ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

INVESTIGATE THE CAUSES OF PAVEMENT DISTRESSES AND ITS REMEDIES

(Case Study: Dessie - Hayk Road Segment)

A Thesis in Road and Transport Engineering

By

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A Thesis

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The undersigned have examined the thesis entitled '**Investigate the Causes of Pavement Distresses and Its Remedies from Dessie to Hayk Road Segment**' presented by **FREZER ENIYEW**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled "INVESTIGATE THE CAUSES OF PAVEMENT DISTRESSES AND ITS REMEDIES FROM DESSIE TO HAYK ROAD SEGMENT" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

Paved roads in tropical and sub tropical climates often detoriorate in different ways than those in temperate regions because of: harsh climatic condions, lack of proper design and quality control, high load, and inadequate assessment in identifying the causes of distresses before carring out maintenance and rehabilitation.

A pavement distress that occures at the surface can have a number of different causes which must be properly identified before corrective action is taken. The visibe manifestation of the problem at the surface may be the same; however, the solution for each cause may be different. Therefore, if the remedial action is to be effective, the cause of the problem must be identified and corrected.

The present road condition from Dessie to Hayke shows rapid deterioration. This is due to traffic volume of: busses, heavy trucks, passenger vehicles and minibuses. These consequently may cause further deterioration of roads due to traffic load.

This research mainly focuses on making assessment of asphalt pavement condition, identifying the causes of pavement distresses and proposing remedial measures for the trunk road from Dessie to Hayke in Amhara Region, Ethiopia. This road segment is most widely utilized, and therefore prone to severe distresses and consequently resulting in repeated maintenance and repair.

Visual distress assessment, extracting pavement and checking moisture content, grain size distribution, compaction, CBR test, standared sieve analysis, Atterberg limits, Los Angelus Abrasion test, shape test and other necessary laboratory investigations were carried out on the road segment in order to have better undestanding and to come up with identification of probable causes. Major causes of pavement distress associated with traffic load, climatic condtion, matarias were identified. The results of the research showed that Subgrade and Base materials materials have low Plasticity Index and low CBR value compared with the specifications. The design traffic load is higher than the actual traffic for this traffic load section.

Key Words: Pavement Distress, Laboratory Test, Pavement Maintenance.

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ACRONOMY

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ASTM	American Society of Testing Method
BS	British Standard
CBR	California Bearing Ratio
ERA	Ethiopian Road Authority
FHWA	The U.S. Federal Highway Administration
HMA	Hot Mix Asphalt
Km	Kilo meter
LA	Los Aneles
LOS	Level of Service
MDD	Maximum Dry Density
mm	millimeter
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
RSDP	Road Sector Development Program
RTFOT	Rolling Thin Film Oven Test
TFOT	Thin Film Oven Test
URRAP	Universal Rural Road Access Program
USCS	Unified Soil Classification System
VDF	Vehicle Damaging Factor
°c	Degree Celsius
°F	Degree Fahrenheit

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CHAPTER ONE

1. INTRODUCTION

1.1 Background and Justification

Developing countries have lost precious infrastructure worth billions of dollars due to the deterioration of their roads. If they do not immediately and properly preserve their roads, they will lose billions of dollars more. These damages are most common especially in the arid and semi-arid regions. Damages are usually manifested through cracks of sidewalks, driveways and tilted retaining walls and pavement structures. The magnitude of the damages can be extended even to the extent of failure of one or all pavement structure by decreasing the structural safety of the road. Maintenance and repair costs can exceed the original costs of the road and creates financial burden to the developing countries. Generally, these damages lead to economic loss for the countries at large (Kati KõrbeKaare et al., 2012).

A comprehensive literature review was conducted related to both local and international contexts to determine the road deterioration factors, road defects, and causes of cracks and deterioration, etc. in both locally and foreign countries. Flexible pavements deteriorate under traffic loads and climate effects. This effect depends on the technology and materials of the road, but the greatest effects depend on traffic loads and volumes (Kati KõrbeKaare et al., 2012). On the same line, climatic conditions were observed to have an effect on road deterioration, vehicle operating costs, road safety and the environment. Under severe weather, it is indicated that climatic factors are the major causes for pavement deterioration. It is a fact that temperature, frost and thaw action as well as moisture are factors that can cause certain types of pavement deterioration.

The effect of poor drainage on road condition increases the moisture content and decreases the strength of the pavement. Therefore, poor drainage causes the premature failure of the pavement (PatilAbhijit, 2011). Similarly, pavement tends to crack at some point of their life under the combined action of traffic, environment and climatic conditions (Wee, 2009). The Wisconsin Department of Transport investigates the pavement fatigue as a result of the number and weight of axle loads; they also discuss how wheel loads, number of truck axles, number of truck tires, quality of sub-grade, pavement thickness and changing seasons contribute to pavement fatigue. In addition, potholes, cracks, edge defects, depressions and corrugation are significant road defects observed in highway collider. At the same time; traffic, age, road geometry, weather, drainage, construction quality as well as construction material, and maintenance policy play the major role as road deterioration agents (Harischandra, 2004). In the pavement or embankment, water plays a primary role in giving shorter service life and in increasing the need of rehabilitation measures (Korkiala and Dawson, 2007).

Pavement distresses are the major problems of the roads and are distributed all over Ethiopia. One of those affected roads due to pavement distresses is the Dessie to Hayk road segment. The effect of pavement distresses in and around these segment results in different structural failures, especially in the road structure. However; nothing has been done so far with regard to failures on the Dessie to Hayk road segments due to different causes. Some of the distresses on the road segment are: edge defects, depressions, corrugated cracks, alligator cracks, longitudinal cracks and large potholes which is totally washed pavement. Therefore, this research will try to investigate the causes of pavement distresses on this subject road and proposes remedial measures.

1.2 Road Networks and Conditions in Ethiopia

1.2.1 General

In the context of Ethiopia, road is the most important infrastructure that provides access to rural and urban areas in the country. Road plays crucial role to reduce transportation costs and support economic growth in the country through enhancement of passenger and freight movements. However, in the late 1990’s; the road network coverage was limited to major urban areas and some rural areas. Most areas in the country were isolated from economic centers, market and basic social services. The prevailing road network was largely deteriorated and in poor condition (ERA, 2016).

Ethiopia's road network has increased from 26,550 km in 1997 to 113,066 km in 2016 (an increase of 326 percent). As a result, the road density per 1,000 sq. km has increased from 24.1 km in 1997 to 102.8 km in 2016. In addition, substantial improvement has been registered in the condition of the country's road network. The proportion of road network in good condition increased from 22% in 1997 to 72% in 2016(ERA, 2016).

In 1997, of the 26,550 km road network, only 3,708 (14%) km were paved. Then, as a result of investments made under the four phases of RSDP during the last 18 years, the total length of the network has increased to 110,414 (113,066 above) km. including URRAP and Municipality roads. According to the 18 years of RSDP performance assessment document, the condition of the road network has also improved. Currently, almost 70% of the total classified road network is in good condition, 21% in fair condition and the remaining 9% is considered to be in poor condition. When this is compared to the condition in 1997 (22% of the total network were in good condition), it is actually a significant improvement (ERA, 2015).

1.2.2 Percentage of Roads in Good Condition

While evaluating the performance of a road sector; in addition to network size and density, considering the conditions of the road network is important. Therefore, taking benchmarked countries as a base at the end of RSDP V, the percentage of road network in good condition should reach 80% from the current 72%. Above all, increasing the percentage of roads in good condition should be given priority because it has an immense benefit for the nation. For instance not only it improves accessibility but also provide efficient transportation service and reduce vehicle operation costs (ERA, 2015).

1.2.3 Percentage of Paved Roads (Paved/unpaved ratio)

The other issue raised together with quality of road network is proportion of asphalt roads. It is clear and believed that asphalt surfaced roads have multidimensional benefits including: travel time savings, reduced vehicle operating costs; reduced transportation costs and comfort. In this regard, currently the length of asphalt roads in the country is 15,244 km and it accounts for only 13.8% of the total road network of the country. Thus, out of the total road network which is believed to be large; 215,000 km, at the end of RSDP V, the proportion of asphalt surfaced road will be 12% (ERA, 2015).

1.2.4 Road Density per 1000 sq.km

With the current 110,414 km of road network, the road density per 1,000 sq.km is 100.4 km. This is equal to the average road density of poor countries. Nevertheless, as indicated before, the country's vision is to reach at the low middle income countries by 2025. In order for the country to reach the average road density of middle income countries, our country's road network has to increase to more than 200,000 km. However, it is realized that because of financial and institutional capacity constraints; the network cannot be increased to 220,000 km and the road density per 1,000 km^2 cannot reach 200 km^2 by 2020 from the current 110,414 km (2015). Taking the financial and institutional constraints into account; the size of the road network to be achieved at the end of RSDP V is set at 215,000 km and the road density per 1,000 km^2 is set at 196 km^2 (ERA, 2015).

Road density per population also demonstrates that Ethiopia's road density will be nearly the same as countries like China and South Korea. Road density per 1,000 population should increase, at the end of 2020 from the current 1.3 km per 1,000 population to 2.1 km per 1,000 population. Even though this figure is less than the average of low middle income countries; achieving the goal is satisfactory by itself (ERA, 2015).

1.3 Statement of the Problem

Now days, it is common to see pavement distresses along the highway corridor from Dessie to Hayk due to different uninvestigated causes. And these pavement distresses due to different cause's leads to the following problems and they will be studied in this research.

- The road section from Dessie to Hayk shows distress which may be due to: traffic load, climatic conditions, poor drainage, improper construction work and others. This problem leads to pavement structural and surface failures such as: different types of cracks, surface deformation, some surface defects and disintegration of pavement aggregate from binding materials. This is the main problem of the study area.

- The travel time and speed of the vehicle at this highway section is affected due to the pavement defects leading to delays. During the delay, the consumption of vehicle fuel will increase and correspondingly emissions to the environment which causes air pollution.

- Due to pavement distress, the condition of vehicles will be adversely affected causing vehicle damages resulting in increasing maintenance costs and this leads to traffic accidents. In addition, it leads to reduction of level of service (LOS) of the road which similarly leads to increases in vehicle operating costs.

1.4 Objectives

1.4.1 General Objective

The main objective of this research is to investigate the causes of pavement distresses on the existing primary road segment between Dessie and Hayk (30km) and proposing remedial measures.

1.4.2 Specific Objectives

To achieve the main objective, the research will have the following specific objectives:

- Investigate major asphalt pavement distresses and their severity on this segment;
- Identify the major causes in relation to condition of base, sub base, sub grade material by conducting condition survey and different laboratory tests;
- Conduct the required analyses; and propose remedial measures.

1.5 Research Questions

This research mainly focuses to answer the following research questions:

- What are the causes of pavement distress on Dessie - Hayk road segment?
- Are traffic volume and loading, poor drainage system, climatic condition as well as quality of road construction and significant causes of pavement distress on Dessie - Hayk road segment?
- How can the effects of pavement distresses on Dessie - Hayk road segment be improved?

1.6 Expected Outcomes

Upon the completion of the research, the following outcomes are expected:

- The causes of pavement distresses on Dessie - Hayk road segment will be explored.

- All the above research questions will be answered.
- The study results will be used by pertinent government offices, especially the ERA as well as by other researchers.
- The report of this research will be used as a supporting document for other related roads in cases when they are dealt with similar undertakings.
- Finally, based on the finding of this study, suitable remedial measures will be determined for pavement distresses in Ethiopia in general and on the project and neighborhood roads in particular.

1.7 Scope and Limitation of the Study

The scope of this research was to investigate the causess of asphalt pavement failures due to base course materials, subbase and subgrade soil properties on Dessie - Hayk road segment taking as a case study. In this regard, laboratory tests were carried out on the materials of the road segment; and similarly traffic loadings were checked. Finally, possible remedial mesures in respect of each causes of distress type are forwarded. The research was conducted based on six sampled test pits from the existing distressed road segment.

Nevertheless, the the limitations of the study were:

- The Kombolcha District of the Ethiopian Roads Authority (ERA), had no laboratory facility. So, the tests of base course and sub grade material were conducted at Awash - Kombolcha - Hara Gebeya Railway project with the help of a foreign contractor of Yapi Merkezi. However, there were no enough laboratory equipment like bitumen test at this project. In this place, only three test pits were conducted and the remaining test pits were conducted in the laboratory of Woldia University. The laboratory at Woldia University however did not have asphalt extractor chemical that was supposed to extract the asphalt surfacing from the bitumen and the aggregate. Therefore, the logistics of finding the right equipment at the right place was time consuming and full of challenges.
- Another limitation was transporting voluminous sample from the distressed road segment in respect of each layer type. This was also subject to the limitation of some laboratory tests.

- Lack of available and/or reliable data from any governmental and non-governmental institution, related to the road construction in the study area was also a limitation. Lack of reliable data will likely limit the scope of analysis, the size of sample, or can be a significant obstacle in finding an appropriate remedial measures for the problem in the study area.
- Lack of other equipment, such as sample bore holes' machine, to collect relevant data in the study area was also a significant limitation.
- Measurement errors due to insufficient control of testing procedures and equipment were inescapable.

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

1.8 Organization of the Thesis

- Chapter One deals with the Introduction; Road Network and condition in Ethiopia; Statement of the Problem; Objectives of the research; Research questions; Scope and Limitations; and Organization of the thesis work.

- Chapter Two deals with discussions of pavement functions; pavement types and factors that are influencing the performance of a pavement. In addition, this Chapter deals in discussions regarding bitumen-bound pavement materials and unbound pavement materials. Similarlly, engineering basic soil information, pavement deterioration and its types, causes of pavement deterioration and finally highway maintenance are discussed here.

- Chapter Three deals with discussions regarding research methodologies such as; study area, study period, study design, sample size and their procedures, data collection process, data analysis and ethical considerations.

- 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. In addition, comparison was made between the quality requirements set for, base course materials and subgrade in the specification of the project to that of the requirements set for the same in the ERA's and other specifications.

- Chapter Five finally deals with the development of the conclusions and with devising and forwarding recommendations of the study for possible considerations by pertinent policy makers.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Pavement Functions

According to Sharad et al., (2009), the primary functions of a pavement are to:

- Provide 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.
- Protect the subgrade: The supporting soil beneath the pavement is commonly referred to as the subgrade. If over-stressed by the applied axle loads, the subgrade 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 strength and thickness requirements of a pavement can vary greatly depending on the combination of subgrade type and loading condition (magnitude and number of axle loads).
- Provide waterproofing: The pavement surfacing acts as a waterproofing surface that prevents the underlaying 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.

2.2 Types of Pavement

Pavements are typically divided into the following three general categories: flexible, rigid and unpaved (Johon, 1994):

- **Flexible Pavement**: usually asphalt, is laid with no reinforcement or with a specialized fabric reinforcement that permits limited flow or repositioning of the roadbed underground changes. Flexible pavements comprised of several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath.

- **Rigid Pavement**: are made of cement concrete plain, reinforced or prestressed concrete. Rigid characteristic of the pavement are associated with rigidity or slab action so that the load is distributed over a wide area of subgrade soil.

2.3 Factors Influencing the Performance of Pavement

Road deterioration is caused by the effects of the physical environment, traffic, material properties, quality of road construction, design standards and the age of the pavement. The details are discussed in the following paragraphs.

- **Environmental Factors**: Climatic factors such as rain water, solar radiation, temperature, soil type and terrain may cause roads to deteriorate. Rain water can alter the moisture balance in the sub grade of a road with clayey and silty soils. This may cause swelling and shrinkage resulting in reflective cracking and heaving in the road surface. Sunlight may cause a continuous, slow hardening action on bituminous surfaces. This can increase the cracking process of the surface chip seal. Seasonal changes in temperature or night and day temperatures may cause expansion and contraction of the carriage way. This may progressively cause fatigue, failures and reflective cracks in the road surface (TRRL, 1988).

- **Traffic volume and loading**: Roads are structures basically built to carry and sustain vehicular loads. Therefore, traffic is an important factor that influences pavement performance. The impact of traffic on the deterioration of pavements is caused by vehicle loads and volume. Every vehicle, which passes over a road, causes a momentary but significant deformation in the road structure. This is determined by the magnitude of each of its axle loads, the spacing between the axles, the number of wheels, the contact pressures of the tyres and the travelling speed. The passage of many vehicles has a cumulative effect which causes repeated flexing of the pavement leading to fatigue, crazing and structural failure (Paterson, 1987).

- **Material properties and composition**: The choice of materials used for the construction of pavement layers may also cause road deterioration. This is due to inherent variability in the materials used for road construction in terms of soil properties such as strength or load bearing capacity, gradation, mix properties, elastic and resilience modulus. Poor choice of materials used for pavement layers can have a drastic effect on the strength of the layers and their subsequent performance (TRRL, 1988).

- **Construction quality**: The quality of road construction, if not built to the desired specifications, can also facilitate road deterioration. For example, failure to obtain proper compaction, improper moisture conditions during construction, poor quality of materials and inaccurate layer thickness (after compaction) all directly affect the performance of a pavement (TRRL, 1988).

- **Road maintenance standards**: The rate of pavement deterioration is directly affected by the maintenance standards applied to repair road defects. When a maintenance standard is defined, it imposes a limit to the level of deterioration that a pavement is allowed to attain. Low maintenance standard therefore causes roads to deteriorate at a faster rate (TRRL, 1988).

- **Age of pavement**: As pavements age and experience traffic repetitions, pavement distresses begin to accumulate. For example, the hardening effect increases the stiffness of asphalt with age making the material more susceptible to thermal cracking (Yonder et al., 1975).

2.4 Pavement Material

2.4.1 Bitumen-Bound Materials

Hot premixed bituminous pavement materials (hot mix asphalt or HMA) wearing courses are the most critical layer in a pavement structure and must be of high quality and have predictable performance.

HMA wearing courses need to possess the following characteristics (ERA, 2013):

- High resistance to deformation;
- High resistance to fatigue and the ability to withstand high strains i.e. they need to be flexible; Sufficient stiffness to reduce stresses in the underlying layers to acceptable level
- High resistance to environmental degradation i.e. good durability;
- Low permeability to prevent the ingress of water;
- Good workability to allow adequate compaction to be obtained during construction;
- Sufficient surface texture to provide good skid resistance in wet weather; and Predictable performance.

2.4.1.1 Composition of HMA

Components of a MixThe types of HMA most frequently used in tropical countries are manufactured in an asphalt plant by hot-mixing appropriate proportions of the following materials;

- Coarse aggregate, defined as material having particles larger than 2.36 mm;
- Fine aggregate, defined as material having particles less than 2.36 mm and larger than 0.075 mm;
- Filler, defined as material having particle sizes less than 0.075mm which may originate from fines in the aggregate or be added in the form of cement, lime or ground rock; and
- A paving grade bitumen with viscosity characteristics appropriate for the type of HMA, the climate and loading conditions where it will be used (ERA, 2013).

Types of HMA in Common Use

Two generic types of HMA are presently used in countries with tropical climates. These are: Mixes in which traffic stresses are transmitted mainly through an aggregate structure which has a continuous particle size distribution. Asphalt Concrete and Bitumen Macadam are examples of this type. Mixes in which stresses are passed through the fines/filler/bitumen matrix. In these mixes, the aggregate particle size distribution is discontinuous or ‘gap-graded’. Hot Rolled Asphalt is in this category (ERA, 2013).

Materials for HMA

It is essential that the properties of the component materials of HMA meet minimum standards to ensure the material has a satisfactory performance.

Aggregate: is the major component in HMA and the quality and physical properties of this material has a large influence on mix performance. The qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity and porosity. In addition to these properties, the micro texture of the aggregate particles will also strongly influence the performance of a compacted HMA layer. Smooth-surfaced river gravel, even partly crushed, may not generate as much internal friction as a totally crushed aggregate from particles having a coarse micro texture. The coarse aggregates used for making HMA should be produced by crushing sound, unweathered rock or natural gravel. Gravel should be crushed to produce at least two fractured faces on each particle (ERA, 2013).

The aggregate should have the following characteristics:

- Be angular and not excessively flaky, to provide good mechanical interlock;
- Be clean and free of clay and organic material;
  Be strong enough to resist crushing during mixing and laying as well as in service;
- Be resistant to abrasion and polishing when exposed to traffic;
- Be non-absorptive - highly absorptive aggregates are wasteful of bitumen and also give rise to problems in mix design; and
- Have good affinity with bitumen - hydrophilic aggregates may be acceptable only where protection from water can be guaranteed or a suitable adhesion agent is used.

Filler (material finer than 0.075 mm) can be crushed rock fines, Portland cement or hydrated lime. Portland cement or hydrated lime is often added to natural filler (1-2 per cent by mass of total mix) to improve the adhesion of the bitumen to the aggregate (ERA, 2013).

Bitumen for HMA: There are three important properties or characteristics of paving grade bitumens. These are consistency (usually called viscosity), purity and safety.Traditionally, paving grade bitumens have been specified in terms of their penetration but the measurement of viscosity provides a more accurate method of specifying binder consistency and a more effective method of determining the temperature susceptibility of the bitumen. Several authorities now produce alternative specifications based on viscosity. Suitable apparatus for measuring viscosity may not be readily available and, therefore, both methods of specification are presented below. When ordering bulk bitumen supplies, it should be possible to obtain evidence of compliance with viscosity specifications since the necessary equipment will be available at the refinery (ERA, 2013).

Pre-hardening of bitumen: Bitumen samples should be tested in both the 'as delivered state' and also after prehardening, which is intended to simulate the ageing of bitumen during storage, mixing and construction. Two test methods are used to pre-age bitumen, the Thin Film Oven Test (TFOT) and the Rolling Thin Film Oven Test (RTFOT). The RTFOT test is considered to be the best method of simulating the ageing of bitumen during the construction process. The TFOT can be used for penetration graded specifications but, where possible, the RTFOT equipment and a viscosity graded specification should be used (ERA, 2013).

2.4.2 Unbound Pavement Materials

Base course materials: A wide range of materials can be used as unbound base course including crushed quarried rock, crushed and screened, mechanically stabilised, modified or naturally occurring 'as dug' or 'pit run' gravels. Their suitability for use depends primarily on the design traffic level of the pavement and climate. However, all base course materials must have a particle size distribution and particle shape which provide high mechanical stability and should contain sufficient fines (amount of material passing the 0.425 mm sieve) to produce a dense material when compacted (ERA, 2013).

Sub-Bases: 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, 2013).

Selected Subgrade Materials and Capping Layers: 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. A minimum CBR of 15 per cent is specified at the highest anticipated moisture content measured on samples compacted in the laboratory at the specified field density. This density is usually specified as a minimum of 95 per cent of the maximum dry density in the ASTM Test Method D 1557 (Heavy Compaction). 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 gradings 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, 2013).

2.5 Engineering Basic Soil Information

2.5.1 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.

2.5.2 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).

- Gravel: Fraction passing the 3-inch sieves and retained on the No. 10 sieve.
- Sand: Fraction passing No. 10 sieve and retained on the No. 200 sieve.
- 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.

2.5.3 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.

In the AASHTO system (see Table 2.1 below), 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).

Table 2.1 Revised AASHTO System of Soil Classification

General Classification	General Materials (35% or less passing 0.075)							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-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis % Passing											
2.00 mm (No 10)	50 max										
0.425 mm (No 40)	30 max	50 max	51 min								
0.725 mm (No 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 Min	36 min	36 min	36 min
characteristics of friction											
Passing											
Liquid limit				40 max	41 min	40 max	41 min	40 Max	41 min	40 max	40 min
Plastic Index	6 max		N.P	10 max	10 max	11 min	11 min	10 Max	10 max	11 min	11 min
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			

2.6 Pavement Deterioration and Its Types

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions (Sharad et al., 2009).

Types of Pavement Deterioration: The four major categories of common asphalt pavement surface distresses are (Sharad et al., 2009):

Cracking: The most common types of cracking are:

- **Fatigue cracking:** This is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue). Eventually, the cracks lead to disintegration of the surface. The final result is potholes. Alligator cracking is usually associated with base or drainage problems. Small areas may be fixed with a patch or area repair. Larger areas require reclamation or reconstruction. Drainage must be carefully examined in all cases. Figure 2.1 below illlustrates fatigue cracking in flexible pavement.

Figure 2.1 Fatigue Cracking in Flexible Pavement
Source: https://www.kth.se

- **Longitudinal cracking**: Longitudinal cracks are long cracks that run parallel to the center line of the roadway. These may be caused by frost heaving or joint failures or they may be load-induced. Understanding the cause is critical to selecting the proper repair. Multiple parallel cracks may eventually form from the initial crack. This phenomenon, known as deterioration, is usually a sign that crack repairs are not the proper solution.

- **Transverse cracking**: Transverse cracks form at approximately right angles to the centerline of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced (over 20 feet apart). They usually begin as hairline or very narrow cracks and widen with age. If not properly sealed and maintained, secondary or multiple cracks develop, parallel to the initial crack. The reasons for transverse cracking, and the repairs, are similar to those for longitudinal cracking. In addition, thermal issues can lead to low-temperature cracking if the asphalt cement is too hard. Figure 2.2 below shows transverse cracking in flexible pavement.

Figure 2.2 Transverse Cracking in Flexible Pavement

Source: https://www.theconstructor.org

- **Block cracking**: Block cracking is an interconnected series of cracks that divides the pavement into irregular pieces. This is sometimes the result of transverse and longitudinal cracks intersecting. They can also be due to lack of compaction during construction. Low severity block cracking may be repaired by a thin wearing course. As the cracking gets more severe, overlays and recycling may be needed. If base problems are found, reclamation or reconstruction may be needed. Figure 2.3 blow shows Block Cracking in Flexible Pavement.

Figure 2.3 Block Cracking in Flexible Pavement

Source: https:// https://www.pavementinteractive.org

- **Slippage cracks**: These are half-moon shaped cracks with both ends pointed towards the oncoming vehicles. They are created by the horizontal forces from traffic. They are usually a result of poor bonding between the asphalt surface layer and the layer below. The lack of a tack coat is a prime factor in many cases. Repair requires removal of the slipped area and repaving. Be sure to use a tack coat in the new pavement. Figure 2.4 below shows slippage cracks in flexible pavement.

Figure 2.4 Slippage Cracks in Flexible Pavement

Source: https://www.pavementinteractive.org

- **Reflective cracking**: Reflective cracking occurs when a pavement is overlaid with hot mix asphalt concrete and cracks reflect up through the new surface. It is called reflective cracking because it reflects the crack pattern of the pavement structure below. As expected from the name, reflective cracks are actually covered over cracks reappearing in the surface. They can be repaired in similar techniques to the other cracking noted above. Before placing any overlays or wearing courses, cracks should be properly repaired. Figure 2.5 shows Reflective Cracking in Flexible Pavement.

Figure 2.5 Reflective Cracking in Flexible Pavement

Source: https://www.pavementinteractive.org

- **Edge cracking**: Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture. They may occur in a curbed section when subsurface water causes a weakness in the pavement. At low severity, the cracks may be filled. As the severity increases, patches and replacement of distressed areas may be needed. In all cases, excess moisture should be eliminated, and the shoulders rebuilt with good materials.

Surface Deformation: Pavement deformation is the result of weakness in one or more layers of the pavement that has experienced movement after construction. The deformation may be accompanied by cracking. Surface distortions can be a traffic hazard. The basic types of surface deformation are:

- **Rutting**: This is the displacement of pavement material that creates channels in the wheel path. Very severe rutting will actually hold water in the rut. Rutting is usually a failure in one or more layers in the pavement. The width of the rut is a sign of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a sub-grade failure. Inadequate compaction can lead to rutting. Deeper ruts may be shimmed with a truing and leveling course, with an overlay placed over the shim. If the surface asphalt is unstable, recycling of the surface may be the best option. If the problem is in the sub-grade layer, reclamation or reconstruction may be needed. Figure 2.6 below shows rutting type surface deformation in flexible pavement.

Figure 2.6 Rutting Type Surface Deformation in Flexible Pavement

Source: https://www.pavementinteractive.org

- **Corrugation**: This is referred to as wash boarding because the pavement surface has become distorted like a washboard. The instability of the asphalt concrete surface course may be caused by too much asphalt cement, too much fine aggregate, or rounded or smooth textured course aggregate. Corrugations usually occur at places where vehicles accelerate or decelerate. Minor corrugations can be repaired with an overlay or surface milling. Severe corrugations require a deeper milling before resurfacing.

- **Shoving**: Shoving is also a form of plastic movement in the asphalt concrete surface layer that creates a localized bulging of the pavement. Locations and causes of shoving are similar to those for corrugations. Repair minor shoving by removing and replacing. For large areas, milling the surface may be required, followed by an overlay. Figure 2.7 below shows shoving type surface deformation in flexible pavement.

Figure 2.7 Shoving Type Surface Deformation in Flexible Pavement

Source: https://www.pavementinteractive.org

- **Depressions**: Depressions are small, localized bowl-shaped areas that may include cracking. Depressions cause roughness, are hazard to motorists, and allow water to collect. Depressions are typically caused by localized consolidation or movement of the supporting layers beneath the surface course due to instability. Repair by excavating and rebuilding the localized depressions. Reconstruction is required for extensive depressions. Figure 2.8 below shows depressions type surface deformation in flexible pavement.

Figure 2.8 Depressions Type Surface Deformation in Flexible Pavement

Sources: https://www.kth.se

- **Swell:** This is a localized upward bulge on the pavement surface. Swells are caused by an expansion of the supporting layers beneath the surface course or the sub-grade. The expansion is typically caused by frost heaving or by moisture. Sub-grades with highly plastic clays can swell in a manner similar to frost heaves (but usually in warmer months). Repair swells by excavating the inferior sub-grade material and rebuilding the removed area. Reconstruction may be required for extensive swelling.

Disintegration: the progressive breaking up of the pavement into small, loose pieces is called disintegration. If the integration is not repaired in its early stages, complete reconstruction of the pavement may be needed. The two most common types of disintegration are:

- **Potholes**:These are bowl-shaped holes similar to depressions. They are progressive failures. First, small fragments of the top layer are dislodged. Over time, the distress will progress downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage. Potholes are formed when the pavement disintegrates under traffic loading, due to inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water. Most potholes would not occur if the root cause was repaired before development of the pothole. Repair by excavating and rebuilding. Area repairs or reconstruction may be required for extensive potholes. Figure 2.9 below shows potholes type disintegration in flexible pavement.

Figure 2.9 Potholes Type Disintegration in Flexible Pavement.
sources: https://www.kth.se

- Patches: This is defined as a portion of the pavement that has been removed and replaced. Patches are usually used to repair defects in a pavement or to cover a utility trench. Patch failure can lead to a more widespread failure of the surrounding pavement. Some people do not consider patches as a pavement defect. While this should be true for high quality patches as is done in a semipermanent patch, the throw and roll patch is just a cover. The underlying cause is still under the pothole. To repair a patch, a semi-permanent patch should be placed. Extensive potholes may lead to area repairs or reclamation. Reconstruction is only needed if base problems are the root source of the potholes. Figure 2.10 below shows patches type disintegration in flexible pavement.

Figure 2.10 Patches Type Disintegration in Flexible Pavement

Source: https://www.kth.se

Surface Defects: Surface defects are related to problems in the surface layer. The most common types of surface distress are:

- **Raveling**: This is the loss of material from the pavement surface. It is a result of insufficient adhesion between the asphalt cement and the aggregate. Initially, fine aggregate breaks loose and leave small, rough patches in the surface of the pavement. As the disintegration continues, larger aggregate breaks loose, leaving rougher surfaces. Raveling can be accelerated by traffic and freezing weather. Some raveling in chip seals is due to improper construction technique. This can also lead to bleeding. Repair the problem with a wearing course or an overlay. Figure 2.11below shows raveling type surface defects in flexible pavement.

Figure 2.11 Raveling Type Surface Defects in Flexible Pavement

Source: https://www.pavementinteractive.org

- **Bleeding:** This is defined as the presence of excess asphalt on the road surface which creates patches of asphalt cement. Excessive asphalt cement reduces the skid-resistance of a pavement, and it can become very slippery when wet, creating a safety hazard. This is caused by an excessively high asphalt cement content in the mix, using an asphalt cement with too low a viscosity (too flow able), too heavy a prime or tack coat, or an improperly applied seal coat. Bleeding occurs more often in hot weather when the asphalt cement is less viscous (more flow able). Figure 2.12 below shows bleeding type surface defects in flexible pavement.

Figure 2.11 Bleeding Type Surface Defects in Flexible Pavement

Source: https://www.pavementinteractive.org

- **Polishing**: is the wearing of aggregate on the pavement surface due to traffic. It can result in a dangerous low friction surface. A thin wearing course will repair the surface.

2.7 Causes of Pavement Deterioration

Sudden increase in traffic loading, especially on new roads where the design is based on lesser traffic is a major cause of cracking. After construction of good road, traffic of other roads also shifts to that road. This accelerates the fatigue failure (Alligator Cracking). Temperature variation ranging from 50º C to below zero conditions in the plain areas of North and Central India leads to bleeding and cracking. Provision of poor shoulders leads to edge failures. Provision of poor clayey subgrade results in corrugation at the surface and increase in unevenness.

Poor drainage conditions especially during rainy seasons, force the water to enter the pavement from the sides as well as from the top surface. In case of open graded bituminous layer, this phenomenon becomes more dangerous and the top layer gets detached from the lower layers. If the temperature of bitumen/bituminous mixes is not maintained properly, then it also leads to pavement failure. Over heating of bitumen reduces the binding property of bitumen. If the temperature of bituminous mix has been lowered down then the compaction will not be proper leading to longitudinal corrugations (Sharad et al., 2009).

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. Non-preventive maintenance can also be described as routine, recurrent and urgent (TRRL, 1988), 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 and includes repair of washouts, rigid pavement blow-ups, and earth slides (TRRL, 1988). 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 classification of highway maintenance activities will be preventive maintenance and remedial maintenance described as follows:

- 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

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).

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.

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.

Patching (flexible pavement): entails the removal and repair of edge breaks, potholes, showing severely cracked and deformed areas and surface failures. 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).

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.

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.

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

3. METHODOLOGY

3.1 The Study Area

The research will be conducted from Dessie to Hayk road segments which is 30 km long, located in South Wollo. The road segment is a trunk road which directly runs from Addis Ababa to Mekele. Similarly, it runs to Gonder and Bahir Dar with a supportive link road between Woldia to Debretabor**.**

The study area started at Dessie town located at a latitude and longitude of 11°8′N 39°38′E respectively and with an elevation between 2,470 and 2,550 meters above sea level. The study area ends at Hayk town located at a latitude and longitude of 11°18′N 39°41′E respectively and on an elevation of 2,030 meters above sea level. The topography of the road terrain can be classified as flat and rolling (ERA, 2012). Climate wise, Dessie is endowed with beautiful scenery, and good air located at an altitude of 2,470 meters above sea level in low-shrouded mountains and hills and the surrounding mountains (Climate, 2016). Table 3.1 below provides the climatic condition of Dessie City.

Table 3.1 Climatic Condition of Dessie City (source: Climate-Data.org, altitude: 2470m)

Climate data for Dessie													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C(°F)	22.7 (72.9)	23.1 (73.6)	22.4 (72.3)	23.4 (74.1)	24.5 (76.1)	25.3 (77.5)	24.1 (75.4)	23.0 (73.4)	22.2 (72.0)	22.6 (72.7)	21.7 (71.1)	22.0 (71.6)	23.1 (73.6)
Average low °C (°F)	5.4 (41.7)	7.1 (44.8)	6.9 (44.4)	8.4 (47.1)	8.1 (46.6)	9 (48)	10.3 (50.5)	10 (50)	9.2 (48.6)	6.3 (43.3)	4.1 (39.4)	4.1 (39.4)	7.4 (45.3)
Average precipitation mm(inch)	25 (0.98)	40 (1.57)	81 (3.19)	95 (3.74)	75 (2.95)	41 (1.61)	273 (10.75)	283 (11.14)	144 (5.67)	45 (1.77)	20 (0.79)	23 (0.91)	1145 (45.07)

3.2 Study Period

The research duration was estimated to be six months, i.e. from Jan, 01/2018 to June, 30/2018 to accomplish the research. And this will be indicated on the work plan of this proposal.

3.3 Study Design

Experimental study design will be used to achieve the ultimate goal of the research. In experimental study design, it consists of two tasks; field work and laboratory tests. The field work extends from detail observation of the road environment, taking sample from different places within the study area to investigate the possible causes which leads pavement distresses and also to investigate the engineering properties of sub grade soil, sub base materials, base and the surface condition. In laboratory tests, the samples, taken from the study area, were tested to measure the physical properties of the soil, the materials strength and pavement moisture content and to identify possible remedies after conducting laboratory tests and observing the results in order to reduce the problems the distresses.

In this study design, laboratory tests such as checking moisture content, grain size distribution, density, CBR test, standard sieve analysis, Atterberg limits test, Los Angeles Abrasion test, shape test and another necessary laboratory test were conducted. The laboratory results were needed for interpretation and to come up with accurate remedies.

3.4 Population

In this study, pavement distresses on Dessie - Hayk road segment were considered as the population of the study.

3.5 Sample Size and Sampling Process

Basically, there are two types of sampling techniques and these are probability (random) and non-probability sampling. Probability sampling offers an equal opportunity or chance for each element (e.g. persons, households) being included in the sample. However; in non-probability sampling, population elements are selected on the basis of their availability or because of the researcher's personal judgment that they are representative.

Probability sampling is considered to be objective, empirical, scientific, quantitative and representative. To conduct this, detail investigation, different laboratory as well as field test equipment and longer time are required. Whereas, non-probability sampling is considered to be interpretive, subjective, not scientific, qualitative and unrepresentative; but, from time considerations, resource and higher budget availability conducting detail investigation have those limitations.

Therefore, in this study, random sampling method was used and implemented based on visual inspection for already distressed paved road and were categorized into the same pavement surface distresses. From this, representative samples were selected depending on the ERA manual.

3.6 Study Variable

There are two variables that will be taken into consideration; dependent variables and independent variables. The independent variables which will be determined during data collection include traffic load, CBR value, Atterberg limit value, Gradation size distribution, moisture content of material, pavement age, drainage and climatic condition and other causes of pavement failure. The dependent variable is pavement distress.

3.7 Data Collection Process

In order to achieve the objectives of the research stated in chapter one, data were required. The methodologies applied to collect the data are discussed below. The first stage in data collection was to be obtain consent letter from ERA, local governments and from the municipality of Dessie city. Field visits in the study area were undertaken and samples were collected from the prevalent distressed paved road. Base course and sub-grade materials were collected at each failed section based on colure change.

Representative samples at each test pits and photographs at representative location were collected. The road was categorized into different road failures based on condition survey. In addition, adequate number of representative samples were carefully selected based on visual inspection. Finally, the collected representative samples were tested in laboratory.

3.8 Field Work

Preliminary visual survey was undertaken along the Dessie - Hayk road segment. Field observations were performed and representative samples were transported to laboratory for testing. The samples were tested and the results 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 road segment. The initial site visit was undertaken on the whole portion of the road. After finishing the initial visual inspection, the conditions of the road failures along the road section were categorized. Next, the representative locations for sampling based on their failure conditions/types were selected. Accordingly, six sample locations/stations of test pits that represent the type of failures observed along the road section were selected.

Six major types of failures were observed along the study road. Relative to this, possible distress types were organized based on the existing condition of the pavement surface together with the extent of damage.

Regarding the samples, the following statement are provided:

Sample One: Depressions type of failure mode which is the dominant failure on Dessie - Hayk road segment. The Description, problem and possible cause are stated below:

- Description: Localized pavement surface areas with slightly lower elevations than the surrounding pavement. Depressions are very noticeable after a rain when they fill with water.
- Problem: Roughness, depressions filled with substantial water can cause vehicle hydroplaning.
- Possible Causes: Irregular frost heave or subgrade settlement resulting from inadequate compaction during construction or poor quality (soft) subgrade.

Sample Two: Raveling type of failure mode which is also the main failure on Dessie - Hayk road segment. Its description, problem and possible cause are:

- Description: The progressive disintegration of the HMA 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 in vehicle hydroplaning, loss of skid resistance.
- Possible Causes: Several including; loss of bond between aggregate particles and the asphalt binder as a result of a dust coating on the aggregate particles that forces the asphalt binder to bond with the dust rather than the aggregate. If fine particles are missing from the aggregate matrix, then the asphalt binder is only able to bind the remaining coarse particles at their relatively few contact points. Inadequate compaction during construction.High density is required to develop sufficient cohesion within the HMA (paving in cold weather). Mechanical dislodging by certain types of traffic (studded tyres or tracked vehicles). Figure 3.1 below shows representative raveling damage.

Figure 3.1 Representative Raveling Damage and their Sample (19/09/2010E.C)

Sample Three: patching type of failure mode which is the dominant failure on Dessie - Hayk road segment. Its description, problem and possible cause are:

- 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.
- Possible Causes: Previous localized pavement deterioration that has been removed and patched.Figure 3.2 below shows representative patched damage.

Figure 3.2 Representative Patched Damaged and their Samples (27/09/2010 E.C)

Sample Four: Corrugation types of failure mode which is also a failure on Dessie - Hayk road segment. Its description, problem and possible cause are:

- Description: A form of plastic movement typified by ripples (corrugation) or an abrupt wave across the pavement surface. The distortion is perpendicular to the traffic direction. Usually occures at points where traffic starts and stops (corrugation) or where HMA abuts a rigid object.
- Problem: Roughness
- Possible Causes: usually caused by traffic action combined with: an unstable (i.e. low stiffness) HMA layer (caused by mix contamination, poor mix design, poor HMA manufacturing, or lack of aeration of liquid asphalt emulsions) and excessive moisture in the pavement structure. Figure 3.3 below shows representative corrugation type damaged.

Figure 3.3 Representative Corrugation Type Damaged and their Samples (27/09/2010 E.C)

Sample Five: pothole types of failure mode which is a failure on Dessie - Hayk road segment. Its description, problem and possible cause are:

- Description: Small, bowl-shaped depressions in the pavement surface that penetrate all the way through the HMA layer down to the base course.They generally have sharp edges and vertical sides near the top of the hole.Potholes are most likely to occur on roads with thin HMA surfaces (25 to 50 mm) and seldom occur on roads with 100 mm or deeper HMA surfaces.
- Problem: Roughness (serious vehicular damage can result from driving across potholes at higher speeds), moisture infiltration.
- Possible Causes: Generally, potholes are the end result of alligator cracking. As alligator cracking becomes severe, the interconnected cracks create small chunks of pavement, which can be dislodged as vehicles drive over them.The remaining hole after the pavement chunk is dislodged is called a pothole. Figure 3.4 below shows representative potholes damage.

Figure 3.4 Representative Potholes Damages and their Samples (27/09/2010 E.C)

Sample Six: fatigue cracking type of failure mode which is also failure on Dessie - Hayk road segment. Its description, problem and possible cause are:

- Description: Series of interconnected cracks caused by fatigue failure of the HMA surface (or stabilized base) under repeated traffic loading. In thin pavements, cracking is initiated at the bottom of the HMA layer where the tensile stress is the highest then propagates to the surface as one or more longitudinal cracks.This is commonly referred to as "bottom-up" or "classical" fatigue cracking. In thick pavements, the cracks are most likely initiated from the top in areas of high localized tensile stresses resulting from tire-pavement interaction and asphalt binder aging (top down cracking). After repeated loading, the longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile.
- Problem: Indicator of structural failure, cracks allow moisture infiltration, roughness, may further deteriorate to a pothole.
- Possible Causes: Inadequate structural support, which can be caused by a number of things. A few of the more common ones are:
  - Loss of base, subbase or subgrade support (e.g., poor drainage or spring thaw resulting in a less stiff base);
  - Stripping on the bottom of the HMA layer (the stripped portion contributes little to pavement strength so the effective HMA thickness decreases);

- Increase in loading (e.g., more or heavier loads than anticipated in design);
- Inadequate structural design; and
- Poor construction (e.g., inadequate compaction)

3.9 Data Processing and Analysis

After the data were collected, the next step is processing and analyzing the data. First; classify the soil material based on the laboratory test results using AASHTO and other Standard manual. Then, characterize the soil by comparing and relating different parameters of engineering properties of soil. In addition, interpretation of the results of the tests and the classification were done in parallel to determine; the index properties, bearing capacity and maximum dry density of different layers along the failed road alignment. Further, some aggregate tests like shape tests which provide information concerning the presence of fluky, elongated and angular pieces in a given sample of road aggregate, determination of the abrasion value of coarse aggregate by Los Abrasion machine and specific gravity as well as water absorption test were conducted. By comparing different pavement design manuals, it had been attempted to provide or checked the cause of pavement failure due to soil properties. Finally, 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 were explored. Data collected from physical/field observation were presented statistically and in different categories and due to this, qualitative analysis method was followed. The analyzed data were presented by graphs, charts, table, etc.

3.10 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 the Ethiopian Railways Corporation (Yapi Merkezi) and Woldiya University. 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 at horizontal effective size to the vertical effective stress. The degree of compaction is measured in terms of its dry weight increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and curb undesirable settlement of structures. The mould was 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 base course, sub-base, sub-grade soil material. The soaked method of CBR was conducted to characterize the soil for use as a base course, sub-base and sub-grade 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.

Specific Gravity and Water Absorption Test

Specific gravity is the ratio of the mass of a given volume of the substance to the mass of an equal volume of water, the temperature of both being specified. The aggregate particles generally used for construction purpose typically consist of some amount of solid material along with a certain amount of air voids. The specific gravity test procedures take some times as a soaking period for the purpose of allowing penetration of binder or water into these voids. So in aggregate particle, there are several different kinds of specific gravity depending up on the different volume consideration.

Water absorption depends on the porosity of the particle. As the porosity is high percentage of water absorption will be more. Water absorption gives an idea about the strength of aggregate particles. A highly absorptive aggregate could lead to a low durability bituminous mixture. (Singh, 1981).

Shape Test

The aggregate particles may in general be equi-dimensional, thin flat or flaky and elongated in shape. Two relatively independent properties that control particle shape are sphericity and roundness. Sphericity describes the relation of surface area of the particle to its volume or the relative volume of the particle, and that of the circumscribing sphere. Roundness measures relative sharpness of the edges and corners of the particles.

The shape tests provide information concerning the presence of fluky, elongated and angular pieces in a given sample of road aggregate. The presence of fluky and elongated particle in aggregates used in pavement construction is likely to affect adversely the pavement strength as these particles have inherent weakness leading to possible breakdown under compaction or heavy traffic loads, progressive polishing giving rise to slippery surface. Their proportion in a given aggregate should be limited so that the compacted pavement mix performs satisfactorily and stable. The strength, bitumen content, and workability of asphaltic mixture and the frictional characteristics of graded aggregates are all influenced by particle shape on the quality of aggregate. (Singh, 1981).

Aggregate Abrasion Test

For an aggregate to perform satisfactorily in highway pavement, it must be sufficiently hard to resist the abrasive effects of traffic over a long period of time. The abrasion tests are basically accelerated tests which enable the user to eliminate aggregates which may be unsuitable from this point of view. Whether the tests simulate abrasion under actual traffic conditions, is, however, debatable. Abrasion tests on aggregates are generally carried out by one of the following methods (Singh, 1981):

- Los Angeles (LA) abrasion test;
- Deval abrasion test; and
- Dorry abrasion test.

3.11 Ethical Considerations

Before the beginning of the study, a consent letter from the Addis Ababa institute of Technology (AAiT) would be written and the local government of Dessie city and ERA would be informed in order to conduct this study. They had to know the collected data would be used only for research purposes in order to ensure the confidentiality of the data. This will be important to ensure the culture of informants being respected. Accordingly, the data would be collected honestly and based on the willingness of informants or organizations.

3.12 Data Quality Assurance

In order to assure data quality, the following measures were taken:

- Giving adequate training for data sample collectors;
- Paying sufficient payment for data collectors;
- Proceeding with appropriate checks after data collection;
- Having adequate tests on the equipment used for data collection in order to check the efficiency of the equipment;

- Making daily diary on data collection process; and
- Having an interesting communication among individuals or organizations.

3.13 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 for established categories for the variables and the standard of comparisons are briefly presented below:

- **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 sub-grade and depends on a firm continuous sub-grade, aggregate interlock, particle friction, and cohesion for stability.
- **Roadbed Material**: The material below the sub-grade 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 sub-grade to support a base course (or in the case of rigid pavements, the Portland cement concrete slab).
- **Sub-grade**: 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 sub-grade to support a surface course.
- **Damage**: The defect of a road not to function within its design life span.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 General

Soil sub-grade and aggregate are the most important constituents of highway or pavement structure. Sub-grade soil or simply the sub-grade is the bottom most layer of the pavement. It can be natural or stabilized, on which all the other layers' rest upon. Thus, it is easy to note that the overall performance of pavement layers as a whole is dependent upon the strength of the sub-grade. Aggregates or granular materials from a major portion (92% to 96% for bituminous mixes and 70% to 80% for Portland cement concrete mixes, by volume) of the pavement layers above the sub-grade till the surface. The surface and base layers generally comprise aggregates bounded by bitumen or Portland cement. The layers below are unbound granular layers of various sizes. Characterization of the properties of sub-grade and aggregate is done through a series of tests on physical and chemical properties (Singh, 1981). Different types of laboratory tests were done in this research and discussed in brief below. The laboratory analysis was performed according British standard, AASHTO standard method and ASTM standard test methods.

4.2 Test Pit Locations for Pavement Material Sampling

The causes of deterioration and the selection of appropriate remedial treatments may be very straightforward and require only confirmatory testing. When a road is failing, it is perhaps, quite natural to want to concentrate investigations on the failed areas. However, this is not always the best option, especially if structural failures are occurring. This is because such areas will display cracks, ruts, potholes and so on. Water will have already entered the structure through the failures and therefore the properties of the pavement materials will have changed considerably; hence, it will be impossible to identify the primary cause of the problems. The areas that will prove to be the most informative will be those that are beginning to show signs of failure because they are likely to display only one form at the early stage. This will be the primary or main reason for the failure (ERA, 2013).

After dividing the road into lengths of nominally similar construction, it may be necessary to subdivide it again based upon the current condition of the road. This can be done by carrying out a condition survey. The best way to do such a survey is for the survey vehicle to stop at 500 meter or one kilometer intervals to enable the condition of the road pavement to be recorded accurately using a selection of the road pavement deterioration criteria. Important aspects of road deterioration may be missed if the vehicle is not stopped and survey staff given the opportunity to inspect the road closely. Surface condition data may be available from a PMS survey but it may not be up-to-date (ERA, 2013).

During the field observation, it was found necessary to start by visual inspection of the whole stretch of the Dessie - Hayk road segment. During the 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, six failed sections were inspected visually. The observation results and relevant remarks about the road condition are presented in Table 4.1 below.

Table 4.1: Station and Location Representative Failed Pavement Section

Sample No.	Station	Sample side	Date of sample Taken	Pavement damage remark
1	21+550	Left	15/09/2010E.C	Depression type of damages were exist at extreme level
2	07+200	Right	30/09/2010E.C	Raveling type of damages were exist at extreme level
3	13+040	Middle	30/09/2010E.C	Patches type of damages were exist at extreme level
4	16+500	Left	15/11/2010E.C	Corrugation at the edge of the road
5	22+075	Right	20/11/2010E.C	Potholes at the edge some portion of the road near to the edge
6	03+400	Right	20/11/2010	Fatigue cracking at the edge of the road

4.3 Visual Pavement Condition Survey

The road condition survey is an important part of maintenance management. The road condition survey collects data on the condition of the road network. It is used to plan and quantify the maintenance required on the road network. The Pavement condition evaluation has been done from May to June 2018. The main objectives of the condition survey were to evaluate and record the type of pavement distress and formulate the causes of the distresses.

The condition survey would be measured in terms of severity of a distress and the extent of the distress or defect. The Severity and Extent are recorded as a number from ‘0’ (Good) to ‘3’ (Poor). The extent of the defect is the extent or area of the distress or defect. This is recorded with a number indicating the extent. ‘0’(no extent) to ‘3’ (great extent). The extent combined with the severity would determine the quality of the relevant activity to be undertaken on the road section. Many of the distresses or defects have extents as below:

- Less than 20% of area/length affected
- Between 20% and 50% area/length affected
- Greater than 50% area/length affected

Carriageway defects were recorded in the Carriageway section of the form and the defects to be recorded were the following:

- Depression
- Corrugation
- Cracking
- Raveling
- Potholes
- Patching

The distresses type and the intervention levels are described below as sited in, (ERA, 2005):

Severity 1. - Rut depth <20mm

- Corrugations between 10mm and 20mm

- Cracks: Any

- Raveling < 10% area raveled

- Potholes: Pothole depth only in the surfacing

- Depression < 1 minor depression in the section

Severity 2. - Rut Depth between 20mm and 50mm

- Corrugations between 20mm and 50mm
- Cracks: Any
- Raveling: between 10% and 20% area raveled
- Pothole: 2 or more potholes greater than $0.5m^2$ in surface area or depth of pothole
- Depression: less than between 2 and 5 depressions in the section

Severity 3. - Rut Depth > 50mm

- Corrugations > 50mm
- Cracks: Any
- Raveling > 20% area raveled
- Pothole: 2 or more potholes greater than $1m^2$ in surface area or depth of pothole
- Depression > 5 depressions in the section

The condition survey was conducted at every 0.5km interval for failure types of Depression, Corrugation, Cracking, Raveling, Potholes and Patching. The variations of extent of different failure types in respect with the stations of the project road are plotted using charts.

The extent of Corrugations failure varies along the stations of the project road as shown in Figure 4.1 below. From station 4km to station 14km, Corrugations were not observed. In most of the stations from 20km to the end of the road, the severity of rutting was almost more than 50%. The severity of the rutting at 24km -26km and 15km was observed about 30%. Figure 4.1 blow shows Variations of Extent of Corrugation Failure along Road Section.

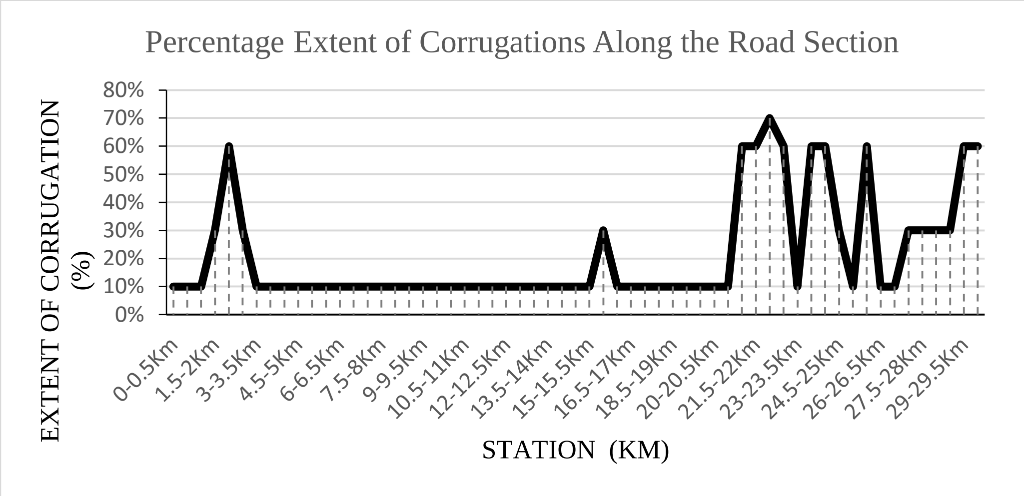

Figure 4.1: Variations of Extent of Corrugation Failure (% Area) along Road Section

Extent of Pothole varies along the road section as shown Figure 4.2 below. In most of the stations from 14km to the end of the road section, the extents of Pothole were observed more than 50%. From station 3.5km to station 9.5km, Pothole was not observed. In the rest of the project section, the extent varies from 5%-70% as shown in the Figure 4.2 below.

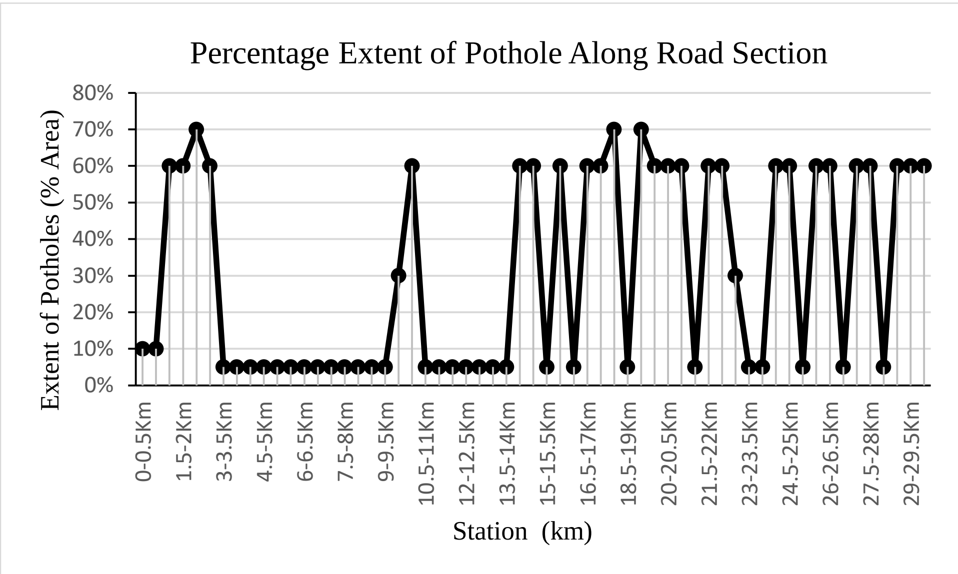

Figure 4.2 Variations of Extent of Pothole (% Area) Along the Road Section

Patching and repair were observed in the road section. Variation of extent of patching and repairing (% age area covered) were summarized as shown in Figure 4.3 below. The extent of patching and repairing failure were ranging from 5% to 10% in most of the stations of the road section. In stations from 21km-23km, 27.5km- 28.5km, 29.5km- 30km and some other stations the extent of patching and repairing failure were 60%. Figure 4.3 blow shows Variations of Extent of Patching and Repairing Along Road Section.

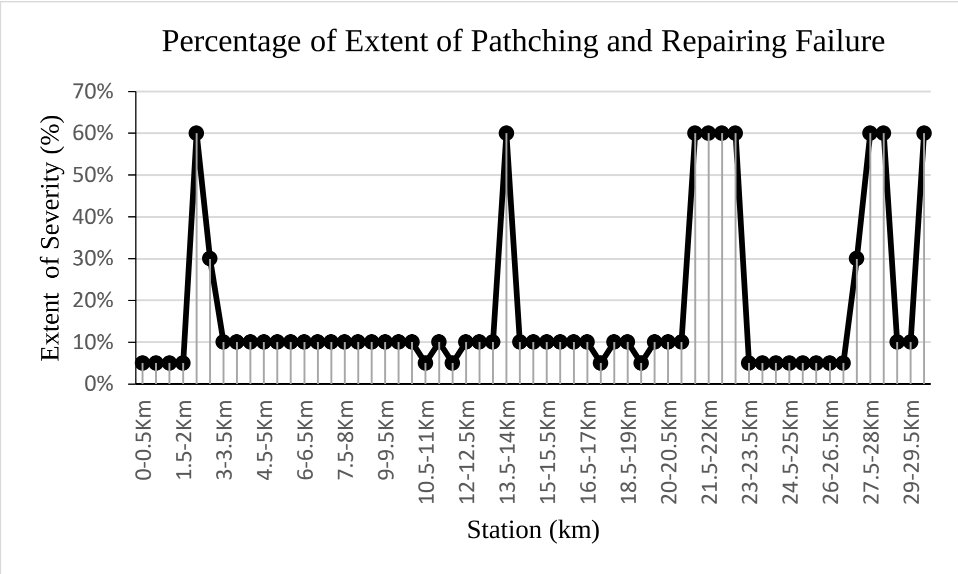

Figure 4.3: Variations of Extent of Patching and Repairing (% Area) Failure Along Road Section

Fatigue cracking was observed along the road section as shown in Figure 4.4. The extent of severity in those sections were mostly 10% which is relatively lower than stations16.5km-17Km, 24.5Km-25Km& 2Km-2.5Km which were of 30%. The maximum severity level observed at stations 1.5Km -2.5Km which were 60% as shown in the Figure 4.4 below.

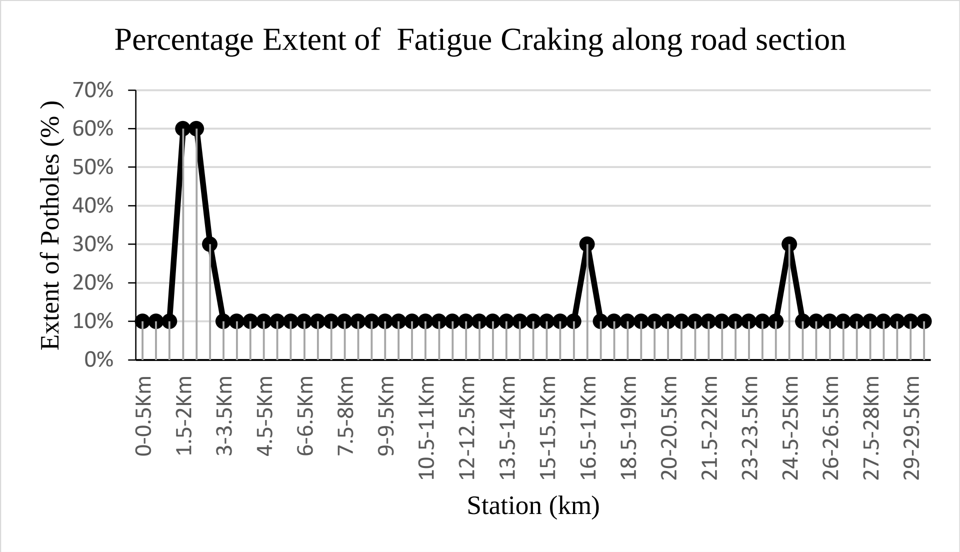

Figure 4.4: Variations Extent of Fatigue Cracking (% Area) Along Road Section

Depression was observed along the road section as shown in Figure 4.5. The extents of severity in those sections were mostly between 5%-10%. The severity of the Depression at 23.5km-25.5km and 20km-21km was observed about 30%. The maximum severity level observed at stations 21km -22.5km which were 60% as shown in the Figure 4.5 blow.

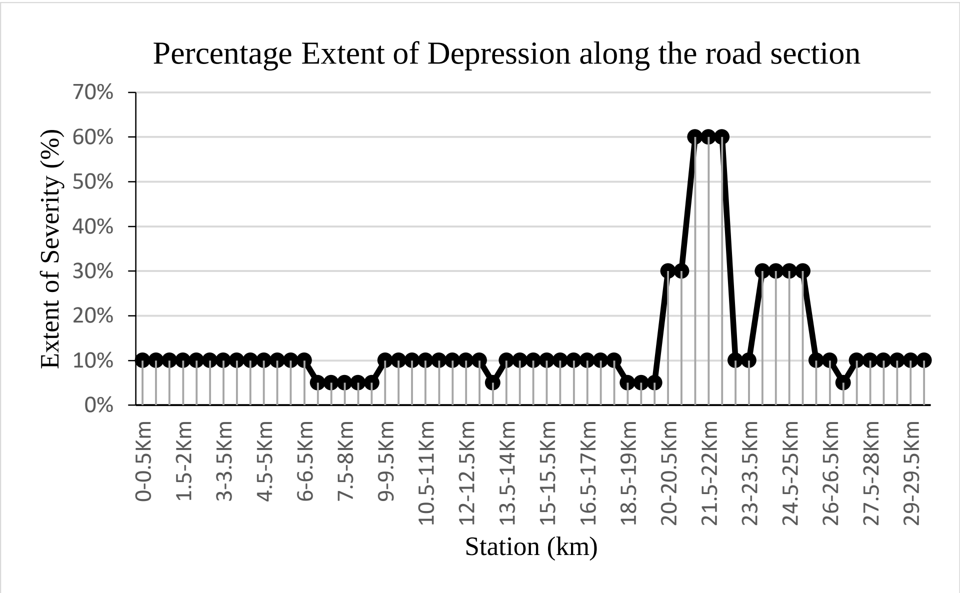

Figure 4.5: Variations of Extents of Depression (% Area) Along Road Section

Raveling was observed along the road section and the variations of failure along the road section were presented as shown in Figure 4.6. In most of the project road the extent of raveling was less than 20%. The station from 6.5km-8km, 20km-20.5km and 21.5km-23km have faced relatively higher stripping and raveling failure as shown in Figure 4.6.

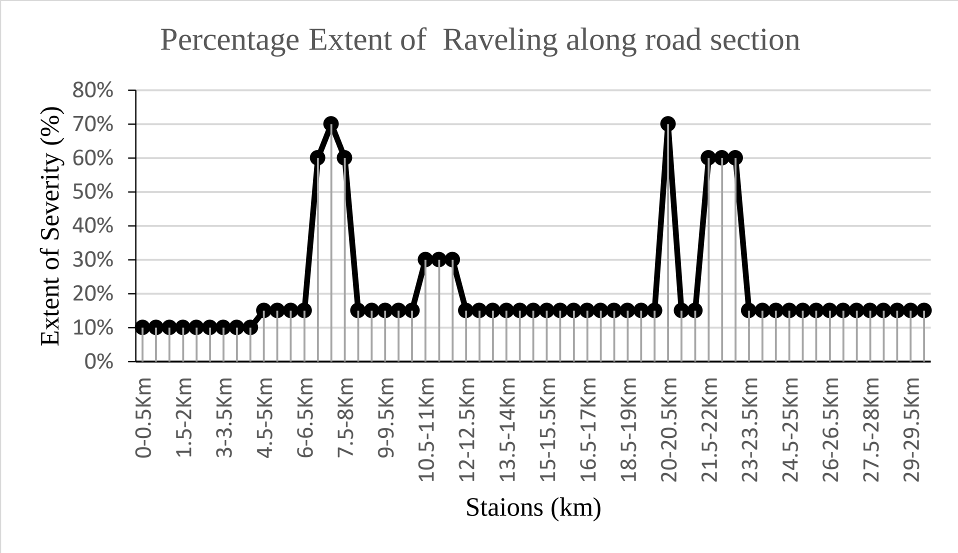

Figure 4.6: Variations of Extent of Raveling (% Area) Along Road Section

4.4 Laboratory Test Results

The laboratory analysis was performed according AASHTO standard method, ASTM standard test methods and the British standard. The laboratory test was carried out to determine the suitability of the soils for use as base course, sub-base and sub-grade using the AASHTO standard method in relation to the generation specification for roads.

The types of basic laboratory tests for each pits should be subjected to analysis. These tests are useful for identification and classification purposes and to establish the quality of materials according to the specifications and design procedures. Most basic physical tests for sub-grade, subbase, and base are similar except that they are conducted in greater number and details when used for analyses of unbound granular materials. In the majority of cases, no single test procedure will satisfy specification and design requirements and a combination of test procedures will be needed.

Gradation test results (Sieve Analysis)

This test was performed to determine the percentage of different grain sizes contained within the subject soil. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method which was used to determine the distribution of the finer particles; and, its classification is a laboratory based process of grouping soils and rocks with similar engineering characteristics based on the measured properties. Table 4.2 below show the Sieve Analysis Test Results of Base Course Materials.

Table 4.2 Sieve Analysis Test Results of Base Course Materials

Material type	Base course						
Sample		1	2	3	4	5	6
	Sieve Size	Percentage Passing					
	3 in. (75 mm)	100	100	100	100.0	100.0	100.0
	$2^{1/2}$in.(63 mm)	100	100	100	100.0	100.0	100.0
	2 in. (50 mm)	100	100	100	100.0	100.0	100.0
	(31.5 mm)	92.24	100	98.80	91.4	98.5	100.0
	1 in. (25 mm)	83.83	89.64	96.18	82.9	95.5	90.7
	3/4in. (19mm)	75.00	79.86	88.34	73.7	86.2	82.2
	3/8 in. (9.5 mm)	41.12	52.53	59.45	41.4	58.7	58.7
	No 4 (4.75 mm)	25.23	35.62	39.29	22.0	35.9	37.5
	No 10 (2.00 mm)	16.91	24.62	26.64	12.3	22.2	22.2
	No 40 (0.425 mm)	9.66	14.53	15.52	7.6	12.1	10.7
	No 200 (0.075 mm)	6.19	9.77	8.93	4.1	5.4	3.4

The most used soil classification is unified soil classification system (ASTM D 2487). The USCS outlines field procedures for determining plasticity, dilatancy, dry strength, particle size, and other engineering parameters. The AASHTO classification system (M 145), which is also commonly used for highway projects, groups soils into categories having similar load carrying capacity and service characteristics for pavement sub-grade design.

The USCS is provided here for information but in most cases of site investigation in Ethiopia, the AASHTO classification system is recommended. The USCS is based on identifying soils according to their textural and plastic characteristic, and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component. They are usually found as mixtures with varying proportions of particle sizes. Each component part contributes its characteristics to the soil mixture. The USCS is based on those characteristics that control how the soil behaves as an engineering material (ERA, 2013). Table 4.3 below shows the sieve analysis test results of the sub-grade materials.

Table 4.3: Sieve Analysis Test Results of Sub- Grade Materials

Material type	Sub –Grade						
Sample		1	2	3	4	5	6
	Sieve Size	Percentage Passing					
	3 in. (75 mm)	100	100	100	100.0	100.00	100.0
	$2^{1/2}$ in. (63 mm)	100	100	100	91.5	86.52	95.3
	2 in. (50 mm)	94.65	100	94.91	85.6	78.72	91.9
	$1^{1/2}$ in. (37.5)	84.96	100	94.91	78.3	71.10	80.2
	1 in. (25 mm)	75.17	92.57	81.60	66.8	62.40	74.2
	3/4 in. (19mm)	69.74	80.78	72.63	56.1	49.74	57.9
	3/8 in. (9.5 mm)	54.37	60.24	53.46	44.8	38.55	42.6
	No 4 (4.75 mm)	45.16	47.83	43.03	32.4	32.49	31.9
	No 10 (2.00 mm)	34.78	36.70	34.12	22.5	24.04	21.6
	No 40 (0.425 mm)	22.83	24.46	23.55	13.9	21.01	17.8
	No 100 (0.150 mm)	18.40	19.30	19.62	6.4	18.84	14.7
	No 200 (0.075 mm)	16.42	17.04	17.32	3.9	17.21	12.4

The properties have been found most useful for this purpose and from the basis of soil identification. They can be determined by simple tests and, with experience, can be estimated with some accuracy.

- Percentages of gravel, sand, and fines (fraction passing the 75-micron sieve).
- Shape of the grain-size-distribution curve.
- Plasticity and compressibility characteristics. In the USCS, the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

Soils are primarily identified as course grained, fine grained and organic. On a textural basis, coarse-grained soils have 50% or more by weight of the overall soil sample retained on the 75μm sieve (No. 200 sieve) and fine-grained soils are those that have more than 50% by weight passing the 75 μm sieve (No. 200 sieve). Highly organic soils are, in general, readily identified by visual examination.

The coarse-grained soils are subdivided into gravel and gravelly soils (G) and sands soils and sandy soils (S). Fined grained soils are subdivided on the basis of their liquid limit

(LL) and plasticity properties. The symbol L is used for soils with LL of 50 and less and symbol H for soils with LLs in excess of 50. Peat and other highly organic soils are designated by the symbol Pt (ERA, 2013). Table 4.4 below shows the laboratory test results of sieve analysis for all samples and subsequently, Table 4.5 show the Atterberg Limit Values of the representative soil sample of the Dessie - Hayk road section.

Table 4.4: Laboratory Test Results of Sieve Analysis for all Samples

Soil sample	Pavement layers	Particle Size Distribution		
		Gravel (%)	Sand (%)	Clay and silt (%)
1	Base course	83.09	10.72	6.19
	Sub grade	65.22	18.36	16.42
2	Base course	75.38	14.85	9.77
	Sub grade	63.30	19.66	17.04
3	Base course	73.36	17.71	8.93
	Sub grade	65.88	16.80	17.32
4	Base course	87.66	8.24	4.1
	Sub grade	77.5	18.6	3.9
5	Base course	77.8	16.8	5.4
	Sub grade	75.96	6.83	17.21
6	Base course	77.8	18.8	3.4
	Sub grade	78.4	9.20	12.4

Table 4.5: Atterberg Limit Values of the Representative Soil Sample of Dessie to Hayk Road Section.

Soil sample	Pavement layers	Atterberg Limits		
		Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)
1	Base course	20.0	16.0	4.0
	Sub grade	36.0	21.0	15.0
2	Base course	21.0	17.0	4.0
	Sub grade	34.0	19.0	15.0
3	Base course	26.0	18.0	8.0
	Sub grade	50.0	30.0	20.0
4	Base course	28.0	17.0	11.0
	Sub grade	56.0	24.0	32.0
5	Base course	23.0	18.0	5.0
	Sub grade	30.0	20.0	10.0
6	Base course	26.0	19.0	7.0
	Sub grade	47.0	31.0	16.0

Representative Natural Subgrade soil sample classification based on AASHTO soil classification of Dessie to Hayk road section

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. Table 4.6 below shows the AASHTO Soil Classification of representative sub-grade soil sample.

Table 4.6: AASHTO Soil Classification of Representative Subgrade Soil Sample

Soil Sample	Soil Type	Atterberg limits			AASTHO Soil Classification
		Liquid limits (%)	Plastic limit (%)	Plastic index (%)	Group Classification
1	Sub grade	36.0	21.0	15.0	**A-2-6**
2	Sub grade	34.0	19.0	15.0	**A-2-6**
3	Sub grade	50.0	30.0	20.0	**A-2-7**
4	Sub grade	56.0	24.0	32.0	**A-2-7**
5	Sub grade	30.0	20.0	10.0	**A-2-4**
6	Sub grade	47.0	31.0	16.0	**A-2-7**

Proctor Test Results (Compaction Test)

Test results for compaction are presented in Table 4.7 below for the six soil samples of each pavement soil layer properties.

Table 4.7: Values of Proctor Test for all Soil Samples in the Study Area

Soil sample	Pavement layers	Modified Proctor Test	
		MDD (Kg/m³)	OMC (%)
1	Base course	2.307	7.75
	Sub grade	2.094	11.74
2	Base course	2.212	6.58
	Sub grade	2.061	12.64
3	Base course	2.313	6.59
	Sub grade	1.894	13.54
4	Base course	2.07	17.39
	Sub grade	1.99	14.29
5	Base course	1.59	30.70
	Sub grade	2.05	14.08
6	Base course	1.87	21.96
	Sub grade	2.09	12.13

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 4.8.

Table 4.8: 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	Base course	12.8	21.2	Repeated
	Sub grade	6.4	8.2	Repeated
2	Base course	59.2	88.3	Repeated
	Sub grade	4.3	4.4	Repeated
3	Base course	47.8	62.1	Repeated
	Sub grade	22.0	22.8	Repeated
4	Base course	81.2	78.5	
	Sub grade	3	2.5	
5	Base course	35.84	43.91	Repeated
	Sub grade	34.5	32.8	
6	Base course	47.35	55.8	Repeated
	Sub grade	4.32	3.41	

4.5 Comparison of Test Results

4.5.1 Comparison of Base course materials

Sieve Analysis (Gradation)

The sieve analysis test results for base material from laboratory test result are shown below. They are more or less within the limits of the specification. The specification limits are shown in Table 4.9 below. The results of the particle size analysis contained in Table 4.4 indicates that the soil's clay content for all base course samples ranged from 3.40% to 9.77%. According to the Federal Ministry of Works and Housing (1997) specification, the clay content for base materials must not exceed 5%. They are exceeding within the limit of specifications except one sample. Figure 4.7 below graphically illustrate the Sieve Analysis of Base Course Materials Samples.

Table 4.9: Gradation Requirements for the Base Material Based on the Specification of Addis Ababa – Woldiya Road Rehabilitation Project

Sieve size, mm	Specification
50	–
37.5	100
25	83 – 96
19	70 – 85
11.2	50 – 66
4.75	35 –50
2.36	25– 38
0.425	12– 22
0.075	5 – 10

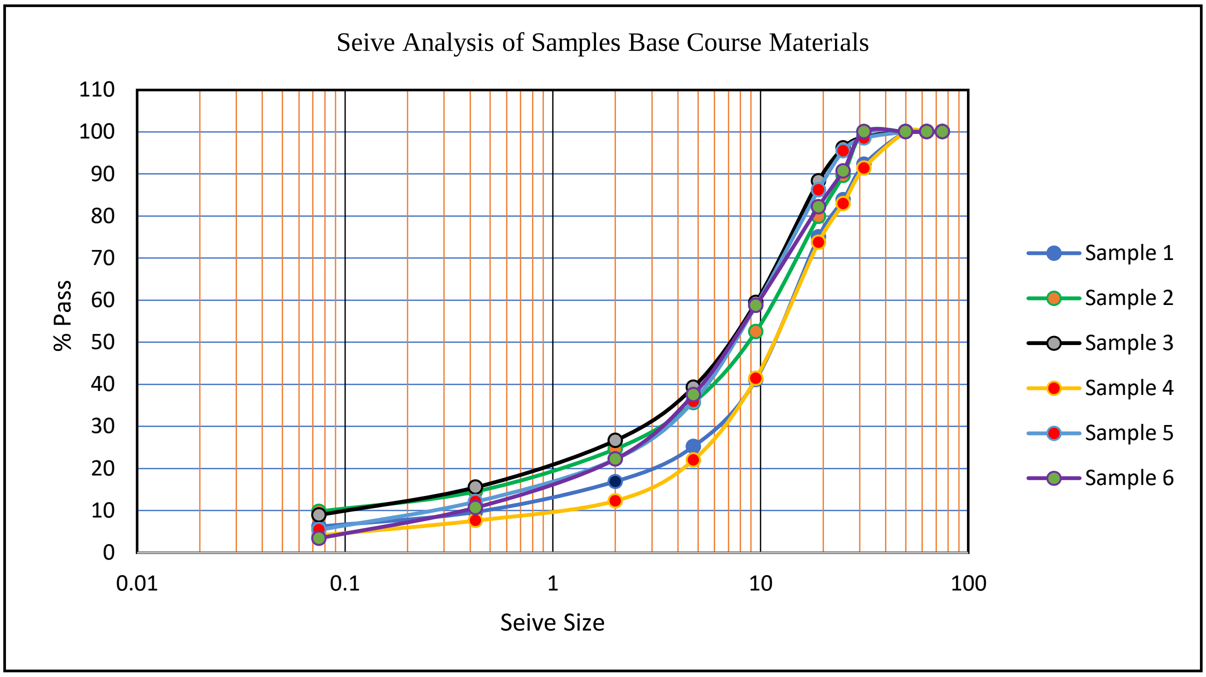

Figure 4.7: Sieve Analysis graph of Base Course Materials Samples

According to the specification of Addis Ababa – Woldiya road rehabilitation project, the aggregate used for crushed stone base shall be derived from a parent rock that is hard, sound, durable and unweathered. It shall contain no deleterious material such as decomposed rock, clay, shale or mica.

The material obtained by normal crushing methods is consistently above or below the average of the grading limits given above, the supervisor may fix a target grading to suit the average grading of the material available provided that the target grading shall be within the grading limits above. The material shall then conform to the target grading within the tolerances given in Table 4.10 below. The gradation of base course material lays within a specification for all of the test pits.

Table 4.10: Tolerance on Target Grading

Sieve size (mm)	Tolerance on Target Grading (% passing by mass)
37.5	± 5.0
20.0	± 4.0
11.2	± 3.0
0.425	± 2.0
0.075	± 1.0

Atterberg Limits

This was based on the Ethiopian Roads Authority (ERA) study of the Addis Ababa – Woldiya road rehabilitation project material specification requirements. Accordingly, for fine fraction, for example, the material passing the 0.425mm (No.40) sieve shall be non-plastic and maximum plastic index of 6%.

The ERA technical specification for road maintenance works requirements are of liquid limits of 25% maximum and plasticity index of 6 % maximum for base materials. Table 4.5 above shows that the liquid limit of the base course materials ranged from 20% to 28% and the plasticity index ranged from 4 to 11. Based on these two specifications, the base course material samples met these required specifications except sample 3, 4 and 6.

Compaction Test

Table 4.7 above shows that the maximum dry density (MDD) of the base course materials ranged between 1.59 and 2.313 kg/m^3, while the optimum moisture content (OMC) ranged from 6.58% to 30.70%. The Federal Ministry of Works and Housing, (1997) specified OMC to be less than 18% for base course materials. Based on these specifications, base soil samples 4 and 6 are not suitable for base material. This was based on ERA's, Technical specification for road maintenance works and compaction was determined based on AASHTO T-180. The average in place of the dry density of the compacted layer shall be a minimum of 95.0% of the maximum dry density. Figure 4.8 below graphically illustrates the compaction test of base course samples.

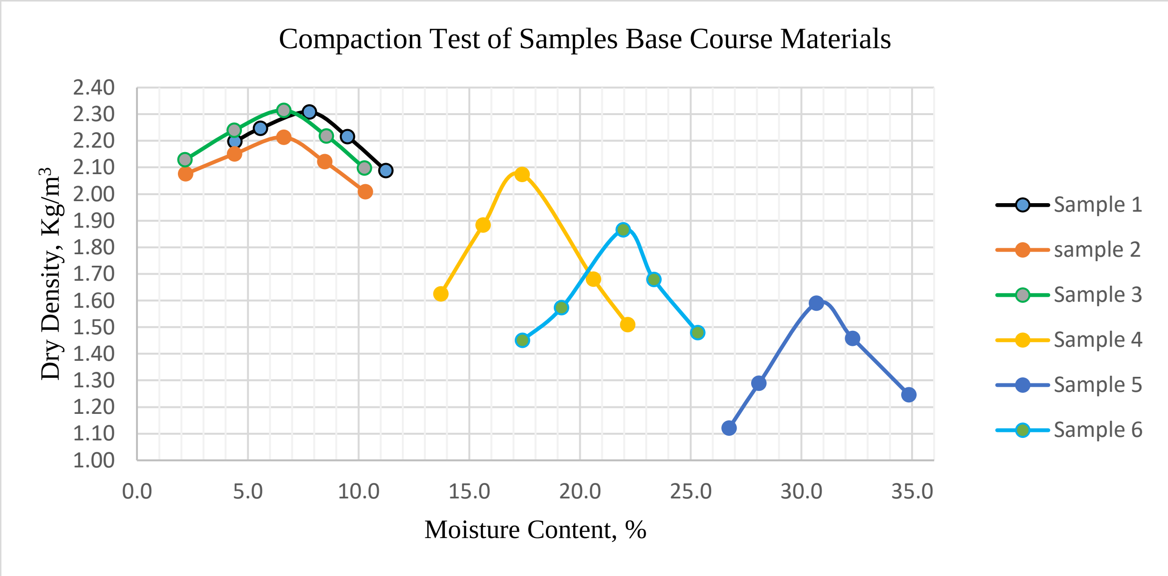

Figure 4.8: Compaction Test Graph of Base Course Samples

California Bearing Ratios

Table 4.8 above shows that the four days soaked CBR values of base course materials ranged from 21.2 % to 88.3 %. The ERA, Addis Ababa – Woldiya road rehabilitation as well as ERA, Technical specification for road maintenance works requirement specified CBR value, for minimum of 4 days soaked.

The CBR strength at 95.0% of the maximum dry density shall be 80%. Based on these specifications, base course material samples 1, 3, 5 and 6 are not suitable as base material. Figure 4.9 below graphically illustrate the California Bearing Ratio Test Graphs of Base Course Samples.

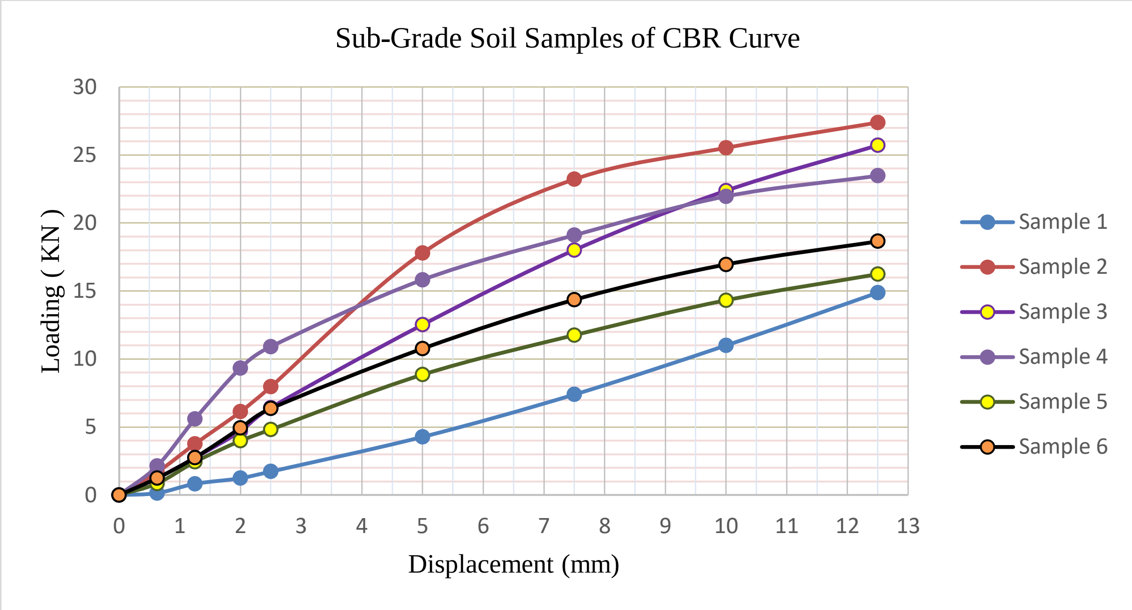

Figure 4.9: California Bearing Ratio Test Graphs of Base Course Samples

Flakiness Index

According to the Ethiopian Roads Authority (ERA), Addis Ababa – Woldiya rehabilitation project material specification requirements rehabilitation as well as the Ethiopian Roads Authority (ERA), Technical specification for road maintenance works requirement specified the flakiness index shall not exceed 35%. In this study, all the base course samples met this required specification.

Los Angeles

The Ethiopian Roads Authority (ERA), Addis Ababa – Woldiya rehabilitation project material specification requirements as well as the Ethiopian Roads Authority (ERA), Technical specification for road maintenance works have both specified that the Los Angeles shall not exceed 50%. In this study, all the base course samples met this required specification.

4.5.2 Comparison of Subgrade Soil Materials

Sieve Analysis (Gradation)

The result of the particle size analysis contained in Table 4.4 above indicates that the soil's clay content for natural sub-grade samples ranged from 3.9 % to17.32 %. According to the Federal Ministry of Works and Housing (1997) Nigeria specification, the clay content for natural sub-grade 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, all natural sub-grade soil sample are suitable as embankment. Also, general rating as sub-grade (in accordance with AASHTO (1986)) is Excellent to Good 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%. Figure 4.10 below graphically illustrates the Sieve Analysis Test of Sub-Grade Soil Samples.

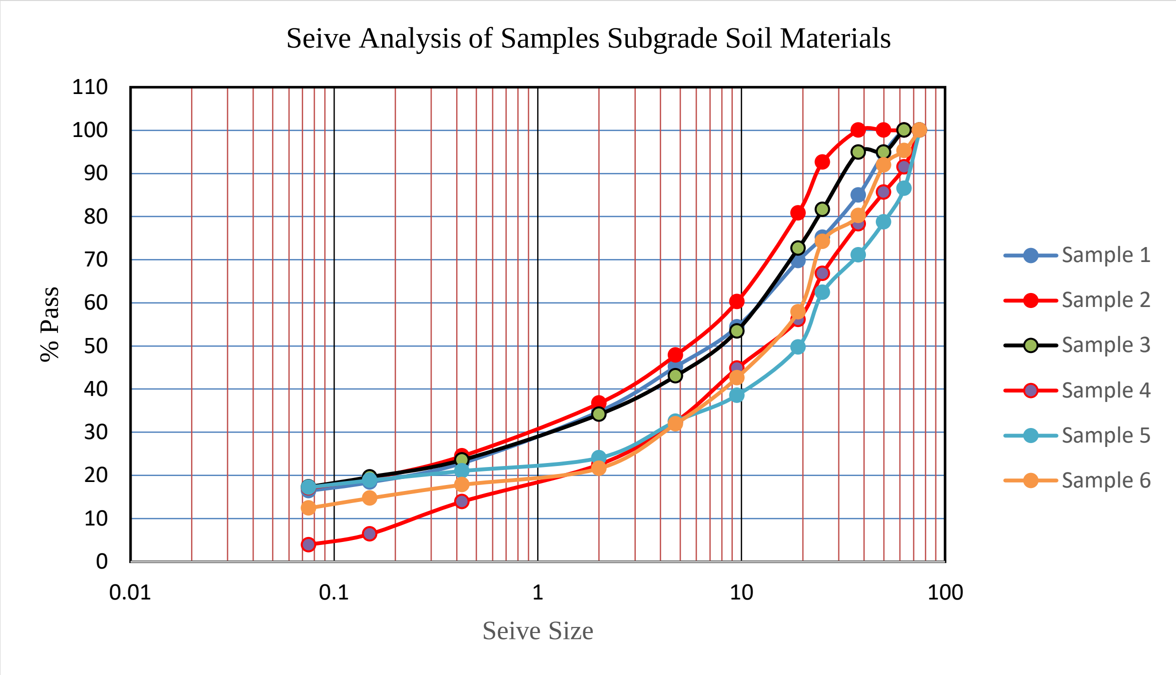

Figure 4.10: Sieve Analysis Test Graphs of Sub-Grade Soil Samples

Atterberg Limits

According to the Ethiopian Roads Authority (ERA), Addis Ababa – Woldiya road rehabilitation project material specification, no requirements were set to plasticity index but it states the minimum plasticity index of natural material to be chemically stabilized which shall be directed by the supervisor for each source and type of material used. However, the ERA specification requires the Maximum PI to be 30%. Based on these specifications, all natural sub-grade soil samples are met this required specification except sample 4. This indicates that the results are within the acceptable ranges for soil sample that can be used as sub-grade during construction of highway.

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. Based on this, natural subgrade soil samples 1, 2, 3, 5 and 6 fall within the medium plasticity while sample 4 fall within the high plasticity/compressibility.

From the AASHTO soil classification of soil samples for highway, A-1, A-3, and A-2 soils are excellent to good for highway with percentage passing Sieve No. 200 not more than 35% while A-4 to A-7 soils are fair to poor with percentage passing Sieve No. 200 greater than 35%. Based on this, all natural subgrade soil Samples are classified as excellent to good sub-grade soils. Figure 4.11 below graphically illustrates the Liquid Limit Test of Subgrade Soil Samples.

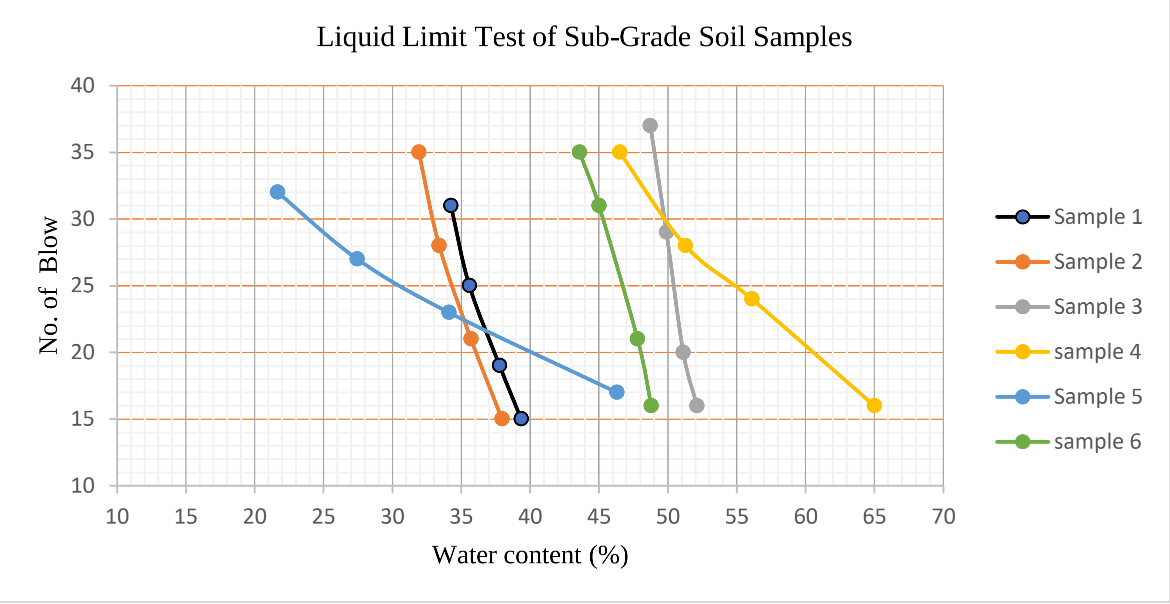

Figure 4.11: Liquid Limits Test Graphs of Sub-Grade Soil Samples

Compaction Test

Table 4.7 above shows that the maximum dry density (MDD) of the subgrade soil materials ranged between 1.894 kg/m³ and 2.094 kg/m³, while the optimum moisture content (OMC) ranged from 11.74 % to 14.29%. The Federal Ministry of Works and Housing of Ethiopia, (1997) specified OMC less than 18% for subgrade soil materials. Based on these specifications, all subgrade soil samples are suitable as subgrade (embankment) material. Figure 4.12 below graphically illustrates Compaction Test of Sub-Grade Soil Samples.

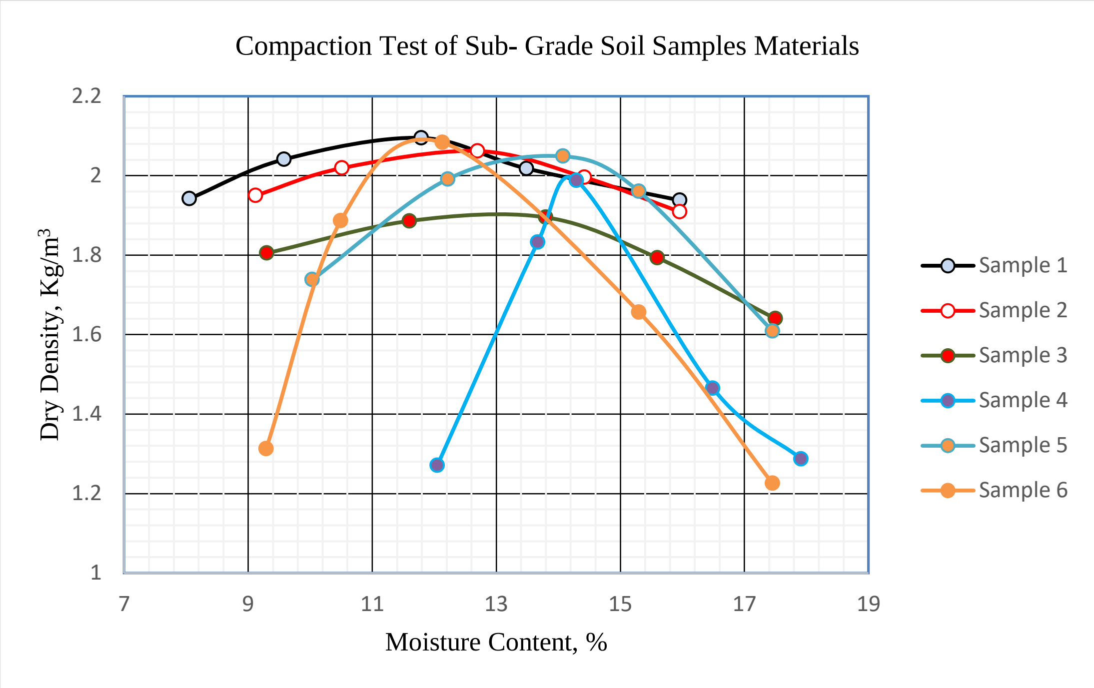

Figure 4.12: Compaction Test Graphs of Sub-Grade Soil Samples

California Bearing Ratio

Table 4.8 shows that the four days soaked CBR values of natural subgrade soil materials ranged from 3 % to 34.5 %. The Ethiopian Road Authority (ERA), Addis Ababa – Woldiya road rehabilitation project material specified CBR to be greater than or equal to 5 % for natural subgrade materials. Based on these specifications, natural subgrade soil samples 2, 4, and 6 were found to be not suitable as subgrade material in this study while in the case of Sample 5, high quality subgrade material with CBR value of 34.5% was observed. Figure 4.13 below graphically illustrates the California Bearing Ratio Test of Sub-Grade Soil Samples in this study.

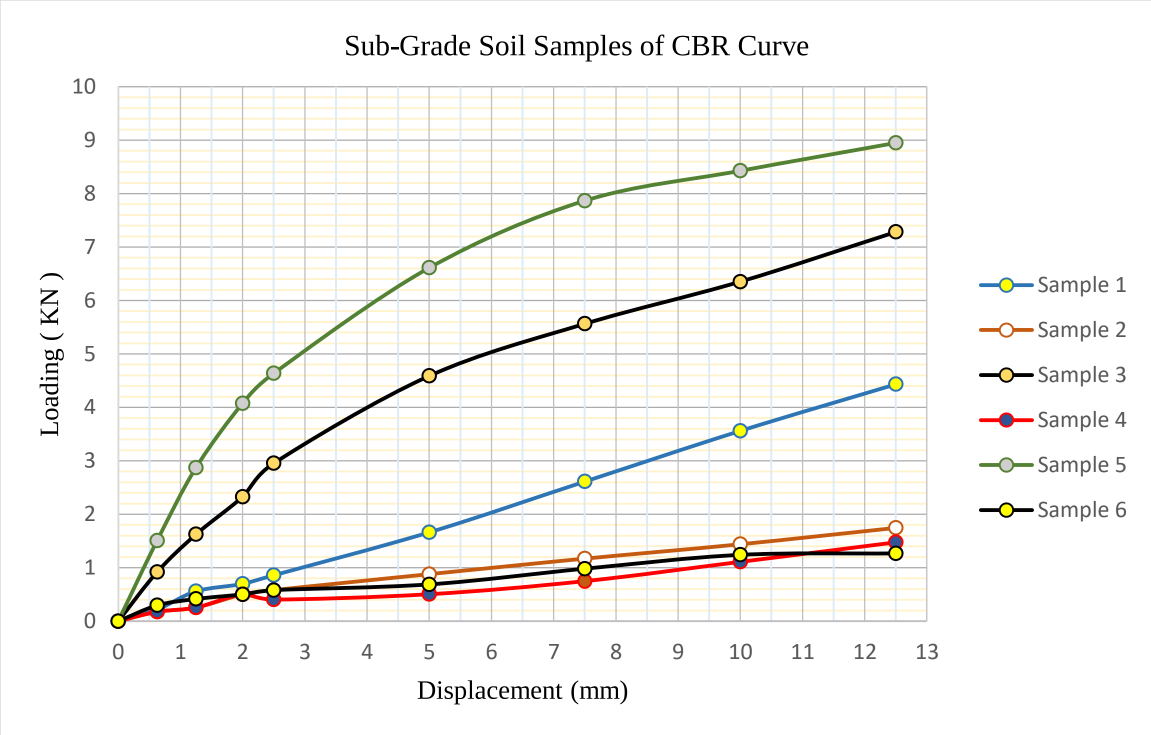

Figure 4.13: California Bearing Ratio Test Graphs of Sub-Grade Soil Samples

4.6 Traffic Analysis

4.6.1 Traffic Volume

The road section from Dessie to Hayk was constructed in 1971E.C and it upgrade in 2002E.C.The traffic analysis of this road section was made based on the data obtained from ERA Road asset management. And historical traffic counts were obtained at sections which have different traffic volume. The data were obtained from 2002-2018 for different traffic category as shown in Table 4.11.

4.6.2 Total Equivalent Axle Load

Total Equivalent axle load was determined for traffic volume using Vehicle Damaging Factor (VDF) as shown in Table 4.12 below. The Total equivalent axle load from 2002 to 2018 year is calculated **37101.2** from Dessie to Hayk road section. The design traffic load is higher than the actual traffic for this traffic load section.

Table 4.11 Dessie to Hayk Traffic Count Data (ERA Road Asset Management Directorate)

Year	Car	L/Rover	S/Bus	L/Bus	S/Truck	M/Truck	H/Truck	Truck& Trailer	Total AADT
2002	0	42	34	51	43	47	54	76	347
2003	2	29	43	36	60	32	17	34	253
2004	0	71	53	50	25	71	60	82	412
2005	0	43	56	25	48	33	21	45	271
2006	1	34	129	42	95	35	36	40	412
2007	4	48	105	89	102	49	72	40	509
2008	2	46	125	32	77	52	24	40	398
2009	5	176	264	129	203	134	92	81	1084
2010	4	144	183	28	103	27	66	184	739
2011	22	335	592	70	21	326	27	57	1450
2012	13	233	474	78	208	106	66	82	1260
2013	16	127	528	43	2	384	72	79	1251
2014	17	232	597	49	158	85	20	68	1226
2015	12	338	704	62	255	133	27	88	1619
2016	21	247	670	77	126	157	53	102	1453
2017	60	46	307	54	66	53	46	43	675
2018	7	89	967	54	15	253	105	106	1596

Table 4.12 ESAL for Dessie to Hayk Road Section

VDF	0.03	0.30	2.00	1.50	5.00	10.00	10.00	
Year	L/Rover	S/Bus	L/Bus	S/Truck	M/Truck	H/Truck	Truck& Trailer	ESAL - one direction
2002	1.26	10.2	102	64.5	235	540	760	1712.96
2003	0.87	12.9	72	90	160	170	340	845.77
2004	2.13	15.9	100	37.5	355	600	820	1930.53
2005	1.29	16.8	50	72	165	210	450	965.09
2006	1.02	38.7	84	142.5	175	360	400	1201.22
2007	1.44	31.5	178	153	245	720	400	1728.94
2008	1.38	37.5	64	115.5	260	240	400	1118.38
2009	5.28	79.2	258	304.5	670	920	810	3046.98
2010	4.32	54.9	56	154.5	135	660	1840	2904.72
2011	10.05	177.6	140	31.5	1630	270	570	2829.15
2012	6.99	142.2	156	312	530	660	820	2627.19
2013	3.81	158.4	86	3	1920	720	790	3681.21
2014	6.96	179.1	98	237	425	200	680	1826.06
2015	10.14	211.2	124	382.5	665	270	880	2542.84
2016	7.41	201	154	189	785	530	1020	2886.41
2017	1.38	92.1	108	99	265	460	430	1455.48
2018	2.67	290.1	108	22.5	1265	1050	1060	3798.27
Total One Direction Loading								**37101.2**

4.7 Drainage Conditions

Effect of poor drainage condition from Dessie to Hayk road Segment had different property. Based on the observation from Dessie – Hayk road section, I had seen variety of failures on paved way, shoulders and side ditches. Those failures are caused by different factors such as: the catchment characteristics and mountainous topography in one side of the road, rain starting from the top of the mountainous and the surrounding catchment forming a high flood i.e. flowing down to the road pavement. This flood had higher sediment and it set on side ditches and on asphalt surfacing. Such problem was mainly visible in the section from station 7+200 to 18+500 (from villages Korki to Amomo).On the side drain, the Silt and Scour defects were recorded against the side drains and turnouts. Based on these, the severity of Silt on left side of roadway starting from Dessie to Hayk direction were observed 75% severity level one, 25% severity level two and no severity level three. And on the right side of the road sections the extents of severity were observed 81.67% severity level one, 18.33% severity level two and no severity level three. The severity of Scour in both directions was observed 100% severity level one. Additionally, Rock and soil barriers in which it fallen from the mountainous section by sliding or erosion fills the side ditches, which was also factors to the pavement were not functional in many sections; it leads the ditches had poor quality and it would be the cause of poor delivery of the collected water to culvert structure. Such problem is common in same part of the road section on Dessie - Hayk road segment.

Erosion on the lower side of the road section (opposite to the mountainous side), because of high flood and over flows on pavement structures, the shoulders part on one side of the road way was eroded and similarly it causes sliding lower part of the pavement layers that leads to pavement edge structural failures. Such cases were visible on road section mainly from 7+050 station to 14+850 (korki to sulula villages). Other factors that affect surface drainage was man made factors like blocking the water way and diversion of stream water flows to the carriage way which was forced to across over the road way. Generally, 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.

4.8 Proposed Remedial Measures for Distressed Type

The proposed remedial mesures or repaire method for distress types from Dessie to Hayk road segmet are as follow:

Sample One

Distress type: 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.

Sample Two

Distress type: Raveling

Repair: A raveled pavement should be investigated to determine the root cause of failure. Repair strategies generally fall into one of two categories:

- If the small, localized areas of raveling. Remove the raveled pavement and patch.
- Large raveled areas indicative of general HMA failure. Remove the damaged pavement and overlay.

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.

Sample Four

Distress type: Corrugation

Repair: A heavily corrugated pavement should be investigated to determine the root cause of failure. Repair strategies generally fall into one of two categories:

- If it is small, localized areas of corrugation. Remove the distorted pavement and patch.

- If it is large corrugated areas indicative of general HMA failure. Remove the damaged pavement and overlay.

Sample Five

Distress type: Potholes

Repair method: Remove the distorted pavement and patch.

Sample Six

Distress type: Fatigue Cracking

Repair: A fatigue cracked pavement should be investigated to determine the root cause of failure. Any investigation should involve digging a pit or coring the pavement to determine the pavement's structural makeup as well as determining whether or not subsurface moisture is a contributing factor. Once the characteristic alligator pattern is apparent, repair by crack sealing is generally ineffective. Fatigue crack repair generally falls into one of two categories:

- If it is small, localized fatigue cracking indicative of a loss of subgrade support. Remove the cracked pavement area then dig out and replace the area of poor subgrade and improve the drainage of that area if necessary. Patch over the repaired subgrade.
- If it is large fatigue cracked areas indicative of general structural failure. Place an HMA overlay over the entire pavement surface. This overlay must be strong enough structurally to carry the anticipated loading because the underlying fatigue cracked pavement most likely contributes little or no strength.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis aimed at investigation of the cause of pavement failure on Dessie to Hayk Road segment. The overall analysis in the study is based on the road condition at the time of testing. Material sampling and testing have been conducted in order to investigate the causes of failure. Based on the investigation; Subgrade materials have medium Plasticity Index exception of one sample which have high plasticity and compressibility in addition it have low CBR value compared with the specifications. Base materials tend to the finer side of the specification and lower Plasticity index as compared to the specification.

To find out the real cause of pavement damaged related to base and subgrade soil, the pavement layers property was conduct different laboratory tests. 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 subgrade soil materials are between 3%-34.5%, the values of PI (10- 32), MDD (1.894kg/m^3- 2.094 kg/m^3). And its clay contents range from 3.9%- 17.32%. The Base Course materials are almost less amount of clay contents in the representative samples, and also the values of PI (4.0- 11.0), MDD (1.59kg/m^3- 2.313 kg/m^3), and soaked CBR values ranged from (21.2%- 88.3%). And its clay contents range from 3.4%- 9.77%. The flakiness index of Base course materials shall not exceed 35%. In this study, all the base course samples met this required specification. Similarly, Los Angeles test results of Base course materials shall not exceed 50%, based on these all the base course samples met this required specification.

The laboratory results showed that the soil materials used along the road have suitable clayey material for almost all of the natural subgrade soil sample and (it rated as Excellent to Good materials for road use) similarly low percentages of clayey and silt/gravel/sand materials of base course samples. The OMC are almost suitable for all the soil samples the exception of few samples. The Plasticity Indices and Liquid limits are low for half base course materials and it met all subgrade soil samples for the required specification except one sample. Half of the samples of CBR values for the sub- grade soil materials almost meet specification requirements while that of base course materials almost did not meet the specification requirements with the exception of one sample. Based on these comparisons the soil materials are good quality for all station. Conclusively, the pavement failure may necessarily be due to weak/ poor soil base course pavement layer performance in the different failed location.

Traffic data analysis showed that the design traffic ESAL is greater than the actual traffic for this traffic load section; hence, the road has been carrying traffic less than design form the opening up to now. The underloading of the pavement blow the design loading had not caused pavement structural failure which can be easily maintened by silling or non structural overlay.

Effect of poor drainage condition on Dessie - Hayk road Segment had seen variety of failures on paved way, shoulders and side ditches. Those failures are caused by different factors such as: the catchment characteristics and mountainous topography in one side of the road way and erosion on the lower side of the road section (opposite to the mountainous side). Those factors would be means of flooding, rock and soil barrier of the asphalt surfacing, means for ditches had poor quality and which was also factors to the pavement were not functional in many sections of the road segment. Other factors that affect drainage was man made factors like blocking the water way and diversion of stream water flows to the carriage way which was forced to across over the road way.

Finally based on the investigation of condition survey, 5% of the road shows cracks with severity-3 and 5% of the road shows crack with severity-2. When compared with the thesis research entitled with “Assessment of Road Pavement Failure along Addis Ababa - Modjo Trunk Road” which was observed 52% of the road shows crack with severity-3 and 32% of the road shows crack with severity-2; the road section on Dessie - Hayk has low percentage of severity. This effect implies the trunk road from Addia Ababa – Modjo has higher traffic volume and loading than Dessie - Hayk road section because one of the root causes of this cracks are increase in loading i.e. more or heavier loads than anticipated in design.

Similarly, the condition survey indicates rutting from Addis Ababa – Modjo shows, 49% of the road indicates severity-3 and 30% of the road indicates severity-2. And the road segment from Dessie to Hayk has 5% of the road shows Depression type of surface deformation with severity-3 and 10% severity-2. The rutting defect implies from Addis Ababa – Modjo road segment has relatively higher insufficient compaction of pavement layers during construction, compression of unbound layers of base course and sub base, subgrade rutting i.e. as a result of inadequate pavement structure and also improper mix design or manufacture i.e. excessively high asphalt content, excessive mineral filler, insufficient amount of angular aggregate particles than of the road section from Dessie to Hayk which has lower subgrade settlement resulting from inadequate compaction during the construction or poor quality of subgrade materials.

5.2 Recommendation

Future road design & Construction shall avoid subgrade with high swell or shall incorporate proper treatment method of expansive inset subgrade by excavation and replacement to a depth where the moisture variation is minimal and shall provide enough cover to overcome the swell pressure due to moisture increase under subgrade.

For all failed segment of the road section it should replace suitable materials and must be compacted to the required minimum density.

Use good stabilizing agent for the subgrade soil due to the type of clayey soils used for it. And any materials to be used for road maintenance and rehabilitation must be in strict compliance with the specified values.

Low traffic and associated cracking exist on the road segment, it must be preventing using surface and crack sealing and corrected using patches and chip seal.

Effect of level of ground water table on the expansive subgrade material needs to be further investigation.

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

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

5.3 Recommendations for further studies

The present study carried out uses some selected laboratory tests to characterize and check the material properties and composition of differentiate pavement layers within different specifications, checked traffic loading and conducted condition survey for finding the causes of pavement distresses. It could be extended to: detail investigation of poor drainage condition and underground water for the effect of pavement distresses; Investigate the provision of poor shoulders condition which leads to edge and other failures types; and investigate the quality of road construction, if not built to the desired specifications, can also facilitate road deterioration.

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APPENDIX A

Sieve Analysis Results of Representative Samples for Base Course and Subgrade Soil.

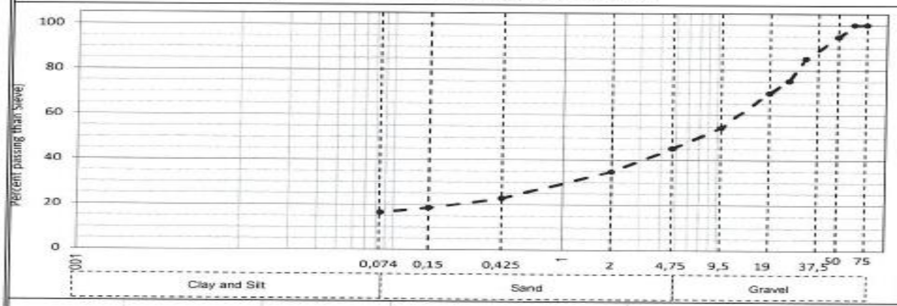
ERC SYSTRA MD AKH Railway Project yapı merkezi

DETERMINATION OF WATER (MOISTURE) CONTENT, SIEVE ANALYSIS FOR SOIL

Laboratory Code No			
Project Name	AWASH - KOMBOLCHA - HARA GEBEYA RAILWAY PROJECT	Date Specimen Accepted	10.08.2018
		Date Test Started	13.08.2018
Sample Information	Dessie hayk road segment-1 / Natural ground material	Date of Test Result	13.08.2018

RESULTS	
LL	36,0
PL	21,0
PI	15,0

(PARTICAL-SIZE ANALYSIS) (SIEVE ANALYSIS) (EN 933-1)



Sieve No (Sieve Dia)	Passing
3 in. (75mm)	% 100,00
$2^{1/2}$ in. (63mm)	% 100,00
2 in. (50mm)	% 94,65
$1^{1/2}$ in. (37,5mm)	% 84,96
1 in. (25mm)	% 75,17
3/4 in. (19mm)	% 69,74
3/8 in. (9,5mm)	% 54,37
No 4 (4,75mm)	% 45,16
No 10 (2,00mm)	% 34,78
No 40 (0,425mm)	% 22,83
No 100 (0,15mm)	% 18,40
No 200 (0,075mm)	% 16,42

Total Sample Weight= 6960,58 g

WATER CONTENT, % ASTM D2216-10	
Container+Moist Soil Mass	
Container+ Oven Dry Specimen Mass	
Mass of Water	
Container Mass	
Mass of Solids	
Water Content	

SOIL CLASSIFICATION & SOIL DESCRIPTION

(ASTM D 2487-00)

Soil Classificaiton **GC**

Soil Description **Clayey Gravel with Sand**

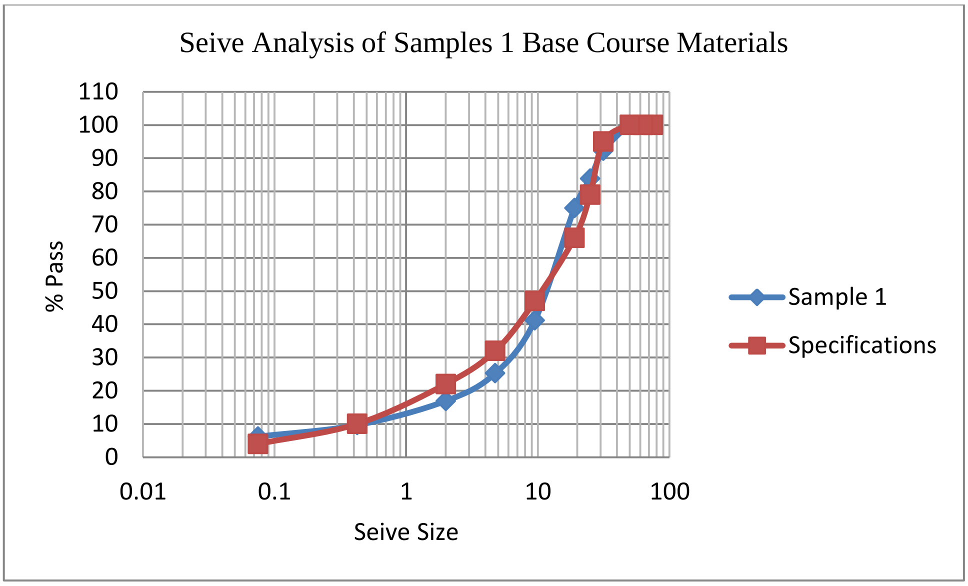
Notes:

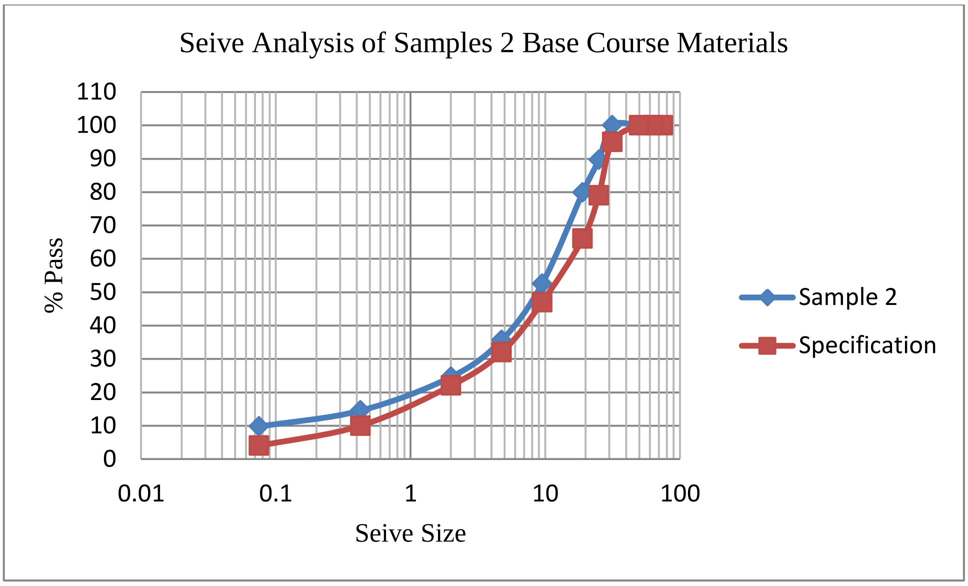
RESULTS: **Failed** ☐ **Passed** ☐

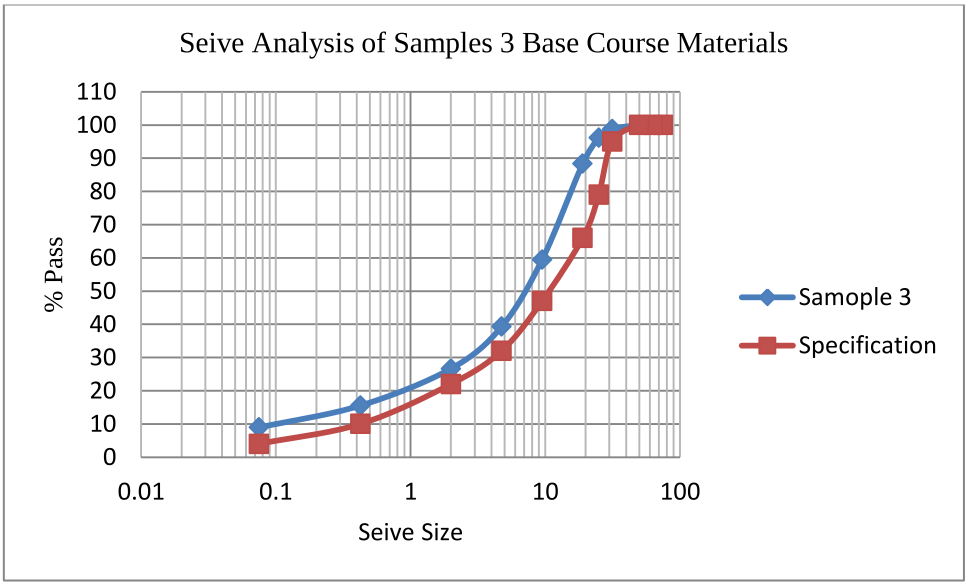
YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. / CONSTRUCTION AND INDUSTRY INC.		EMPLOYER'S REPRESENTATIVE
Name/Signature	Name/Signature	Name/Signature
Frezer Eniyew Fitigu	Approved By YMI QC Departmer	

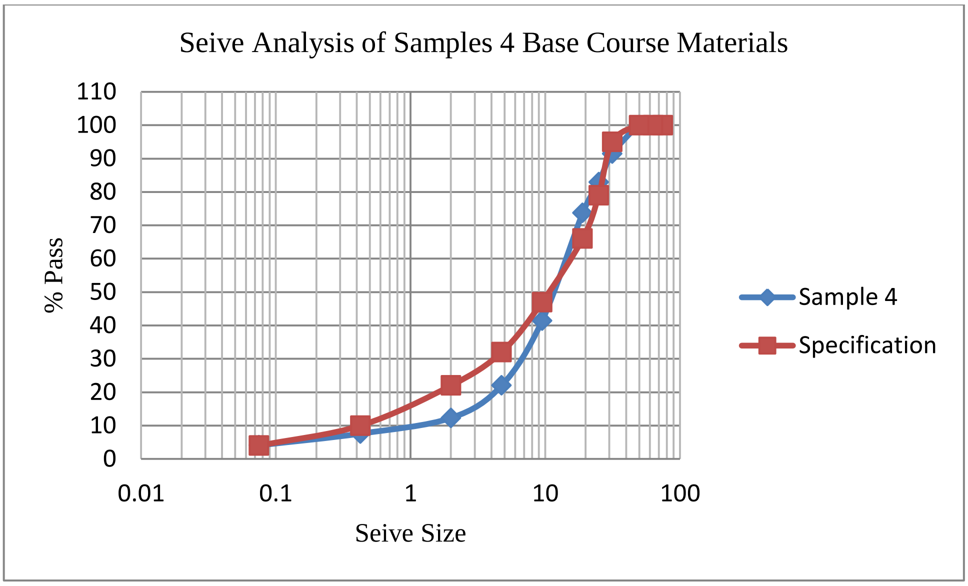
Determination of Water Content-Sieve Analysis for Soil	AKH - YMI - AL - GL00X - G - QC - FRM - 0030 - 3	27.06.2017

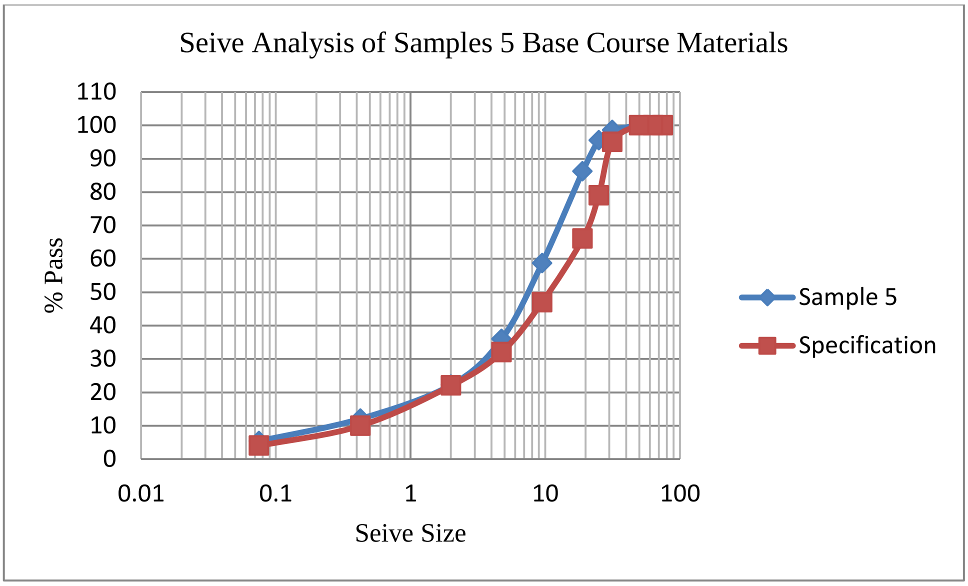
Page: 1 / 1

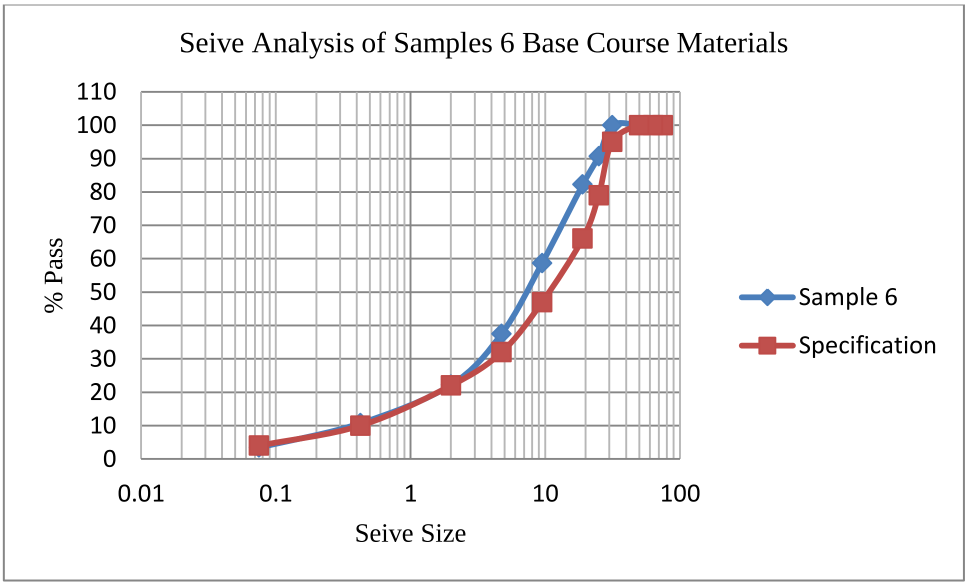

Seive Analysis of Samples 1 Base Course Materials
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Sample 1
Specifications

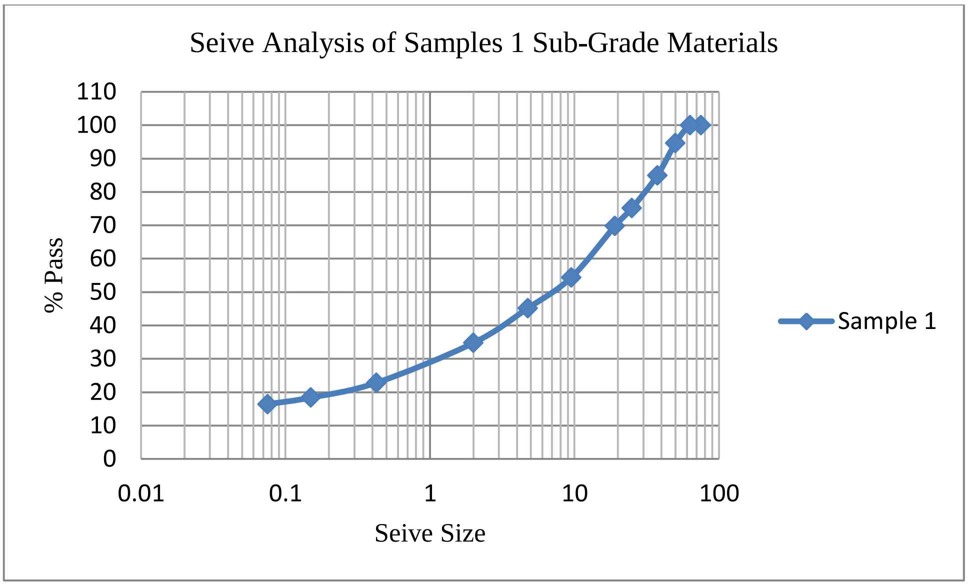

Seive Analysis of Samples 2 Base Course Materials
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Sample 2
Specification

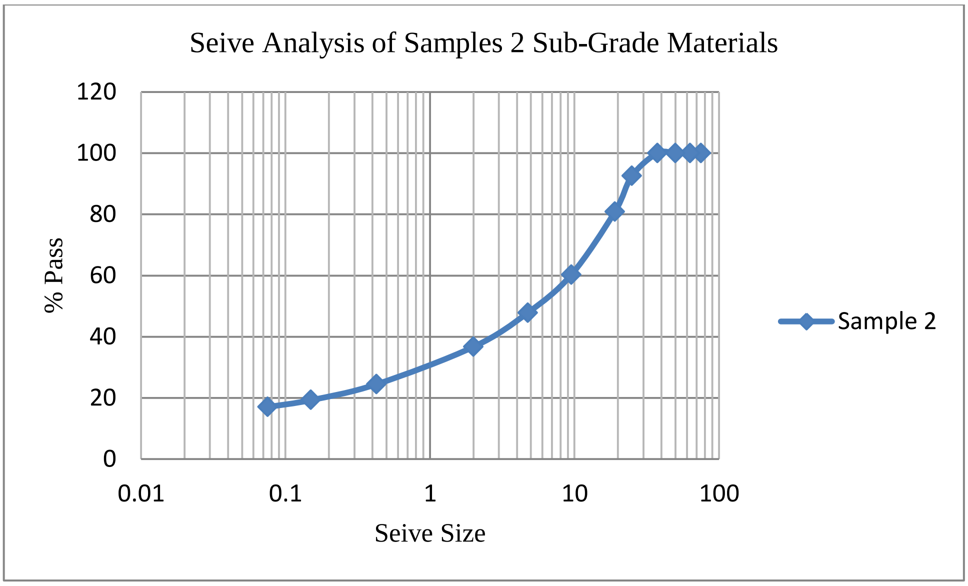

Seive Analysis of Samples 3 Base Course Materials
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Samople 3
Specification

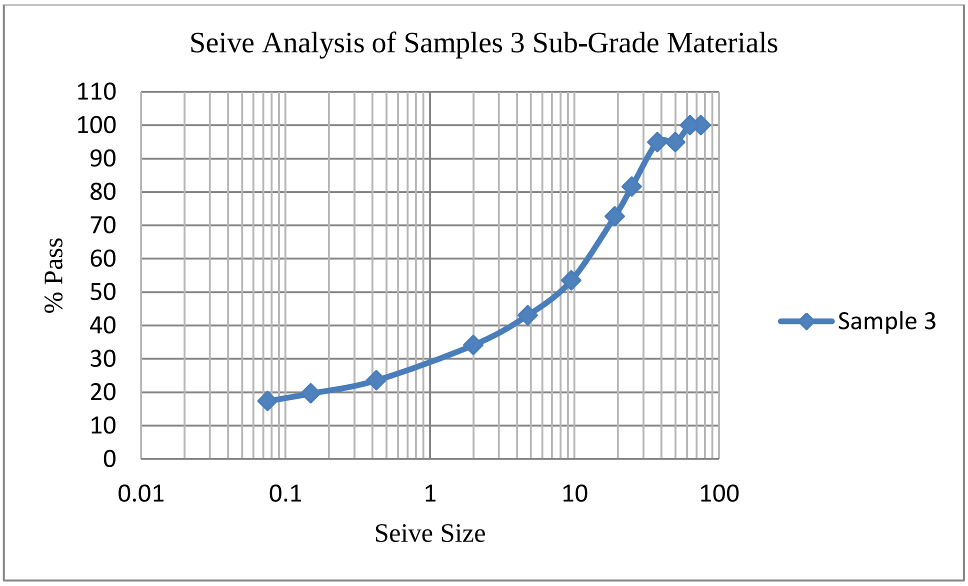

Seive Analysis of Samples 4 Base Course Materials
% Pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive Size
Sample 4
Specification

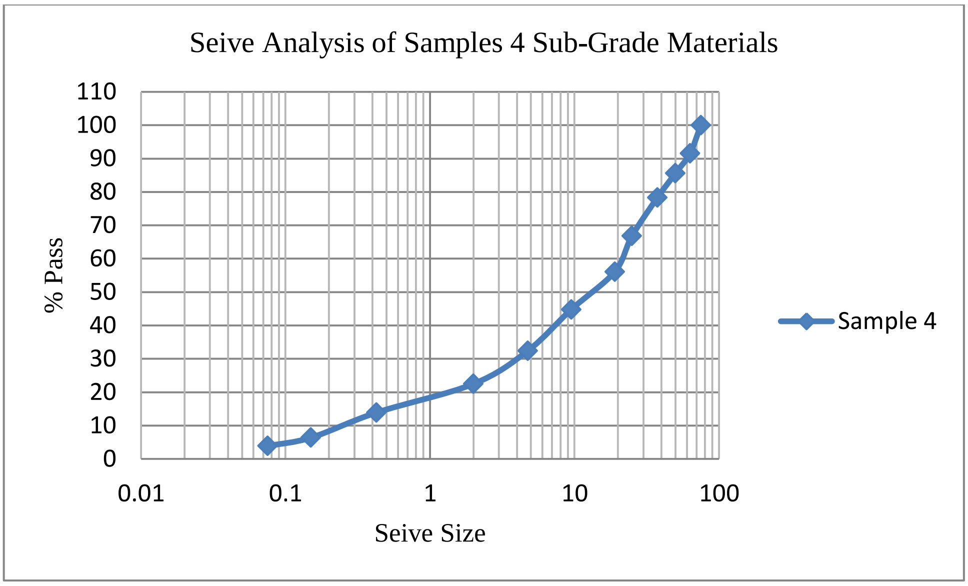

Seive Analysis of Samples 5 Base Course Materials
% Pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive Size
Sample 5
Specification

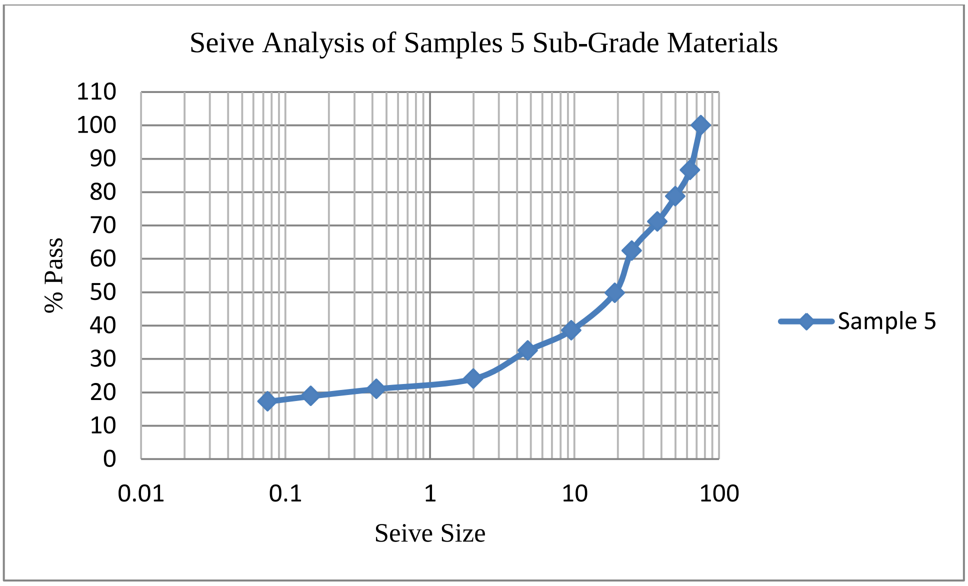

Seive Analysis of Samples 6 Base Course Materials
% Pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive Size
Sample 6
Specification

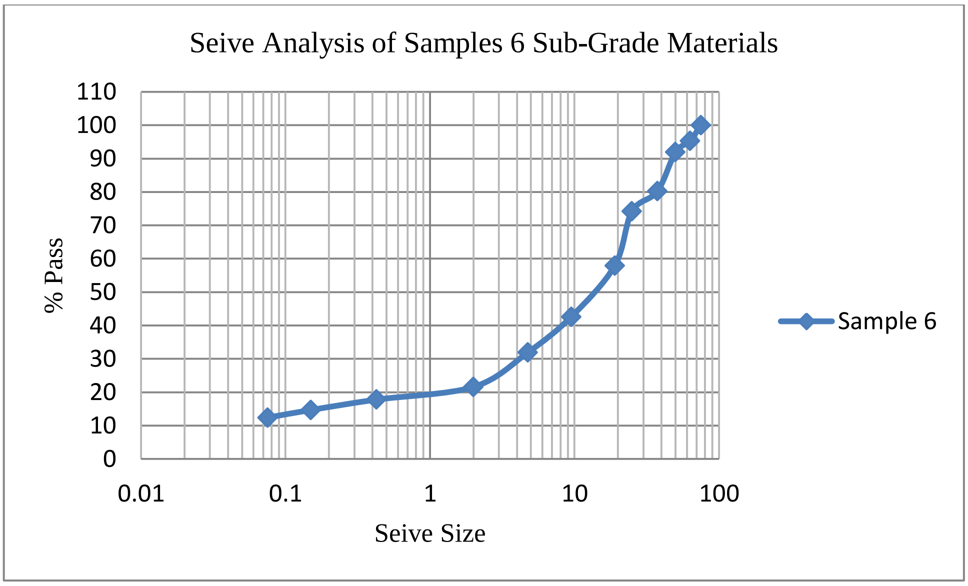

Seive Analysis of Samples 1 Sub-Grade Materials
% Pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive Size
Sample 1


Seive Analysis of Samples 2 Sub-Grade Materials
% Pass
120
100
80
60
40
20
0
0.01
0.1
1
10
100
Seive Size
Sample 2


Seive Analysis of Samples 3 Sub-Grade Materials
% Pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive Size
Sample 3


Seive Analysis of Samples 4 Sub-Grade Materials
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Sample 4


Seive Analysis of Samples 5 Sub-Grade Materials
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Sample 5


Seive Analysis of Samples 6 Sub-Grade Materials
110
100
90
80
70
60
50
40
30
20
10
0
% Pass
0.01
0.1
1
10
100
Seive Size
Sample 6

APPENDIX B

Atterberg Limit Test Results

ERC SYSTRA AKH Railway Project yapı merkezi

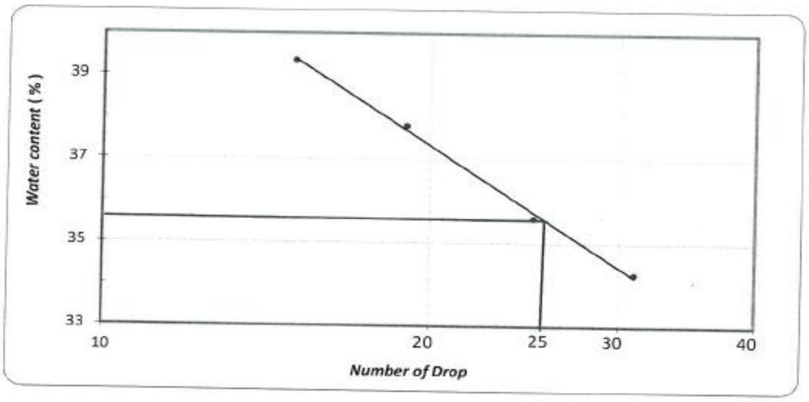
ATTERBERG LIMITS TEST RESULT (*ISO/DIS 17892 (EN)*)

Customer's Name:	ERC	*Date of Samp. Accept:*	10.08.2018
Project/Location:	Dessie hayk road segment-1 Natural ground material	*Date of Test:*	11.08.2018
Depth:	-	*Date of Test Result:*	13.08.2018
		Laboratory No:	

Calculations

Sample No	1	2	3	4
Cup No	3	30	73	1
Number of Drop	31	25	19	15
Wet Sample + Cup (gr)	38,46	38,13	36,36	34,40
Dry Sample + Cup (gr)	33,13	32,99	31,22	30,02
Amount Water (gr)	5,33	5,14	5,14	4,38
Weight of Cup (gr)	17,55	18,56	17,61	18,88
Weight of Dry Sample (gr)	15,57	14,43	13,61	11,14
(%) Water Content	34,25	35,59	37,79	39,35

Sample No	1	2
Cup No	63	89
Wet Sample + Cup(gr)	20,16	20,94
Dry Sample + Cup(gr)	19,56	20,43
Amount Water (gr)	0,60	0,50
Weight of Cup (gr)	16,81	18,04
Weight of Dry Sample (gr)	2,75	2,39
(%) Water Content	21,74	21,09



CALCULATION	
Number	Water Content
31	34,25
25	35,59
19	37,79
15	39,35

(LL) *Liquid Limit*	36,00
(PL) *Plastic Limit*	21,00
(PI) *Plasticity Index*	15,00

Remarks:

RESULTS: ☐ Failed ☐ Passed

Tested By	YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. CONSTRUCTION AND INDUSTRY INC.	EMPLOYER'S REPRESENTATIVE
Frezer Enyew Fitigu	Approved By YMI QC Department	

Atterberg Limits Test Result	AKH - YMI - AL - GL00X - G - QC - FRM - 0060 - 2	27.06.2017
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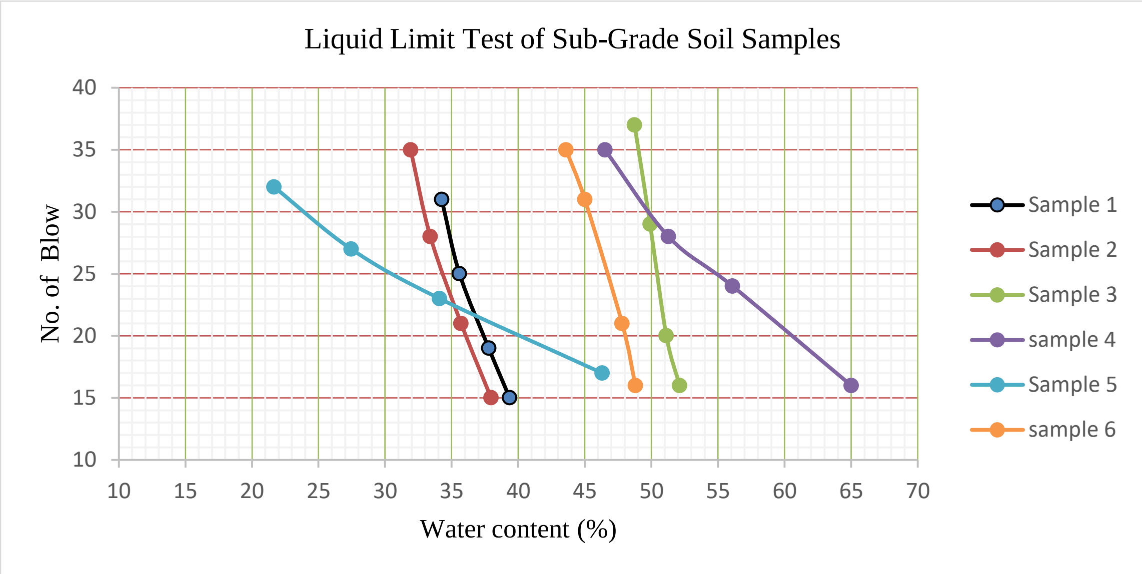

Liquid Limit Test of Sub-Grade Soil Samples
No. of Blow
Water content (%)
40
35
30
25
20
15
10
10
15
20
25
30
35
40
45
50
55
60
65
70
Sample 1
Sample 2
Sample 3
sample 4
Sample 5
sample 6

APPENDIX C

Dry Density VS. Moisture Content for Samples of Base Course and Subgrade Materials.

ERC SYSTRA MD

AKH Railway Project

yapı merkezi

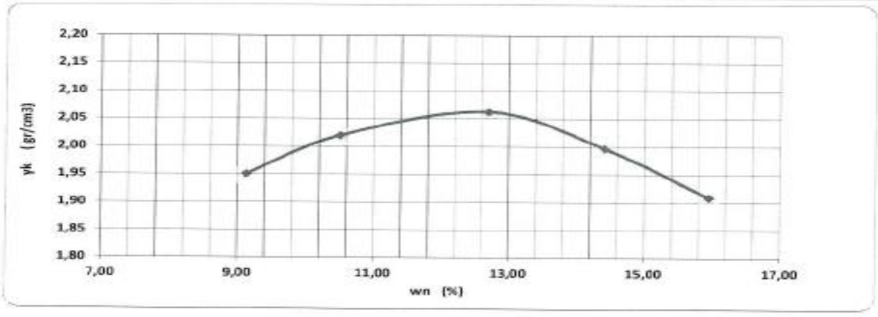
PROKTOR TEST SONUCU
PROCTOR TEST RESULTS

Yuklenici Firma / *Customer's Name*	ERC	Numune Alım Tarihi / *Date of Sample Accept*	10.08.2018
Ariyet/Bolge / *Project/Location*	Dessie hayk road segment-2 / Natural ground material	Deney Tarihi / *Date of Test*	11.08.2018
Laboratuvar No / *Laboratory No*		Raporlama Tarihi / *Date of Test Result*	12.08.2018

Kalip Agirligi / *Weight of Mould*	(gr)	5877	Deney Numune Agirligi / *Weight of Total Sample*	(gr)	6000
Kalip Hacmi / *Volume of Mold*	(cm³)	2084	Tokmak Agirligi / *Weight of Rammer*	(kg)	4,5
Deney Elek Booyutu / *Sieve Size*	(mm)	19	Darbe Sayisi / *Drop Number*	(adet)	56

Kuru Birim Hacim Agirliklari / *Dry Unit Weight* (kN/m³) (γ_k)		1	2	3	4	5
Kalip + Numune Agirligi / *Weight of Mold + Sample*	(gr)	10312	10528	10720	10637	10490
Sikismis Malzeme Agirligi / *Weight of Compacted Soil*	(gr)	4435	4651	4843	4760	4613
Yas Birim Hacim Agirligi / *Wet Unit Weight*	(gr/cm³)	2,128	2,232	2,324	2,284	2,214
Kuru Birim Hacim Agirligi / *Dry Unit Weight*	(gr/cm³)	**1,950**	**2,019**	**2,062**	**1,996**	**1,909**

Su Muhtevasi / *Water Content* (%) (w_n)		1	2	3	4	5
Kap No / *Cup No*		10	15	112	36	19
Yas Numune + Kap Agirligi / *Wet Sample + Cup*	(gr)	538,65	574,37	553,82	589,53	550,65
Kuru Numune + Kap Agirligi / *Dry Sample + Cup*	(gr)	497,45	523,96	496,85	521,32	481,26
Su Agirligi / *Weight of Water*	(gr)	41,2	50,41	56,97	68,21	46,59
Kap Agirligi / *Weight of Cup*	gr)	45,89	44,48	48,24	48,2	46,38
Su Muhtevasi / *Water Content*	(%)	**9,12**	**10,51**	**12,70**	**14,42**	**15,96**



Hesap / Calculations	
9,12	1,950
10,51	2,019
12,70	2,062
14,42	1,996
15,96	1,909

Proctor Correction Formula

$$\rho'_d = \frac{\rho_d}{1 + \frac{m}{100}\left(\frac{\rho_d}{\rho_s} - 1\right)}$$

$$w' = w - \Delta w$$

$$\Delta w = \frac{m}{100} w$$

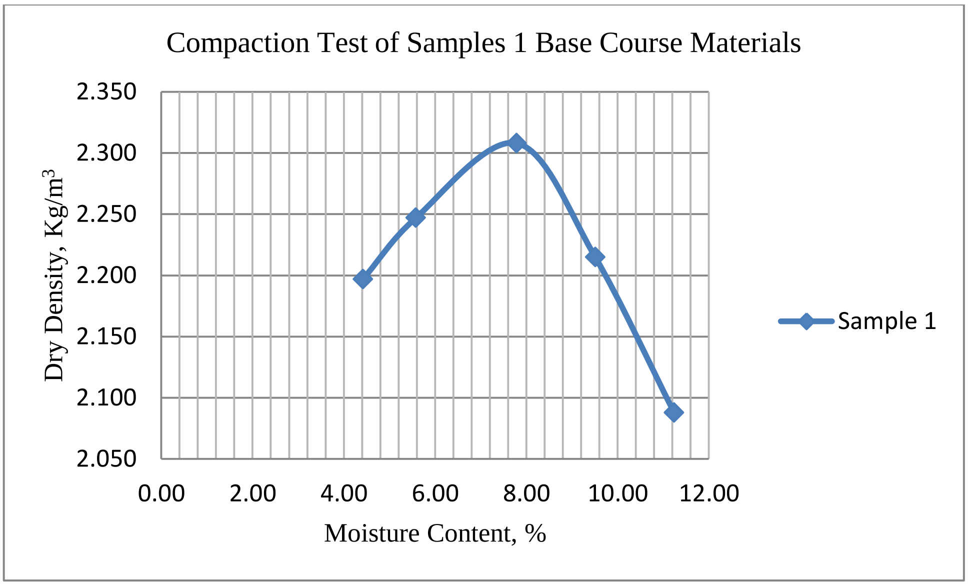
w' : Optimum Water Content (Correction)

'qd: Rectified proctor
qd : Find proctor
m : 19mm weight correction (%)
qs : 2.70gr/cm³

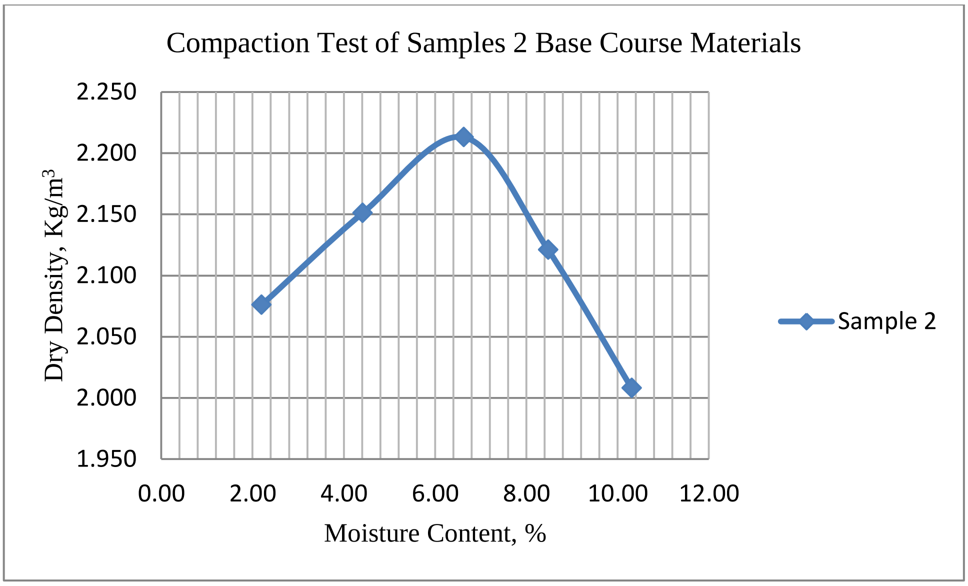
Max.Kuru Birim Hacim Agirligi / *Maximum Dry Unit Weight*	2,061	gr/cm³
Optimum Su Muhtevasi / Optimum Water Content	12,64	%
Duzeltme / Correction		
Max.Kuru Birim Hacim Agirligi / *Maximum Dry Unit Weight*	2,061	gr/cm³
Optimum Su Muhtevasi / Optimum Water Content	12,64	%

Notes:
Tests were done from the samples that are delivered by the related firm.
This test is being done according to the NP 94-093, ASTM D-698 standarts.

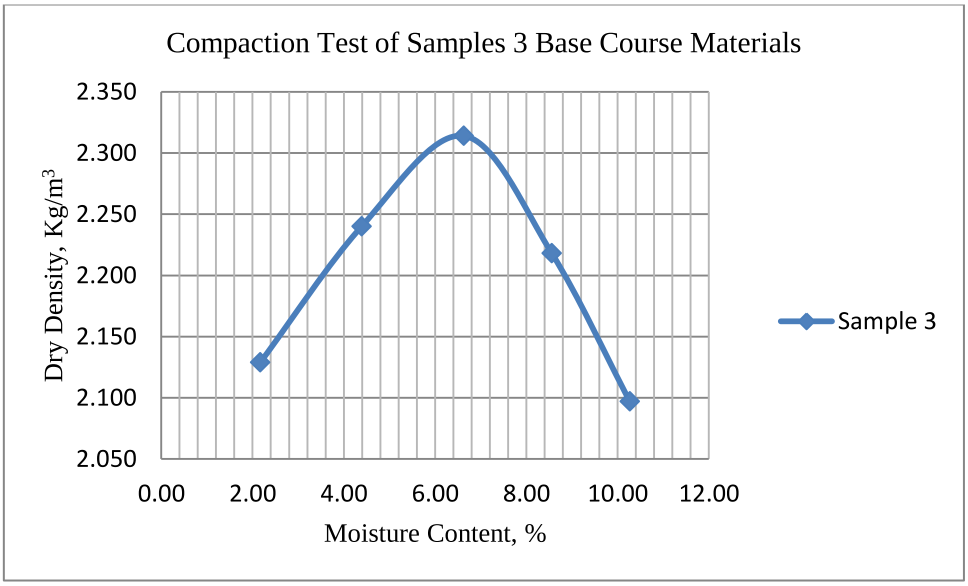
Tested By	YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. CONSTRUCTION AND INDUSTRY INC.	EMPLOYER'S REPRESENTATIVE
Frezer Eniyew Fitigu	Approved By YMI QC Department	
Proctor Test Results Form	AKH - YMI - AL - GL00X - G - QC - FRM - 0156 - 0	22.05.2017
		Page: 1 / 1



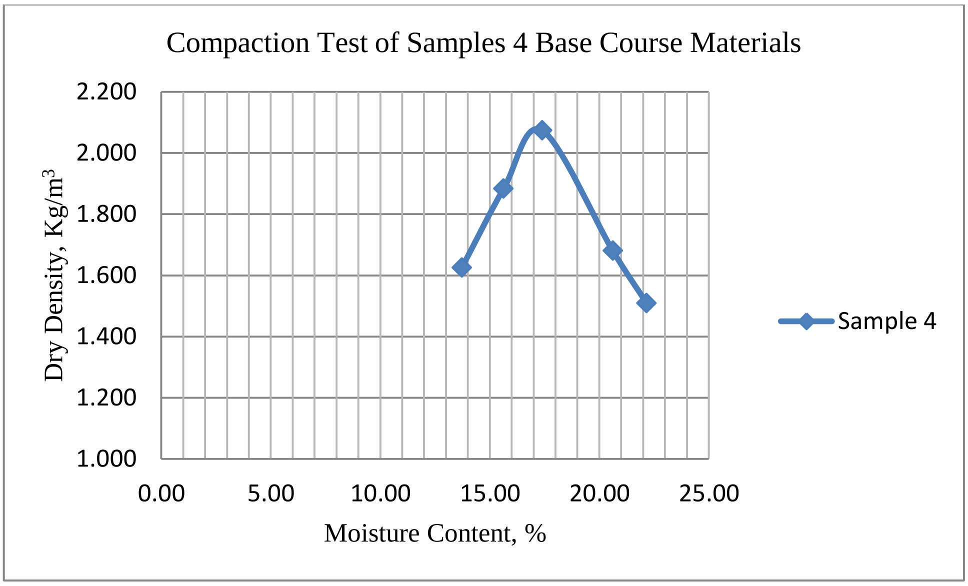
Compaction Test of Samples 1 Base Course Materials
Dry Density, Kg/m3
2.350
2.300
2.250
2.200
2.150
2.100
2.050
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Moisture Content, %
Sample 1

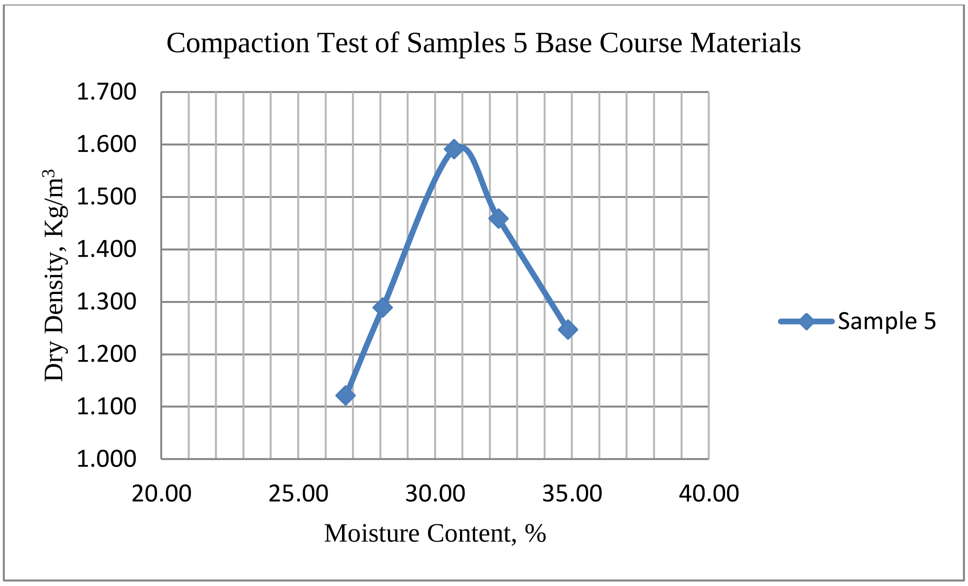


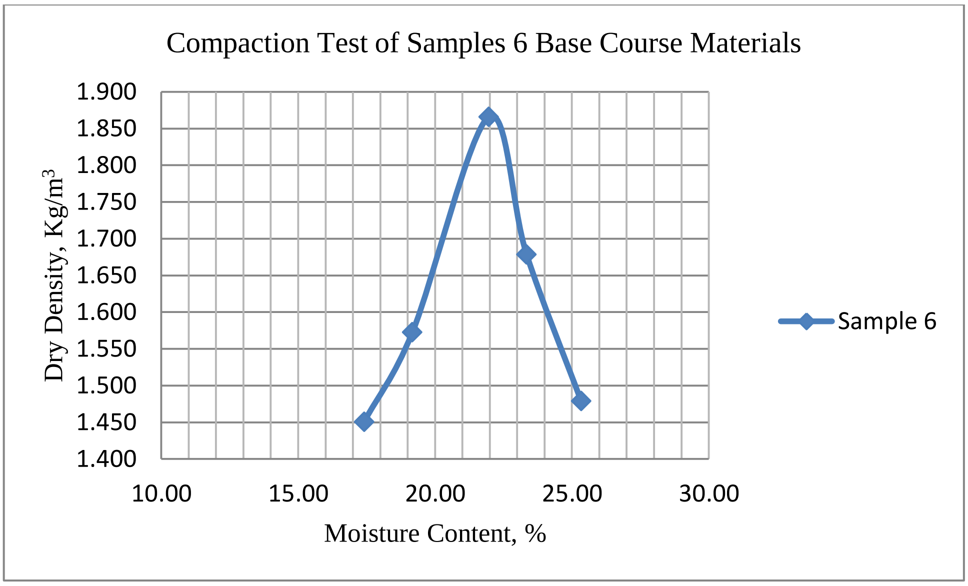
Compaction Test of Samples 2 Base Course Materials
Dry Density, Kg/m3
2.250
2.200
2.150
2.100
2.050
2.000
1.950
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Moisture Content, %
Sample 2

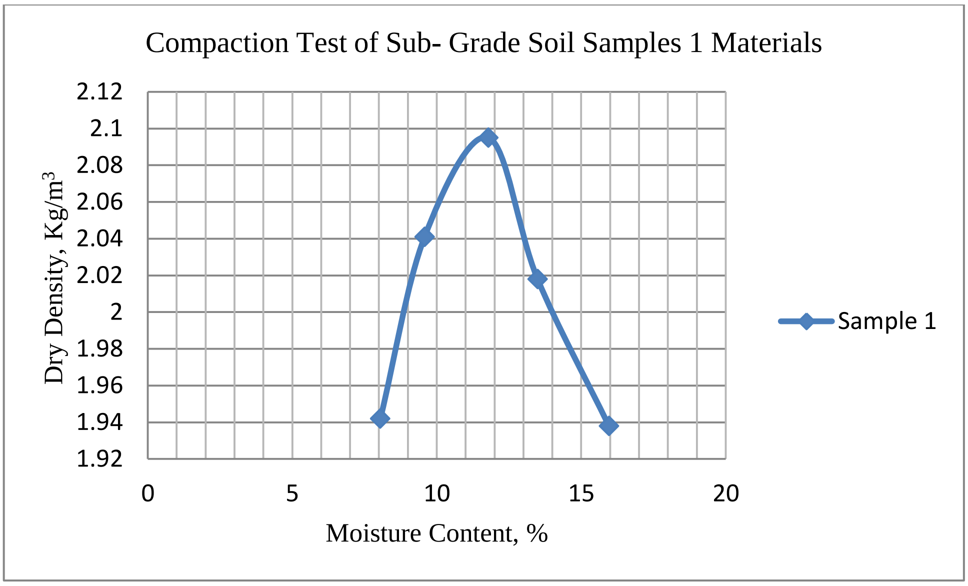


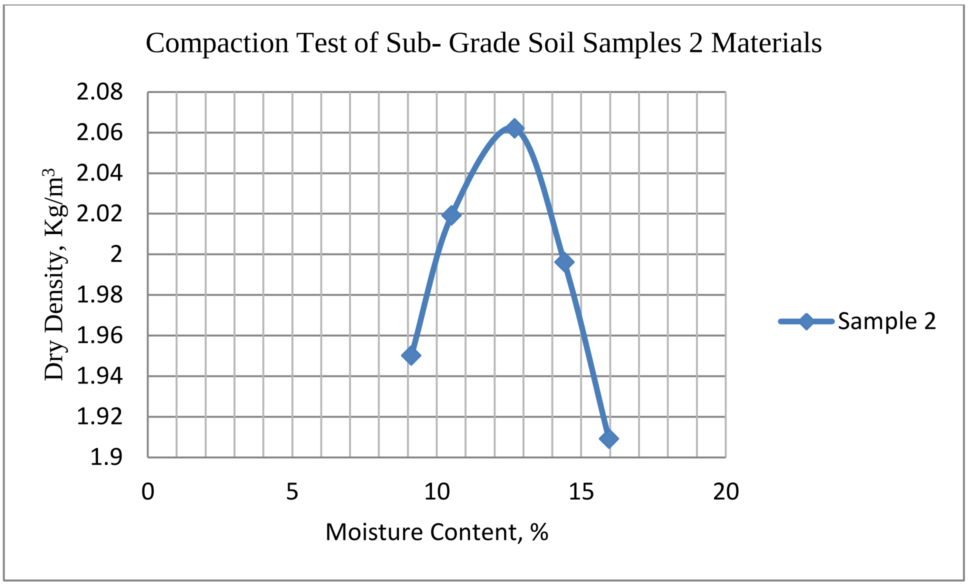
Compaction Test of Samples 3 Base Course Materials
Dry Density, Kg/m3
2.350
2.300
2.250
2.200
2.150
2.100
2.050
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Moisture Content, %
Sample 3

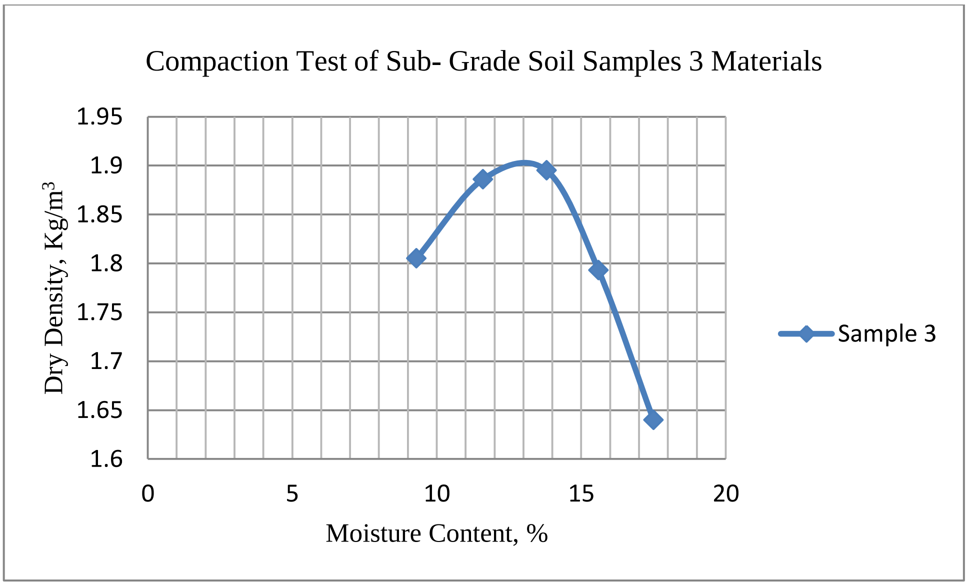

Compaction Test of Samples 4 Base Course Materials
Dry Density, Kg/m3
2.200
2.000
1.800
1.600
1.400
1.200
1.000
0.00
5.00
10.00
15.00
20.00
25.00
Moisture Content, %
Sample 4

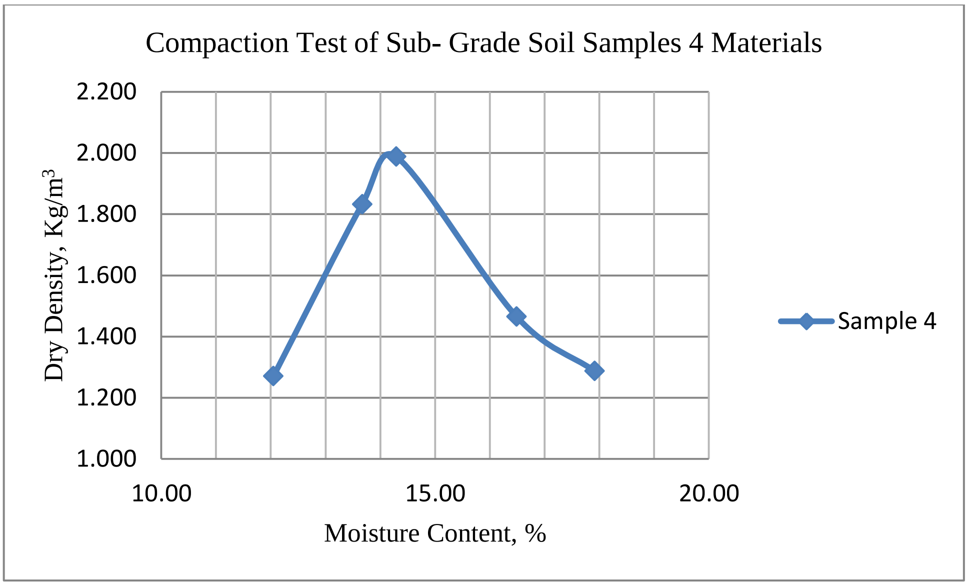

Compaction Test of Samples 5 Base Course Materials
Dry Density, Kg/m3
1.700
1.600
1.500
1.400
1.300
1.200
1.100
1.000
20.00
25.00
30.00
35.00
40.00
Moisture Content, %
Sample 5

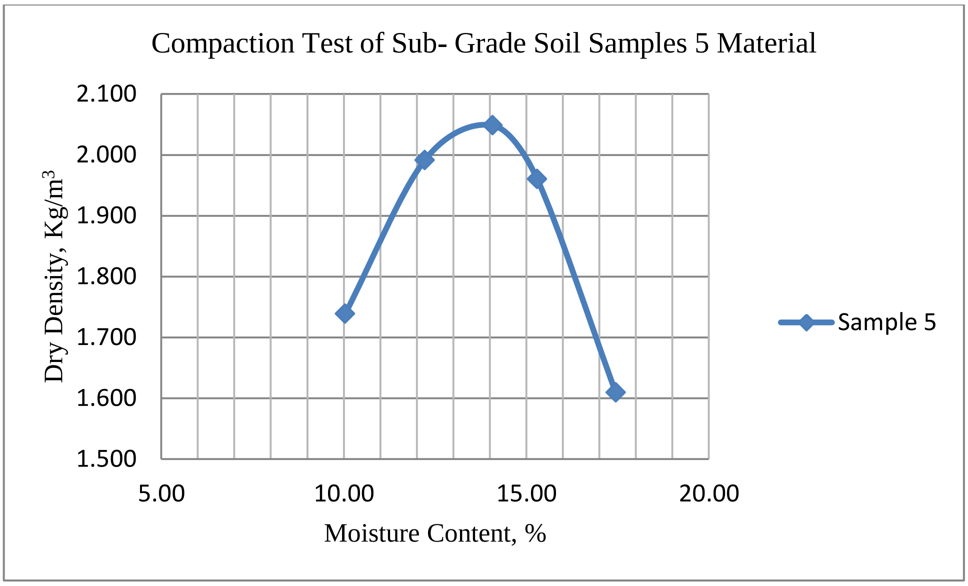

Compaction Test of Samples 6 Base Course Materials
Dry Density, Kg/m3
1.900
1.850
1.800
1.750
1.700
1.650
1.600
1.550
1.500
1.450
1.400
10.00
15.00
20.00
25.00
30.00
Moisture Content, %
Sample 6

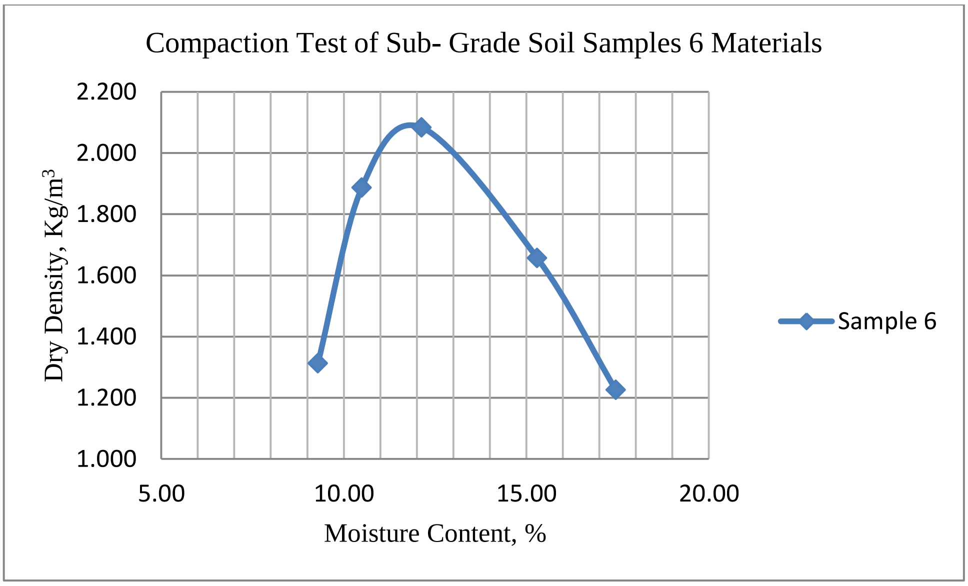

Compaction Test of Sub- Grade Soil Samples 1 Materials
Dry Density, Kg/m3
2.12
2.1
2.08
2.06
2.04
2.02
2
1.98
1.96
1.94
1.92
0
5
10
15
20
Moisture Content, %
Sample 1


Compaction Test of Sub- Grade Soil Samples 2 Materials
Dry Density, Kg/m3
2.08
2.06
2.04
2.02
2
1.98
1.96
1.94
1.92
1.9
0
5
10
15
20
Moisture Content, %
Sample 2


Compaction Test of Sub- Grade Soil Samples 3 Materials
Dry Density, Kg/m3
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
0
5
10
15
20
Moisture Content, %
Sample 3


Compaction Test of Sub- Grade Soil Samples 4 Materials
2.200
2.000
1.800
1.600
1.400
1.200
1.000
Dry Density, Kg/m3
10.00
15.00
20.00
Moisture Content, %
Sample 4


Compaction Test of Sub- Grade Soil Samples 5 Material
2.100
2.000
1.900
1.800
1.700
1.600
1.500
Dry Density, Kg/m3
5.00
10.00
15.00
20.00
Moisture Content, %
Sample 5


Compaction Test of Sub- Grade Soil Samples 6 Materials
2.200
2.000
1.800
1.600
1.400
1.200
1.000
Dry Density, Kg/m3
5.00
10.00
15.00
20.00
Moisture Content, %
Sample 6

APPENDIX D

Load VS. Penetration test Result for Base Course and Subgrade soils Materials.

E R C SYSTRA MD

AKH Railway Project

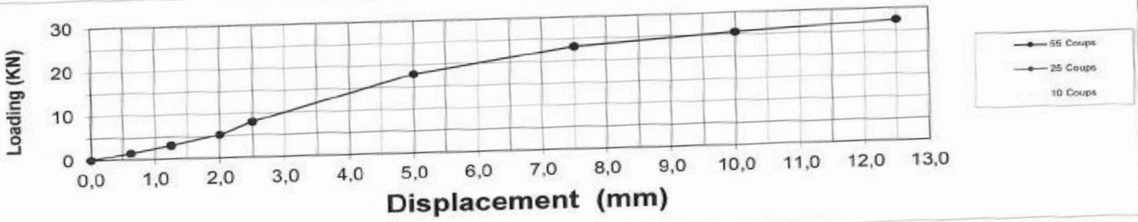
yapı merkezi

CBR TEST SONUCU
CBR TEST RESULT

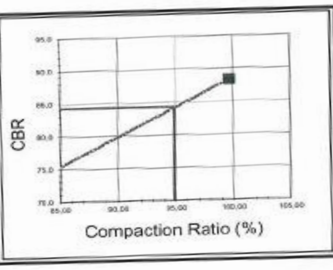
Laboratuvar/Laboratory		Deney Standardi / Test standard		Tarih / Date
Dosya No Report No		EN 13286-47		19.08.2018
Bolge/Region	Dessie hayk road segment Base Course-2		Numune Alinis Tarihi Date of Sample	10-Aug-18
Ariyet/Borrow	Dessie hayk road segment Base Course-2	Derinlik/Depth	Numune No Sample No	

Okumalar / Reading of CBR

											Sonuclar/Result
Enforcement	(mm)	0,00	0,625	1,25	2,00	2,50	5,00	7,50	10,00	12,50	
Force	kn	0,000	1,404	3,000	5,167	7,963	17,799	23,212	25,526	27,384	88,3
CBR 55 Blow	%					59,2	88,3				
Force	kn										0,0
CBR 25 Blow	%										
Force	kn										0,0
CBR10 Blow	%										



ρd	w
opn	opn
t/m3	%
2,076	2,2
2,151	4,41
2,213	6,63
2,121	8,48
2,008	10,31
Results	2,212
	6,58

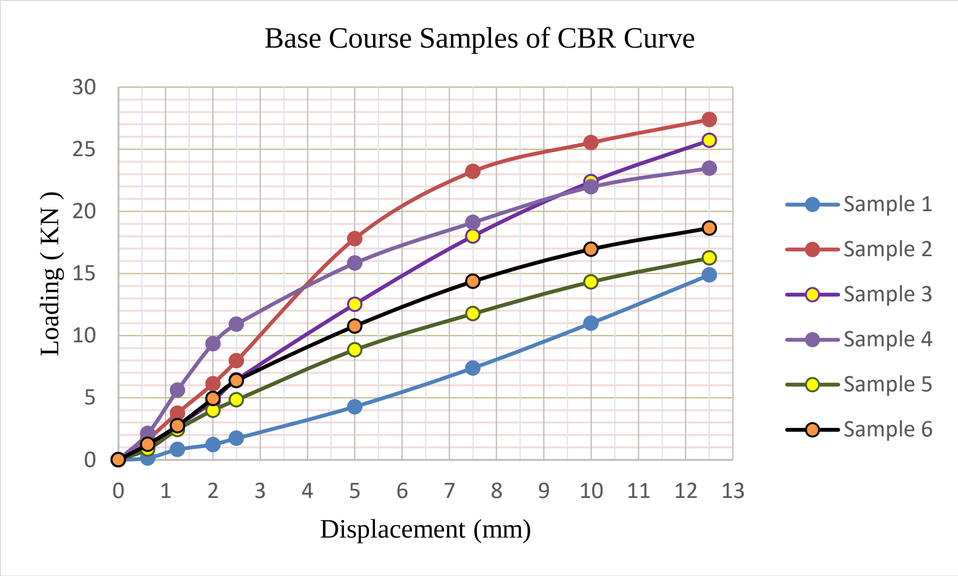


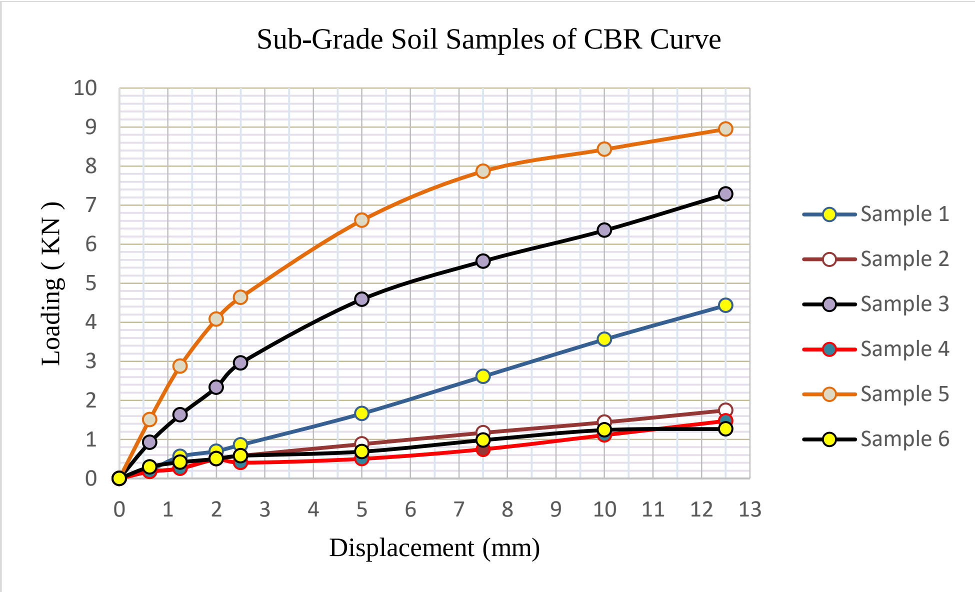
Darbe Blow	Yd IPI g/cm3 apres corr.	Compaction Ratio (%)	CBR	Swelling
55	2,20	99,7	88,3	0,51
CBR a 95% =84%				

Notes:

Tested By	YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. CONSTRUCTION AND INDUSTRY INC.	EMPLOYER'S REPRESENTATIVE
Frezer Eniyew Fitigu	Approved By YMI QC Departmer	

CBR Test Result Form	AKH - YMI - AL - GL00X - G - QC - FRM - 0155 - 0	22.05.2017
		Page: 1 / 1


Base Course Samples of CBR Curve
Loading (KN)
Displacement (mm)
0
5
10
15
20
25
30
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6


Sub-Grade Soil Samples of CBR Curve
Loading (KN)
Displacement (mm)
0
1
2
3
4
5
6
7
8
9
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6

APPENDIX E

Specific Gravity and Water Absorption Test Result for Representative Base material.

ERC SYSTRA MD **AKH Railway Project** yapı merkezi

COARSE AGGREGATE

SOURCE of SAMPLE : Dessie hayk road segment base course-2

SPECIFIC GRAVITY AND WATER ABSORPTION

STANDART NO:	EN 1097-6
Type of Material:	
Sample No:	
Date of Sampling:	10.08.2018
Date of Testing:	11.08.2018 / 13.08.2018

	DETERMINATION			Sample 1	Sample 2
A	Weight of Dry Sample		gr	2543,00	2544,00
B	Weight of SSD Sample in Air		gr	2594,50	2596,00
C	Weight of Saturated Sample in Water		gr	1670,50	1675,50
D	Bulk Specific Gravity-Dry	A / (B-C)		2,752	2,764
E	Bulk Specific Gravity-SSD	B / (B-C)		**2,808**	**2,820**
F	Apparent Specific Gravity	A / (A-C)		2,915	2,929
G	Water Absorption	(B-A)/A x100	%	**2,03**	**2,04**

AVERAGE SPECIFIC GRAVITY	**AVERAGE WATER ABSORPTION**
2,814	**2,03**

Remarks:

RESULTS: ☐ **Failed** ☐ **Passed**

TEST PERFORMED BY	YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. CONSTRUCTION AND INDUSTRY INC.	EMPLOYER'S REPRESENTATIVE
Fezer Eniyew Fetign	Approved By YMI QC Departmer	

Coarse Aggregate Specific Gravity and Water Absorption	AKH - YMI - AL - GL00X - G - QC - FRM - 0066 - 2	10.03.2016
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APPENDIX F

Grain Shape Determination (Flakiness Index) Test Result for Representative Base course material.

ERC SYSTRA MD AKH Railway Project yapı merkezi

GRAIN SHAPE DETERMINATION (FLAKINESS INDEX) TEST RESULT

Müşteri Adı / *Customer's Name* : ERC
Num.Alındığı Yer / *Project/Location* : Dessie hayk road segment base course-2
Num.Kabul Tarihi / *Date of Samp. Accept* : 10.08.2018
Num No :

Deney Tarihi / *Date of Test* : 16.08.2018
Deney Rapor Tarihi / *Date of Test Result* : 16.08.2018
Laboratuvar No / *Laboratory No* :

Elek No (Dİ/di) / Sieve Number	Deney Num. Kütlesi (gr) / Test Sample Weight	Deney Sonu Kütle (gr) / Sample Weight After Test
80/63		
63/50		
50/40		
40/31,5		
31,5/25		
25/20	482,5	13,0
20/16	455,5	84,5
16/12,5	589,5	73,0
12,5/10	684,0	35,0
10/8	413,5	108,5
8/6,3	527	116
6.3/5	149,5	31
5/4	224,5	18,5
Toplam Total	3526,0	479,5
Yassılık İndeksi/ Flakiness index		13,6

- Deneyler ilgili firma tarafından laboratuvarımıza teslim edilen numuneler üzerinde yapılmıştır.
  Tests were done from the samples that are delivered by the related firm.
- Bu deney TS 9582 EN 933-3 standartlarına göre yapılmaktadır.
  This test is being done according to the TS 9582 EN 933-3 standards.
- Bu deney raporu Laboratuarımızın yazılı izni olmadan basılamaz ve çoğaltılamaz.
  This tests results must not be reproduced in any form without the written permission of laboratory.
- T.C.Bayındırlık ve İskan Bakanlığı logosu 03,04,2003 tarih ve 42 numaralı Laboratuvar İzin Belgesi kapsamında kullanılmaktadır.
  T.C.Department of State sign used by 03,04,2003 and 42 number of Laboratory permission notes.

Remarks:

RESULTS: ☐ Failed ☐ Passed

Tested by	YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. CONSTRUCTION AND INDUSTRY INC.	THE EMPLOYER'S REPRESENTATIVE
Freter Eniyew Fitigu	Approved By YMI QC Departmer	
GrainShape Determination (Flakiness Index) Test Result Form	AKH - YMI - AL - GL00X - G - QC - FRM - 0072 - 2	26.02.2016 / Page: 1 / 1

APPENDIX G

Determination of Resistance to Fragmentation (Los Angeles) Test Result for Representative Base course material.

ERC SYSTRA AKH Railway Project yapı merkezi

DETERMINATION OF RESISTANCE TO FRAGMENTATION (LOS ANGELES)
Standard No. TS EN 1097-2

Laboratory Code No:		Date of Test Start:	11.07.2018
Date of Specimen Accept:	06.07.2018	Date of Test Result:	11.07.2018

Sample No:	**Dessie hayk road segment base course**	
Revolution Number:	**500**	
Mass of Sample:	**5001**	
Mass of Sample Retained on Sieve 1.6 mm:	**4031**	
Los Angeles Coefficient:	**% 19,4**	

Remarks-Düşünceler:

RESULTS: ☐ **Failed** ☐ **Passed**

YAPI MERKEZİ İNŞAAT VE SANAYİ A.Ş. CONSTRUCTION AND INDUSTRY INC.	EMPLOYER'S REPRESENTATIVE
Freter Enityt	

Determination of Resistance to Fragmentation	AKH – YMI – AL – GL00X – G – QC – FRM – 0020 – 2	24.02.2016

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APPENDIX H

Road Condition Survey for Representative Road Section Sample

Ethiopian Roads Authority-Paved Road Condition Form

paved road condition survey		date		Ispector		district	kombolcha	section		page of
road no		start km	270+000	segment no		start km		direction		calibration factor

kilometre			Km 21				Km				Km				Km				Km				Action Required
			0-500		500-1000		0-500		500-1000		0-500		500-1000		0-500		500-1000		0-500		500-1000		
			Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	
Carriageway	Rutting		2	2	2	2	3	3	3	3	3	3					2	2	2	2			
	Corrugations						3	3	3	3	3	3	3	3			2	2	3	3	2	2	
	Cracking	Wheel Track																					
		other																			2	2	
	stripping/Fretting																						
	Potholes		3	3	3	3			3	3	3	3	2	2					2	3	2	3	
	Bleeding																						
	Failures						3	3	3	3	3	3	3	3									
	Safety																						
	Lane marking																						
Notes																							

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