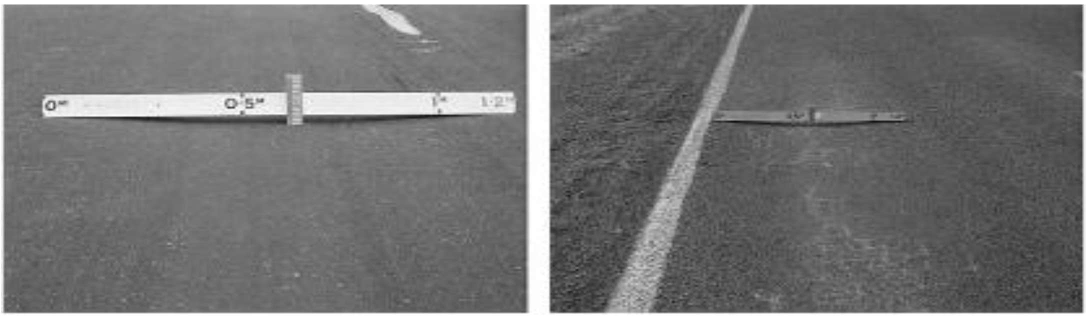

Figure2.4: Rutting in flexible pavements (Source: Zahidul, 2006).

d. Shoving

Shoving or creep is the horizontal displacement of surfacing materials occurring mainly in the direction of traffic where braking or acceleration actions take place; Permanent displacements can cause single ridges or depressions similar to corrugations. Possible causes for shoving are weak bond between pavement layers, lack of edge support, and insufficient pavement thickness or stability (Zahidul, 2006).

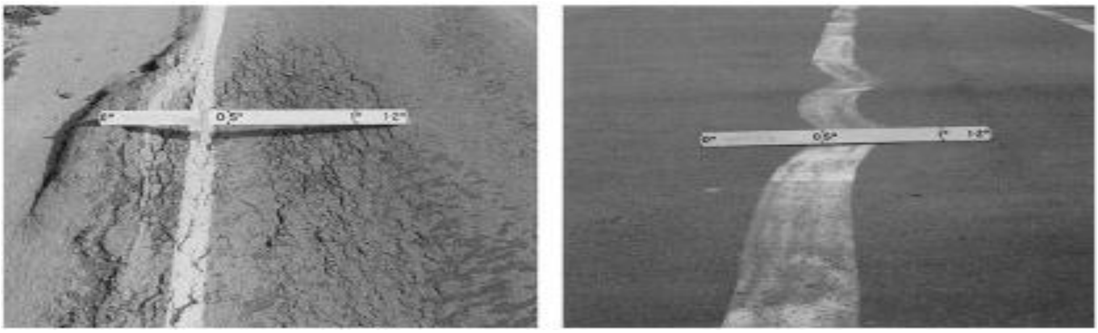

Figure2.5: Shoving in flexible pavements (Source: Zahidul, 2006).

2.7.2.2 Cracks

Cracks are fractured pavement condition resulting from a number of causes and are found in a variety of patterns ranging from single to an interconnected pattern. Possible causes of cracks are deformations, fatigue life exceeded, reflection of cracks from underlying layers, shrinkage, and poor construction joints. Presence of cracks causes numerous problems in the pavement including limiting load spreading capability through loss of structural strength, loss of waterproofing, and loss of roughness level (Zahidul, 2006).

i. Crocodile Cracks

As the term implies, crocodile cracks are interconnected cracks forming a series of small polygons resembling a crocodile skin. Crocodile cracks are usually fatigue cracks and are the early signs of pavement distress. They indicate a pavement condition where excessive movements occur in or more underlying layers. These cracks are caused due to inadequate pavement thickness, low modulus base course and aged wearing course, shrinkage of aged bitumen, very low temperature, and over-loaded vehicles. Crocodile cracks usually appear only in the traffic loading areas and allow water entering in the pavement (Zahidul, 2006).

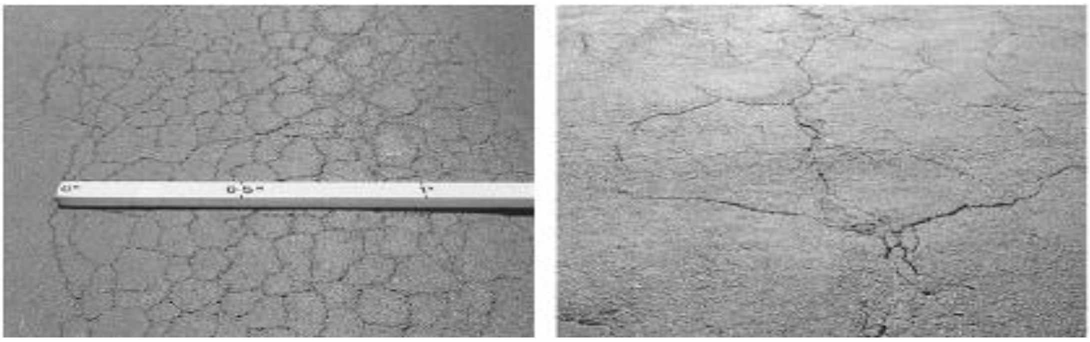

Figure2.6: Crocodile Cracks in flexible pavements (Source: Zahidul, 2006).

i. Longitudinal Cracks

Single or a number of parallel cracks appear longitudinally along the pavement due to reflection of a shrinkage crack or joint in the underlying layer, weak bond between pavement lanes, asphalt hardening, volume change in the subgrade, and differential settlement between cut and fill. Poorly constructed lane joint may also cause longitudinal cracks. These cracks do not usually result from load but wide cracks will permit water to enter the pavement structure (Zahidul, 2006).

Figure2.7: Longitudinal Cracks in flexible pavements (Source: Zahidul, 2006).

ii. Transverse Cracks

Transverse cracks run transversely across the pavement and are common in aged asphalt surfaces. These cracks are caused due to primarily reflection of a shrinkage crack or joint in the underlying layer, construction joint and structural failure in the cement base. Similar to longitudinal cracks, wide cracks permits water in the pavement (Zahidul, 2006).

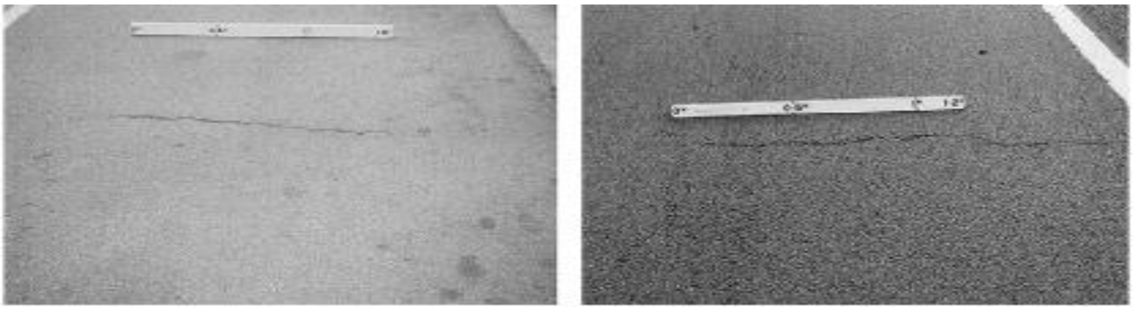

Figure2.8: Transverse Cracks in flexible pavements (Source: Zahidul, 2006).

ii. Diagonal Cracks

These are single cracks that form diagonally across the pavement, as shown in Figure 19.14. Differential settlement, service trenches, and shrinkage crack or joint in the underlying layers are possible causes for diagonal cracks (Zahidul, 2006).

Figure2.9: Diagonal Cracks in flexible pavements (Source: Zahidul, 2006).

2.7.2.3 Surface Defects

As the term implies, surface distresses are associated with the pavement surface and usually do not indicate structural problem in the pavement layers. However, they cause significant effect on pavement serviceability and skid resistance, and, if not treated, may lead to structural problems (Zahidul, 2006).

a) Raveling

Raveling is used to define a distress condition where both aggregate and binder are progressively lost from pavement surface. Raveling is caused due to inadequate binder, deterioration of binder condition, or inferior asphalt mix design. Inadequate compaction or construction in the wet or cold periods may also cause raveling. Delamination and raveling in sprayed seal pavements may not be easily differentiated (Zahidul, 2006).

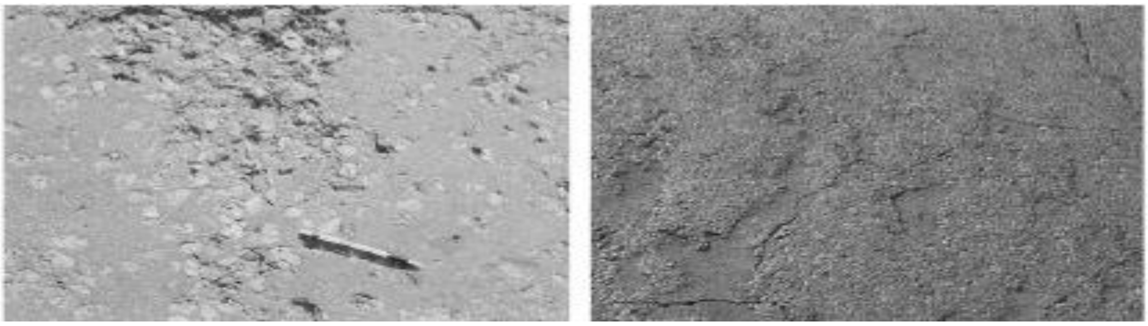

Figure2.10: Raveling in flexible pavements (Source: Zahidul, 2006).

b) Stripping

Stripping is normally associated with sprayed seal pavements and is a condition where only coarse aggregate is lost leaving the binder in good condition. Possible causes of stripping are (i) poor mix design, (ii) weak bonding between binder and stone, (iii) aging or absorption of binder, (iv) use of weak aggregate, (v) presence of water, and (vi) poor compaction (Zahidul, 2006).

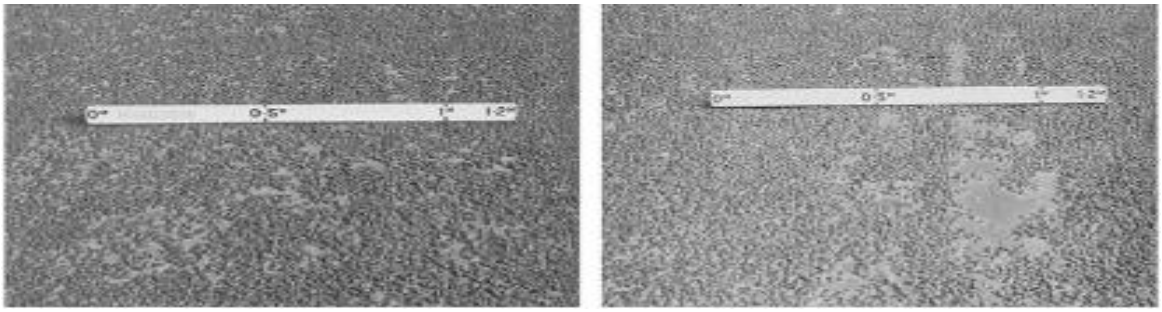

Figure2.11: Stripping in flexible pavements (Source: Zahidul, 2006).

c) Edge Defects

Defects that occur along the joint of the pavement edge and shoulder are known as edge defects. These defects may appear in isolated areas or continuously along the joint and they are particularly significant for unsealed shoulders. Edge defects reduce pavement width and affect ride quality. They also allow water entry into the pavement. Two types of edge defects, such as, edge break and edge drop-off (Zahidul, 2006).

❖ Edge drop-off

The difference between the elevation of pavement surface and shoulder is termed as edge drop-off. Inadequate pavement width, lack of support to protect shoulder erosion, and pavement resurfacing are common causes for the drop-off.

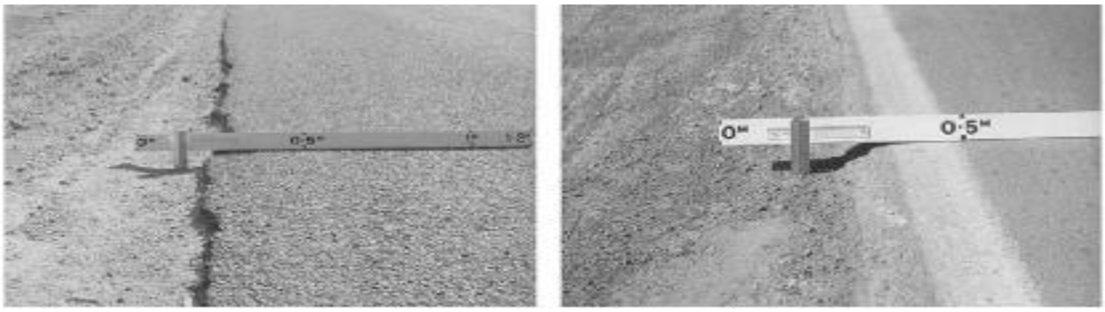

Figure2.12: Edge drop-off in flexible pavements (Source: Zahidul, 2006).

- ❖ Edge break

Irregular or broken pavement edge is caused due to lack of edge support, inadequate pavement width, poor bonding between seal and base course, and improperly designed pavement alignment.

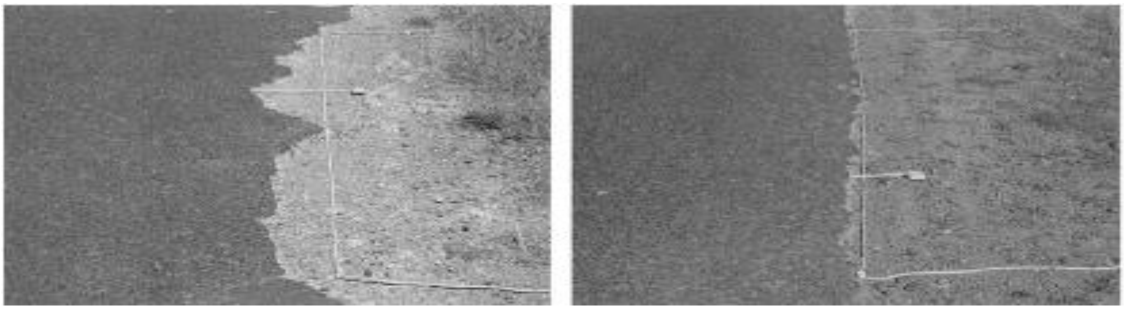

Figure2.13: Edge break in flexible pavements (Source: Zahidul, 2006).

2.8 Highway Maintenance

2.8.1 Description and Definition of Highway Maintenance

Road maintenance has been defined by the Permanent International Association of Road Congresses, (PIARC, 1982a) as “Suitable routine, periodic and urgent activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as-constructed or renewed condition. Maintenance includes minor repairs and improvements to eliminate the cause of defects and avoid excessive repetition of maintenance efforts.” (Ian, 2006).

Periodic maintenance is akin to preventive maintenance defined by the American Association of State Highway and Transportation Officials (AASHTO) as follows (Galehouse et al., 2003): “…preventive maintenance is a planned strategy of cost-effective treatments that preserves and maintains or improves a roadway system and its appurtenances and retards deterioration, but without substantially increasing structural capacity." The U.S. Federal Highway Administration, FHWA (1999a) defines pavement preservation as: "all activities undertaken to provide and maintain serviceable roadways; this includes corrective maintenance and preventive maintenance, as well as minor rehabilitation projects."

Periodic or preventive maintenance is non-structural and is applied to extend the life of the pavement, to enhance the performance and to reduce user delays (Galehouse et al., 2003).

Non-preventive maintenance can also be described as routine, recurrent and urgent (TRRL, 1981), where routine refers to the "fixed-cost" activities such as grass cutting, drainage maintenance and road sign maintenance; recurrent to activities required throughout the year such as pothole patching, crack sealing, and grading, and urgent to the repair of defects caused by disasters (e.g., floods) or accidents (Ian, 2006).

Routine maintenance activities are not influenced by the traffic, while the recurrent maintenance activities are. Both these sets of activities can also be defined as reactive maintenance, where activities are unscheduled and immediate response sometimes required.

The urgent maintenance is required to keep the highways open, protect property and road users. This has also been referred to as emergency maintenance (Galehouse et al., 2003) and includes repair of washouts, rigid pavement blow-ups, and earth slides.

AUSTROADS (1991) divides road maintenance into preventive and remedial maintenance, with preventative maintenance involving actions to prevent the roads from deteriorating and remedial maintenance involving the repair of defects (Ian, 2006).

The following classification of highway maintenance activities will be:

- ❖ Preventive maintenance refers to actions associated with restoring the condition of the highway, reducing the rate of deterioration and increasing the life of the pavement. The restoration of the condition of the pavement is primarily related to the functional, i.e., skid resistance and riding quality, properties of the pavement. These activities are normally planned based on an assessment and processing of information in a pavement or bridge management system. All maintenance should include attention to drainage as water is the single most important factor affecting pavement performance.

- Remedial maintenance refers to actions associated with the rectification of defects on the carriageway or the road reserve.
- Emergency maintenances refer to activities associated with the urgent repair of defects caused by natural disasters or accidents.

2.8.2 Remedial Maintenance activities

(i) Road sign repair and replacement: Road signs include all road signs, guide posts, and delineators. Road signs must be clearly visible at all times, including at night. Road signs can lose their effectiveness from deterioration due to environmental weathering or traffic accidents or vandalism. Missing or severely damaged road signs must be immediately replaced. Others should be replaced or repaired before they reach a critical level of effectiveness (Ian, 2006).

(ii) Safety barrier repair and replacement: Safety barriers, guard-rails and New Jersey concrete barriers are placed in areas where extra safety precautions are required such as at high fills, at sharp curves and as direction dividers. Any ineffective or missing guard-rails must immediately be repaired, replaced or installed. This is normally the case after a traffic accident.

(iii) Drainage: Drains are constructed to remove or keep water from the pavement surface and groundwater road formation. Subsurface drains are used to intercept water flowing towards the road formation while a variety of drain configurations are used to intercept or remove water from the road surface and shoulders.

(iv) Patching (flexible pavement): entails the removal and repair of edge breaks, potholes, showing severely cracked and deformed areas and surface failures. The patching can either be confined to the surface or involve replacement of a number of pavement layers. With all patching it is important to remove the failed area entirely and preferably cut 50 to100 mm into the sound material as well. The side and bottom of the patch should be squared-off and all loose material removed (Ian, 2006).

(v) Crack sealing (flexible pavements): Crack sealing comprises the cleaning of cracks, the application of a weed killer and primer (if necessary), and the application of a bituminous product as sealant. A bitumen emulsion is normally used to fill cracks less than 3 mm wide.

(vi) Blading (or grading): is an important maintenance activity for unsealed highways and intended to keep the road well drained and the riding quality in a satisfactory condition. The blading process consists bringing in material from the sides and cutting down corrugations and filling low spots. The effectiveness of grading is increased if a roller is utilized and the material is moist.

(vii) Mill and replacement: When the surfacing is in a poor condition the top 40 to 50 mm can be removed and replaced with asphalt cement having the same thickness as the removed portion. This is an effective technique where the surfacing has aged and is cracked, but no structural strengthening is required (Ian, 2006).

CHAPTER THREE

RESEARCH METHODS

3.1 Location of the study area

3.1.1 Location and accessibility

The study area undertaken was Kemmise – Desssie road section which was found in Amhara region. It was located approximately 375km from Addis Ababa and approximately 76km length from Kemisse to Dessie Road section. The road connects Harbu Woreda and Kombolcha town passes through different kebeles between the case study locations.

The study road was constructed by G and P (Gragadios) of foreign contractor in 1993 E.C from Tarma-ber to Kombolcha but from Kombolcha to Dessie study roads was constructed by ERA (Ethiopia Road Authority) kombolcha district in 1998 E.C. this road provides a key link in the route from Addis Ababa to Woldiya. So this makes the road very busy all very round.

Figure 3.1 Road Google Satellite Map from Addis Ababa to Dessie

3.1.2 Project location and Topography

The study area started at Kemmise town with an elevation of 1424 m above mean sea level (a.s.l.) and ends Dessie town at elevation of 2470 m a.s.l. Therefore, the route of the road descends and ascends thereafter from the starting to end points. Generally the altitude ranges in the order of 1400 – 2500 m above mean sea level. The topography of the road terrain can be classified as flat, rolling and mountainous terrain (ERA, 2012). The studied highway locations and their profiles of major towns showed (Table 3.1).

Table 3.1 Major town location and their profile that would pass the road project

Town	Region	Zone	Coordinates in Ethiopia	Elevation, m	Population	Distance from Addis Ababa
Kemise	Amhara	Oromia	10°43'N 39°52'E	1424	19,420 (in 2007)	325 Km
Kombolcha	Amhara	south wollo	11°5'12"N 39°44'12"E	1842	108,667 (in 2007)	376 Km
Dessie	Amhara	south wollo	11°8'N 39°38'E	2470	279,423 (in 2012)	401 Km

Figure 3.2 Road Google Satellite Map from Kemise to Dessie

3.1.3 Temperature and Rainfall (Kombolcha Meteorological Agency, 2007-2008).

Table 3.2 Monthly Min. and Max. Temperature (˚c)

Major Town Average Temperature Data (˚c)						
Month	**Kemise**		**Kombolcha**		**Dessie**	
	Min.	Max.	Min.	Max.	Min.	Max.
January	10.98	30.06	9.9	25.6	6.4	22.54
Febrary	14.99	30.8	13.3	26	7.2	22.7
March	14.68	32.68	13.6	27.7	8.6	24.4
April	13.5	33.08	14.5	28.7	10.2	24.8
May	14.16	32.93	14.8	28.3	10	24.2
June	15.58	35.76	15.2	30.9	10.38	26.7
July	16.81	33.98	15.3	29.6	11.34	27.5
August	16.62	30.73	14.9	27.1	10.89	26.5
September	18.32	30.61	14	26.7	10.55	23.7
October	11.68	30.21	11.5	25.7	7.46	24.7
November	12.78	30.59	10.6	25.8	6.76	24.1
December	13.08	29.6	7.9	24.8	5.46	22.4

Table 3.3 Mean Monthly Rainfalls (mm)

Major Town Mean Rainfall Data (mm)			
Month	**Kemise**	**Kombolcha**	**Dessie**
January	0.0	1.8	14.9
Febrary	9.6	21.7	21.0
March	21.3	41.7	73.0
April	57.5	55.1	38.2
May	123.2	90.9	54.3
June	6.5	9.3	7.0
July	280.9	247.5	328.0
August	435.3	319.5	360.2
September	92.9	135.2	0.0
October	143.6	96.9	76.0
November	0.0	4.7	7.0
December	4.0	6.0	7.0

3.2 Study Period

The study was conducted from April to June, 2016

3.3 Study Design

The research study was conducted by using both experimental and analytical methods. Qualitative and quantitative studies were employed in this study area. Qualitative study gives impression on the findings where a quantitative study was used to describe the numerical aspects of the research findings, based from laboratory results.

3.4 Population

The research population are from Kemmise to Dessie main roads. But the target population was sub-base and subgrade soil materials on the pavement failures existed within the range of the study area which covers from Kemisse – Dessie road sections.

3.5 Study variables

The study variables both dependent and independent are assessed in this research. Which display the pavement failure caused by the characteristics of sub base and subgrade soil materials.

Independent variables

- Gradation size distribution
- Atterberg limit value
- OMC and MDD value
- CBR value

Dependent variable

- Asphalt pavement failure

3.6 Software and instruments

The following instruments and software were used for this study:

Mater tape, plastic bags, Digital Camera for documentation, MS word and Excel to analysis laboratory data and display research data were used in this study.

3.7 Data collection process

The following procedures were used for data collection in the study area;

- Literature review to acquire background information of the regional and local geological soils characteristics, physiography and climatic conditions, that are used as the foundation for this research study.
- Field visits to overview the study area and Samples were collected away from (at end of) the paved road. The three soil samples were collected at each failed section based on colour change with a view to determining the characteristics of the various soil types present in the natural subgrade, fill material and sub-base soil materials.
- The maximum depth dug was 1.2 m below the asphaltic surface. The soils were suitably packed into an air tight sack and labelled sample 1- sample 7.
- Collection of representative soils samples at each test pits and photographs at representative locations.
- Classification of the soil material based on the laboratory test results using AASHTO and other Standard manual.
- Characterizing the soil by comparing and relating different parameters of engineering properties of soil.
- Interpretation of the results of the tests and the classification in parallel to determine, the index properties, bearing capacity and maximum dry density of

different soil layers along the failed road alignment.

- ❖ By comparing different pavement design manuals, it has been attempted to provide or checked the cause of pavement failure due to soil properties.
- ❖ Then to find remedial measures of asphalt pavement failure for upgrading or rehabilitation of asphalt pavement for the use of a long life without a disturbance of road users.

3.8 Field Work

Preliminary visual survey was undertaken along Kemmise- Dessie road section. Field observations and representative samples were taken to laboratory tests. Moreover, results from laboratory test were compared with different design specifications. During field observation, it was necessary to begin by conducting visual inspection and site inventory of the whole stretch of the Kemmise- Dessie road section. The initial site visit was taken on the whole portion of the road. After finishing the initial visual inspection and categorizing the conditions of the road failures along the road section. The next step was then to select the representative locations for sampling based on their failure conditions/types. The researcher selected seven (7) sample locations/stations of test pits that represent the type of failures observed along the road section.

In order determine the extent/rate of damage observed from the visual inspection would become reliable, proper identification was made to select representative sections. The following representative photographs can show the type and extent of failure along the road.

In figure below there were seven major types of failures observed along the study area of Kemmise- Dessie road. Relative to this, the researcher had organized the possible distress types based on existing condition of the pavement surface together with the extent of damage.

The following figures show the different photos taken from field observation of the different types of failures along Kemmise- Dessie road section.

- ✓ In **sample one** to describe and problems of **Raveling** type of damaged

Description: The progressive disintegration of a pavement layer from the surface downward as a result of the dislodgement of aggregate particles.

Problem: Loose debris on the pavement, roughness, water collecting in the ravelled locations resulting loss of skid resistance.

Figure 3.3 Representative Raveling Damage and their sample (20/09/2008)

- ✓ In **sample two** to describe and problem of **transverse crack** type of damaged

Description: Cracks perpendicular to the pavement's centreline or lay down direction. Usually a type of thermal cracking.

Problem: Allows moisture infiltration, roughness

Figure 3.4 Representative Transverse cracks and their sample (20/09/2008)

- ✓ In **sample three** to describe and problems of **patching** type of damaged

Description: An area of pavement that has been replaced with new material to repair the existing pavement. A patch is considered a defect no matter how well it performs.

Problem: Roughness.

Figure 3.5 Representative patched damaged and their samples (23/09/2008)

- ✓ In **sample four** to describe and problems of **transversal depression** type of damaged

Description: Localized pavement surface areas with slightly lower elevations than the surrounding pavement.

Problem: Roughness

Figure 3.6 Representative transversal depression and their samples (23/09/2008)

- ✓ In **sample five** to describe and problems of **shoving/ corrugation** type of damaged

Description: A form of plastic movement typified by ripples (corrugation) or an abrupt wave (shoving) across the pavement surface. The distortion is perpendicular to the traffic direction. Usually occurs at points where traffic starts and stops (corrugation) or areas where pavement abuts a rigid object (shoving).

Problem: Roughness

Figure 3.7 Representative Shoved/ Corrugation damaged and their samples (28/09/2008)

- ✓ In **sample six** to describe and problems of **rutting** type of damaged

Description: Surface depression in the wheel path. Pavement uplift (shearing) may occur along the sides of the rut. Ruts are particularly evident after a rain when they are filled with water.

Problem: Ruts filled with water, can be hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut.

Figure 3.8 Representative Rutting damaged and their samples (28/09/2008)

- ✓ In **sample seven** to describe and problems of **potholes/ debonding** type of damaged

Description: potholes are bowl shaped voids or depressions in the pavement surface. Debonding is when the surface layer separates from its underlying layer of asphalt.

Problem: Roughness (serious vehicular damage can result from driving across potholes at higher speeds), moisture infiltration.

Figure 3.9 Representative Potholes/debonding damages and their samples (29/09/2008)

3.9 Laboratory tests

Enough representative samples were collected from damaged road section and immediately after extracting samples from the road section of the study area, these were transported to the laboratory of Ethiopian Railway Corporation (Yapi merkezi) and Ethiopian Road Construction Cooperation Kombolcha District Laboratory. The tests were performed according to AASHTO Specification and ASTM.

- ✓ **Gradation Test (Sieve Analysis)**

Sieve analysis was performed in order to determine the soil particle size distribution. Representative sample was used for the test after washing and oven-dried. The sample was washed using the BS 200 sieve and the fraction retained on the sieve was air dried and used for the sieve analysis. The sieving was done by mechanical method using an automatic shakers and a set of sieves.

- ✓ **Atterberg Limit Tests (LL & PL)**

This test determines the clay content in terms of liquid limit, plastic limit and plasticity index in order to estimate plasticity, strength and settlement characteristics of the soil sample. For the determination of liquid limit, the soil sample passing through 425 μm sieve, weighing 200 g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was recorded. Similarly, for plastic limit determination, the soil sample weighing 200 g was taken from the material passing the 425 μm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit.

- ✓ **Proctor Test (Modified Compaction Test)**

Compaction tests were performed for sub-base, selected fill and natural subgrade soil materials based on AASHTO T-180 test procedure for compaction. The densification of soil with mechanical equipment thereby rearranging the soil particles which makes them more closely packed resulting in an increase of the ratio horizontal effective size to the vertical effective stress. The degree of compaction is measured in term of its dry weight and it increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and curb undesirable settlement of structures. The mould is filled and compacted with soil in five layers of a 4.5 kg rammer.

- ✓ **California Bearing Ratio Test**

The California bearing ratio (CBR) test is a penetration test carried out to evaluate the mechanical strength of a sub-base, selected fill and natural subgrade soil material. The soaked method of CBR was conducted to characterize the soil for use as a sub-base and selected fill material. A portion of air-dried soil sample was mixed with optimum moisture content. This was put in CBR mould in 5 layers with each layer compacted with 56 blows using 4.5 kg hammer (Modified proctor test). The compacted soil and the mould was weighed and placed under CBR machine and a seating load was applied. Load was recorded at penetration of 0.625, 1.25, 1.875, 2.54, 3.75, 5.08, 7.5, 10 and 12.5 mm.

3.10 Ethical consideration

In study area the ethical considerations were not that much of a problem because, the causes and remedial measures of asphalt pavement damage are the concerns of nearly in every area of the country.

3.11 Data Quality Assurance

The quality of data collection is exactly assured. Because, the method of data collections were used from field investigation survey and visually observation of the asphalt pavement failure due to the samples were taken.

3.12 Operational Definitions

The operational definitions establish the rule and procedure an investigator use to plans to use to measure and give meaning to variable and terms. The operational definition established categories for the variables and the standard of comparisons.

- ✓ Asphalt pavement: A pavement comprised of a surface mineral aggregate, coated and cemented together with asphalt cement on supporting asphalt layers.
- ✓ Flexible Pavement: A pavement structure of bituminous concrete that distributes loads to the subgrade and depends on a firm continuous subgrade, aggregate interlock, particle friction, and cohesion for stability.
- ✓ Roadbed Material: The material below the subgrade in cuts and embankments and in embankment foundations, extending to such depth as affects the support of the pavement structure.
- ✓ Select Material: A suitable native material obtained from a specified source such as a particular roadway cut or borrow area having specified characteristics to be used for a specific purpose.
- ✓ Sub base: The layer or layers of specified or select material of designed thickness placed on a subgrade to support a base course (or in the case of rigid pavements, the Portland cement concrete slab).
- ✓ Subgrade: The top surface of a roadbed soil upon which the pavement structure and shoulders are constructed
- ✓ Base Course: the layer or layers of specified or select material of designed thickness placed on a subgrade to support a surface course.
- ✓ Damage: The defect of a road not to function within its design life span.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 General

The laboratory analysis was performed according British standard methods of test for soil for civil engineering purposes (BS 1377: Part 1-9, 1990). The laboratory test carried out to determine the cause of pavement failure due to soil properties. Such as; sub-base material, selected subgrade (Fill material) and natural subgrade soil using the AASHTO standard method in relation to the generation specification for roads. For the design and construction of highway and airfield, it is imperative to carry out tests on construction materials. The inherent economy in construction depends upon the maximum use of local material. The prime objective of the different tests in use is to know and to classify the pavement materials into different groups depending upon their physical and strength or stability characteristics.

4.2 Test pit locations for pavement material sampling

During the field observation, it was found necessary to start by visual inspection of the whole stretch of the Kemise – Dessie road. During initial visit the whole portion of the road was covered and the failed sections were identified visually for further detailed observation. In the following visit seven failed sections were inspected visually. The observation results and relevant remarks about the cracks condition are presented in Table 4.1.

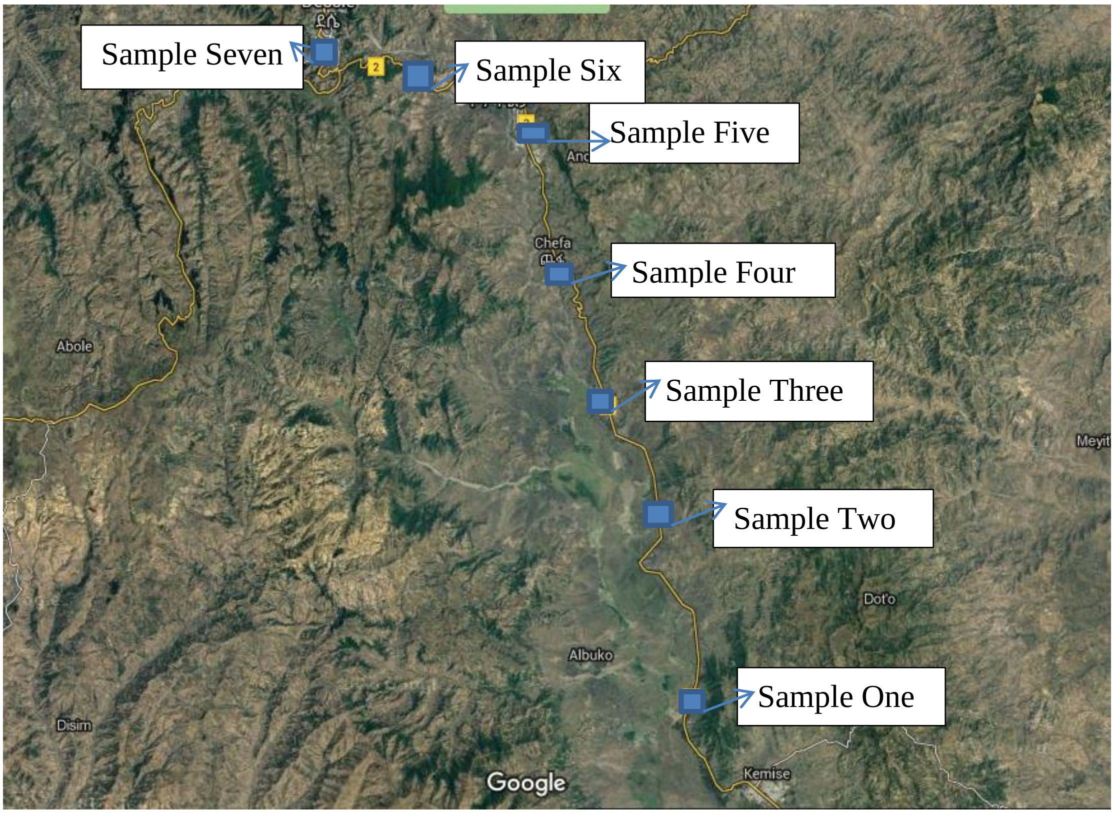

Figure4.1: Pavement damaged and test pit location

Table4.1: station and location representative failed pavement section

Sample No.	Station	Sample side	Date of sample taken	Pavement damage remark
1	07+400	Right	20/09/2008	Raveling type of damages were exist at extreme level
2	15+700	Left	20/09/2008	Transverse crack were developed from around the centre up to the edge
3	28+200	Left	23/09/2008	Patches were exist around the centre
4	37+300	Right	23/09/2008	Transversal depression from edge to edge

5	45+040	Right	28/09/2008	Shoving were exist at some area on the section
6	51+100	Left	28/09/2008	Rutting at the edge of the road
7	63+150	Left	29/09/2008	potholes at the edge, remove some portion of the road near to the edge

4.5 Laboratory test results

The laboratory analysis was performed according British standard methods of test for soil for civil engineering purposes (BS 1377: Part 1-9, 1990). The laboratory test carried out to determine the suitability of the soils for use as sub-base and select fill material and natural subgrade using the AASHTO standard method in relation to the generation specification for roads.

4.5.1 Gradation test results (Sieve Analysis)

Table 4.2 Sieve Analysis test results of Sub-base materials

Material type	**Sub-base**							
Sample		1	2	3	4	5	6	7
	Sieve Size	**Percentage Passing**						
	60	100.0	100.0	94.6	100.0	100.0	100.0	100.0
	50	93.5	95.3	87.5	100.0	100.0	100.0	97.2
	37.5	90.1	91.3	73.6	91.4	100.0	100.0	95.4
	25	76.7	80.9	62.7	77.4	90.7	93.1	92.4
	19	70.9	75.9	56.8	71.4	79.9	87.1	91.0
	9.5	60.3	60.7	43.0	52.8	68.4	63.3	86.0
	4.75	49.6	46.9	31.3	41.8	57.4	49.2	67.0
	2.36	39.2	36.5	21.7	33.2	44.6	35.2	48.4
	0.425	26.6	26.9	12.7	19.6	29.8	20.2	27.0
	0.15	21.7	21.0	10.2	15.6	25.0	10.0	8.0
	0.075	18.9	18.8	8.9	13.0	14.9	12.2	16.7

Table 4.3 Sieve Analysis test results of Selected fill materials

Material type	Selected Fill					
Sample		1	3	4	5	6	7
	Sieve Size	**Percentage Passing**					
	60	100.0	100.0	100.0	100.0	100.0	100.0
	50	93.8	85.5	82.2	100.0	100.0	100.0
	37.5	89.1	78.0	74.2	91.6	100.0	93.8
	25	80.5	68.9	66.4	80.4	100.0	83.4
	19	78.1	61.7	57.8	73.1	89.2	76.1
	9.5	65.5	51.1	44.6	64.1	75.8	57.3
	4.75	53.2	40.6	33.0	43.0	53.4	46.4
	2.36	41.7	33.4	26.1	31.1	53.2	36.9
	0.425	35.8	22.8	16.4	21.3	30.5	26.0
	0.15	25.6	19.3	13.4	9.0	27.2	10.0
	0.075	22.8	18.0	11.9	13.8	16.0	16.6

Table 4.4 Sieve Analysis test results of Natural subgrade materials

Material type	Natural Subgrade						
Sample		1	2	3	4	5	7
	Sieve Size	**Percentage Passing**					
	60	100	100.0	100.0	100.0	100.0	100.0
	50	95.5	100.0	90.2	100.0	100.0	100.0
	37.5	93.9	100.0	86.0	98.0	100.0	100.0
	25	89.7	98.0	77.8	96.0	95.4	99.2
	19	87.2	96.2	72.4	92.9	93.5	98.8
	9.5	76.8	93.5	60.8	90.8	87.0	97.6
	4.75	65.2	91.3	50.9	88.9	79.4	96.3
	2.36	52.8	89.6	44.5	86.6	68.9	94.7
	0.425	28.5	86.9	32.4	83.8	54.5	91.7
	0.15	19.7	85.3	28.5	81.9	40.9	86.3
	0.075	17.8	84.3	27.1	80.8	20.3	82.6

Soils are generally classified into four groups using the Unified Soil Classification System, depending on the size of the majority of the soil particles (ASTM D 3282, AASHTO M 145).

- ✓ Gravel: Fraction passing the 3 inch sieve (76.2 mm) and retained on the No. 10 sieve (2.0 mm).
- ✓ Sand: Fraction passing the No. 10 sieve (2.0 mm) and retained on the No. 200 sieve (0.0075 mm).
- ✓ Silt and Clay: Fraction passing the No. 200 sieves (0.0075 mm).

Table4.5: Laboratory test results of sieve analysis for all samples

Soil sample	pavement layers	PARTICLE SIZE DISTRIBUTION		
		Gravel (%)	Sand (%)	Clay & Silty (%)
1	Sub- base	60.8	20.3	18.9
	Selected fill	58.3	18.9	22.8
	Natural subgrade	47.2	35	17.8
2	Sub- base	63.5	17.7	18.8
	Natural subgrade	10.4	5.3	84.3
3	Sub- base	78.3	12.8	8.9
	Selected fill	66.6	15.4	18
	Natural subgrade	55.5	17.4	27.1
4	Sub- base	66.8	20.2	13
	Selected fill	73.9	14.2	11.9
	Natural subgrade	13.4	5.77	80.8
5	Sub- base	55.4	29.7	14.9
	Selected fill	68.9	17.28	13.82
	Natural subgrade	31.1	48.6	20.3
6	Sub- base	64.82	22.97	12.21
	Selected fill	46.8	37.2	16
7	Sub- base	51.59	31.74	16.67
	Selected fill	63.15	20.25	16.6
	Natural subgrade	5.6	11.83	82.57

4.5.2 Atterberg limit test results (Liquid limit and Plastic limit)

This test determines the clay content in terms of liquid limit, plastic limit and plasticity index in order to estimate plasticity, strength and settlement characteristics of the soil sample.

Table4.6: Atterberg limit values of the representative soil sample of Kemise to Dessie roadway

Soil Sample	Pavement Layers	ATTERBERG LIMITS		
		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	Sub- base	47.3	29.25	18.05
	Selected fill	48.95	28.45	20.5
	Natural subgrade	47.4	29.05	18.35
2	Sub- base	44.96	27.15	17.81
	Natural subgrade	71.05	38	33.05
3	Sub- base	34.84	25.55	9.29
	Selected fill	47.08	29.55	17.53
	Natural subgrade	41.09	22.9	18.19
4	Sub- base	40.89	30.45	10.44
	Selected fill	38.9	24.75	14.15
	Natural subgrade	74.35	25.1	49.25
5	Sub- base	32.3	21	11.3
	Selected fill	37.2	26	11.2
	Natural subgrade	38.05	21.2	16.85
6	Sub- base	23.6	16.9	6.7
	Selected fill	39.3	26	13.4
7	Sub- base	33.9	22	11.9
	Selected fill	27.6	15.8	11.8
	Natural subgrade	59.3	25.2	34.1

4.5.2.1 Representative Natural Subgrade soil sample classification based on AASHTO soil classification of Kemise to Dessie roadway

In the AASHTO system, the soil is classified into seven major groups: A-1 through A-7. To classify the soil, laboratory tests including sieve analysis, and Atterberg limits are required. After performing these tests, the particle size distribution curve (particle size vs. percept passing) is generated, then to find out percentage passing on the No. 200 sieve (0.075 mm) from the graph.

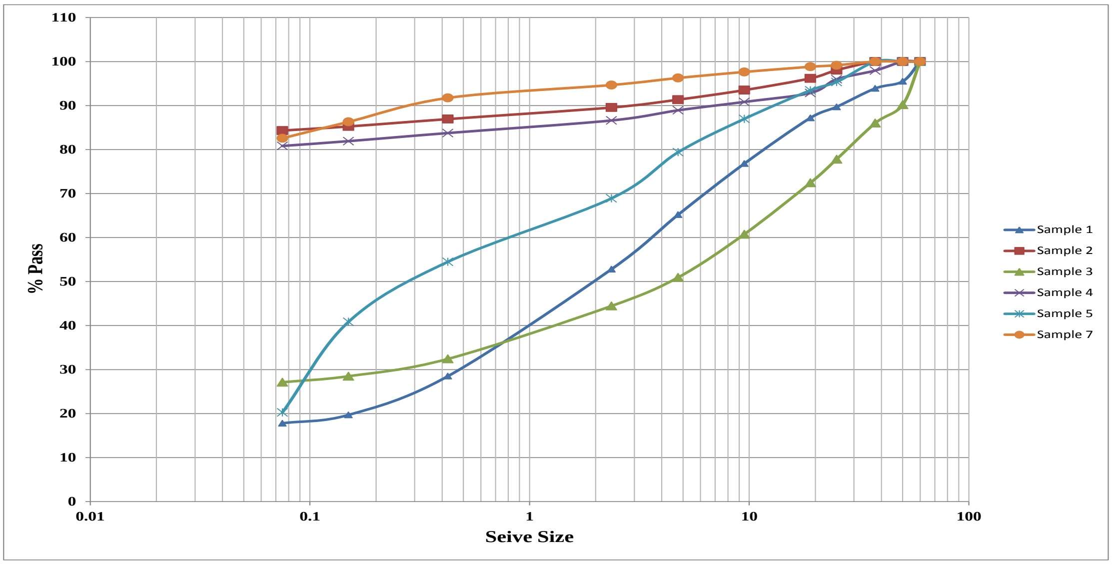

Figure4.2: Sieve Analysis graph for Natural Subgrade soil samples from the study area

Table4.7: AASHTO soil classification of representative Natural Subgrade soil sample

Soil Sample	Soil type	ATTERBERG LIMITS			AASHTO SOIL CLASSIFICATION
		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Group classification
1	Natural subgrade	47.4	29.05	18.35	A-2-7
2	Natural subgrade	71.05	38	33.05	A-7-5
3	Natural subgrade	41.09	22.9	18.19	A-2-7
4	Natural subgrade	74.35	25.1	49.25	A-7-6
5	Natural subgrade	38.05	21.2	16.85	A-2-6
7	Natural subgrade	59.3	25.2	34.1	A-7-6

4.5.2.2 Representative Natural Subgrade soil sample classification based on USCS soil classification of Kemise to Dessie roadway

The exact fine grained soil determined from the plasticity chart as shown fig. 4.16. The A- line has the equation Ip (y) = 0.73(LL-20), it separates clay from silts. When the plasticity and the liquid limit plot in the hatched portion of the plasticity chart, the soil is given double symbol CL-ML. The inorganic soil ML and MH and the organic soils OL, OH plot in the same zones of the plasticity chart. The distinction between organic and inorganic soils is shown fig. 4.16 from plasticity chart.

Table4.8: USCS soil classification of representative Natural Subgrade soil sample

Soil Sample	Soil Type	ATTERBERG LIMITS			USCS SOIL CLASSIFICATION	
		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Group symbols	Typical names
1	Natural subgrade	47.4	29.05	18.35	SM	Silty sands
2	Natural subgrade	71.05	38	33.05	OH	Organic clays of medium of high plasticity
3	Natural subgrade	41.09	22.9	18.19	SC	Clayey sands
4	Natural subgrade	74.35	25.1	49.25	CH	Inorganic clays of high plasticity
5	Natural subgrade	38.05	21.2	16.85	SC	Clayey sands
7	Natural subgrade	59.3	25.2	34.1	CH	Inorganic clays of high plasticity

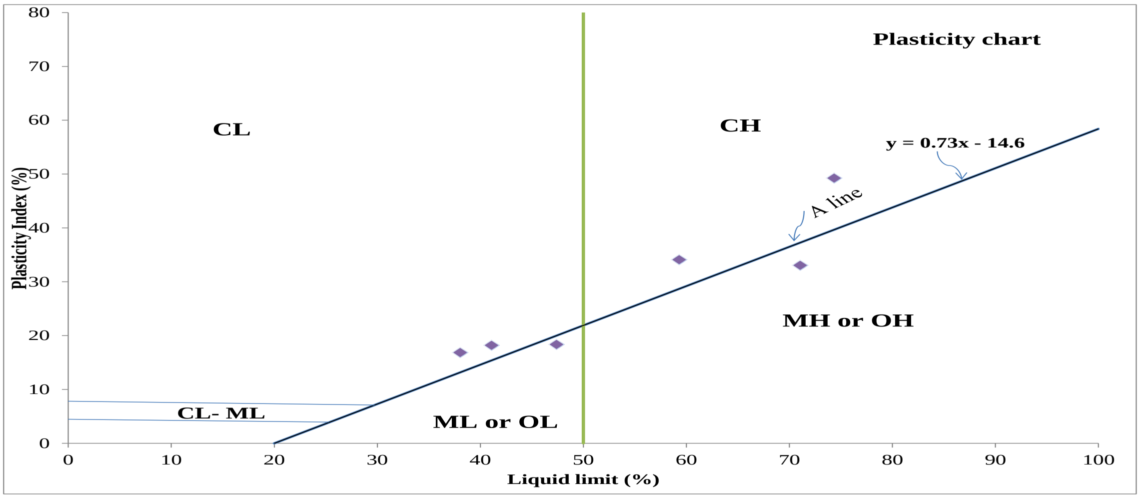

Figure4.3: Plasticity Chart of Natural soils in the study area

4.5.3 Proctor test results (Compaction test)

Test results for compaction are presented in Table 4.9 for the seven soil samples of each pavement soil layer properties.

Table4.9: Values of proctor test for all soil samples in the study area

Soil Sample	Pavement Layers	Modified Proctor Test	
		MDD (Kg/m³)	OMC (%)
1	Sub- base	1.70	20.71
	Selected fill	1.79	20.33
	Natural subgrade	1.66	22.03
2	Sub- base	1.77	20.69
	Natural subgrade	1.33	28.6
3	Sub- base	2.09	10.7
	Selected fill	1.83	17.6
	Natural subgrade	1.72	18.88
4	Sub- base	1.76	18.09
	Selected fill	1.65	15.96
	Natural subgrade	1.43	24.06
5	Sub- base	1.74	9.9
	Selected fill	2.01	12.1
	Natural subgrade	1.96	12.78
6	Sub- base	2.25	8.5
	Selected fill	1.67	11.92
7	Sub- base	1.99	12.9
	Selected fill	2.16	9.4
	Natural subgrade	1.47	19.84

4.5.4 California Bearing Ratio

Four- Days soaked samples at their maximum dry density The California Bearing Ratio test results for all soil samples in the study area are shown below in Table 4.10.

Table4.10: Four day soaked sample of California Bearing Ratio test result values

Soil Sample	Pavement Layers	Soaked CBR (%)		Remark
		2.5 mm	5.08 mm	
1	Sub- base	5.9	7	Repeated
	Selected fill	17.4	16.3	
	Natural subgrade	26.9	31.7	Repeated
2	Sub- base	19.5	19.4	
	Natural subgrade	3.3	3.3	
3	Sub- base	47.7	60.2	Repeated
	Selected fill	15.1	14.3	
	Natural subgrade	16.5	22.1	Repeated
4	Sub- base	27.1	26.4	
	Selected fill	15.5	21.3	Repeated
	Natural subgrade	3	2.5	
5	Sub- base	15.1	17.02	Repeated
	Selected fill	62	61	
	Natural subgrade	48.82	50.58	Repeated
6	Sub- base	53.4	55.8	Repeated
	Selected fill	11.6	13.9	Repeated
7	Sub- base	44	55	Repeated
	Selected fill	39.19	53.2	Repeated
	Natural subgrade	4.21	3.97	

Table4.11: Summary of Overall Test Results

Soil sample	pavement layers	PARTICLE SIZE DISTRIBUTION			ATTERBERG LIMITS			Modified Proctor Test		Soaked CBR (%)	
		Gravel (%)	Sand (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	MDD (Kg/m³)	OMC (%)	2.5 mm	5.08 mm
1	Sub- base	60.8	20.3	18.9	47.3	29.25	18.05	1.696	20.69	5.9	7
	Selected fill	58.3	18.9	22.8	48.95	28.45	20.5	1.787	20.33	17.4	16.3
	Natural subgrade	47.2	35	17.8	47.4	29.05	18.35	1.664	22.03	26.9	31.7
2	Sub- base	63.5	17.7	18.8	44.96	27.15	17.81	1.766	20.69	19.5	19.4
	Natural subgrade	10.4	5.3	84.3	71.05	38	33.05	1.326	28.6	3.3	3.3
3	Sub- base	78.3	12.8	8.9	34.84	25.55	9.29	2.085	10.7	47.7	60.2
	Selected fill	66.6	15.4	18	47.08	29.55	17.53	1.826	17.6	15.1	14.3
	Natural subgrade	55.5	17.4	27.1	41.09	22.9	18.19	1.72	18.88	16.5	22.1
4	Sub- base	66.8	20.2	13	40.89	30.45	10.44	1.761	18.09	27.1	26.4
	Selected fill	73.9	14.2	11.9	38.9	24.75	14.15	1.651	15.96	15.5	21.3
	Natural subgrade	13.4	5.77	80.8	74.35	25.1	49.25	1.428	24.06	3	2.5
5	Sub- base	55.4	29.7	14.9	32.3	21	11.3	1.74	9.9	15.1	17.02
	Selected fill	68.9	17.28	13.82	37.2	26	11.2	2.01	12.1	62	61
	Natural subgrade	31.1	48.6	20.3	38.05	21.2	16.85	1.96	12.78	48.82	50.58
6	Sub- base	64.82	22.97	12.21	23.6	16.9	6.7	2.25	8.5	53.4	55.8
	Selected fill	46.8	37.2	16	39.3	26	13.4	1.67	11.92	11.6	13.9
7	Sub- base	51.59	31.74	16.67	33.9	22	11.9	1.992	12.9	44	55
	Selected fill	63.15	20.25	16.6	27.6	15.8	11.8	2.16	9.4	39.19	53.2
	Natural subgrade	5.6	11.83	82.57	59.3	25.2	34.1	1.47	19.84	4.21	3.97

4.6 Comparison of test results with requirements set in the design specification

4.6.1 Comparison of sub-base soil materials

A. Sieve Analysis (Gradation)

The sieve analysis test results for sub-base material shown from laboratory test result. They are more or less within the limits of the specification. The specification limits are shown Table 4.12.

Table4.12: Gradation requirements for the sub-base material based on the specification of Addis Ababa – Dessie road rehabilitation project

Sieve size, mm	Specification
63	100
50	80 – 100
37.5	70 – 95
25	55 – 90
19	51 – 84
9.5	43 – 73
4.75	30 – 60
2.36	24 – 50
0.425	10 – 30
0.0075	5 – 12

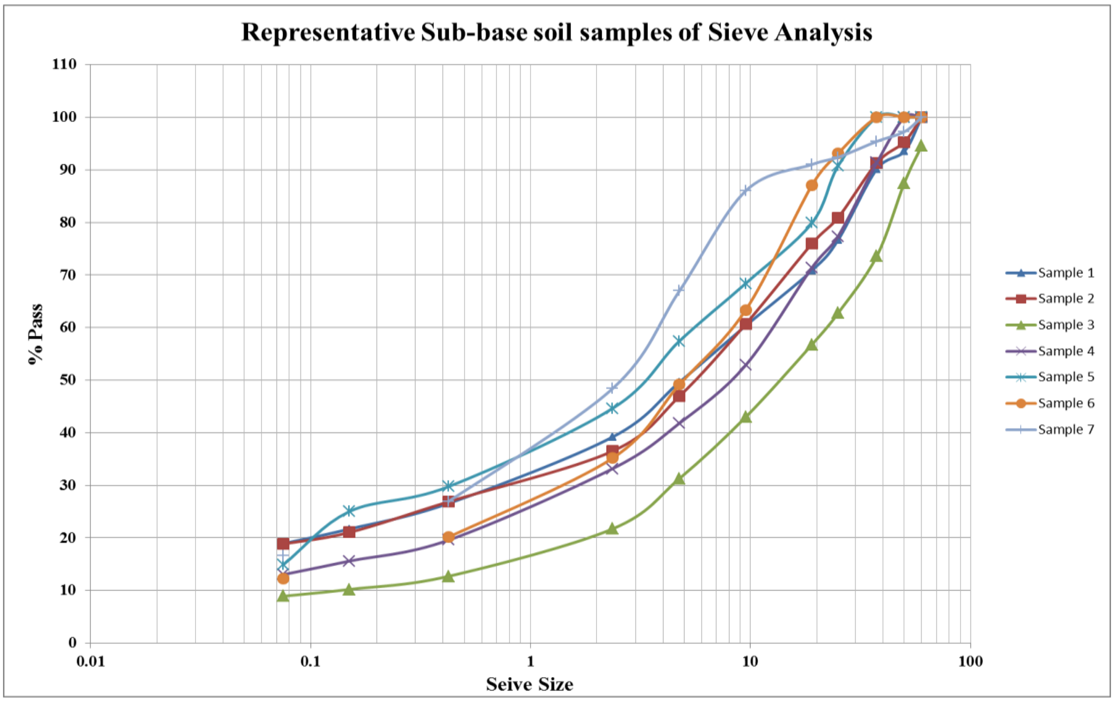

Figure4.4: Sieve Analysis graph of sub-base soil sample

The result of the particle size analysis contained in Table 4.2 indicates that the soil's clay content for all sub-base samples ranged from 8.9% to 18.9%. According to the Federal Ministry of Works and Housing (1997) specification, the clay content for sub-base materials must not exceed 35%. The high clay content could be responsible for instability of road pavement in the area.so from test results for all sub-base materials are fulfilling the FMWH specification.

B. Atterberg Limits

- According to Ethiopian Road Authority (ERA), Addis Ababa – Dessie rehabilitation project material specification requirements. For sub-base material PI ≤ 15. All sub-base soil samples met these required specification except sample 1 and 2 sub-base materials.
- The Federal Ministry of Works and Housing (1997) specifications are liquid limits of 30% maximum, plastic limit of 30% maximum and plasticity index of 13% maximum for sub-base materials. From Table 4.3 shows that the liquid limit of the sub-base soils ranged from 23.6% to 47.3% while the plastic limit ranged from 16.9% to 30.45% and the plasticity index ranged from 6.7 to 18.05. None of the sub-base soil samples met these required specification except sample 6.

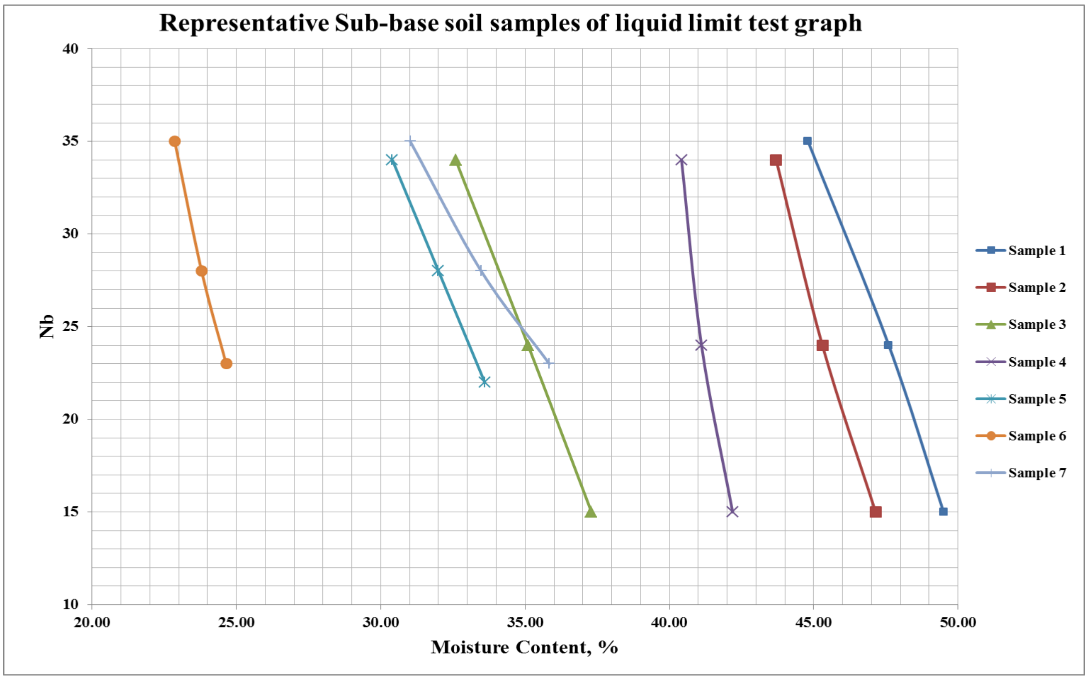

Figure4.5: Liquid limits test graphs of sub-base soil samples

C. Compaction Test

From Table 4.6, shows that the maximum dry density (MDD) of the sub-base soil materials ranged between 1.74 and 2.25 kg/m³, while the optimum moisture content (OMC) ranged from 8.5% to 20.71 %. The Federal Ministry of Works and Housing, (1997) specified OMC less than 18% for sub-base soil materials. Based on these specifications, sub-base soil samples 1 and 2 are not suitable as sub-base material. Sub-base Sample 4 could be suitable with a minimal soil modification.

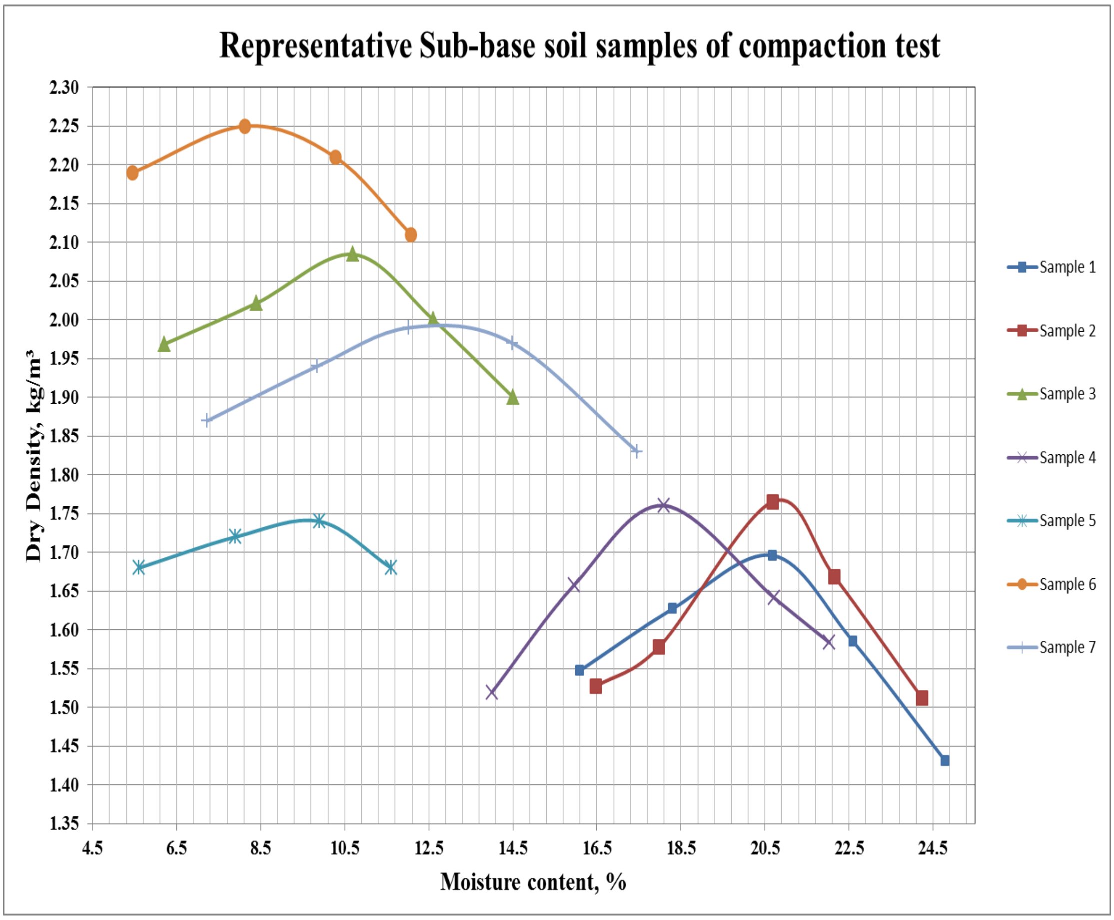

Figure4.6: Compaction test graphs of sub-base soil samples

D. California Bearing Ratios

From Table 4.7, shows that the four days soaked CBR values of sub-base soil materials ranged from 7 % to 60.2 %. The Ethiopian Road Authority (ERA), Addis Ababa – Dessie rehabilitation project material specified CBR greater than or equal to 30 % for sub-base materials. Based on these specifications, sub-base soil samples 1, 2, 4 and 5 are not suitable as sub-base material.

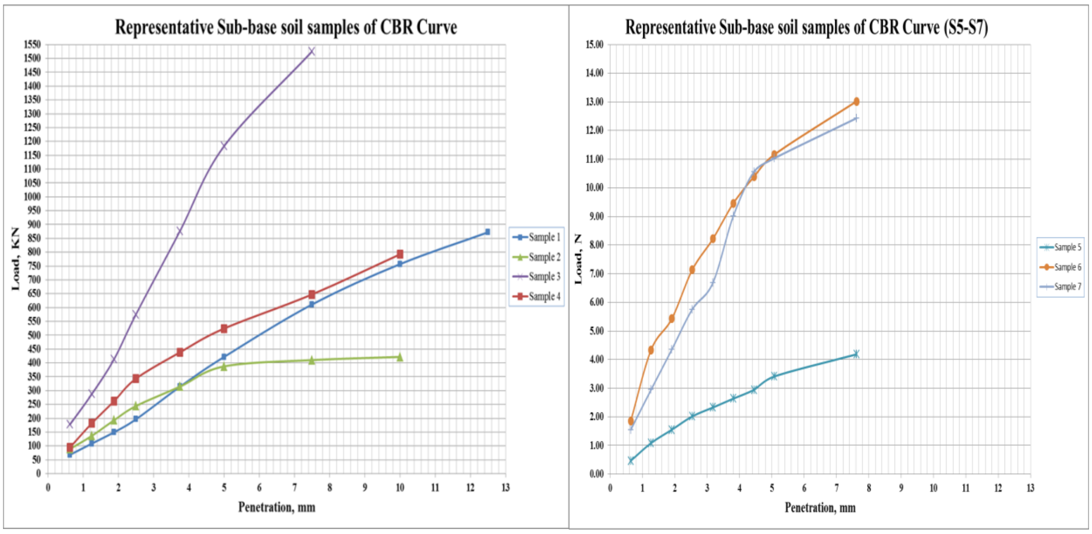

Figure4.7: California Bearing Ratio test graphs of sub-base soil samples

Table4.13: Ethiopian Road Authority Sub-base Material Specification for PI and CBR

Soil Type	Sub - base Material						
Station	07+400	15+700	28+200	37+300	45+040	51+100	63+150
Sample	1	2	3	4	5	6	7
PI ≤ 15	18.05	17.81	9.29	10.44	11.3	6.7	11.9
	Fail	Fail	Pass	Pass	Pass	Pass	Pass
CBR ≥ 30 %	7.0	19.4	60.2	26.4	17.02	55.8	55
	Fail	Fail	Pass	Fail	Fail	Pass	Pass

4.6.2 Comparison of selected fill soil materials

I. Sieve Analysis (Gradation)

The sieve analysis test results for selected fill material shown from laboratory test result. They are more or less within the limits of the specification. The specification limits are shown Table 5.1.but ERA, (2002) recommended grading criteria are not given for selected fill soil materials.

The result of the particle size analysis contained in Table 4.2 indicates that the soil's clay content for all selected fill samples ranged from 11.9 % to 22.8 %. According to the Federal Ministry of Works and Housing (1997) specification, the clay content for selected fill soil materials must not exceed 35%. The high clay content could be responsible for instability of road pavement in the area.so from test results for all selected fill materials are fulfilling the FMWH specification.

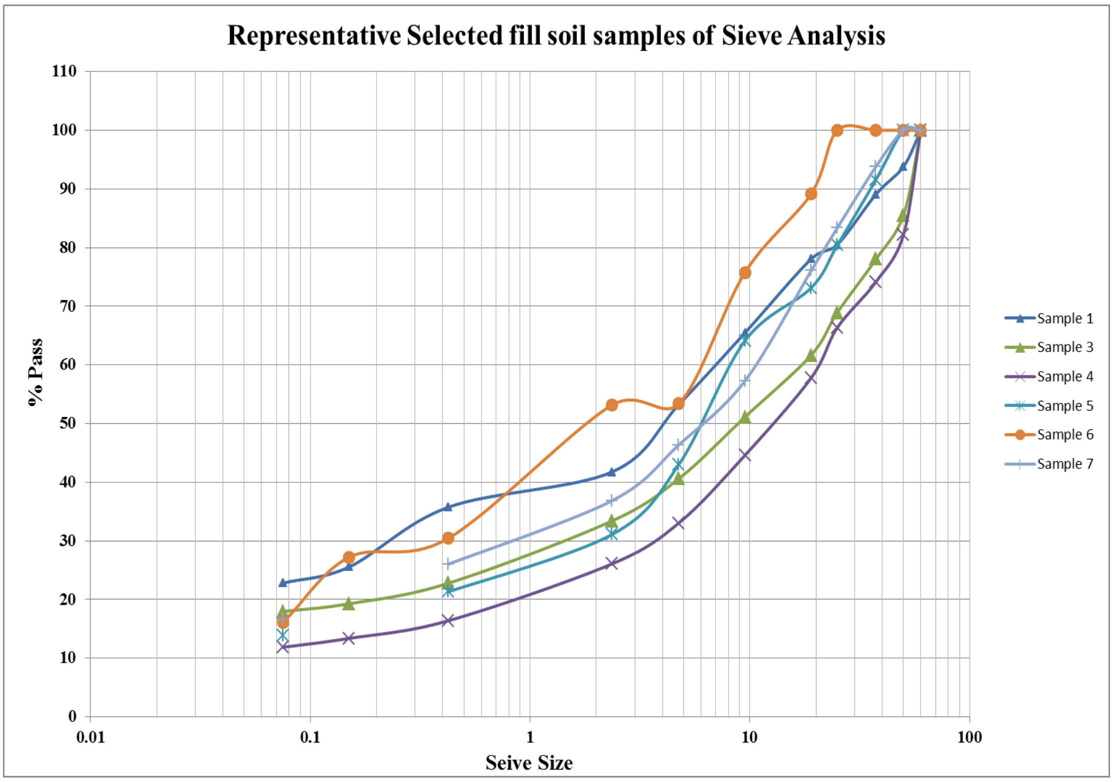

Figure4.8: Sieve Analysis graphs of selected fill soil samples

II. Atterberg Limits

- ✓ According to Ethiopian Road Authority (ERA), Addis Ababa – Dessie rehabilitation project material specification requirements. For selected fill material PI ≤ 25. All selected fill soil samples met these required specification.
- ✓ The Federal Ministry of Works and Housing (1997) specifications are liquid limits of 30% maximum, plastic limit of 30% maximum and plasticity index of 13% maximum for selected fill materials. From Table 4.3 shows that the liquid limit of the selected fill soils ranged from 27.6 % to 48.95 % while the plastic limit ranged from 15.8 % to 29.55 % and the plasticity index ranged from 11.2 to 20.5. None of the selected fill soil samples met these required specification except sample 7.

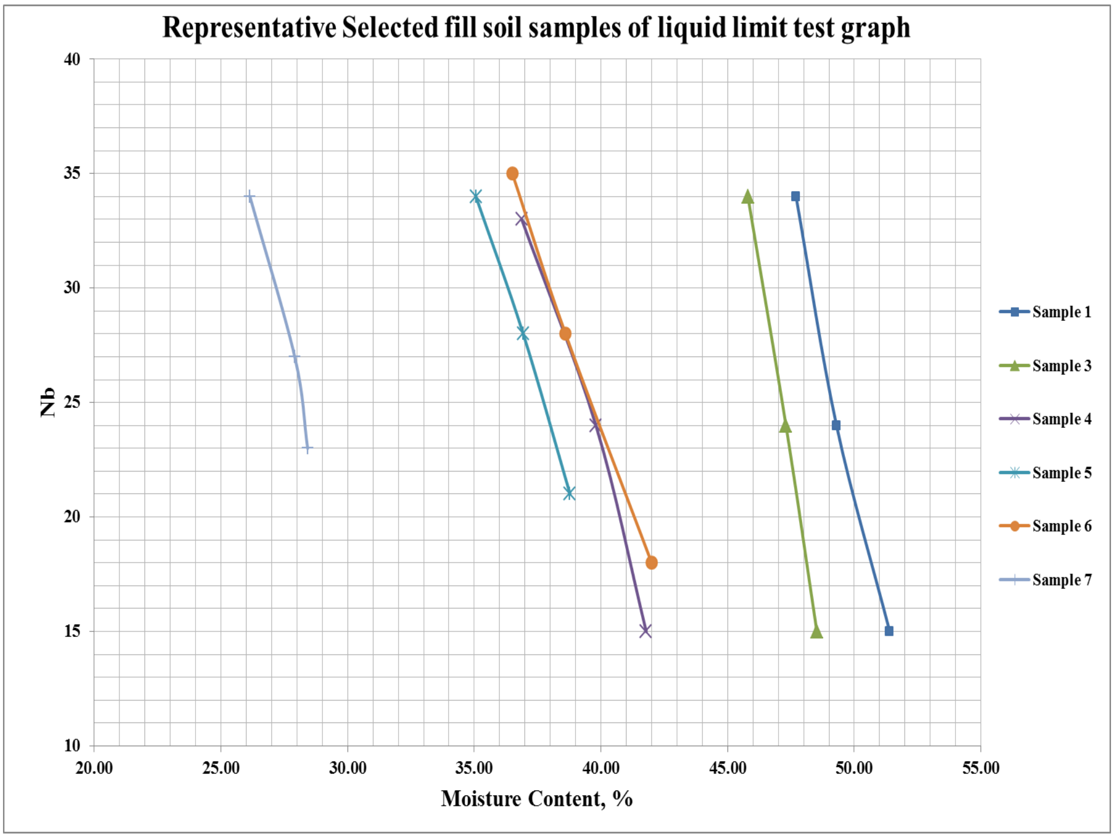

Figure4.9: Liquid limits test graphs of selected fill soil samples

III. Compaction Test

From Table 4.6, shows that the maximum dry density (MDD) of the selected fill soil materials ranged between 1.65 kg/m³ and 2.16 kg/m³, while the optimum moisture content (OMC) ranged from 9.4 % to 20.33 %. The Federal Ministry of Works and Housing, (1997) specified OMC less than 18% for selected fill soil materials. Based on these specifications, selected fill soil sample 1 are not suitable as selected fill material.

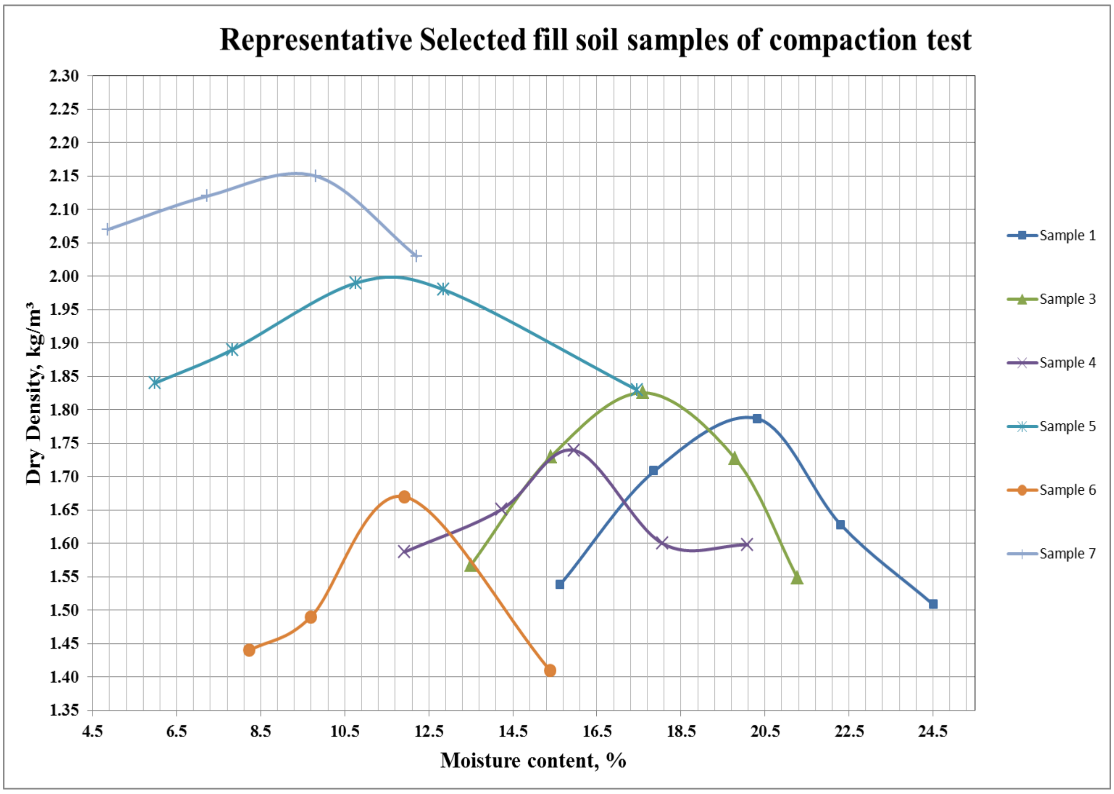

Figure4.10: Compaction test graphs of selected fill soil samples

IV. California Bearing Ratio

From Table 4.7, shows that the four days soaked CBR values of selected fill soil materials ranged from 13.9 % to 62 %. The Ethiopian Road Authority (ERA), Addis Ababa – Dessie rehabilitation project material specified CBR greater than or equal to 15 % for selected fill materials. Based on these specifications, selected fill soil sample 6 are not suitable as selected fill material.

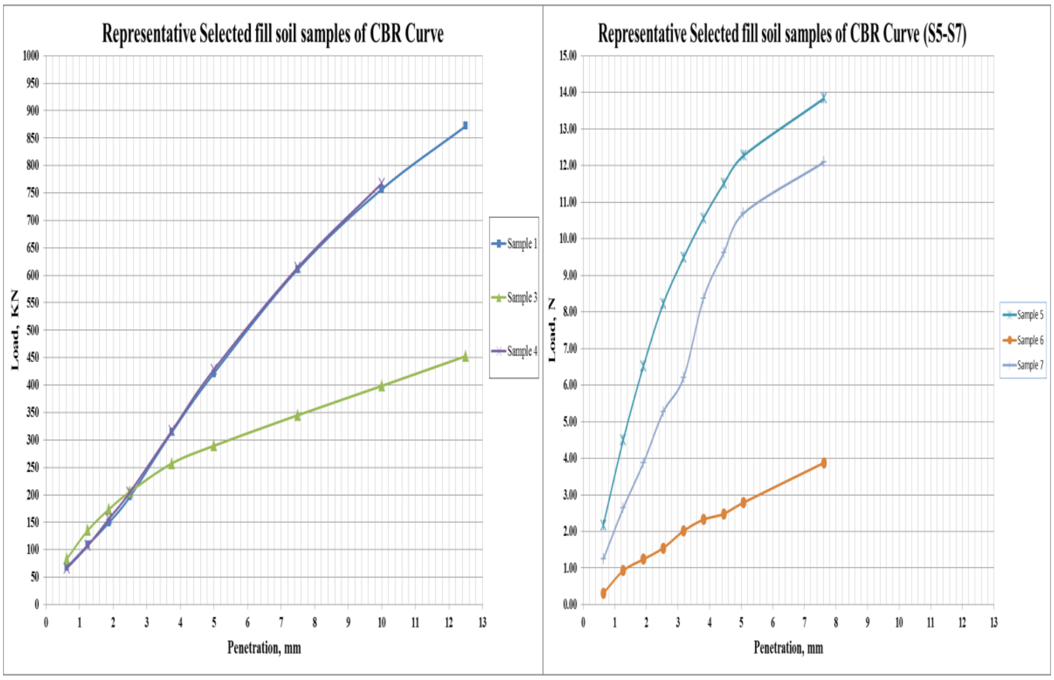

Figure4.11: California Bearing Ratio test graphs of selected fill soil samples

Table4.14: Ethiopian Road Authority Selected Fill Material Specification for PI and CBR

Soil Type	Selected Fill Material					
Station	07+400	28+200	37+300	45+040	51+100	63+150
Sample	1	3	4	5	6	7
PI ≤ 25	20.5	17.53	14.15	11.2	13.4	11.8
	Pass	Pass	Pass	Pass	Pass	Pass
CBR ≥ 15 %	22.3	15.1	21.3	62	13.9	53.2
	Pass	Pass	Pass	Pass	Fail	Pass

4.6.3 Comparison of Natural subgrade soil materials

a) Sieve Analysis (Gradation)

The result of the particle size analysis contained in Table 4.1 indicates that the soil's clay content for most natural subgrade samples ranged from 80.8 % to 84.3 % except for natural subgrade samples 1, 3 and 5 with clay content ranging from 17.8 % to 27.1 %. According to the Federal Ministry of Works and Housing (1997) specification, the clay content for natural subgrade soil materials must not exceed 35%. The high clay content could be responsible for instability of road pavement in the area. Based on these specifications, natural subgrade soil sample 2, 4 and 7 are not suitable as embankment. Also, general rating as sub-grade (in accordance with AASHTO (1986)) is fair to poor materials. They have significant constituent materials of mainly clayey soils while few are silty or clayey gravel and sand whereby the % passing № 200 sieve is <35%.

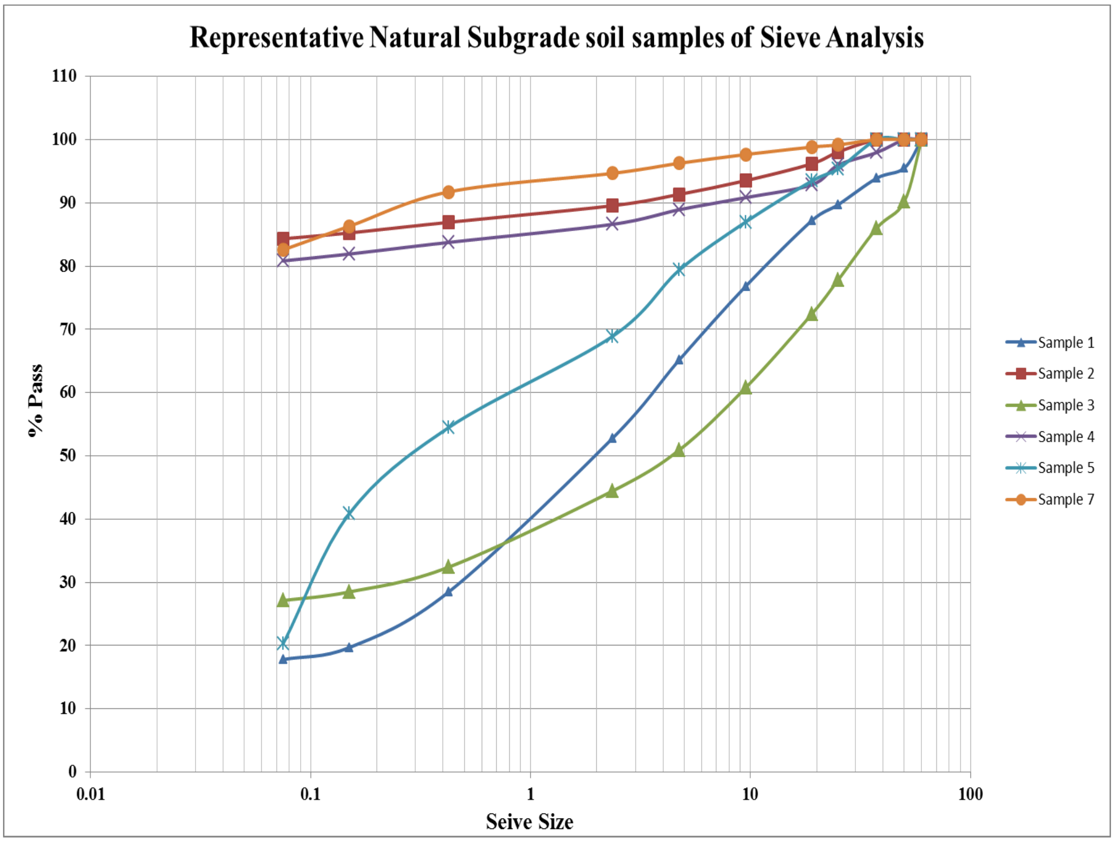

Figure4.12: Sieve Analysis test graphs of natural subgrade soil samples

b) Atterberg Limits

- According to Ethiopian Road Authority (ERA), Addis Ababa – Dessie rehabilitation project material specification requirements. For selected fill material PI ≤ 30. Based on these specification, natural subgrade soil sample 2, 4 and 7 are not met these required specification.
- Figure 4.16 shows the plasticity charts for natural subgrade soils in the study area. Soils with liquid limits <30% are considered to be of low plasticity and compressibility, those with liquid limits between 30% and 50% exhibit medium plasticity while those with liquid limits >50% exhibit high plasticity and compressibility. It follows therefore that, natural subgrade soil samples 1,

3, and 5 fall within the medium plasticity while 2, 4, and 7 fall within the high plasticity/compressibility of the plasticity chart.

- From the AASHTO soil classification of soil samples for highway, A-1, A-3,and A-2 soils are excellent to good soils for highway with percentage passing Sieve No. 200 not more than 35% while A-4 to A-7 soils are fair to poor soils with percentage passing Sieve No. 200 greater than 35%. Based on this, natural subgrade soil Samples 1, 3, and 5 may be classified as excellent to good sub-grade soils while the sample 2, 4, and 7 are fair to poor soils for sub-grade.

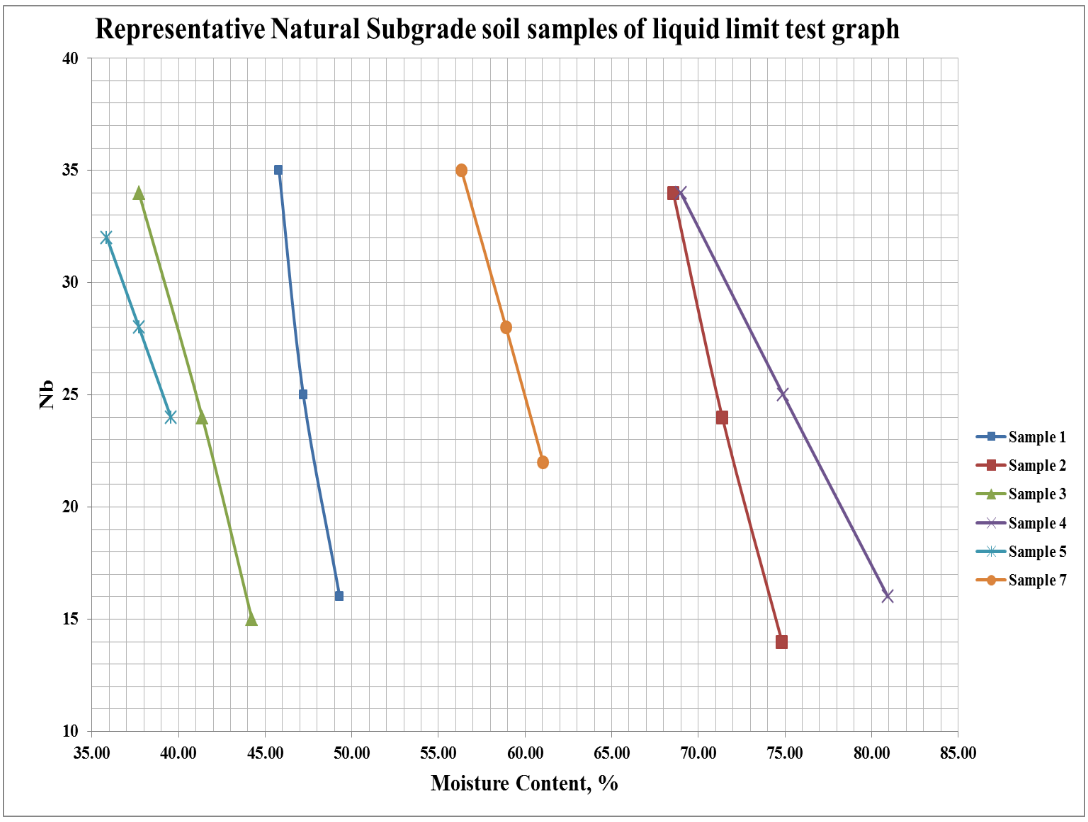

Figure4.13: Liquid limits test graphs of natural subgrade soil samples

c) Compaction Test

From Table 4.6, shows that the maximum dry density (MDD) of the natural subgrade soil materials ranged between 1.33 kg/m³ and 1.96 kg/m³, while the optimum moisture content (OMC) ranged from 12.78 % to 28.6 %. The Federal Ministry of Works and Housing, (1997) specified OMC less than 18% for natural subgrade soil materials. Based on these specifications, natural subgrade soil samples 1, 2, 4, and 7 are not suitable as subgrade (embankment) material. Natural subgrade Sample 3 could be suitable with a minimal soil modification.

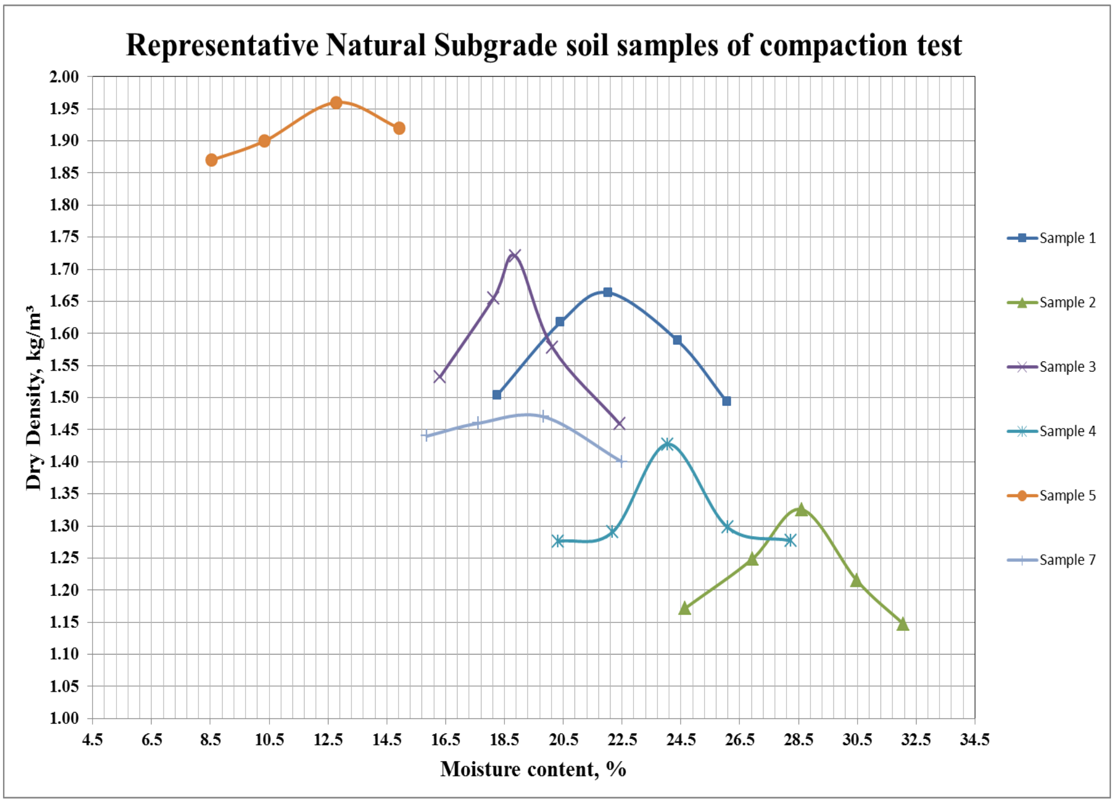

Figure4.14: Compaction test graphs of natural subgrade soil samples

d) California Bearing Ratio

From Table 4.7, shows that the four days soaked CBR values of natural subgrade soil materials ranged from 3 % to 50.58 %. The Ethiopian Road Authority (ERA), Addis Ababa – Dessie rehabilitation project material specified CBR greater than or equal to 5 % for natural subgrade materials. Based on these specifications, natural subgrade soil samples 2, 4, and 7 are not suitable as subgrade material.

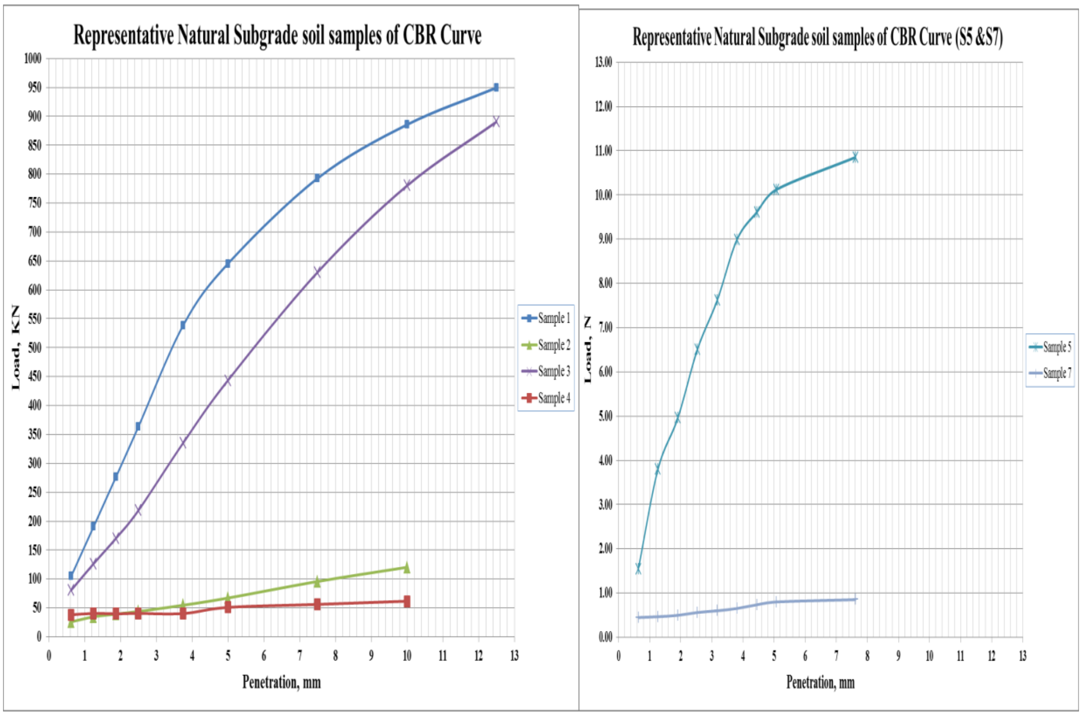

Figure4.15: California Bearing Ratio test graphs of natural subgrade soil samples

Table4.15: Ethiopian Road Authority Natural Subgrade Material Specification for PI and CBR

Soil Type	Natural Subgrade Material					
Station	07+400	15+700	28+200	37+300	45+040	63+150
Sample	1	2	3	4	5	7
PI ≤ 30	18.35	33.05	18.19	49.25	16.85	34.1
	Pass	Fail	Pass	Fail	Pass	Fail
CBR ≥ 5 %	31.7	3.3	22.1	3	50.58	4.21
	Pass	Fail	Pass	Fail	Pass	Fail

4.7 Drainage Conditions

During site investigation, observations has been made in areas of poor drainage some failed sections or pavement damages were existed. The problems encountered are related to water from rain or/and water from showering of pavement layers. At the road sections where pavement damage has occurred, the drainage conditions are not good and they are areas where pounding of water at the toe of the shoulder is prevalent during rainy seasons.

The pavement design and construction practice must be modified in such a way to have structural pavement layers capable of draining free water rapidly after its entry. Such rapid drainage can be achieved by providing highly permeable layers of open graded material with collector pipes to ensure constant gravity drainage. Surface and sub-surface drainages not only protect pavements from large surface inflow, but also from inflows of high ground water in wet periods or any unexpected inflows.

Figure4.16: Drainage problem in Harbu town

4.9 Observations and proposed remedial measures

To give different types of maintenance types for individual different type of pavement damages in the case study road sections are as follows;

a. Sample one

- ❖ Distress type: Raveling damaged

- Repair: A raveled pavement should be investigated to determine the root cause of failure. Repair strategies were large reveled area indicative of general pavement failure. Therefore, to remove the damaged pavement and overlay.

b. Sample Two

- Distress type: Transverse Crack
- Repair: strategies depend upon the severity and extent of the cracking, so in this case low severity cracks. Cracks seal to prevent entry of moisture into subgrade through the cracks and further ravelling of the crack edges.

c. Sample Three

- Distress type: patches
- Repair method: patches are themselves a repair action. The only way they can be removed from a pavement's surface is either a structural or non-structural overlay.

d. Sample Four

- Distress type: transverse depression
- Repair method: A pavement depression should be investigated to determine the root cause of failure (i.e subgrade settlement). Depression repaired by removing the affected pavement then digging out and replacing the area of poor subgrade. Then patch over the repaired subgrade.

e. Sample Five
    - Distress type: shoving
    - Repair method: for small, localized area of shoving to remove the distorted pavement and patch.

f. Sample Six
    - Distress type: rutting
    - Repair method: pavement with ruts should be levelled and overlaid.

g. Sample Seven
    - Distress type: potholes/ debonding
    - Repair method: in accordance with patching techniques

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on valuable tests carried out on the soil samples from failed sections in the study area showed that:

1. To find out the real cause of pavement damaged related to sub-base and subgrade soil pavement layer properties was conduct different laboratory test. Such as; sieve analysis (Wet method) to check the soil layer grain size distribution, Atterberg limit (LL and PL test) to find out the plasticity index of their soil, Compaction test (Modified) to get MDD and OMC of the soil and finally California Bearing Ratio test to check the soil strength and stability. The soaked CBR values of natural subgrade soil materials are between 3%-50.58%. The sub-base soil materials are almost less amount of clay contents in the soil sample, and also the values of PI (6.7- 18.05), MDD (1.74kg/m^3- 2.25 kg/m^3), and soaked CBR values ranged from (7%- 20.71%). And also selected fill materials have clay contents range from 11.9%- 22.8%, PI values ranged from11.2-20.5 and soaked CBR values ranged from 13.9%- 62%.
2. The laboratory results showed that the soil materials used along the road have high percentage clayey material for half of the natural subgrade soil sample (rated as fair to poor materials for road use) and low percentages of clayey and silt/gravel/sand materials of sub-base and selected fill soil samples. The OMC are almost high for all the soil samples the exception of few samples. The Plasticity Indices and Liquid limits are very high for all Sub-base, selected fill and natural subgrade soil samples with the exception of few samples. Most of CBR values for the selected fill soil materials almost meet specification requirements while that of Sub-base and natural Subgrade soil - materials almost did not meet the specification requirements with the exception of few samples. . Based on these comparison the soil materials are poor quality at a station for; Sub-base: (1, 2, 4, 5 & 7), for Selected fill: (only 6), for Natural subgrade: (2, 4, & 7).Conclusively, the pavement failure may necessarily be due to weak/ poor soil pavement layer performance in the different failed location.

3. To apply different remedial maintenance type for individual different pavement damaged sections/stations. Such as;

I. For surface and deformation type of damage: patching type of maintenance are applied

II. For crack type of damage: crack sealing type of maintenance are applied

5.2 RECOMMENDATION

In Kemise – Dessie road project, based on the conclusion made above, the appropriate recommendations of the existed failed road.

A. The sub-base with suitable or good quality materials of minimum group classification of A-2-4 or A-2-5, for all the failed segments of the road should be used in replacement of unsuitable materials earlier used and must be compacted to the required minimum density.

B. Also it is of essence to make use of good stabilizing agent for the subgrade soil due to the type of clayey soils used for it. Any materials to be used for the road rehabilitation must be in strict compliance with the specified values.

C. Adequate drainage system should also be provided to sustain the lifespan of the road.

D. Low severity rate of different pavement damages should be maintain periodically to prevent the increment of road severity and to reduce maintenance cost.

E. The future plan for upgrading or re- construct in the case study road geosynthetics should have made to construct roads and pavements in seemingly difficult situations for example like sample 2, 4, and 7 have poor natural subgrade soil materials.

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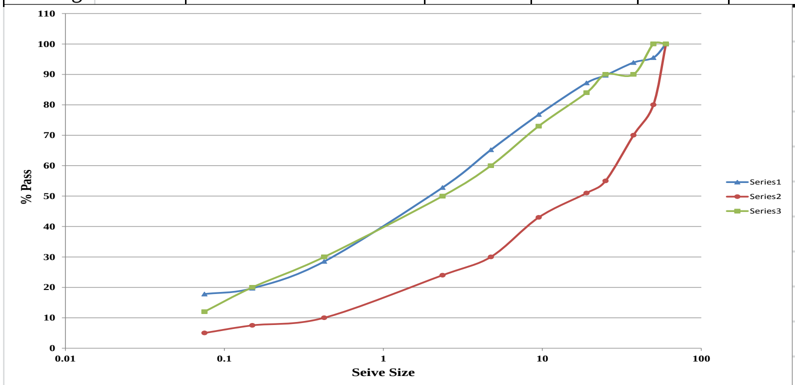
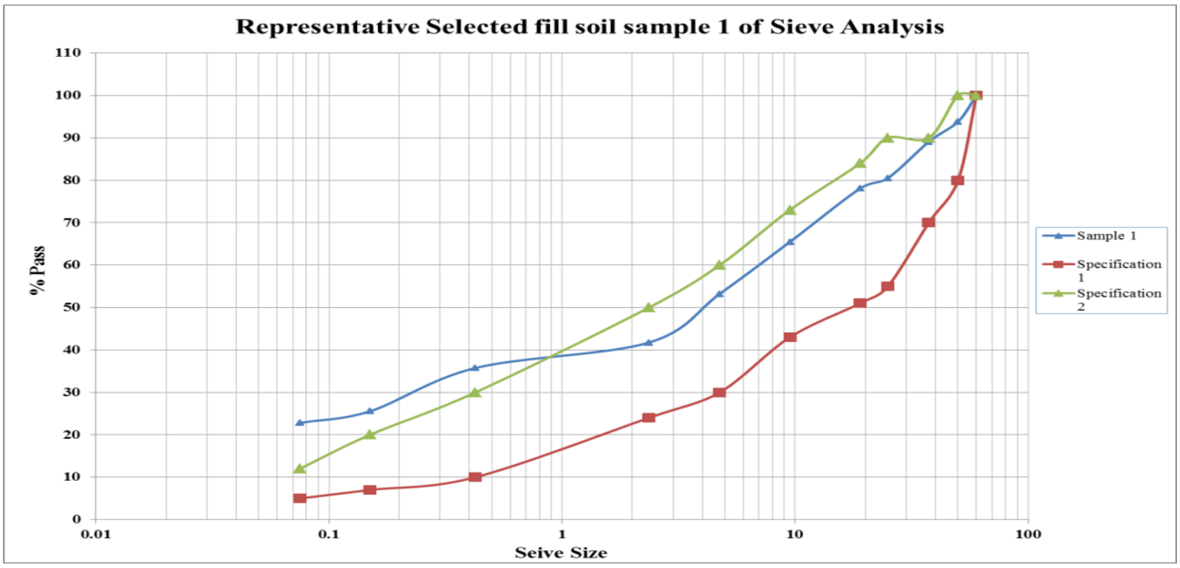
APPENDICES

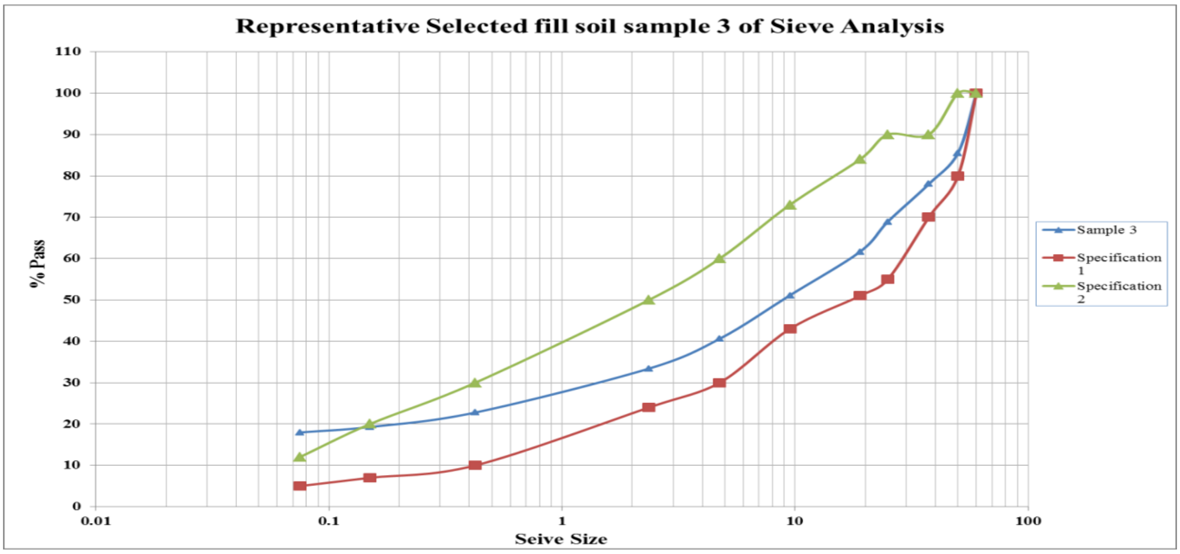
APPENDIX A

Representative Percentage Pass (No. 200 Sieve) VS. Sieve Size

This test result used only for thesis purpose for Mr. Siraj							
DETERMINATION OF SIEVE ANALYSIS							
Standard No							
Laboratory Code No							
Research Place	Kemise to Dessie Roadway						
Laboratory tested in project place	AWASH-KOMBOLCHA-HARA GEBEYA					Date of specimen Ac	28.05.2016
	RAILWAY PROJECT					Date of Test Start	01.06.2016
Sample Information	Sample 1: Natural subgrade					Date of Test Result	02.06.2016
Sieve Size, mm	Weight Retained, g	% Retained	% Passing	% Specification Passing		Before	2201
60	0	0	100	100	100	After	1583.5
50	100	4.5	95.5	80	100		
37.5	35.5	1.6	93.9	70	90	Method of Sieving are Wet	
25	93.5	4.2	89.7	55	90		
19	56	2.5	87.2	51	84		
9.5	230	10.4	76.8	43	73		
4.75	254.5	11.6	65.2	30	60		
2.36	272	12.4	52.8	24	50		
0.425	534.5	24.3	28.5	10	30		
0.15	194.5	8.8	19.7				
0.0075	41	1.9	17.8	5	12		
pan	389.5	2.5	0				
Dry Weight Before Washing	2201						




Representative Selected fill soil sample 1 of Sieve Analysis
% Pass
Seive Size
Sample 1
Specification 1
Specification 2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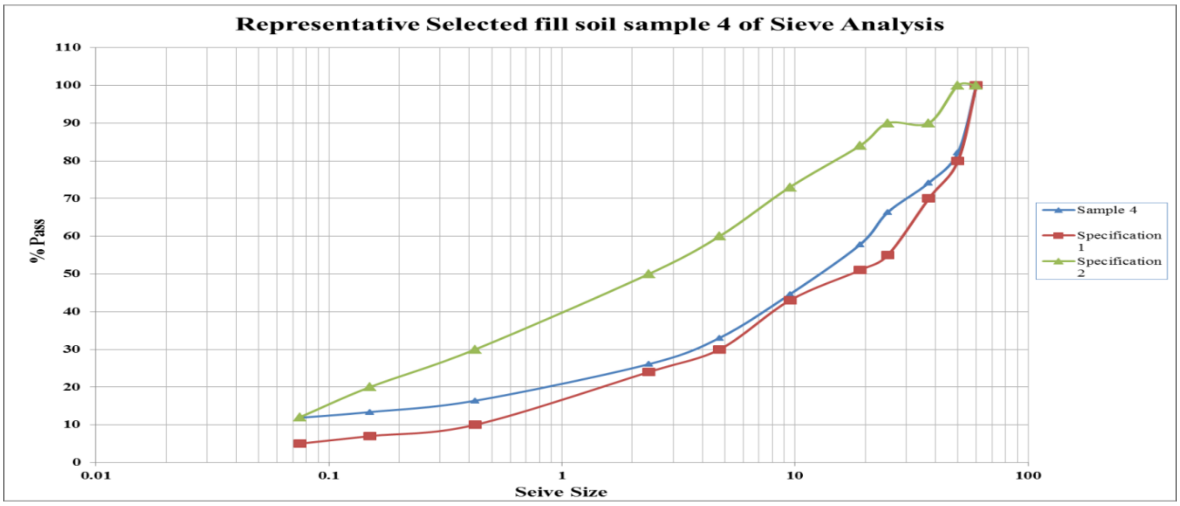
% Pass
Seive Size
Sample 3
Specification 1
Specification 2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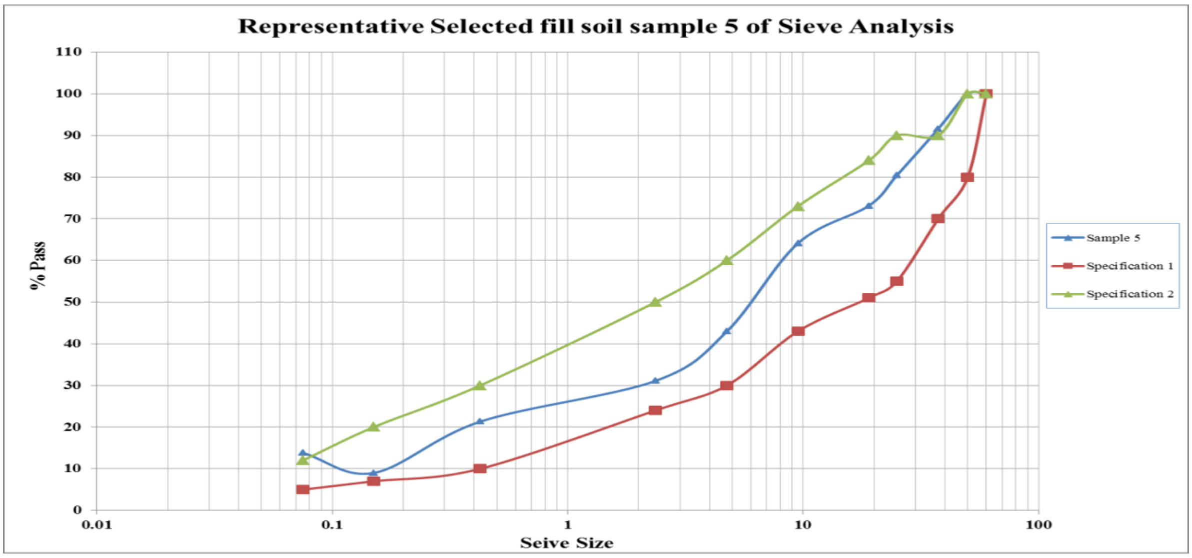
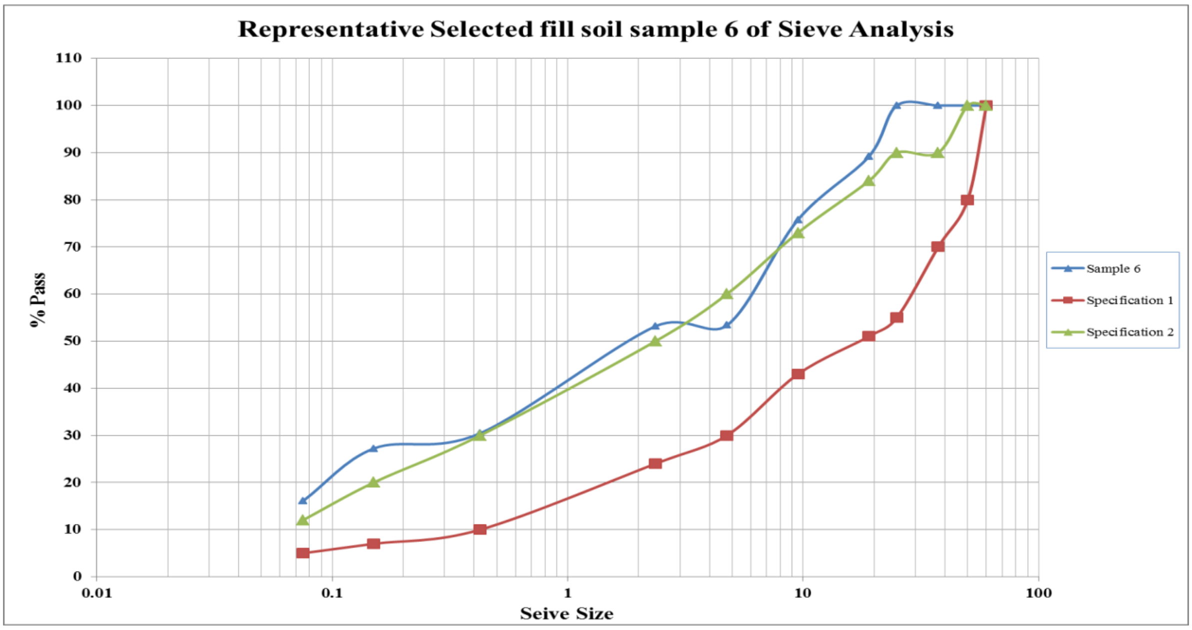
% Pass
Seive Size
Sample 4
Specification 1
Specification 2


Representative Selected fill soil sample 5 of Sieve Analysis
% Pass
Seive Size
0
10
20
30
40
50
60
70
80
90
100
110
0.01
0.1
1
10
100
Sample 5
Specification 1
Specification 2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% Pass
Seive Size
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70
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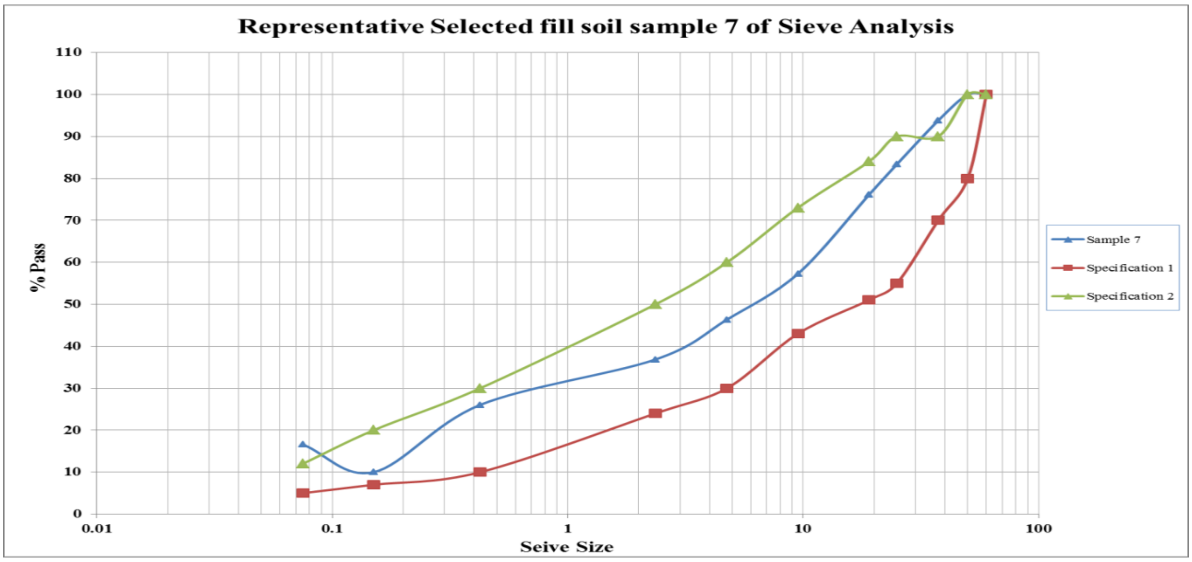
0.1
1
10
100
Sample 6
Specification 1
Specification 2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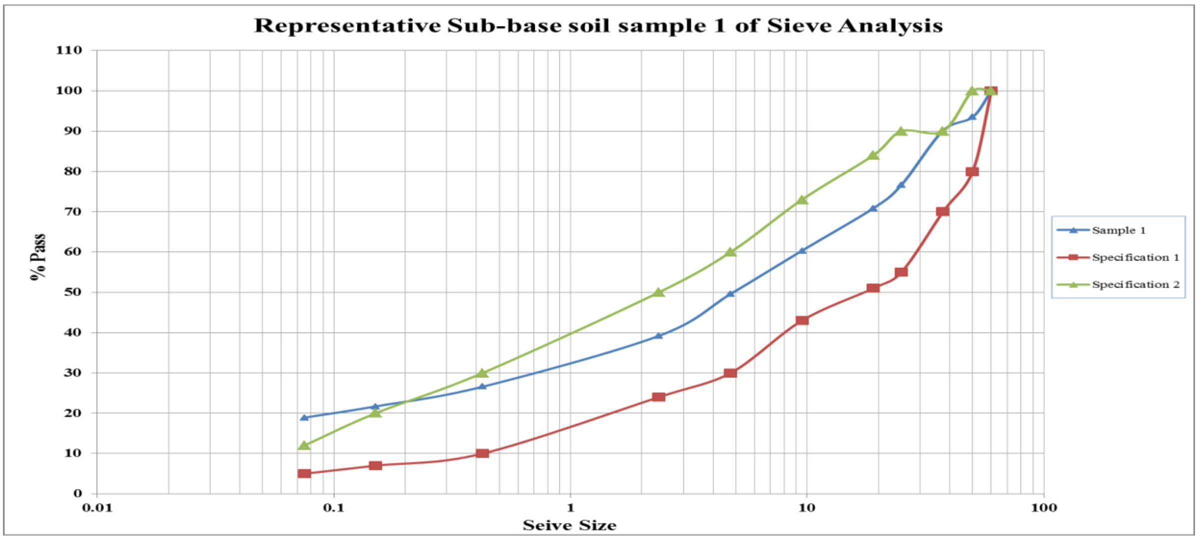
% Pass
Seive Size
Sample 7
Specification 1
Specification 2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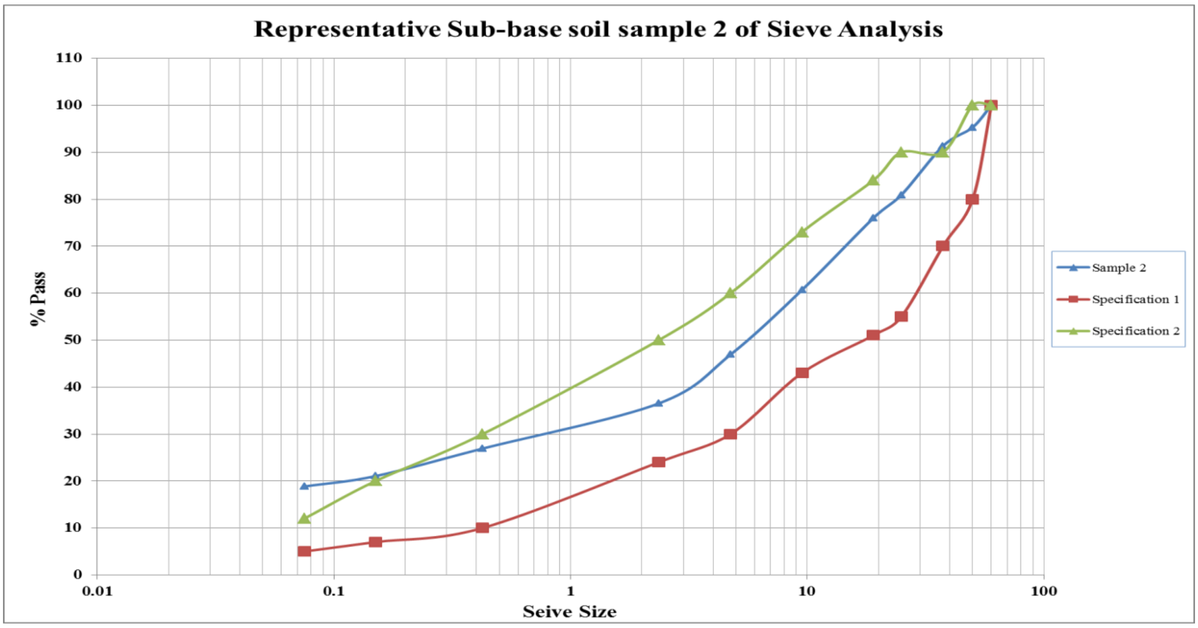
% Pass
Seive Size
Sample 1
Specification 1
Specification 2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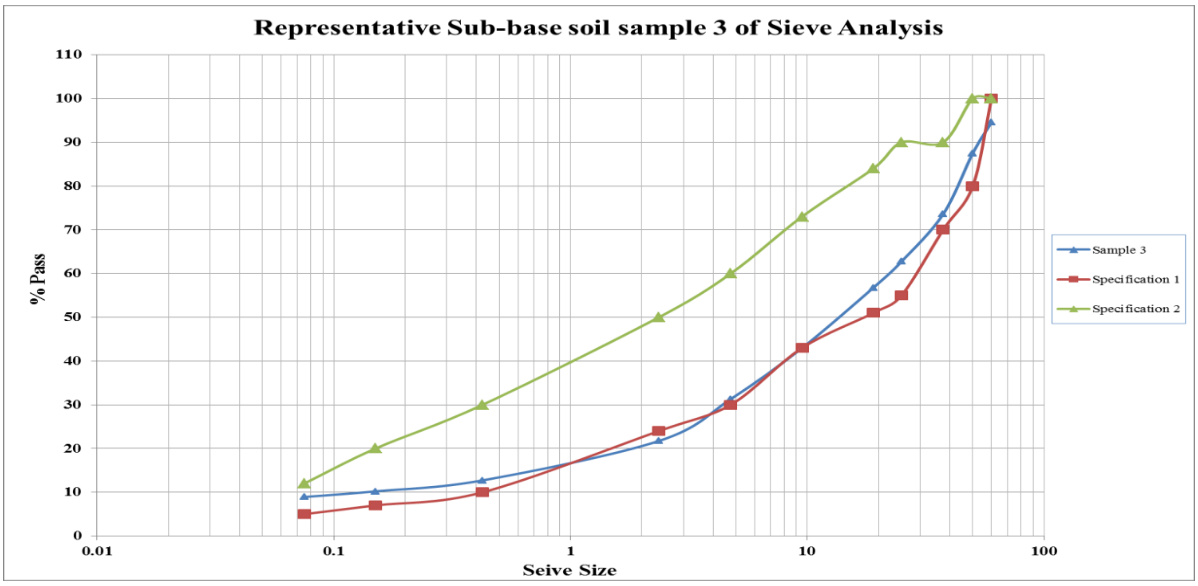
% Pass
Seive Size
Sample 2
Specification 1
Specification 2


Representative Sub-base soil sample 3 of Sieve Analysis
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100
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70
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50
40
30
20
10
0
% Pass
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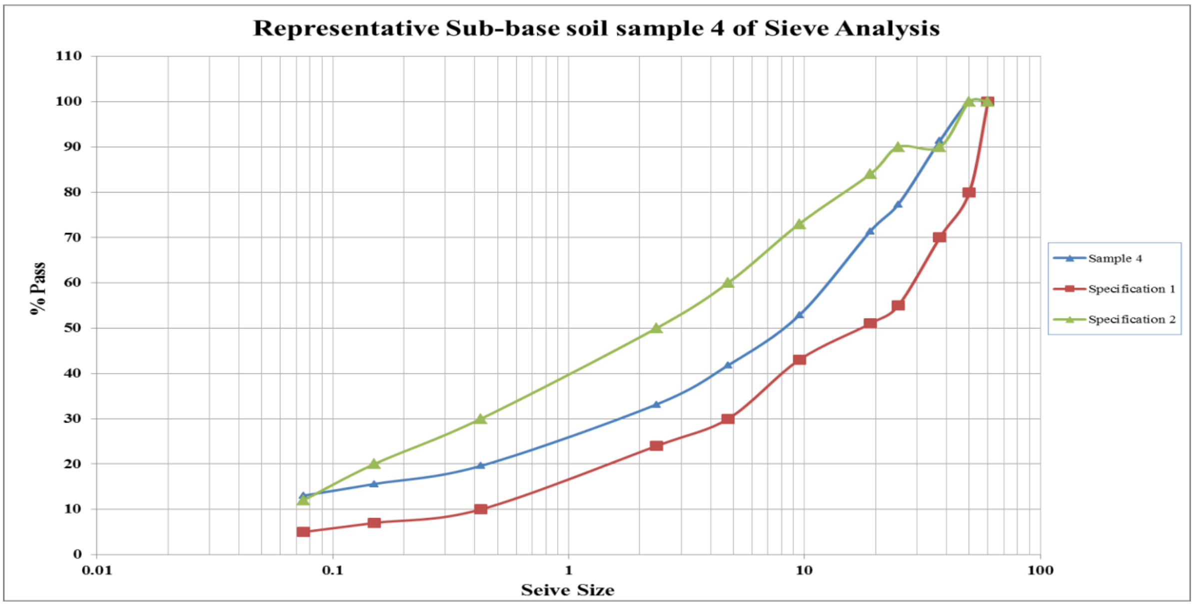
0.1
1
10
100
Seive Size
Sample 3
Specification 1
Specification 2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100
90
80
70
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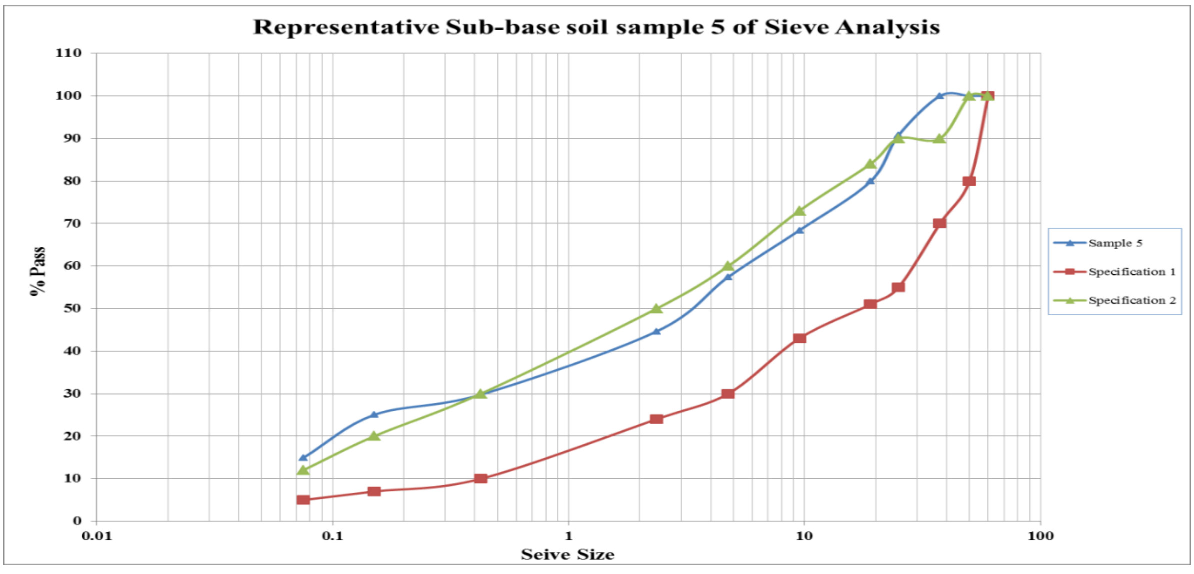
1
10
100
Seive Size
Sample 4
Specification 1
Specification 2


Representative Sub-base soil sample 5 of Sieve Analysis
110
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70
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20
10
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% Pass
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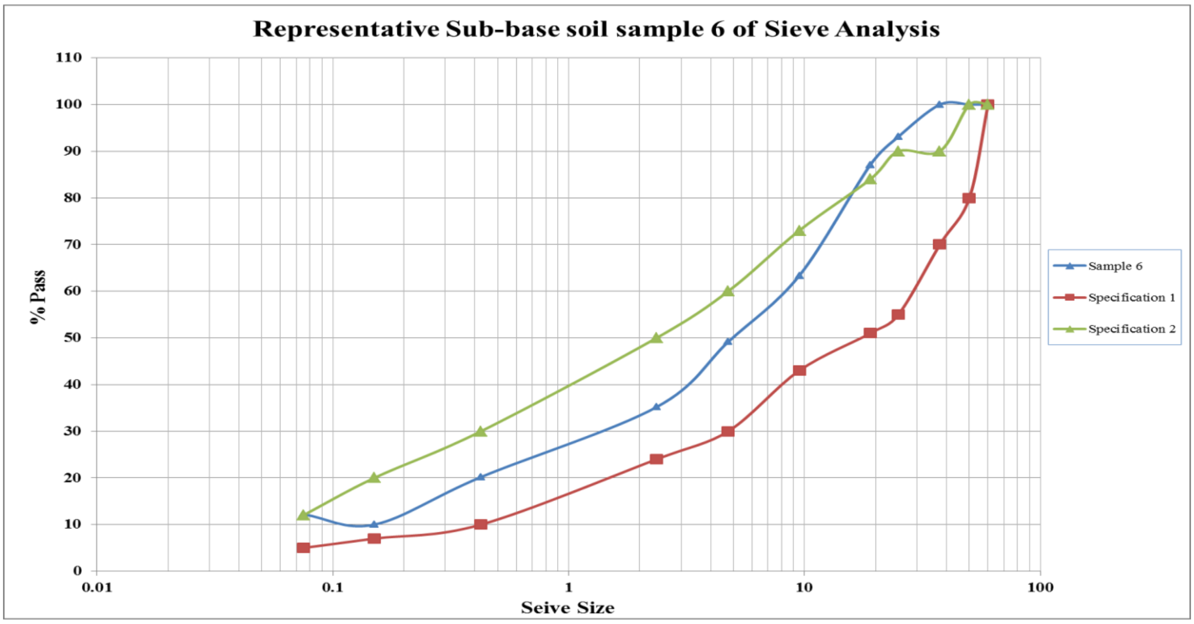
10
100
Seive Size
Sample 5
Specification 1
Specification 2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% Pass
Seive Size
Sample 6
Specification 1
Specification 2
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40
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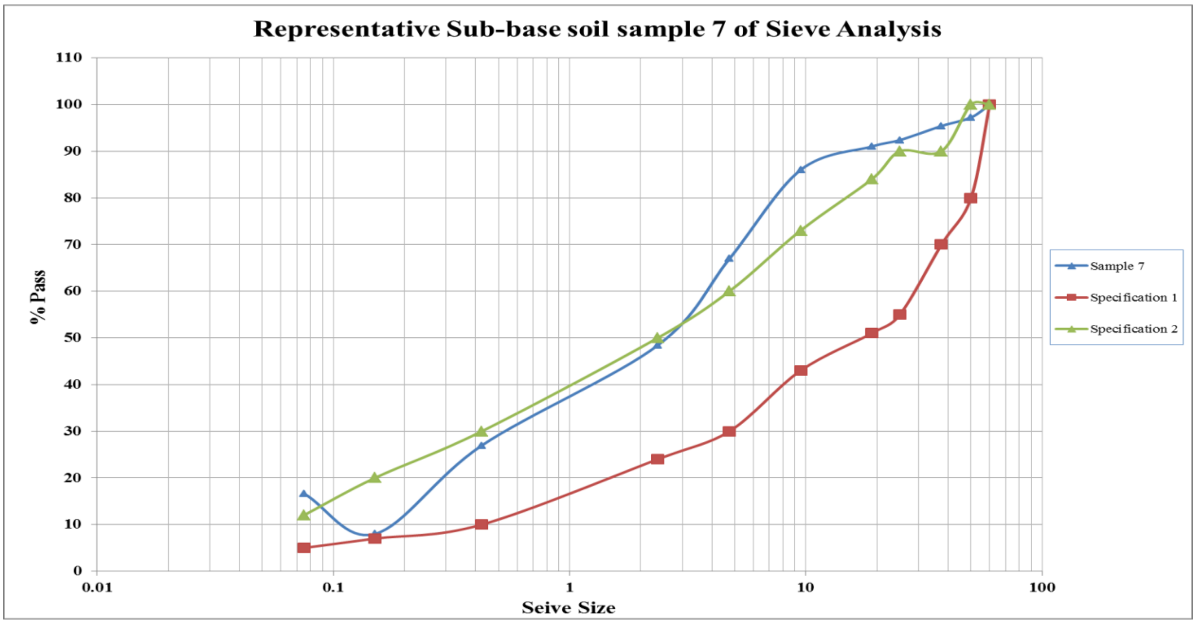
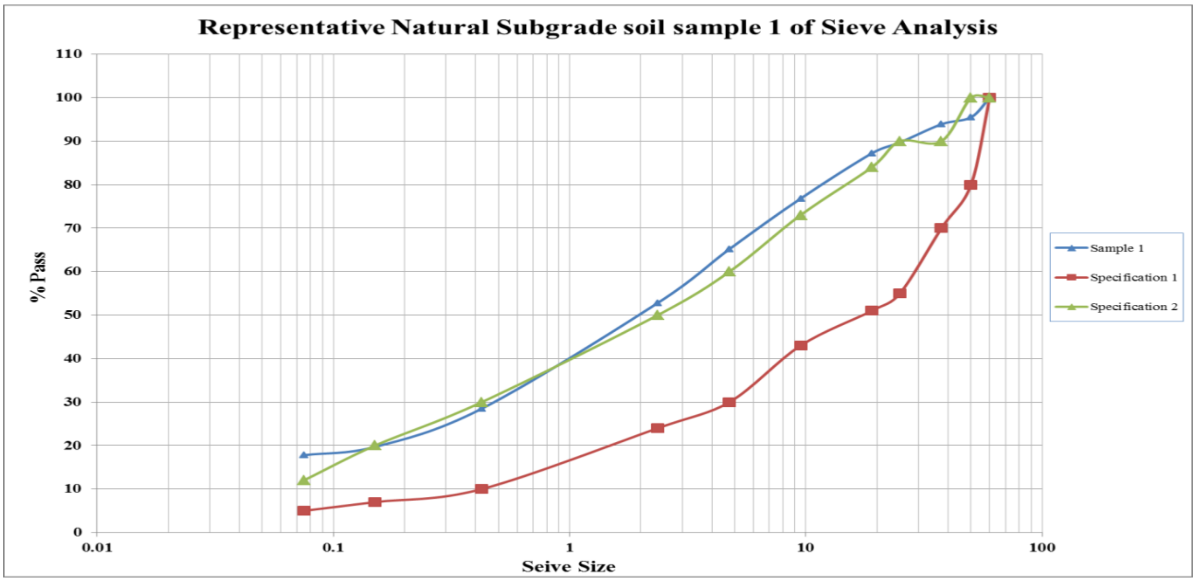
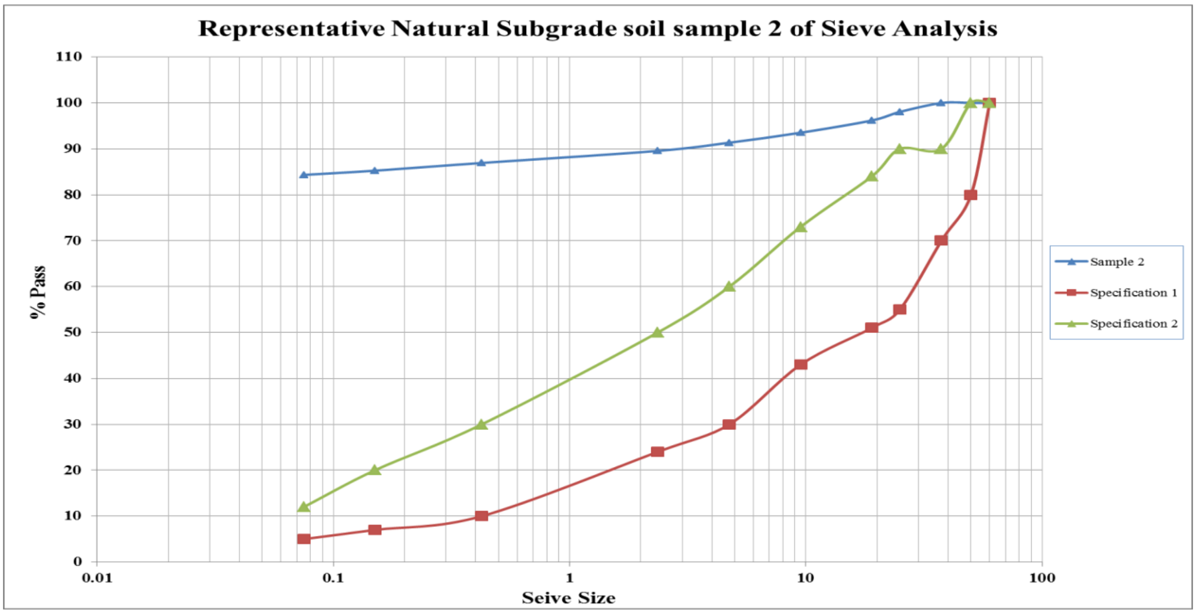
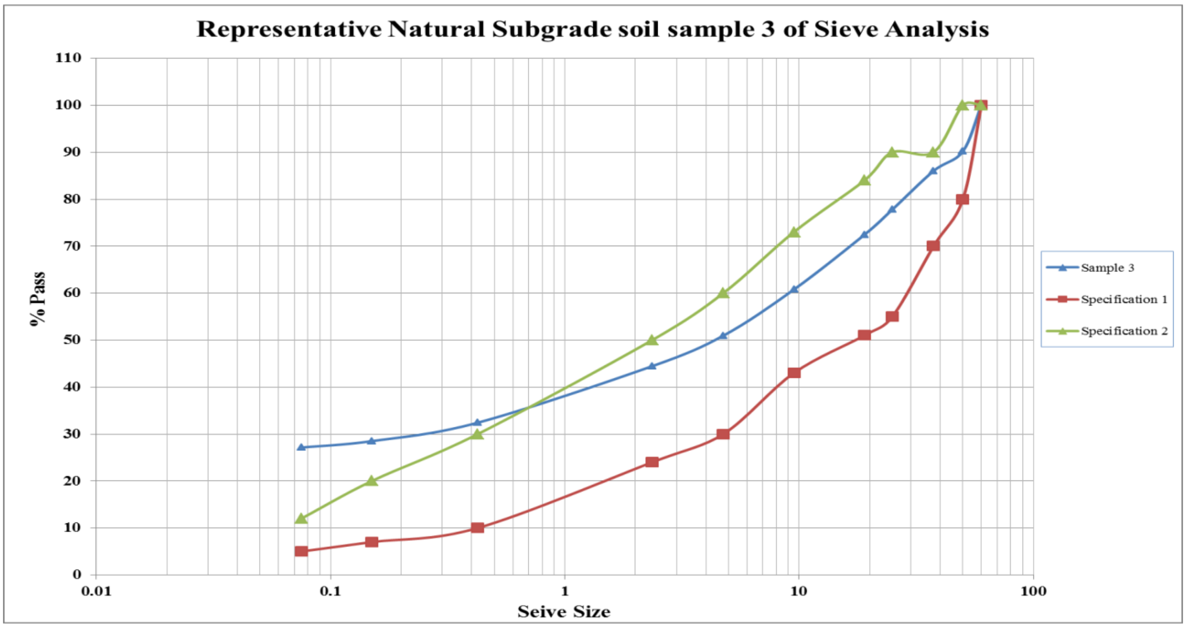
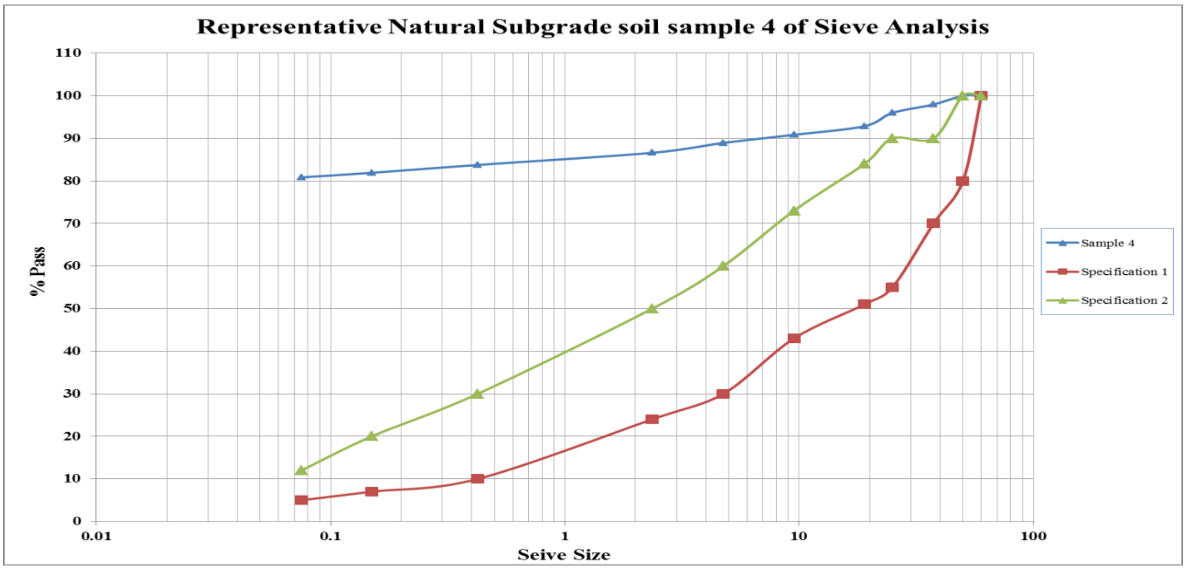
20
10
0
0.01
0.1
1
10
100

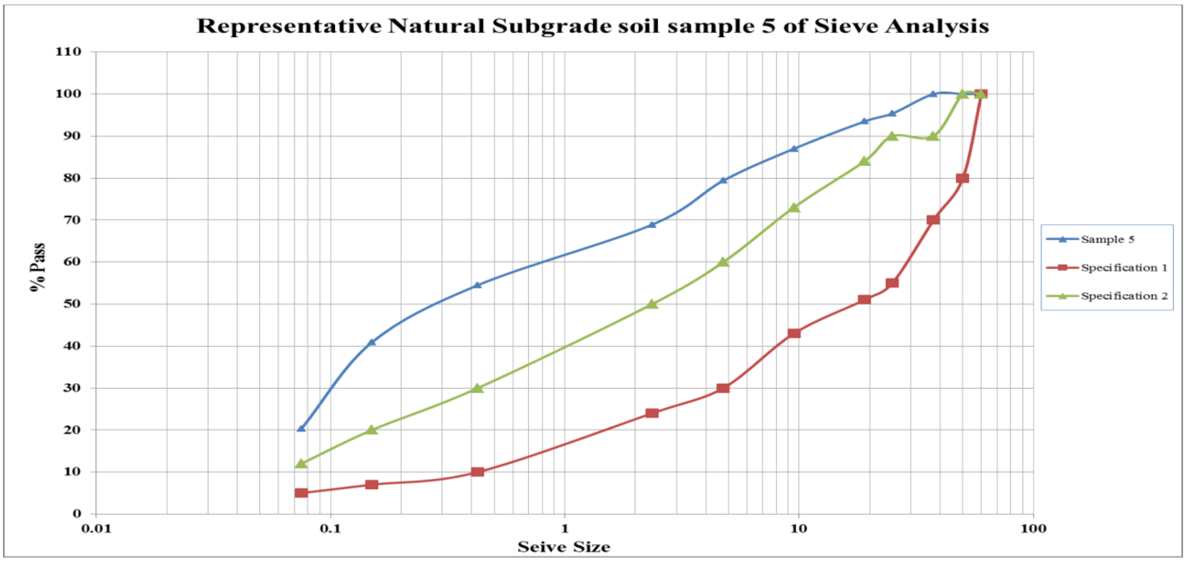

Representative Sub-base soil sample 7 of Sieve Analysis
% Pass
Seive Size
Sample 7
Specification 1
Specification 2
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100

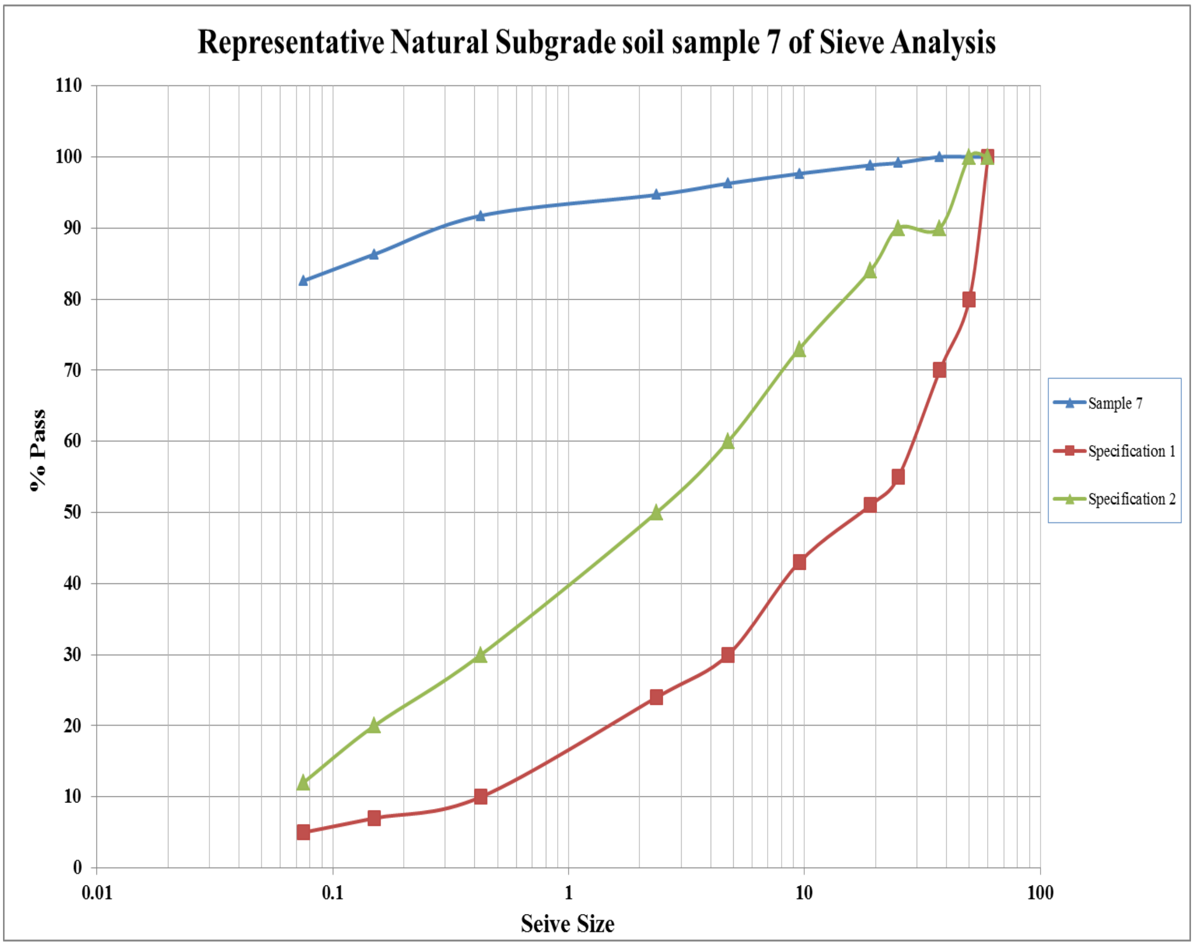

Representative Natural Subgrade soil sample 1 of Sieve Analysis
% Pass
Seive Size
Sample 1
Specification 1
Specification 2


Representative Natural Subgrade soil sample 2 of Sieve Analysis
% Pass
Seive Size
Sample 2
Specification 1
Specification 2


Representative Natural Subgrade soil sample 3 of Sieve Analysis
% Pass
Seive Size
Sample 3
Specification 1
Specification 2


Representative Natural Subgrade soil sample 4 of Sieve Analysis
% Pass
Seive Size
Sample 4
Specification 1
Specification 2


Representative Natural Subgrade soil sample 5 of Sieve Analysis
% Pass
Seive Size
Sample 5
Specification 1
Specification 2


Representative Natural Subgrade soil sample 7 of Sieve Analysis
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Sample 7
Specification 1
Specification 2

APPENDIX B
Representative Moisture Content VS. No. of blow

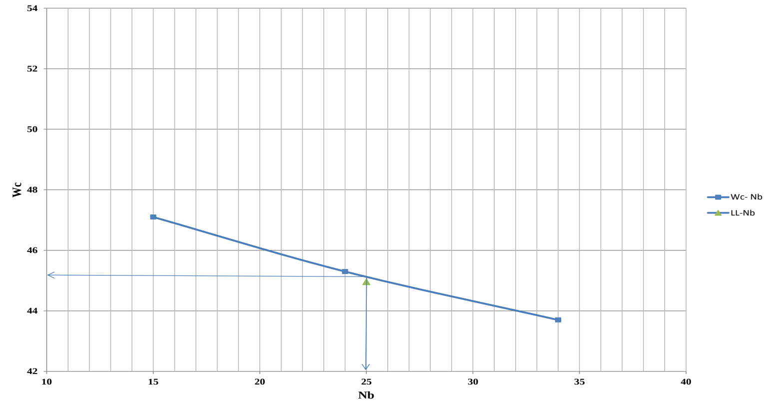
DETERMINATION OF ATTERBERG LIMIT

Standard No: ASSHTO T- 89 & T- 90

Laboratory Code No			
Research Place	Kemise to Dessie Roadway		
Laboratory tested in project place	**AWASH-KOMBOLCHA-HARA GEBEYA**	Date of specimen Accept	**03.06.2016**
	RAILWAY PROJECT	Date of Test Start	**20.06.2016**
Sample Information	**Sample 2 Sub- base Material**	Date of Test Result	**21.06.2016**

LIQUID LIMIT

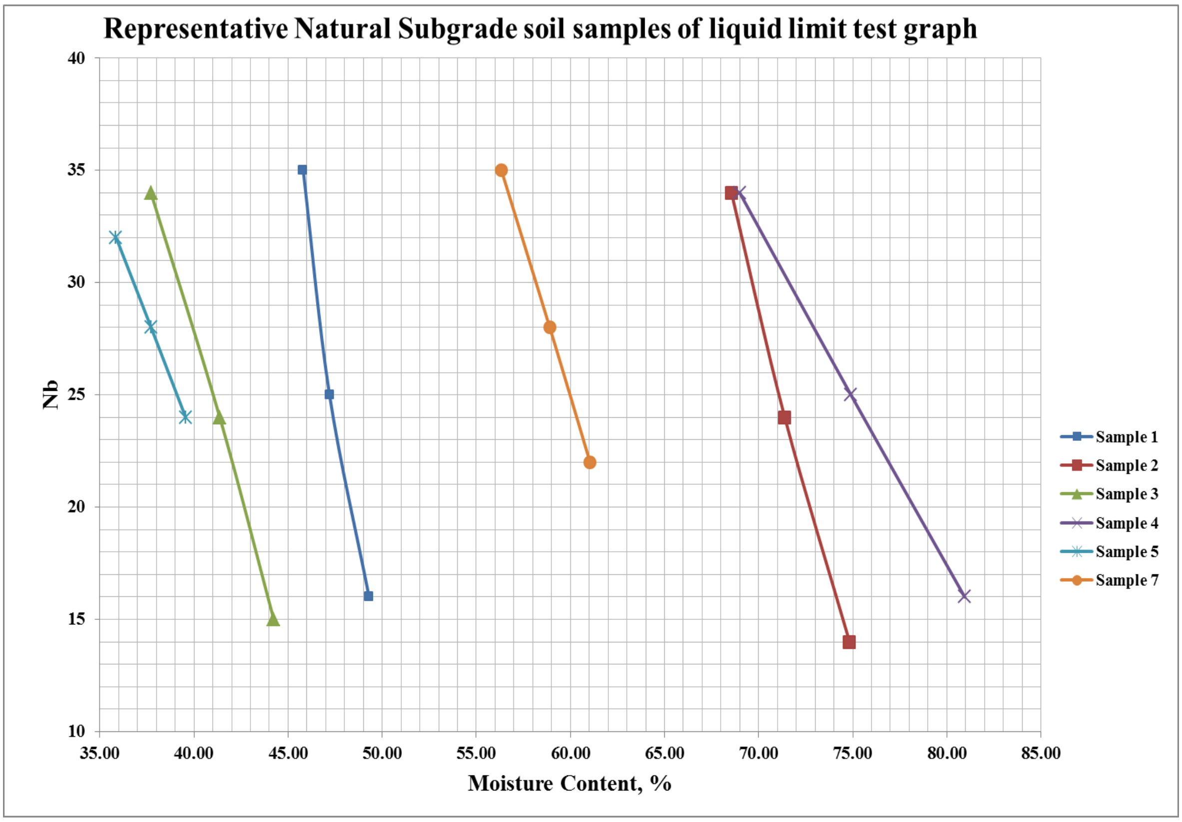
Container No	39	12	59
Weight of Wet Soil + Container, g	45.364	42.891	44.457
Weight of Dry Soil + Container, g	36.875	34.752	35.58
Weight of Water	8.489	8.139	8.877
Weight of Container	17.449	16.785	16.75
Weight of Dry Soil, g	19.426	17.967	18.83
Water Content, %	43.7	45.3	47.1
No. of Blows	34	24	15

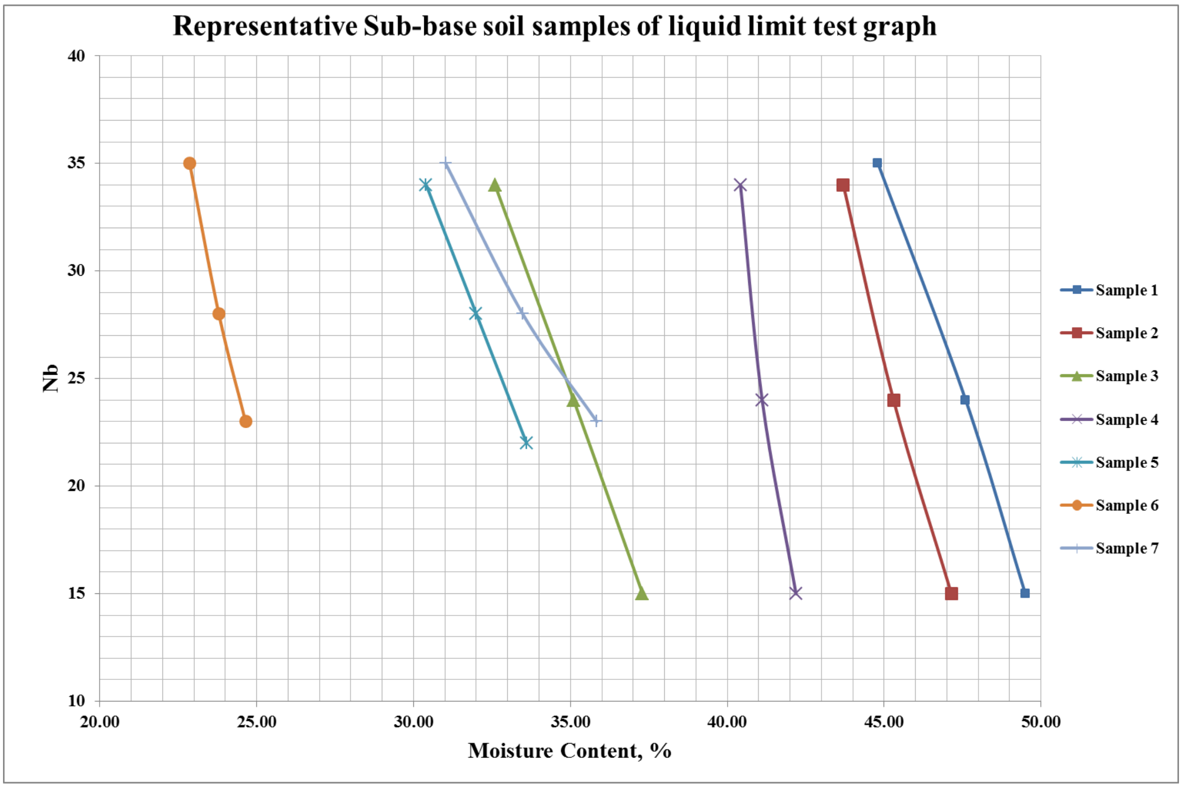


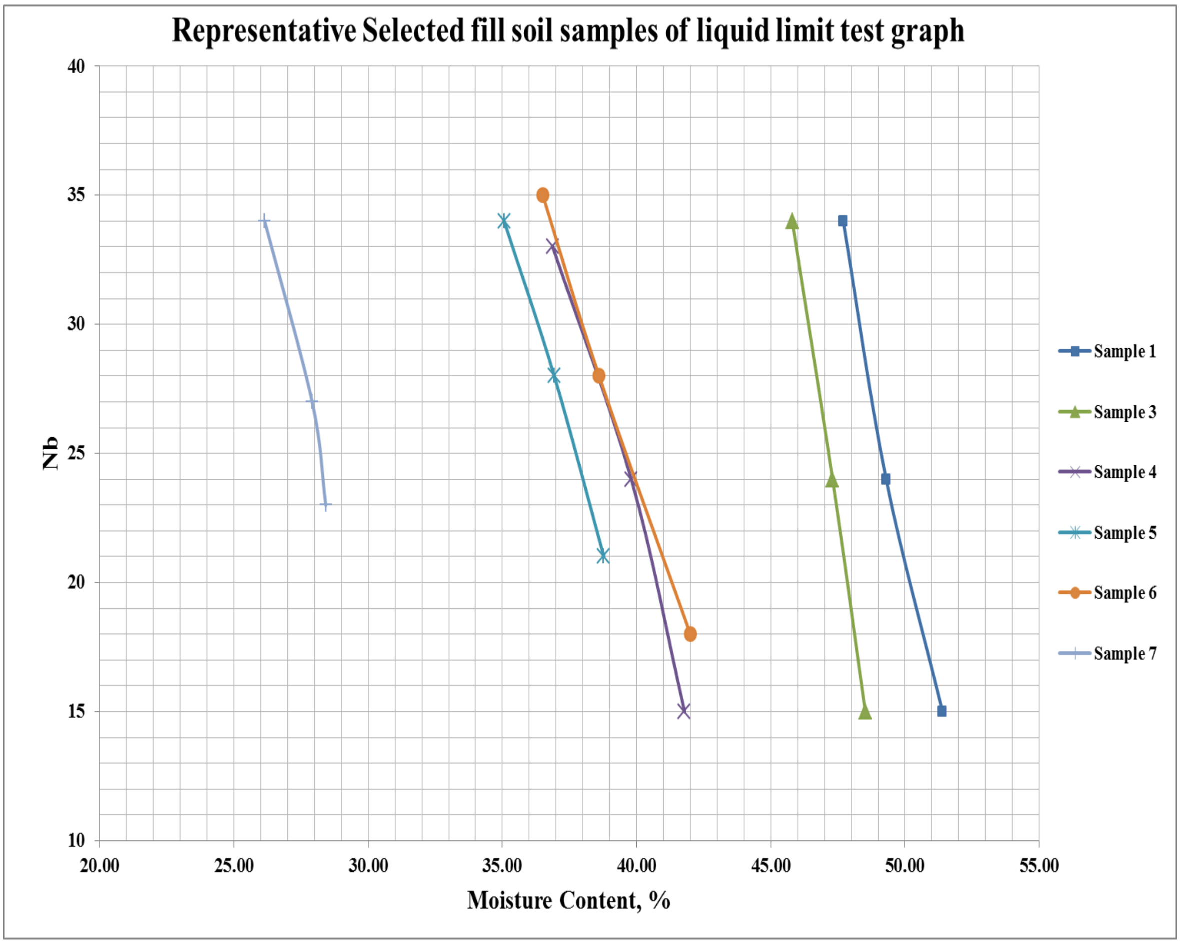
Sample Preparation	
As received	
Washed on 0.425 mm Sieve	
Air dried at 30˚c	
Oven dried at 105˚c	
Proportion retained on 0.425 mm sieve %	
Liquid Limit	**44.96%**
Plastic Limit	**27.15%**
Plasticity Index	**17.81**

PLASTIC LIMIT

Container No	67	15
Weight of Wet Soil + Container, g	22.232	24.235
Weight of Dry Soil + Container, g	20.934	22.961
Weight of Water	1.298	1.274
Weight of Container	16.146	18.277
Weight of Dry Soil, g	4.788	4.684
Water Content, %	27.1	27.2


Representative Natural Subgrade soil samples of liquid limit test graph
Nb
Moisture Content, %
40
35
30
25
20
15
10
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
85.00
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 7

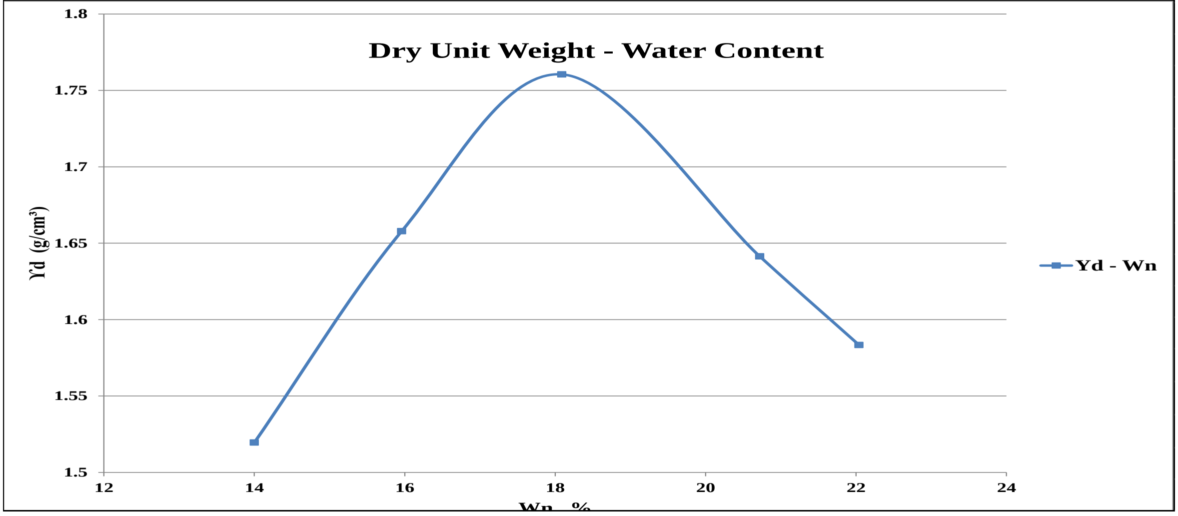

Representative Sub-base soil samples of liquid limit test graph
Nb
Moisture Content, %
40
35
30
25
20
15
10
20.00
25.00
30.00
35.00
40.00
45.00
50.00
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6
Sample 7

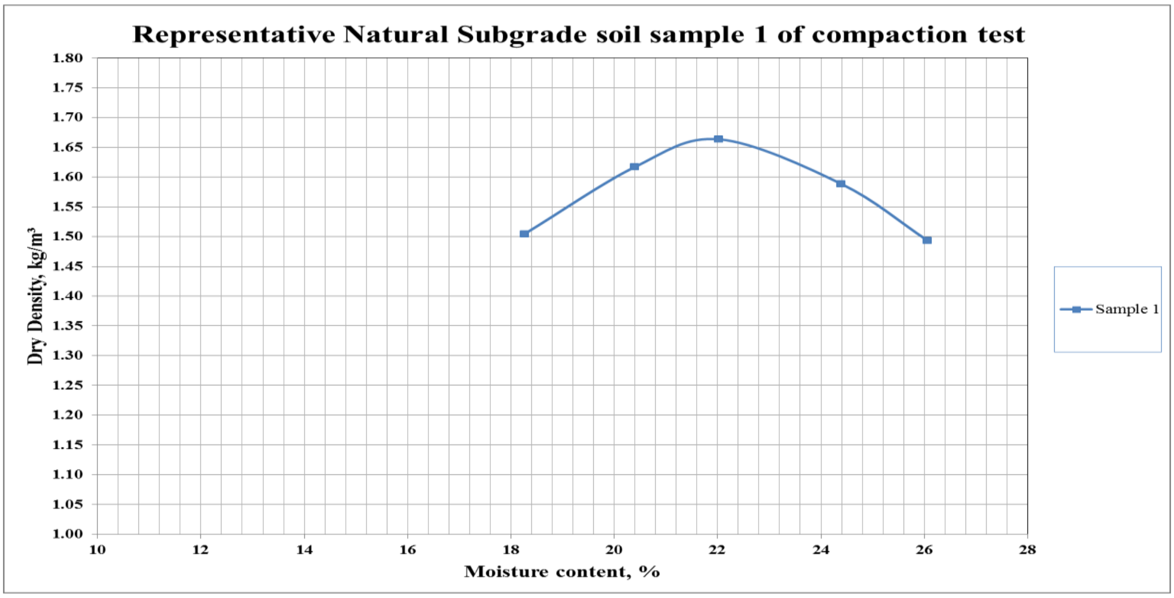

Representative Selected fill soil samples of liquid limit test graph
40
35
30
25
20
15
10
Nb
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Moisture Content, %
Sample 1
Sample 3
Sample 4
Sample 5
Sample 6
Sample 7

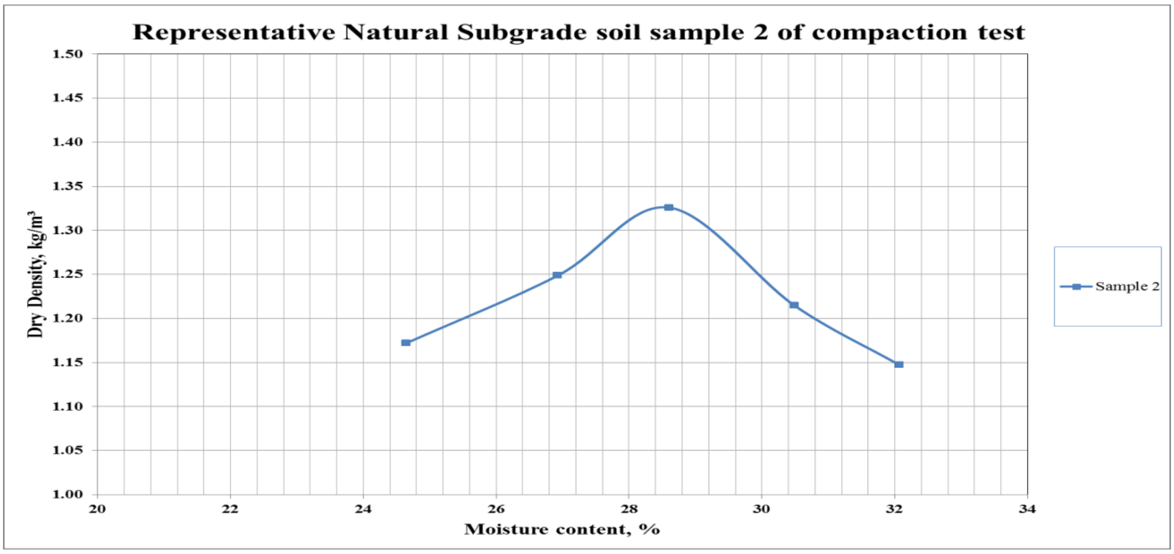
APPENDIX C

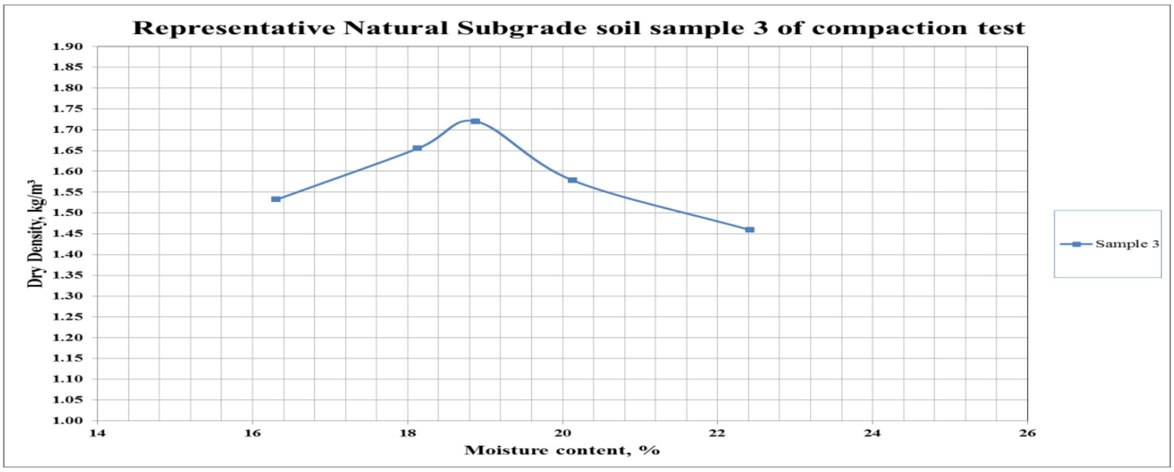
Representative Dry Density VS. Moisture Content

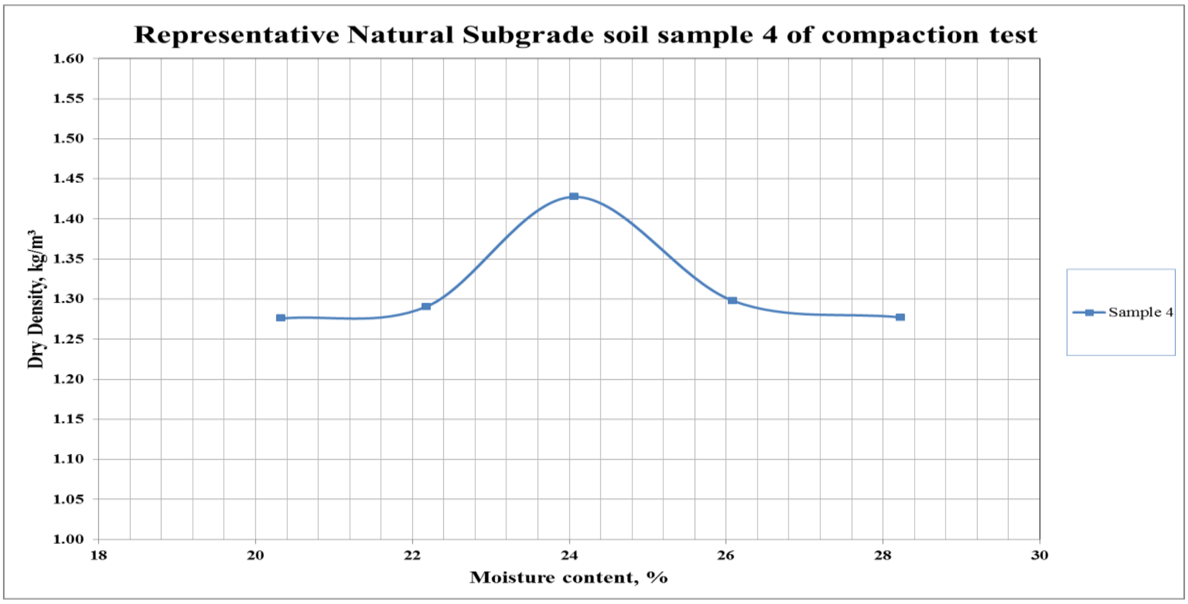
LABORATORY COMPACTION CHARACTERISTICS OF SOIL USING MODIFIED EFFORT (2700KN-m/m3)						
Standard No: ASTM D 1557, Method C						
Laboratory Code No						
Research Place	Kemise to Dessie Roadway					
Laboratory tested in project place	AWASH-KOMBOLCHA-HARA GEBEYA				Date of specimen Accept	20.06.2016
	RAILWAY PROJECT				Date of Test Start	28.06.2016
Sample Information	Sample 4 Sub - base Material				Date of Test Result	29.06.2016
Number of Mould	1				Sieve Size	19.00 mm
Weight of Mould, g	5955.00				Specific Gravity	
Volume of Mould, cm³	2084.00				Weight of Rammer	4.5 kg
Weight of Total Sample, g	7000				Drop Number	25
Water Content Wn %						
	1	2	3	4	5	
	25	60	104	19	82	
Container+Moist Specimen Mass, g	506.17	348.54	372.22	506.21	571.64	
Dry Specimen Mass+Initial Container, g	449.85	307.25	322.01	426.75	476.32	
Mass of Water, g	56.32	41.29	50.21	79.46	95.32	
Container Mass, g	47.63	48.49	44.45	43.25	43.74	
Mass of Solids, g	402.22	258.76	277.56	383.5	432.58	
Water Content, %	**14.00**	**15.96**	**18.09**	**20.72**	**22.04**	**OMC= 18.09 %**
Dry Unit Weight, Ɣd						
	1	2	3	4	5	
Weight of Mold + Sample, g	9565.0	9961.5	10287.5	10084.5	9982.0	
Weight of Compacted Soil, g	3610.0	4006.5	4332.5	4129.5	4027.0	
Wet Unit Weight, g/cm³	1.732	1.923	2.079	1.982	1.932	
Dry Unit Weight, Ɣd max, g/cm³	**1.5195**	**1.6579**	**1.7605**	**1.6414**	**1.5834**	**Ɣd max.= 1.761 g/cm³**

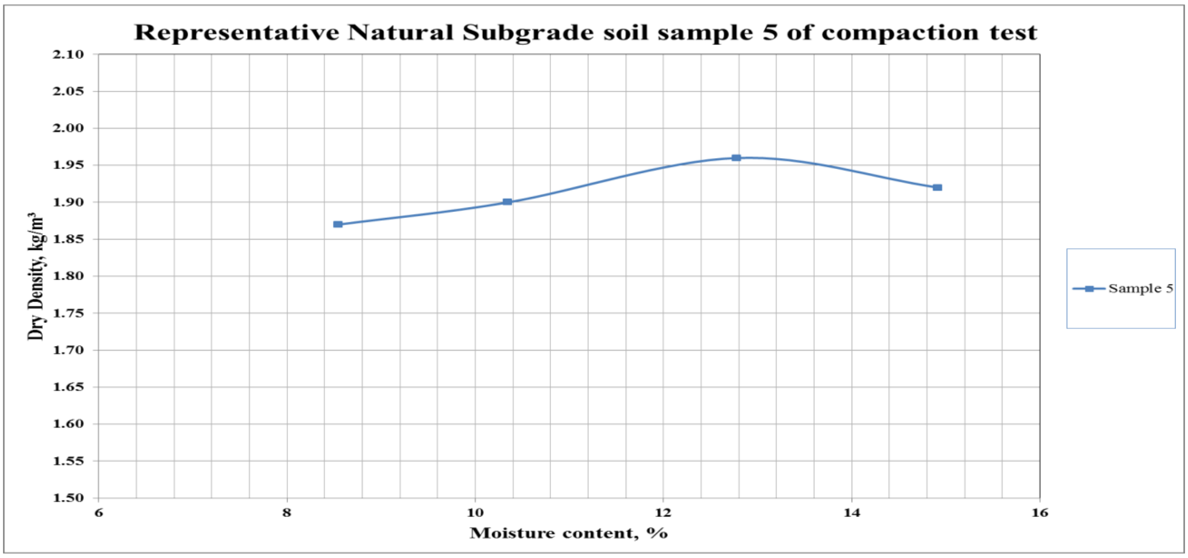


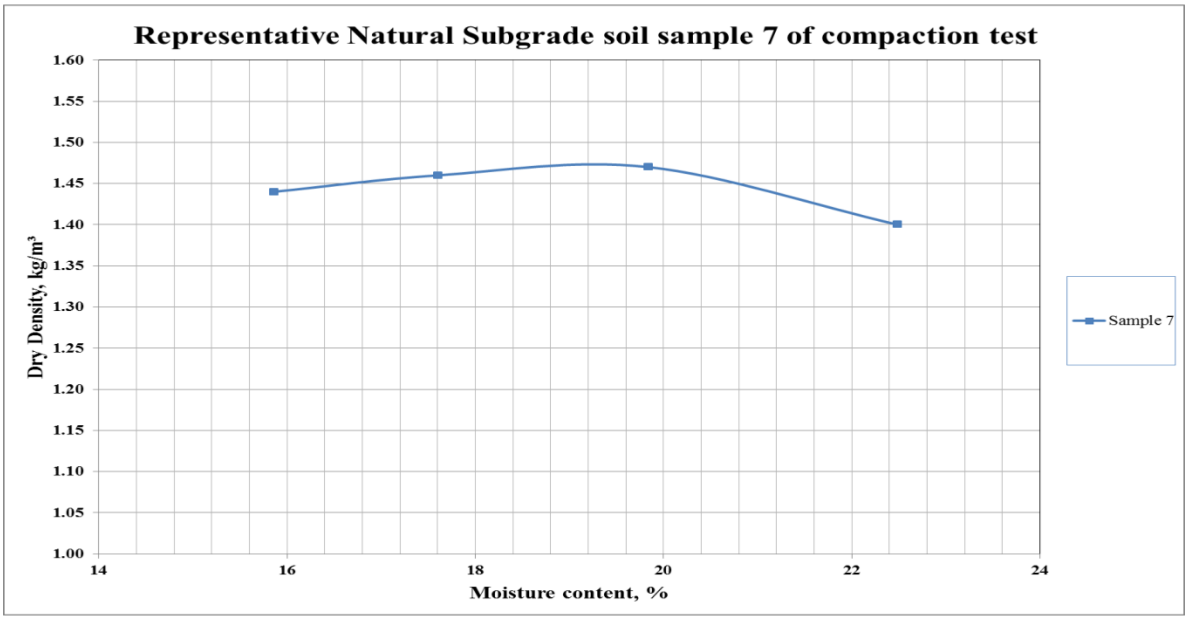

Representative Natural Subgrade soil sample 1 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 1

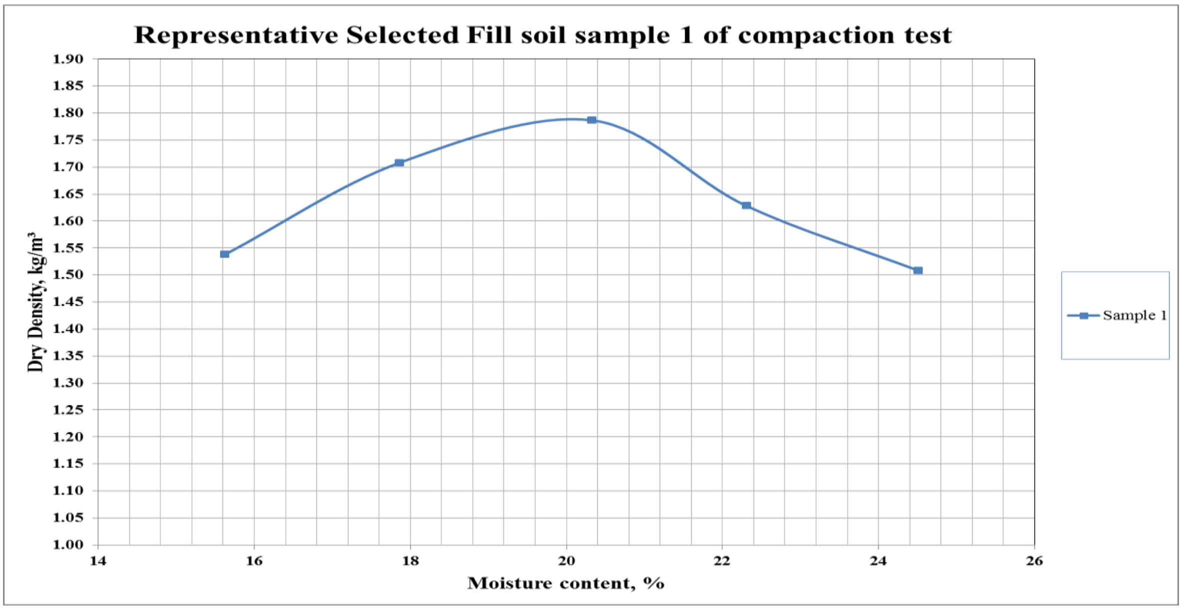

Representative Natural Subgrade soil sample 2 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 2

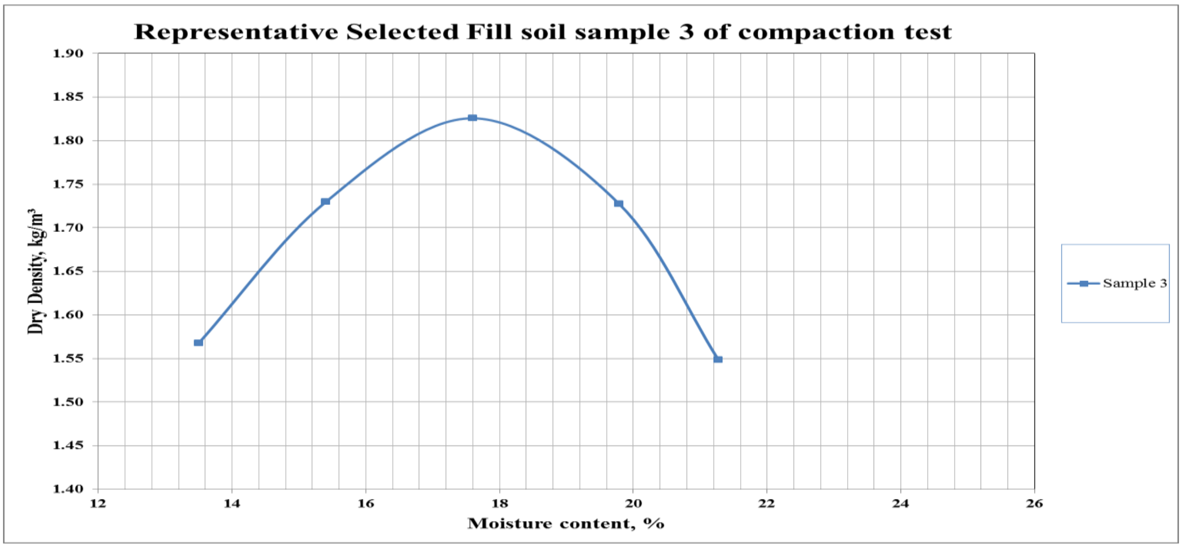

Representative Natural Subgrade soil sample 3 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 3

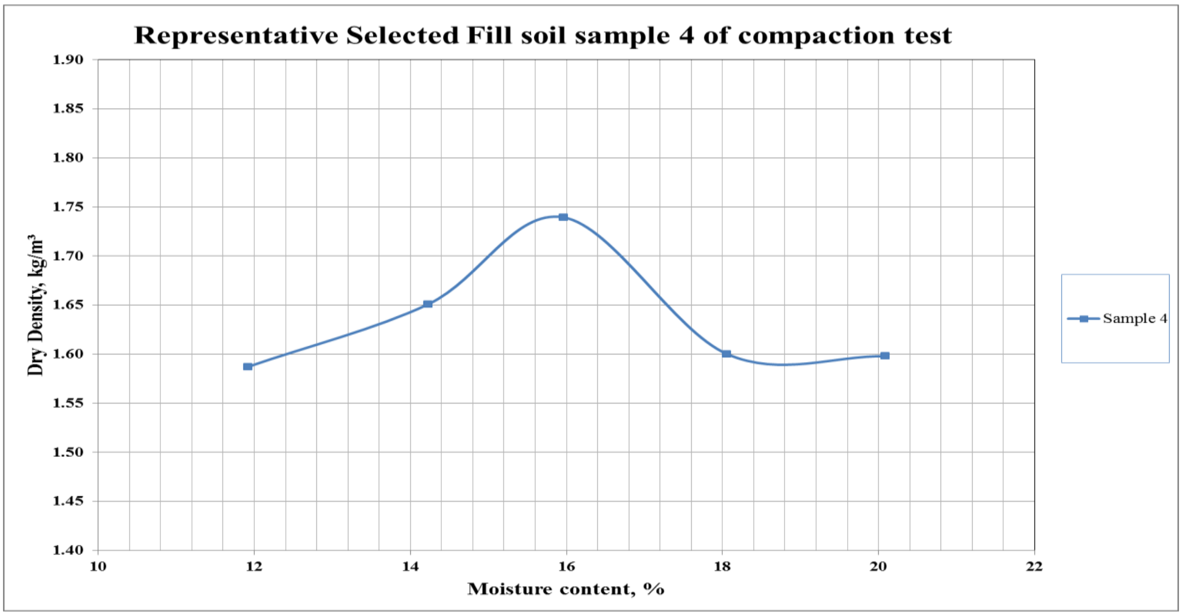

Representative Natural Subgrade soil sample 4 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 4
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
18
20
22
24
26
28
30

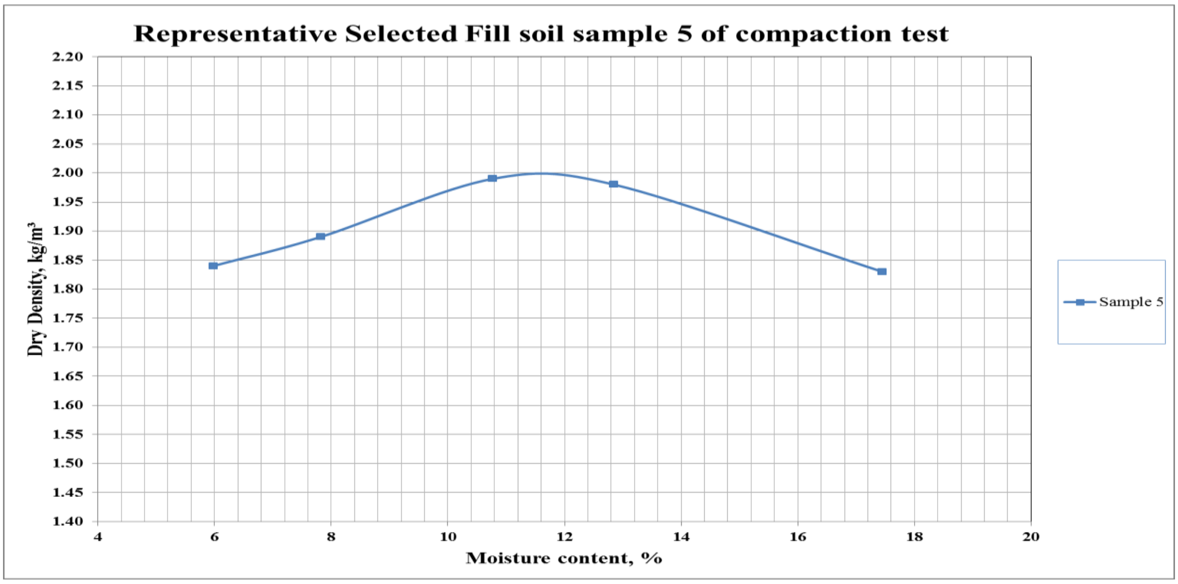

Representative Natural Subgrade soil sample 5 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 5
2.10
2.05
2.00
1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
6
8
10
12
14
16

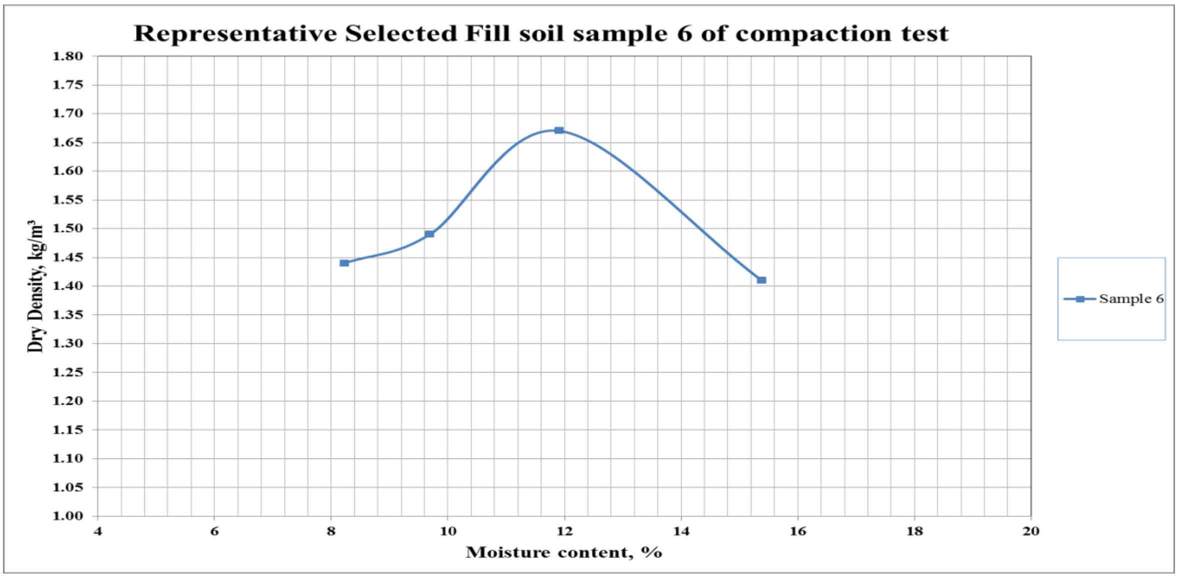

Representative Natural Subgrade soil sample 7 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 7
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
14
16
18
20
22
24

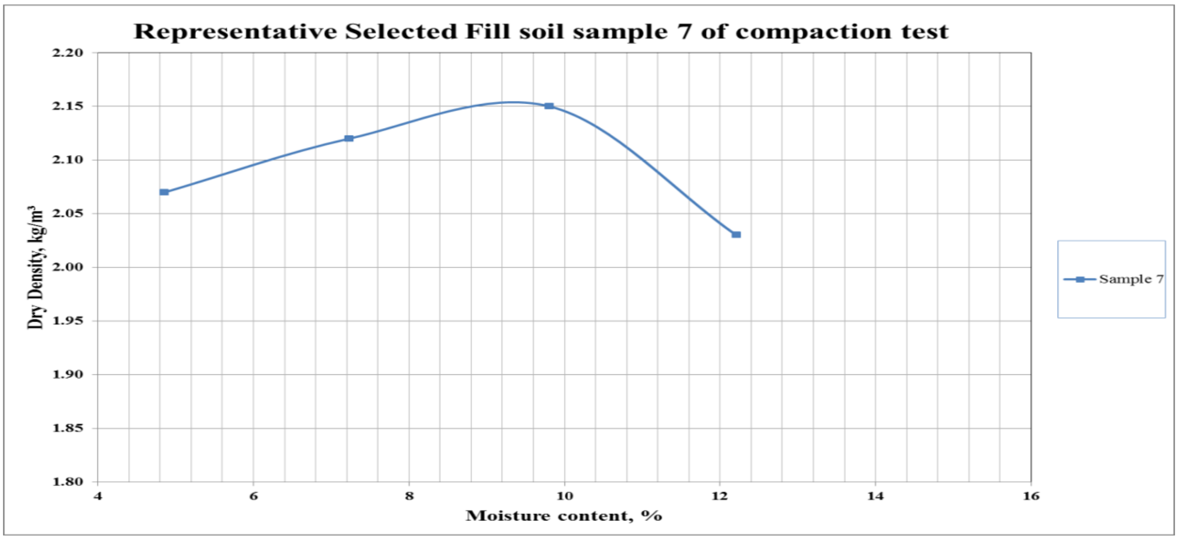

Representative Selected Fill soil sample 1 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 1

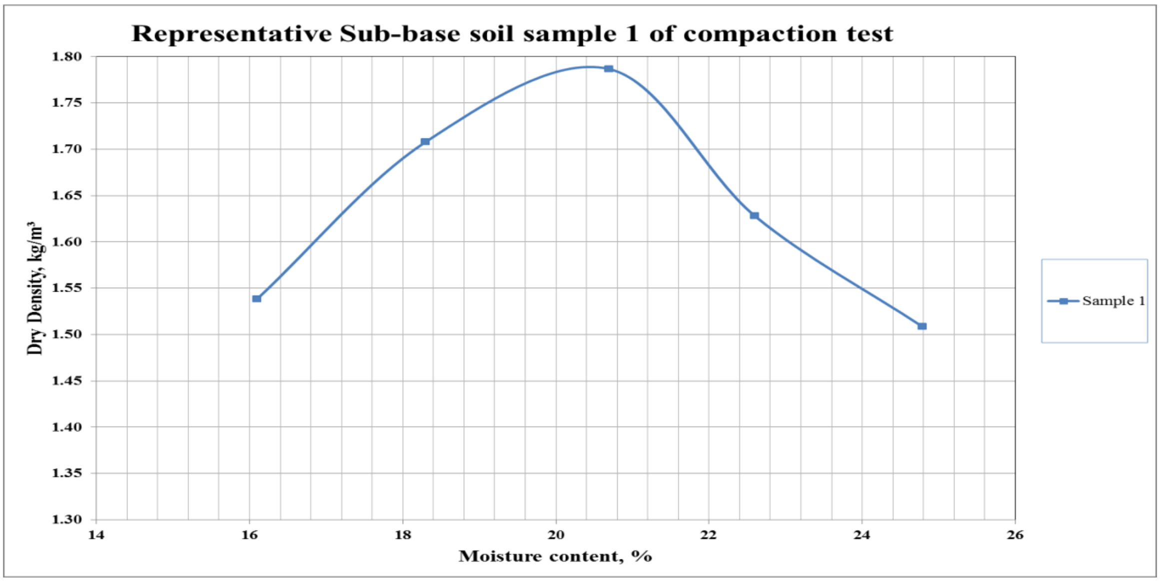

Representative Selected Fill soil sample 3 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 3

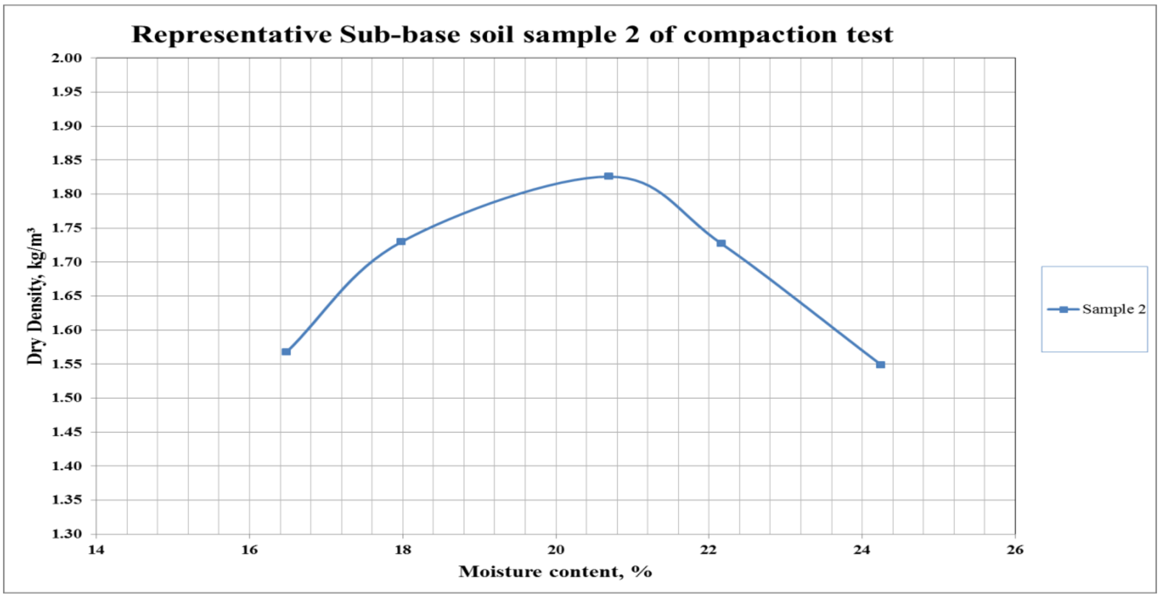

Representative Selected Fill soil sample 4 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 4

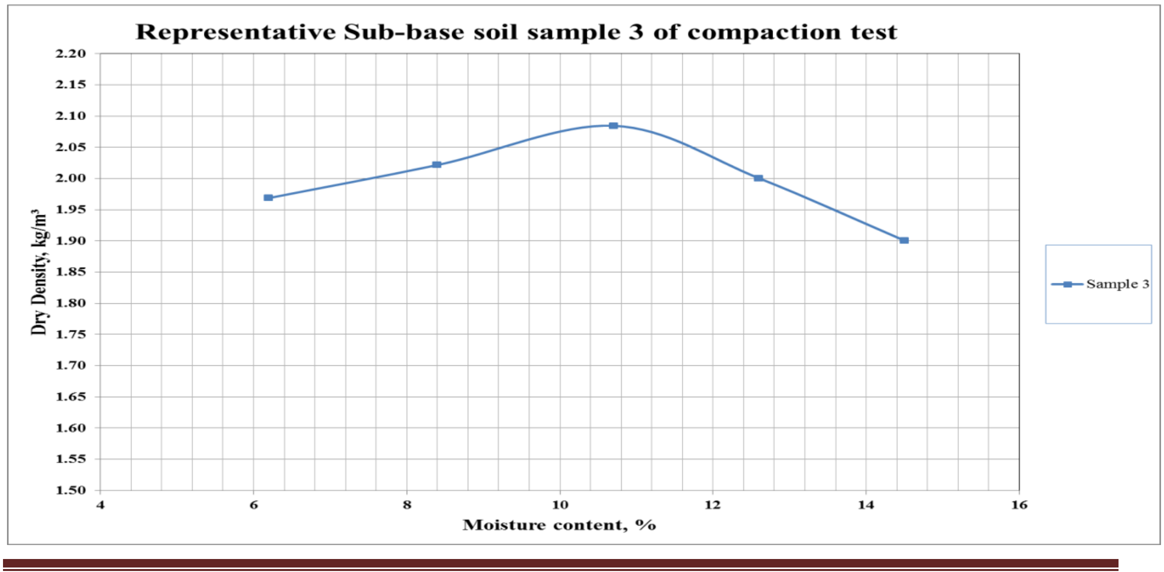

Representative Selected Fill soil sample 5 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 5

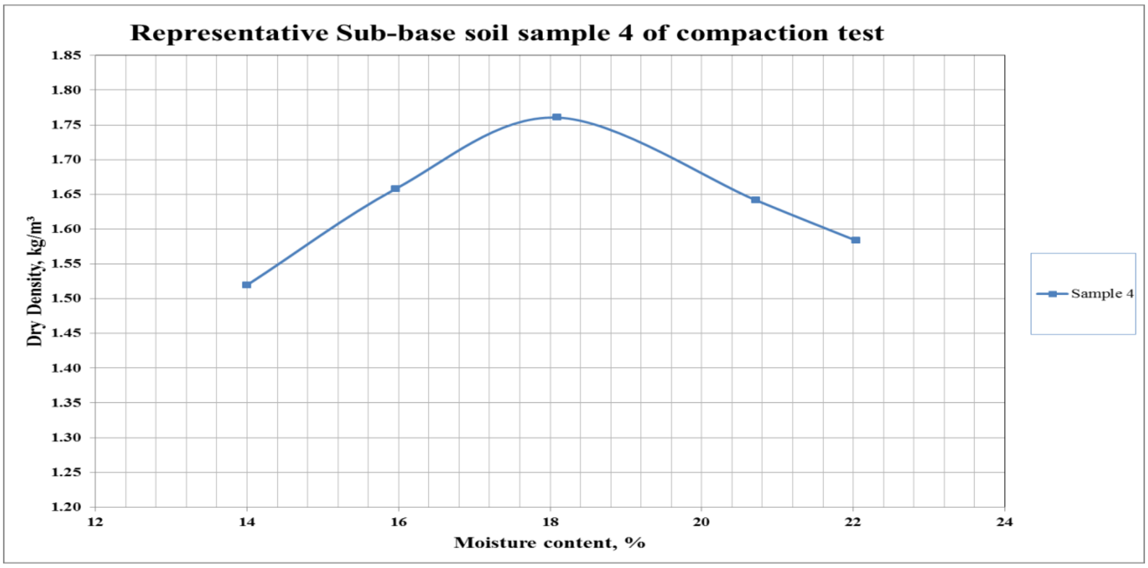

Representative Selected Fill soil sample 6 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 6

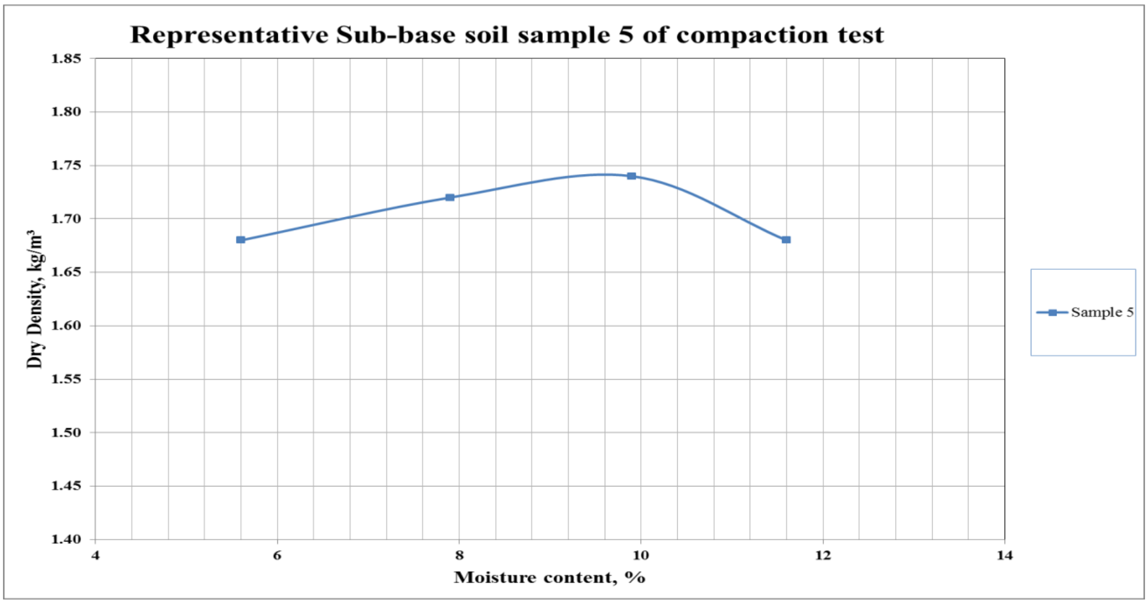

Representative Selected Fill soil sample 7 of compaction test
Dry Density, kg/m3
Moisture content, %
Sample 7

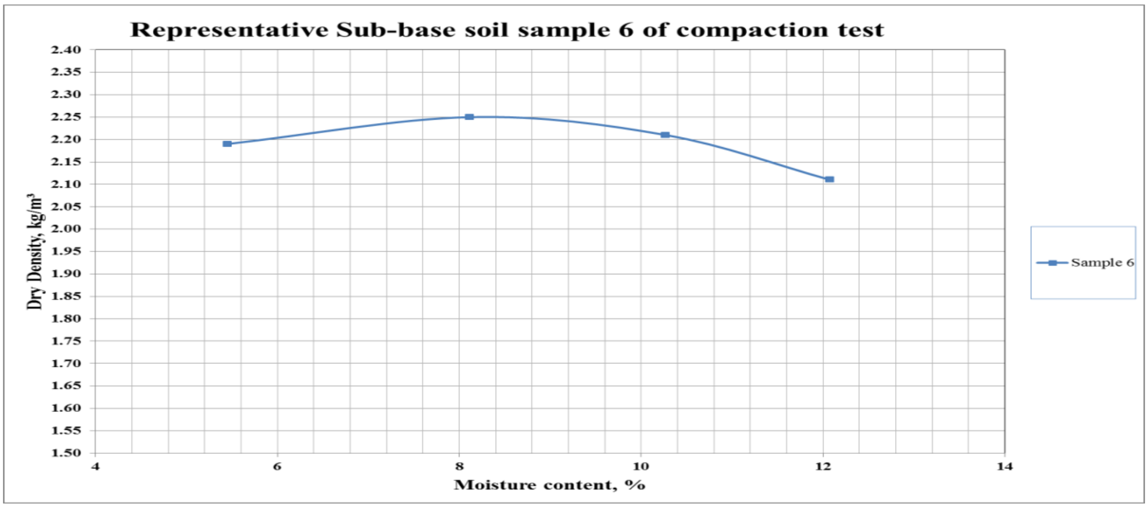

Representative Sub-base soil sample 1 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 1

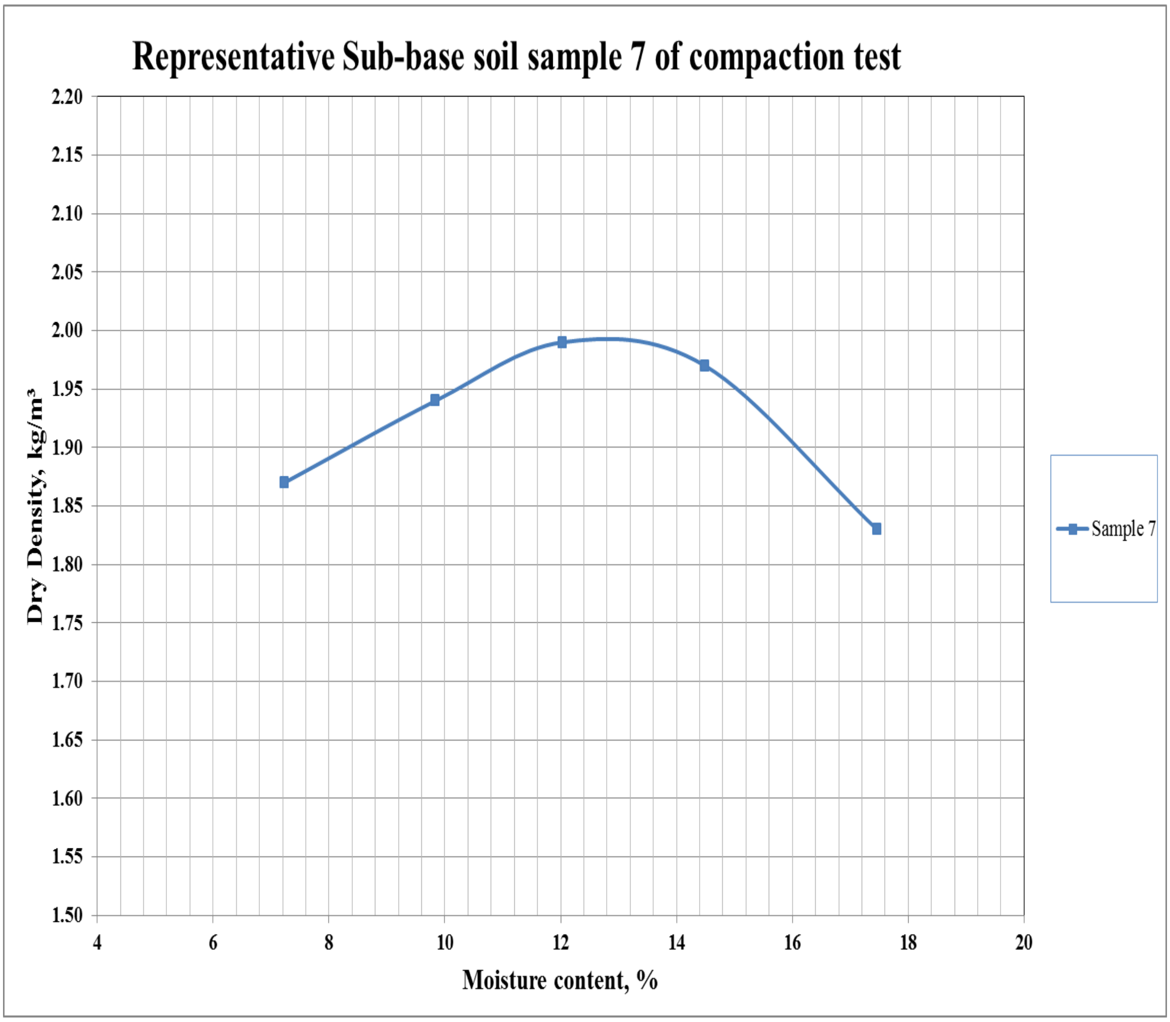

Representative Sub-base soil sample 2 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 2


Representative Sub-base soil sample 3 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 3


Representative Sub-base soil sample 4 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 4


Representative Sub-base soil sample 5 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 5


Representative Sub-base soil sample 6 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 6


Representative Sub-base soil sample 7 of compaction test
Dry Density, kg/m³
Moisture content, %
Sample 7
2.20
2.15
2.10
2.05
2.00
1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
4
6
8
10
12
14
16
18
20

APPENDIX D

I. Representative Load VS. Penetration From Sample 1 up to Sample 4

DETERMINATION OF CBR (CALIFORNIA BEARING RATIO)

Standard No: TS EN 13286-47 - AASHTO T-93 - ASTM D 1883

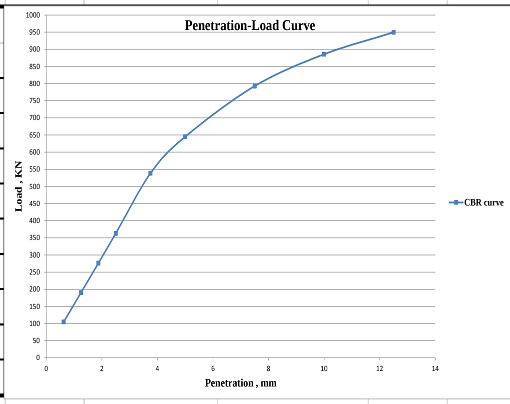
Laboratory Code No			
Research Place	Kemise to Dessie Roadway		
Laboratory tested in project place	AWASH- KOMBOLCHA- HARA GEBEYA RAILWAY PROJECT	Date of Specimen Accept	28.05.2016
		Date of Test Start	06.06.2016
Sample Information	Sample 1: Natural Subgrade	Date of Test Result	10.06.2016

Manner of Compaction					CBR Type
Modified Proctor	γ_d max: 1.664 g/cm^3	Wn opt: 22.03 %	Mallet/Layer	Blow	WET
Used The Amount Of Sample	7000.00 g		4.5 kg / 5 Layer		

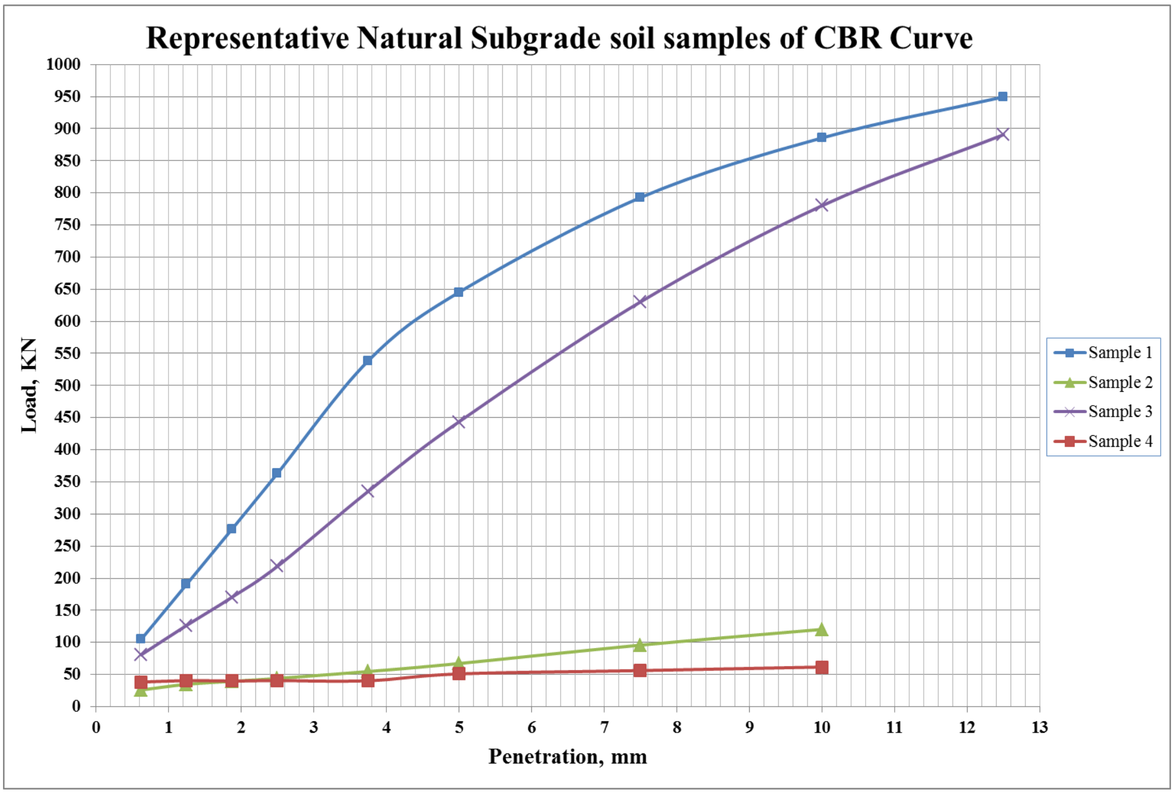
Dry Unit Weight γ_d max	Unsoaked Sample	Soaked Sample	Water Content, Wn	Unsoaked Sample	Soaked Sample
Mold No	11	11	Container No	99	31
Volume of Mold, cm^3	2121.31	2121.31	Wt. Specimen Wet + Cup, g	569.89	327.5
Mass of Mold, g	4185	4185	Wt. Specimen Dry + Cup, g	474.43	262.3
Weight of Mold + Wet Sample, g	8515.5	8577.5	Container Weight, g	48.29	45.73
Weight of Compacted Soil, g	4330.5	4392.5	Wet Specimen Weight, g	521.6	281.77
Wet Unit Weight, g	2.0414	2.0707	Dry Specimen Weight, g	426.14	216.57
Dry Unit Weight, γ_d max, g	1.6678	1.591517	Water Content, %	22.40	30.10574
Compaction Percentage					

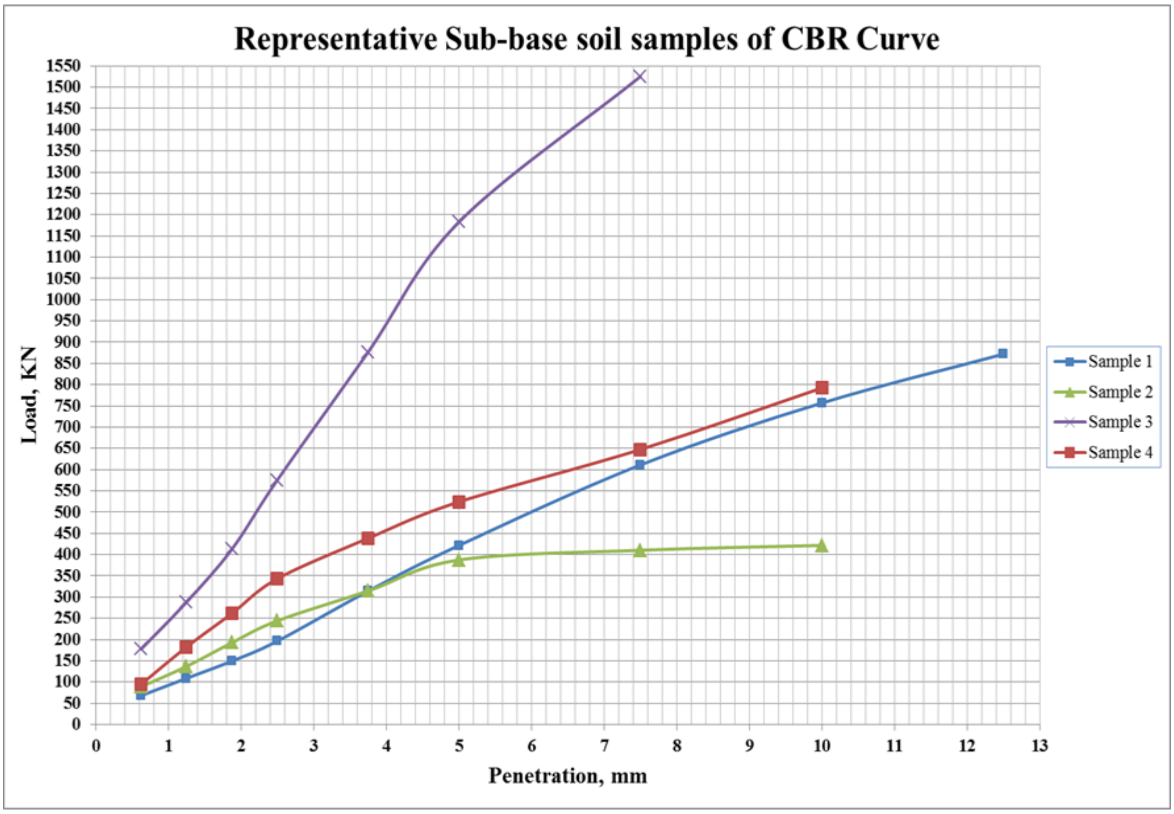
California Bearing Capacity, % CBR

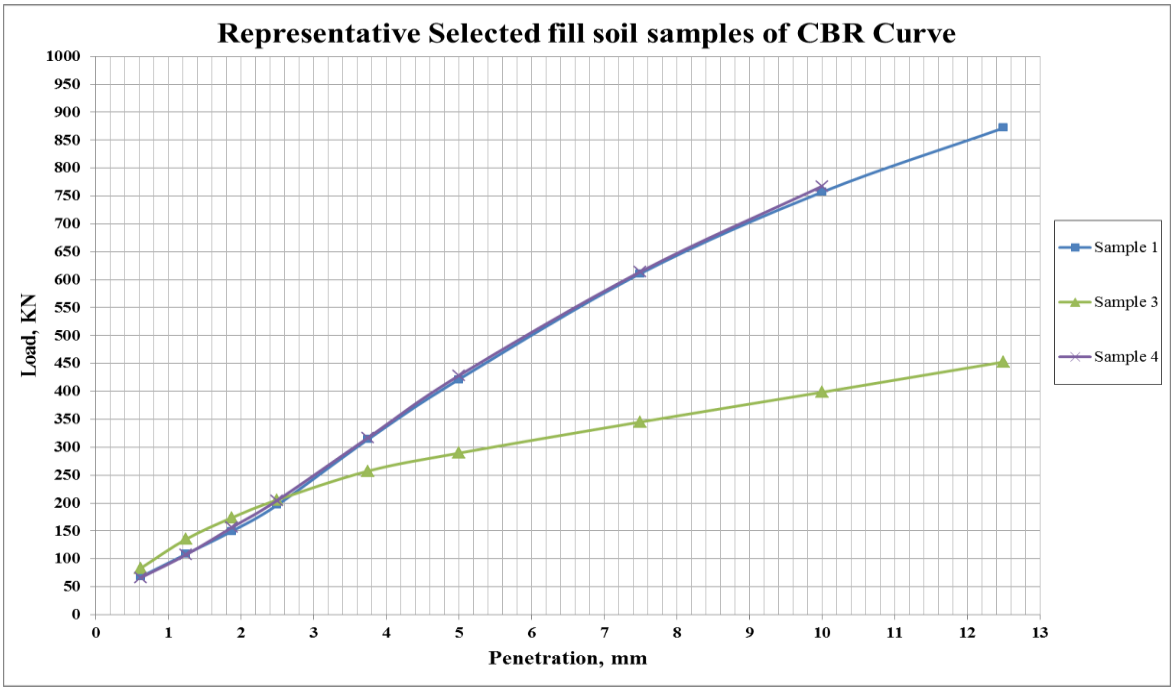
Penetration mm	Load Reading KN
0.625	104.7
1.250	190.3
1.875	276.2
2.500	363
3.750	538.3
5.000	645.1
7.500	792.7
10.000	885.6
12.500	949.5



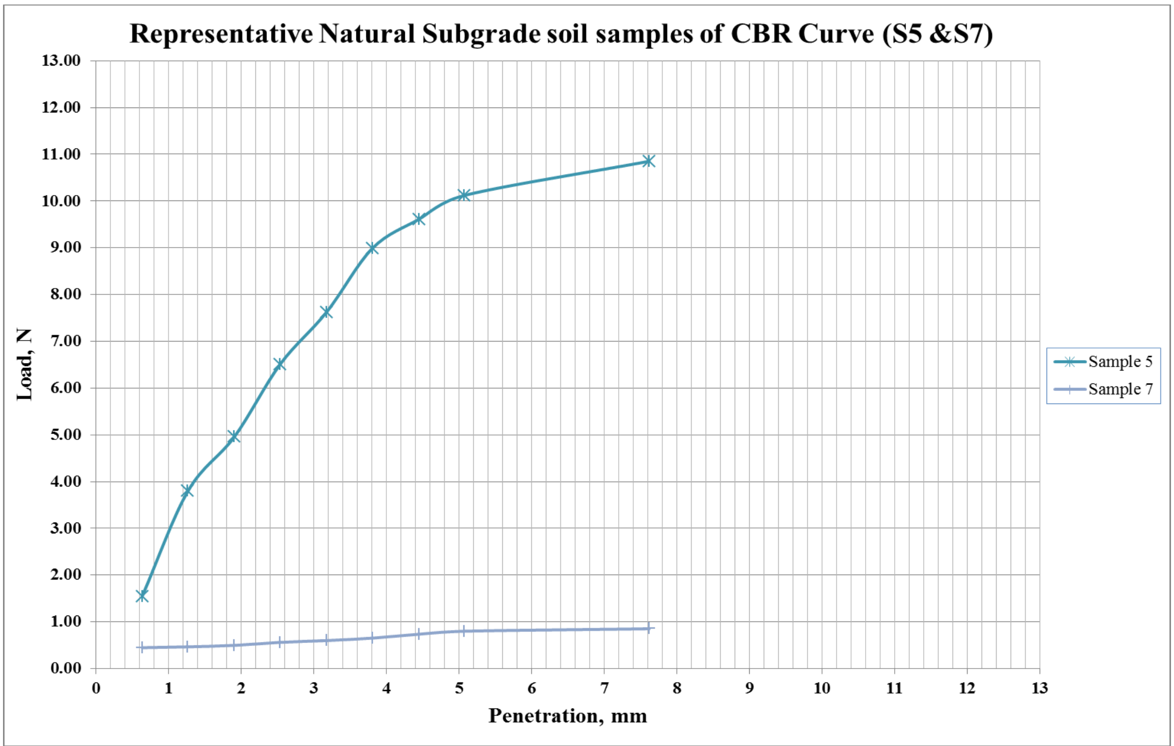
Penetration mm	Standard Load KN	Bearing Capacity %
2.5	13.2	26.9
5	20	31.7

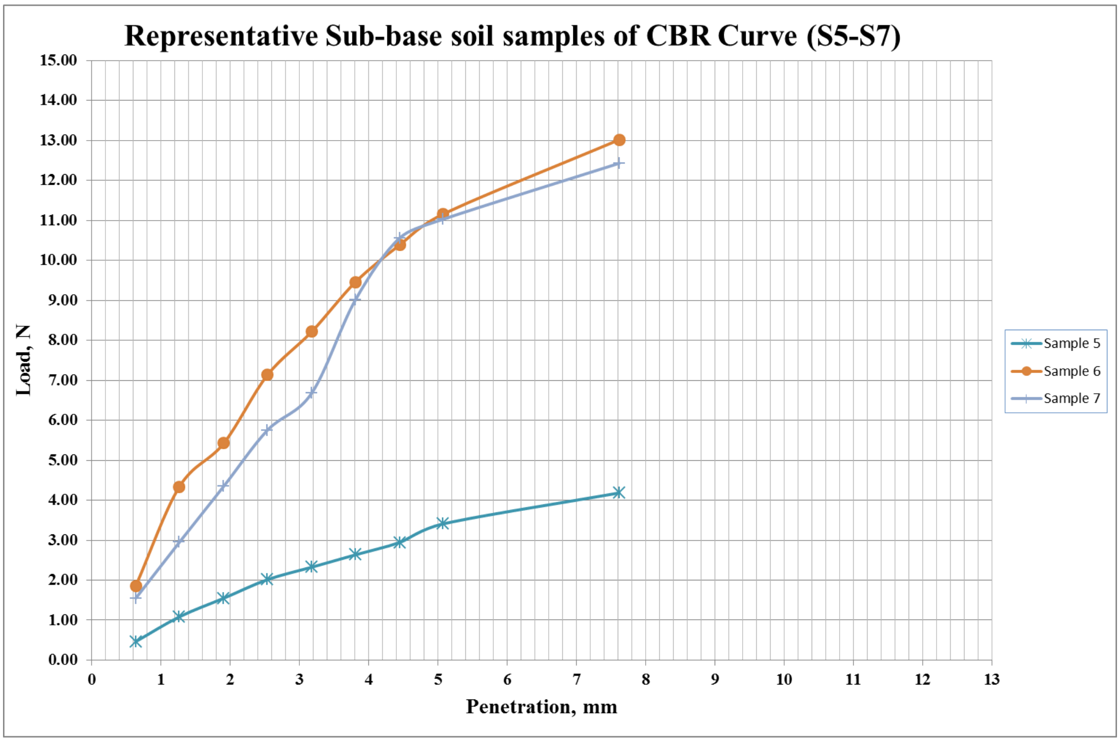

Representative Natural Subgrade soil samples of CBR Curve
Load, KN
Penetration, mm
Sample 1
Sample 2
Sample 3
Sample 4

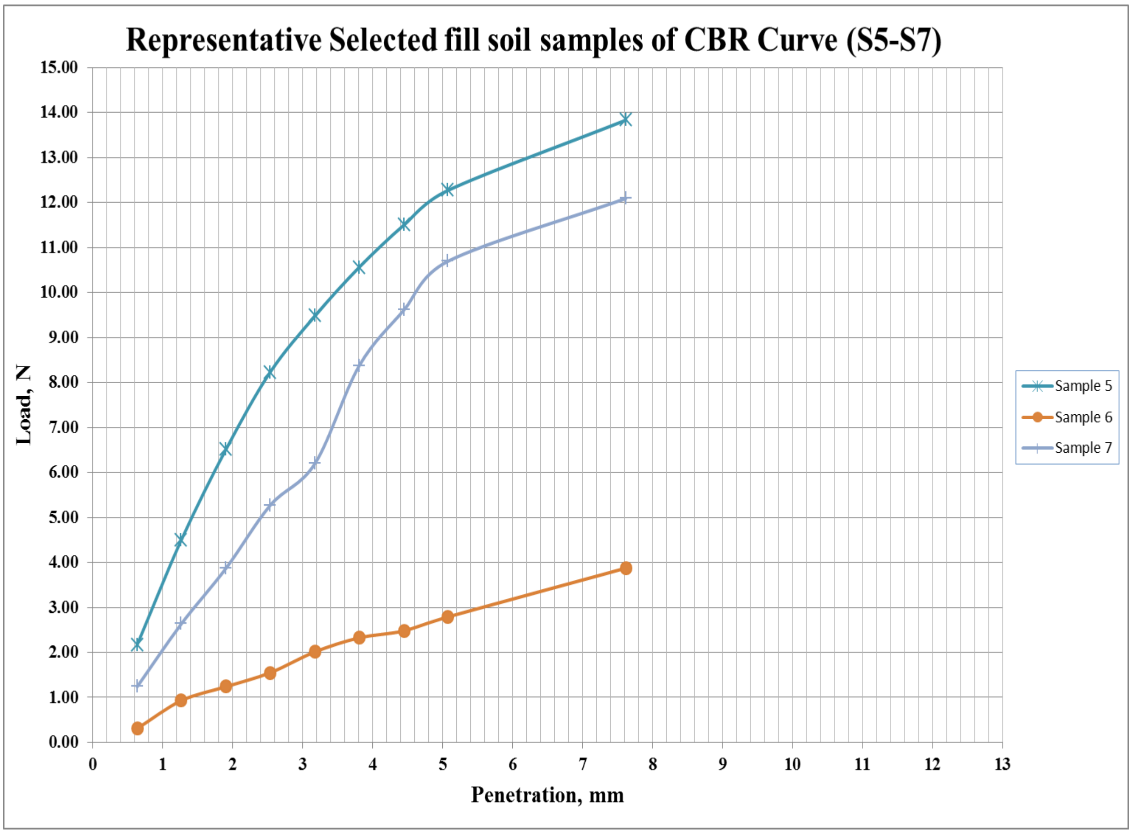

Representative Sub-base soil samples of CBR Curve
Load, KN
Penetration, mm
Sample 1
Sample 2
Sample 3
Sample 4



II. Representative Load VS. Penetration From Sample 5 up to Sample 7




Representative Sub-base soil samples of CBR Curve (S5-S7)
Load, N
Penetration, mm
Sample 5
Sample 6
Sample 7


Representative Selected fill soil samples of CBR Curve (S5-S7)
Load, N
Penetration, mm
Sample 5
Sample 6
Sample 7