# ASSESSMENT OF ROAD PAVEMENT FAILURE ALONG ADDIS ABABA-MODJO TRUNK ROAD

**A thesis submitted to School of Civil and Environmental Engineering**

**In**

**Partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering**

**(Geotechnical Engineering)**

**By: Asnake Abate**

**Advisor: Dr.- Eng. Samuel Tadesse**

**AddisAbaba University**

**March, 2015**

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

# ASSESSMENT OF ROAD PAVEMENT FAILURE ALONG ADDIS ABABA-MODJO TRUNK ROAD

**Submitted By**
**Asnake Abate**

**Approved By Board Of Examiners**

1. Dr Samuel Tadesse_ ________________________ ____________

   Advisors Signature Date

2. Dr Bikila Teklu __________________ ____________

   Internal Examiner Signature Date

3. Ato Raeed Ali ______________________________ _______________

   External Examiner Signature Date

4. Dr. Agizew Nigussie _______________________ ____________

   Chairman Signature Date

## Acknowledgments

I would like to express my sincere gratitude to my advisor Dr. Eng. Samuel Tadesse for his invaluable guidance throughout the thesis work.

Further, my sincere gratitude goes to Ethiopian Roads Authority for the sponsorship and initiation of this study Program.

## List of Abbreviation

ERA-Ethiopian Roads Authority

PLC-Private Limited Company

Km-Kilo meter

cm- Centimeter

mm- millimeter

EALF- Equivalent Axle load Factor

ESAL-Equivalent single axle Load

PI-Plasticity Index

MDD-Maximum Dry Density

AASHTO- American association of State Highway Transportation Officials

ACV- Aggregate Crushing Value

VFB= voids filled with bitumen

IR.S= lndex of retained strength

(RRD) representative rebound deflection value

TFV-Ten percent Fine value

OMC-Optimum Moisture Content

NMC- Natural Moisture Content

# Abstract

Most of the roads constructed in Ethiopia fail prematurely before serving the design life due to various causes arising from many factors. One of these roads failed before reaching design life time is the Addis Ababa-Modjo Trunk Road.

The Addis Ababa-Modjo road is approximately 50 km trunk road and very crucial for the country's transportation and tourism sector as it is the main import export corridor to and from the capital, Addis Ababa. The road carries the highest daily traffic in the country. This road was constructed and opened to traffic in the year 2000. The design pavement life was estimated 15 years, however; pavement structure failure have been manifested since 2005, within the first 5 years after opening to traffic.

From end of 2007 to date the Addis -Modjo trunk road is repeatedly under periodic maintenance. Considerable resources have been spent during this period for periodic maintenance but without solving the basic problem. This maintenance is not working as each maintained section is failing with in short period, hence, it needs finding the root causes of the failure to come up with appropriate solution.

Field and laboratory investigations which include visual condition survey, Benkelman Deflection measurement, test pitting and pavement layer profiling, materials sampling and testing have been conducted in order to investigate causes of failure moreover, the past traffic data was collected and analysed. Finally based on the investigation, expansive subgrade soil, side drain problem, workmanship problems, use of substandard materials are found to contribute for the pavement failure. However, it is noted that the traffic load take the highest share for the cause of pavement failure. Proper treatment of expansive subgrade soil, use of quality construction materials, proper maintenance design based on the forecasted traffic are recommended as mitigation measures.

Key Words: Pavement Failure, Condition Survey, Traffic Loading, Maintenance, Benkelman Beam, Deflection.

# Table of Contents

## List of Tables

## List of Figures

# 1. Introduction

## 1.1. General

The Ethiopian Roads Authority has been working on developing the country's Road Network through expanding (opening of new routes), maintaining and managing the road network for the past 60 years. Most of the newly constructed roads failed before serving the design life time because of different reasons. Problems associated with design, workmanship and inter-pavement & surface water drainage are the main causes of these failures. The most common road distresses observed in many road failures are cracks, potholes, rutting, raveling, depressions, and damaged edges. These distresses affect the safety and riding quality on the pavement as they may lead to premature failure and traffic hazards.

Addis Ababa-Modjo Trunk Road is one of the roads which failed before reaching design life time. This road is 50 km trunk road and very crucial for the country's transportation and tourism sector. This road carries the highest daily traffic in the country which links the import export corridor. The road has been utilized for many decades with maintenances and rehabilitations. It was reinforced with a Telford during Italian Occupation and latter in 1962 surfaced with double surface treatment. In 1976 and 1981 the road was strengthened with first and second overlay using Asphalt Concrete (ERA-Projects Progress Report No. 1,).

DHV Consultants in association with AEC plc (1995) had carried out a detailed assessment of the condition of pavement and proposed maintenance measures. The initial plan was to undertake maintenance and 40mm overlay, however, based on further pavement evaluation, the planned rehabilitation was changed and constructed as:

- The previous Asphalt surface was milled, reshaped, compacted & used as Sub base layer
- 200mm crushed stone base was laid on top of the milled sub base
- 10cm Asphalt Concrete (in two separate layers, i.e.40mm Wearing and 60mm Binder Course) were applied on top of the Base Course.

This road was then opened to traffic for its present state in the year 2000. The design pavement life was estimated to be 15 years, however; pavement structure failure had been manifested since 2005, i.e. within the first 5 years after opening to traffic.

## 1.2 Background of the problem

Most new constructed Roads in the country fail without serving the design period; one of this is the road Addis Ababa to Modjo. This road started exhibiting pavement failure in 2005 (Source ERA, Alemgena District). A number of maintenance had been performed to make the road passable however; each maintained section fail within three to four months. Some of the current conditions of the road are shown below in Table 1.1 and photos.

Table 1.1 Damage type and extent (measured on the road)

| Type of failure | Damage | Extent |
|---|---|---|
| Rut | Rut depth greater than 2cm | More than 40% |
| Potholes | Depth greater than 3cm | More than 20% |
| Ravelling /fretting | | More than 50% |
| **Cracking**<br>Longitudinal<br>Transverse<br>Block Cracking<br>Crazing | Cracks wider than 1cm | More than 70% |

Repeated maintenance which includes removal of the asphalt surface and replacement has been done however; the same problem persisted to date. The Cracks, Ruts and Potholes are measured using Pavement Distress recording and Maintenance Manuals (Such as ERA Pavement Rehabilitation Manual).



Photo 1.1 Existing condition of the pavement and measurement

## 1.3 Objective of the study

The objectives of the research is

- to investigate and analyse the different pavement failure types
- to identify major causes of the different repetitive failures of the road pavement
- to recommend mitigation measures based on the findings.

- to give better geotechnical solution if the identified cause is associated with Geotechnical problems (like expansive soils and other)
- to share the findings for roads of similar nature

### 1.4 Organization of the thesis

The thesis is organized as follows: the first Chapter discusses about introduction, statement of the problem and objectives of the study. The second Chapter contains summary of theoretical and empirical literature. It gives brief discussion on pavement performance and failure criteria, pavement failure causes, mitigation measures, design and construction methodology of the study road. In addition, review of design and construction manuals were made to understand the compliance of the construction process of the road. Chapter three deals with the methodology of the study. Understanding of back ground of the project area like climate, topography, and geological settings etc., will be covered in this chapter.  Chapter four will deal with the analysis of results. Results that will be obtained from literature review, visual condition survey, field investigation, laboratory tests will be presented in this chapter. In addition, comparison of design traffic and actual traffic carried out in this chapter. Chapter five deals with the discussion of the results and analysis obtained in chapter four. The last chapter (chapter six) deals with Conclusion and recommendation of the study. Flow chart of the organization of the study is presented in Figure-1 below.

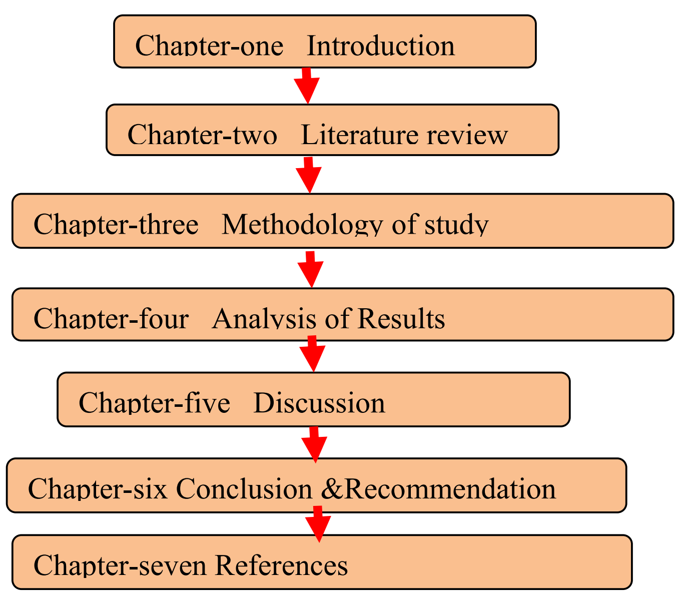


Figure 1-1: Flow chart of organization of the thesis

# 2. Literature Review

## 2.1. General

Deterioration of highway pavement is a very serious problem that causes unnecessary delay in traffic flow, distorts pavement aesthetics, damages of vehicle and most significantly, causes road traffic accident that had resulted into loss of lives and properties, [2]. Pavement surface deformation affects the safety and riding quality on the pavement as it may lead to premature failures.

It is noted in [1, 2, 3] that, it is impossible to design a road pavement which does not deteriorate in some way with time and traffic, hence concluded that the aim of pavement structural design is to limit the level of pavement distress, measured primarily in terms of riding quality, rut depth and cracking, to a predetermined values. Generally these values are set so that a suitable remedial treatment at the end of design period is strengthening overlay of some kind but this is not necessarily so and road can, in principle, be designed to reach a terminal condition at which major rehabilitation or even complete reconstructions are necessary. However, appropriate remedial treatments for roads which have deteriorated beyond a certain level are difficult task.

Acceptable levels of surface condition have usually been based on the expectations of road users [2]. These expectations have been found to depend upon the class of the road and volume of traffic such that the higher the Geometric standard, and therefore the higher the vehicle speeds, the lower the pavement distress which is acceptable. In defining these levels, economic evaluation also considered. Most specification sets a maximum rut depth of 20mm as failure criteria and also the riding quality, which is measured International Roughness index, as performance criteria.

Flexible pavements are intended to limit the stress created at the subgrade level by the traffic traveling on the pavement surface, so that the subgrade is not subject to significant deformations [4]. In effect, the concentrated loads of the vehicle wheels are spread over a sufficiently larger area at subgrade level. At the same time, the pavement materials themselves should not deteriorate to such an extent as to affect the riding quality and functionality of the pavement.

Pavements do deteriorate due to time, climate and traffic. Hence, limiting pavement deteriorations which affect the riding quality from cracking, rutting, potholes and other such surface distresses to acceptable levels is important.

This chapter discusses literatures by different authors and researchers on factors affecting pavement failure, type of pavement failures and failure mitigation measures.

## 2.2. Factors affecting pavement failures

A variety of factors contribute to pavement deterioration were investigated by many researchers [5], [6], [7], [8], [9], [10]. "The Behaviour of Flexible Pavement on Expansive Soil", "Asphalt Pavement, a practical guide to design, production, and maintenance for Engineers and Architects", have revealed that pavement failure is attributed solely to poor design or method of construction. Lack of proper consideration of traffic loading, climate issues, materials quality and drainage issues are main causes of pavement failure due to poor design. On the Other hand lack of proper supervision of the construction, low quality construction materials, poor workmanship are the main causes of pavement failure attributed due to construction [5].

Furthermore, he also suggested that poor highway facilities, no local standard of practice, poor laboratory and in-situ tests on soil and weak local professional bodies in highway design, construction and management will lead pavement failures. Hence, proper pavement design shall have great contributions to protect premature pavement failure [1].

- limit the stresses induced to the subgrade by traffic to a safe level at which subgrade deformation is insignificant,
- Ensuring that the road pavement layers themselves do not deteriorate to any serious extent within a specified period of time,
- Determine pavement thickness by evaluating sub-grade properties, subbase, base properties, and surfacing materials property, traffic loading and environmental factors.

### 2.2.1 Heavy traffic loading

Traffic loading is the major design factor. Traffic load is the total load that the pavement will carry within the design life. Traffic loading greatly affects the performance of an asphalt pavement, [1].

The traffic or load carrying ability of an asphalt pavement is a function of both the thickness of the pavement materials and its stiffness [2]. The deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied.

Fatigue cracking and deformations of pavements are the major defects caused by heavy traffic due to the increased traffic overloading which is more than the design load. As stated by [11] that deterioration of pavements arises from deformation generally associated with cracking under heavy commercial vehicles. Omer et al. [6] observed that pavement failures on west lane of the ring road that might have been caused by the movement of heavy loaded truck trailers, tippers, as well as loaded fuel tankers. Road surfaces often wear under the action of traffic, particularly during the very early life of the road. However, the action of traffic continues to wear the surface texture and thus gradually reduces the high speed skidding resistance, [12]. He reported that with the increase of traffic loads (volume and axle loads) the road network was experiencing a deterioration equivalent to a loss of billions dollars due to road deterioration and vehicle operating cost.

Okigbo [5] indicated that the defects that most often cause injuries to people and damage to vehicles include inadequate road shoulders, pavement surface that is uneven, improperly marked signs, malfunctioning stop lights, construction negligence, and municipal negligence. Traffic volume and size (especially for overloading) contributes to road safety and conditions.

The severity of the pavement failure due to overloading of traffic is based on the fourth power rule. The fourth power rule is an equivalent axle load factor which is damage per pass of a pavement by the axle relative in question to per pass of the standard load (80 KN) of single axle load. In the mechanistic method of design, the EALF can be determined from the failure criteria. The failure criterion for fatigue cracking was shown below with f2 of 3 .291 by the Asphalt Institute and 5 .671 by Shell [13].

$$Nf = f1(\varepsilon t)^{-f2}(E1)^{-f3}$$ ……………………………………………………………eq.1

[9] Conducted a theoretical analysis of EALF by layered theory based on an assumed f2 of 4, or, from Eq.1.

$$EALF = \frac{wt18}{wtx} = \left(\frac{\varepsilon x}{\varepsilon 18}\right)^4 = \left(\frac{Lx}{L18}\right)^4$$ ....................................................................................eq.2

in which $\varepsilon_x$ is the tensile strain at the bottom of asphalt layer due to an x-axle load and $\varepsilon_{18}$ is the tensile strain at the bottom of asphalt layer due to an 18-kip (80-kN) axle load. $L_x$ is the load at the bottom of asphalt layer due to an x-axle load and $L_{18}$ is the load at the bottom of asphalt layer due to an 18kip (80KN) axle load. Eq.2 is called the fourth power. If the load doubles the damaging effect will increase exponentially to the fourth power relative to the damage caused by the standard axle load. Hence, the effect of over loaded traffic can contribute a premature failure significantly.

The other failure criterion as stated [13] is to control permanent deformation by limiting the vertical compressive strain on top of the subgrade, which can be expressed as

$$Nd = f_4(\varepsilon c)^{-f_5} \quad \text{.......................................................................eq.3.}$$

Suggested values of "$f_5$"are 4 .477 by the Asphalt Institute, 4 .0 by Shell, and 3 .571 by the University of Nottingham. It can be seen that the use of 4 for "$f_5$" is also reasonable.

The EALF based on fatigue cracking may not be much different from that based on permanent deformation. However, this is not true when $L_S$ is for a single axle but $L_x$ is for multiple axles, because then the effect of additional axles on the tensile strains at the bottom of asphalt layer is quite different from that on the compressive strain at the top of the subgrade.

### 2.2.2. Environmental variation

Environment has great impact on material selection and thickness design of a pavement. The two critical areas of the environment that cause pavement failure are temperature and water/rainfall [1]. Temperature affects the selection of which grade asphalt binder that would be used in the asphalt pavement. Asphalt pavements are susceptible to damage by water. Water increase moisture in the pavement and reduce bearing capacity, it saturates subgrade or base of an asphalt pavement and causes structural damage to pavement in climates that have extensive rainfall. The best prevention to structural damage due to provision of water is proper drainage. Inspection and cleaning of drainage system insures that they are working properly and will eliminate some of major causes of pavement failure.

Some of the most common modes of failure in the tropics are often different from those encountered in temperate region [1]. It is further demonstrated that, climate also affects the nature of the soils and rocks encountered in the tropics soil forming processes are still active. In accordance with the demonstration; in arid and semi-arid areas (in low rain fall areas in tropics), typically with rainfall of less than 500mm, and where evaporation is high, moisture conditions beneath a well-sealed surface are unlikely to raise above the optimum moisture content. In such conditions, high strengths (CBR>80%) are likely to develop even when natural gravel containing a substantial amount of plastic fines are used. In this situation some relaxation of PI and CBR can be made. Environmental conditions influence the performance of the entire pavement structure, including the subgrade.

Moisture affects the subgrade, sub base, or granular base, while temperature affects the asphalt mixture. For example; Materials of basic igneous rock origin are sometimes weathered and may release additional plastic fines during construction or in service. Problem is likely to worsen if water gains entry in to the pavement and this can lead to rapid and premature failure. The release of these minerals may lead to a consequential loss in the bearing capacity.

Climatic factors include rainfall and annual variations in temperature are an important consideration in pavement deterioration. Rainfall has a significant influence on the stability and strength of the pavement layers because it affects the moisture content of the subgrade soil. The effect of rain on road pavements can be destructive and detrimental as most pavements are designed based on a certain period of rainfall data. In addition, rainfall is well established as a factor affecting the elevation of the water table, the intensity of erosion, and pumping and infiltration [14].

Long periods of rainfall of low intensity can be more adverse than short periods of high intensity because the amount of moisture absorbed by the soil is greater under the former conditions [7]. He further emphasized that water is the critical factor that cause road failures. Once water has entered a road pavement, the damage initially is caused by hydraulic pressure. Vehicles passing over the road pavement impart considerable sudden pressure on the water, this pressure forces the water further into the road fabric and breaks it up. This process can be very rapid once it begins. When vehicles pass over the weak spot, the pavement will start to crack and soon the crack generates several cracks. Water will then enter the surface voids, cracks and failure areas. This can weaken the structural capacity of the pavement causing existing cracks to widen. Eventually, the water will descend to the subgrade, weakening and hence lowering the CBR value of the subgrade on which the road pavement design was based upon.

Wee et al. [15] reported that climatic changes in temperature and rainfall can interact together. Rainfall can alter moisture balances and influence pavement deterioration while the temperature changes can affect the aging of bitumen resulting in an increase in embrittlement of the bitumen which causes the surface to crack, with a consequent loss of waterproofing of the surface seal.

### 2.2.3. Poor Drainage

The highway drainage system includes the pavement and the water handling system which includes pavement surface, shoulders, drains and culverts. These elements of the drainage system must be properly designed, built, and maintained. When a road fails, inadequate drainage often is a major factor. Poor design can direct water back onto the road or keep it from draining away. Too much water remaining on the surface combine with traffic action may cause potholes, cracks and pavement failure [8]. Inadequate drainage leads to major cause of pavement distress due to large amount of costly repairs or replacements long before reaching their design life. Drainage design for pavement is to keep the base, sub-base, subgrade, and other susceptible paving materials from becoming saturated or even being exposed to constant high moisture levels over time.

Patil Abhijit et al. [8] investigated the effect of poor drainage on road pavement condition and found that the increase in moisture content decreases the strength of the pavement. Therefore, poor drainage causes the premature failure of the pavement. Little and Jones [9] investigated moisture damage in asphalt pavements due to poor drainage. They found that the loss of strength and durability due to the effects of water is caused by loss of cohesion (strength) of the asphalt film, failure of the adhesion (bond) between the aggregate and asphalt, and degradation of the aggregate particles subjected to freezing. Moisture damage generally starts at the bottom of an asphalt layer or at the interface of two asphalt layers [16]. Eventually, localized potholes are formed or the pavement ravels or ruts. Surface raveling or a loss of surface aggregate can also occur, especially with chip seals. Occasionally, binder from within the pavement will migrate to the pavement surface resulting in flushing or bleeding [17].

### 2.2.4. Construction with Low Quality Materials

The use of low quality materials for construction adversely affects the performance of the road. This sometimes occurs in the form of the improper grading of aggregates for base or subbase and poor subgrade soil of low bearing strength. The use of marginal or substandard base materials for pavement construction will affect pavement performance [18]. He found that these materials may accelerate deterioration of the pavement and often result in rutting, cracking, shoving, ravelling, aggregate abrasion, low skid resistance, low strength, shortened service life, or some combination of these problems.

Osuolale et al. [19] investigated the possible causes of highway pavement failure along a road in south western Nigeria. He stated that the materials used as subbase have the geotechnical properties below the specification and this is likely to be responsible for the road failure. The base materials with high fines content are susceptible to loss of strength and load supporting capability upon wetting [20]. However, marginal base materials often lead to distress and can lead to premature failure in the form of severe shrinkage cracking followed by accelerated fatigue cracking and a general loss of stability [21].

Subgrade with CBR greater than 5% and plastic index less than 25% are described as good subgrade. Any failure in the subgrade will cause structural failure of the pavement. A minimum CBR of 30% is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum 95% of the maximum dry density achieved. Highly plastic subbase or base materials of highly weathered basaltic origin cause premature pavement failure [22]. Base course material should be angular in shape with Flakiness Index of less than 35%. In a addition, to insure the material is sufficiently durable, it should have PI<6%, minimum TFV 110KN and CBR>80% [23]. Failure in road base leads to in sufficient cover to subgrade and led to subgrade failure. Failure on road wearing course leads to infiltration of water to base, subbase and subgrade and hence causes failure to pavement structure.

**2.2.5. Expansive Subgrade Soil**

Expansive soil as road subgrade is considered one of the most common causes of pavement distresses. Longitudinal cracking results from the volumetric change of the expansive subgrade, is one of the most common distresses form in low volume roads. This type of cracking is initiated from the drying highly plastic subgrade (PI>35) through the pavement structure during the summer [24], [25]. Other forms include fatigue (alligator) cracking, edge cracking, rutting in the wheel path, shoving, and pop outs.

Problem of expansive soils results from a wide range of factors such as swelling and shrinkage of clay soils result from moisture change, type of clay minerals, drainage– rise of ground water or poor surface drainage and compression of the soil strata resulting from applied load. Expansive subgrades have an adverse effect on the performance of the pavement. When a new route is planned, the location of expansive soils must be known early in planning stage so that they can be avoided or treated if possible. If they cannot be avoided provision must be made for higher construction and maintenance costs which are inevitable [26]. It is necessary to define the property of materials in the roadbed which undergo volumetric changes and thus affect the performance of the pavement further it is also necessary to determine the extent of the materials in the field and formulate the more effective and most economic construction or maintenance strategy to counteract these volumetric changes [22].

### 2.2.6 Workmanship and Method of Construction

The ultimate durability of an asphalt mixture and pavement structure is directly dependent on the quality of the workmanship used to construct the project [27]. The best set of specification, if not followed, will not assure a good, long lasting pavement. Poor workmanship can be one of the more significant responsible for premature distress of an asphalt pavement. Many times, poor workmanship involves from an ignorance of a specification, proper construction techniques or proper operation of equipment.

Scarifying and compaction of insitu materials to 93% of maximum density at optimum moisture content are required during construction of subgrade [23, 28, and 29]. If insitu materials are expansive soils all specify removal of the same so that, the level of these expansive materials will be at least below the neutral zone of moisture variation. In addition it is specified that all subgrade with CBR less than 3% needs to be strengthened with capping material of better quality like CBR greater than 15% and maximum Plastic Index 16%.
Further the sub base material is to have minimum CBR of 30%, maximum PI of 12%, Compaction minimum 95% of MDD and grading modulus minimum 1.2%. The specifications [23,28,29] also sets minimum CBR 80%, maximum PI 6%, Compaction minimum 98% of MDD and at least three faces crushed aggregate requirement for Base materials and Asphalt premix surfacing with stability greater than 9kN and flow 2mm-4mm.

A research study [30] indicated that failure on Addis Ababa-Nekempt road is due to poor workmanship and design problem. It is shown that the main reason for the failures of the Addis Ababa-Nekempte road is not the red clay soil used as a subgrade, but failure is due to the improper use of the overlaying materials and poor construction. The base and subbase layer thicknesses used at all sections are too thin to support the traffic loading. From the design the required depth for base is 20cm, but 11.4cm thickness have been on the roads with equivalent traffic loading as Addis Ababa-Nekempte such as some part of Addis Ababa-Jimma and Addis Ababa-GohaTsion, no failure is observed as these roads are constructed on red clay soils with adequate layer thickness and proper construction.

## 2.3. Type of Pavement Failure and Mitigation Measures

Pavement failure is defined in terms of decreasing serviceability caused by the development of surface distresses such as cracks, potholes and ruts, [31]. They reported that before going into the maintenance strategies, highway engineers must look into the causes of failures of bituminous pavements. They found that failures of bituminous pavements are caused due to many reasons or combination of reasons. It has been seen that only three parameters i.e. unevenness index, pavement cracking and rutting are considered while other distresses have been omitted while going for maintenance operations.

According to Woods and Adcox [32], pavement failure may be considered as structural, functional, or materials failure, or a combination of these factors. Structural failure is the loss of load carrying capability, where the pavement is no longer able to absorb and transmit the wheel loading through the structure of the road without causing further deterioration. Functional failure is a broader term, which may indicate the loss of any function of the pavement such as skid resistance, structural capacity, and serviceability or passenger comfort. Materials failure occurs due to the disintegration or loss of material characteristics of any of the component materials.

Caltrans [33] categorized the main types of pavement failures as either deformation failures or surface texture failures. Deformation failures include corrugations, depressions, potholes, rutting and shoving. These failures may be due to either traffic (load associated) or environmental (nonload associated) influences. It may also reflect serious underlying structural or material problems that may lead to cracking. Surface texture failures include bleeding, cracking, polishing, stripping and raveling. These failures indicate that while the road pavement may still be structurally sound, the surface no longer performs the function it is designed to do, which is normally to provide skid resistance, a smooth running surface and water tightness. Other miscellaneous types of pavement failures include edge defects, patching and roughness.

The Cracking consists of visible discontinuities in surface and can be an indication of the pavement's structural condition and serious, [34]. The main problem with cracks is that they allow moisture into pavement, giving accelerated deterioration of pavement. Cracks can occur in a wide variety of patterns. They may result from a large number of causes, but generally are the result of either ageing and embrittlement of surfacing, environmental conditions, structural or fatigue failure of the pavement, or any other causes, [34]. The formation of cracks in the pavement surface causes numerous problems such as discomfort to the users, reduction of safety, etc. In addition to the above, intrusion of water causing reduction of the strength in lower layers as well as lowering of bearing capacity of subgrade soil by pumping of soil particles through the cracks is also a major problem associated with the pavements, [35]. This leads to the progressive degradation of the road pavement structure in the neighborhood of the cracks. The origin of cracks differs by their shapes, configuration, and amplitude of loading, movement of traffic and rate of deformation.

Rutting as described by Caltrans [33] is the permanent downward deformation of the surfacing within wheel paths. It may result from deformation of the surfacing, the pavement materials or the underlying subgrade, or a combination of these. It is important to determine which layer is rutting since this will influence the optimal maintenance strategy. The worse level of rutting is the higher variation in the transverse profile of road surface. Because of this, ruts interfere with surface run-off patterns and increase the risk of wetting in the upper pavement layers. Rutting can also initiate aquaplaning, and hence have adverse impact on safety, [33].

According to Ahmed [35], potholes are an indication of structural surface failure and they result from growth of a break in the surfacing, often as a result of severe alligator cracking. Once water enters pavement layers, the base and/or subgrade become wet and unstable, and the resultant degradation leads to rapid growth of pothole area and depth. Sikdar et al [36] reported that if the potholes are numerous or frequent, it may indicate underlying problem such as inadequate pavement or aged surfacing requiring rehabilitation or replacement. Water entering pavement is often the cause, and could be caused by a cracked surface, high shoulders or pavement depressions ponding water on pavement, porous or open surface, or clogged side ditches.

Kumar and Gupta [31] listed in Table 2-1 below the possible causes of different forms of pavement distresses.

Table 2-1: The most common pavement distress and its possible causes

| Distress | Possible causes |
|---|---|
| Alligator cracking | Fatigue failure due to flexible/brittle base.<br>Inadequate pavement thickness. |
| Block cracking | Reflection of joints cracking in underlying base. |
| Longitudinal cracking | Reflection cracking.<br>Poor paving lane joint.<br>Pavement widening.<br>Cut/fill differential settlement.<br>Fatigue failure of asphalt concrete. |
| Transverse cracking | Reflection of shrinkage cracking.<br>Construction joints. |
| Rutting | Inadequate pavement thickness.<br>Post construction compaction<br>Instability of base surfacing. |
| Shoving | Poor bond between layers.<br>Lack of edge containment.<br>Inadequate pavement thickness. |
| Depression | Settlement of service trench or embankment.<br>Isolated consolidation.<br>Volume change of subgrade. |
| Corrugation | Instability of asphalt concrete or base course. |
| Edge drop | Inadequate pavement width.<br>Erodible shoulder material (lack of plasticity). |
| Edge break | Inadequate pavement width.<br>Inadequate edge support.<br>Traffic travelling on shoulder edge drop.<br>Weak seal coat/loss of adhesion. |

In many pavement failures, excess moisture is the main cause of failure or a contributing cause. Queensland Transport [37] reported the effect of moisture content changes on the strength and stiffness of pavement materials. They found that excess moisture reduces the strength and stiffness of pavement materials, being worse for the subgrade material, than for the subbase or base. Excess moisture and particularly high degrees of saturation result in significant pore pressures within the material. Depending on the degree of saturation, failure may occur as any of rapid shear or bearing failure, premature rutting, lifting of wearing course due to positive pore pressures, or embedment of cover aggregate due to weak base, [37]. It can be seen that for nearly all types of pavement failure, moisture is often the primary or a contributing cause of failure. Moisture entry through the surface may be caused by inadequate pavement surface drainage during construction, exposure of surface to rain during construction, or porous or open graded asphalt, [38]. He found moisture entry from the side may be caused by pondage in pits or poorly constructed surface drainage, and lateral movement of water into pavement. Other factors affecting the moisture in a pavement include the general drainage condition, such as the effectiveness of drainage structures, shoulder cross-fall and condition, longitudinal grade, and whether the pavement is constructed on cut or fill. Pavement failure quantified by its extent (length of road affected) and its severity. The level of quantified damage divided in to three i.e Level -1, Level -2 and level -3, [39].

Table 2.2 Pavement failure quantification [39].

| Damage | Pavement failure Severity | | |
|---|---|---|---|
| | Level-1 | Level-2 | Level-3 |
| Deformation /Rutting | Perception to User but small Depth<2cm | Severe deformations, localized subsidence or rutting $2 \leq f \leq 4$cm | Deformation severely affecting safety or travel time f>4cm |
| Crack | Hairline cracks in wheel path or centerline | Open or branching cracks | Markedly branched or wide open cracks |
| Crazing | Fine crazing with no loss of materials large mesh (>50cm) | Tighter crazing (< 50cm) | Very open crazing forming blocks(<20cm) accompanied by loss of materials |
| Patch and Repair | Rebuilding of pavement | Surface work related | Surface work related |
| Pothole | Number less than 5 Diameter not more than 30cm | Number 5 to 10 Diameter 30cm to 100cm (per 100m of pavement) | Number >10 Diameter 30cm to 100cm (per 100m of pavement) |
| Raveling | Localized | Continuous | Continuous and road base visible |

Types of pavement distress are indications of the cause of the pavement failure. It has been noted from the research paper [40] that, pavement distress (like ruts, Potholes, Raveling/freights, cracks) exhibited on the road surfaces are related with possible causes. The following are summery of distresses type and possible causes [40].

Maintenance is an essential practice in providing for the long term performance and the aesthetic appearance of an asphalt pavement [40]. The purpose of pavement maintenance is to correct deficiencies caused by distresses and to protect the pavement from further damage. Various level of maintenance can be done based on the condition of the road pavement.

In all cases of pavement maintenance, it is necessary to determine the cause of the distress or defects. Determining the distress cause assists in making the proper repair and preventing the distress from reoccurring. Identification of the distress is one of the first steps in a pavement maintenance program.[39]

Pavement maintenance is work performed from time to time to keep a pavement, under normal conditions of traffic and forces of nature, as nearly as possible in its as-constructed condition. Maintenance is sub divided as routine, recurrent and periodic and Urgent [39].

Rehabilitation is work undertaken to significantly extend the service life of an existing pavement. This may include overlays and pre-overlay repairs, and may include complete removal and reconstruction of the existing pavement, or recycling of part of the existing materials [39].

# 3. Methodology of the study

In order to reach the main objective of the research the following research methods are utilized.

## 3.1. Literature Review

Previous history of the project may be reviewed from construction progress report and material test report to overview pavement history, drainage design, pavement material information and specifications, previous materials test results, construction and previous maintenance records, testing methods and frequencies, and other relevant information such as traffic volumes and composition, soil or geological records, and temperature, weather or rainfall. The type of materials used, the method of construction work and other history of the project will also been reviewed and conclusions will be drawn from the documents about the materials used, workmanship and design.

## 3.2. Pavement condition survey

Visual survey of the existing pavement condition has been conducted in order to identify the type and extent of the pavement distress. During Visual survey the type of pavement failures had been recorded, the possible causes of the failures were identified by relating with pre studied documents.

Moreover, visual examination of pavement failures, the effectiveness of drainage structures and other details such as topography and alignment should be recorded during pavement condition survey. The soil and geology of the surrounding areas may also be of importance in determining the causes of the pavement failure. An effective visual survey of pavement failures is essential, to ensure that the cause of the failure can be diagnosed efficiently and it is a guide to what testing should be carried out and where.

In addition, it will provide valuable site information that may have an influence on the best maintenance operation. Distress surveying should be carried out on failed pavement sections to find out the amount, type, and condition or severity level of distress, as well as the condition or effectiveness of any previously applied distress treatments. The width and density of cracking, the depth of rutting shall be measured along the project road.

## 3.3. Experimental work

Deflection test, test pit excavation, field density test, laboratory test performed to identify the major pavement failure types and the major causes of pavement failures.

Deflection test carried out to measure the deflection of uniform section and determine the structural condition of the pavement. Benkelman beam shall be used to measure the pavement deflection. In addition, the width and density of cracking, the depth of rutting were also measured along the project road. In order to verify the major causes of failures, test pit excavations were conducted to undertake both laboratory and field tests. The profile and thicknesses of pavement layers were also observed from the test pit excavation.

### 3.4. Laboratory Tests

Laboratory tests performed on the pavement layer materials i.e Base, Sub Base and Subgrade Materials. Laboratory testing conducted on representative samples taken from pavement layers to determine physical characteristics of the materials. Samples shall be obtained at the test pit of the road, and shall dug out using digger and shovel from base course, subbase and subgrade below the asphaltic surface. They were suitably packed into sacks and labeled in such a manner that each material can be identified distinctly. They were transported to the laboratory for the following tests: Sieve Analysis, Atterberg limit, Compaction, aggregate crushing values, water absorption, freeswell and California Bearing Ratio in accordance with AASHTO testing manual [1].

The tests on soils and aggregates may aim to measure the index properties by particle size and shape, the plasticity and specific gravity and to assess the strength by the compaction and California Bearing Ratio (CBR) tests. Geotechnical tests may include measurement of the shear strength, consolidation and determine the water table level during site investigation. The corresponding laboratory tests for each layer of the pavement are:-

a) Crushed Aggregate base – CBR, Aggregate Crushing Value, Water Absorption, Gradation and Atterberg limits.
b) Sub Base –CBR, Atterberg limits, Gradation, Compaction
c) Subgrade-CBR, Atterberg, Compaction, and for selected section free swell

# 4. Analysis of Results

## 4.1. Review of documents and literatures

### 4.1.1. Project Location

The Project Road is located in Oromia Regional state and starts at the South Eastern outskirt of Addis Ababa (see the location map below). The Addis Ababa –Modjo road is part of the link between the capital and the ports of Djibouti. It also links the southern part of the country with the Capital. Due to this the road is one of highly trafficked route in the country.


Figure 4.1: Location Map

### 4.1.2. Physiographic

The Project route corridor is broadly classified into two physiographic regions mainly based on terrain. These are flat and rolling physiographic regions.

Table 4.1: Physiographic Regions (Inception:- Report Addis –Modjo Road Project 2001)

| Item No | Section | Physiography |
|---|---|---|
| 1 | 0+000-12+000 | Rolling |
| 2 | 12+000-40+000 | Flat |
| 3 | 40+000-50+000 | Rolling |

### 4.1.3. Climate

**i. Temperature**

Based on the Meteorological Map of Ethiopia, the project road corridor can be classified as a moderate to wet. The average monthly rain fall as shown in Table 4.2 is approximately 85mm with maximum of approximately 300mm occurring in the month of July.

The mean minimum and maximum annual temperatures lay between $10^0$C to $16^0$C and $26^0$C to $31^0$C respectively. The mean monthly maximum and minimum temperatures for Akaki, Debezeit and Modjo is shown in Table 4.2.

Table 4.2: Monthly Mean maximum and minimum temperature along the project road (Source NMA, Addis Ababa, Debrezeit and Modjo station)

| Town | Temp | Jan | Fe | Ma | Ap | Ma | Jun | Jul | Au | Se | Oct | No | De |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A.A (Bole | Max | 23.4 | 24. | 25 | 24. | 25 | 23. | 21 | 20. | 21. | 22. | 22. | 22. |
| | Min | | | 9.9 | | 10. | | 10. | | | | | 5.5 |
| Debre zeit | Max | 26.1 | 27. | 28 | 27. | 28. | 27. | 24. | 23. | 25. | 26 | 25. | 25. |
| | Min | | | 12. | | | | | | | 10. | 9.6 | 8.8 |

### ii. Rainfall

The mean monthly rainfall varies from 85mm to 300mm significant rain can be expected in the area from the month of June to September, inclusive, with peaks around July and August (Table 4.3). During the remainder of the year there is very little precipitation.

Table 4.3: Mean monthly Rainfall (mm) along the project road (Source NMA, Addis Ababa, Debrezeit and Modjo station)

| Town | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annuall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Addis Ababa | 14.8 | 36.4 | 70 | 88.3 | 73.6 | 118 | 241.8 | 240.2 | 142.4 | 33.4 | 16.3 | 5.9 | 1071 |
| Debrezeit | 10.3 | 27.3 | 52 | 63.1 | 56.2 | 94.9 | 228.8 | 227.2 | 106.5 | 24.5 | 6 | 3.8 | 901 |
| Modjo | 13.7 | 29.7 | 47.9 | 53.9 | 49.9 | 94 | 238.2 | 220.9 | 109.9 | 27 | 9.1 | 2.9 | 897 |

#### 4.1.4. Regional Geological setting

The project road is located in Quaternary undifferentiated, Policene-Pleistcene and Miocene-Pliocene formations (See Figure 4.2). According to the Geological Map of Ethiopia the Bishoftu formation characterized by alkaline basalt dominates the road. The plateau Basalt which is alkaline basalt and trachyte are also found in Debrezeit area. The Nazareth series formation (which consists of ignimbrites, un welded tuffs, ash flows, rhyolitic flows, domes & trachytes) and Alluvial and Lacustrine deposits (which consists of Sand, Silt, Clay, Diatomite, lime stone and beach sand) are also crossed by the road.

**i. Geology of the Route Corridor**

The Geology of the route corridor was briefly assessed during the sub grade and construction material survey in conjunction with 1:2,000,000 scale Geological Map of Ethiopia. The Geological unit that dominates the route corridor has been investigated in relation to their potential as source of construction material. Based on the existing geological map and field observation, the route corridor of the project area is made up of volcanic rocks consisting predominantly two rock types. Namely; Basalt and Trachyte Basalt.

**a) Basalt**

Basalt is one of the major rock units covering extensive part of the project route corridor, particularly from km 2 to km 15 and km 20 to km 40. Usually it is characterized by hilly and rugged topography mostly covered by thin red to reddish brown residual silty clay soils. Good exposures are seen alongside cuts, stream banks and mountain and hillsides between Akaki and Dukem area. This basalt is predominantly dark gray in color, fine grained, aphanites to porphyritic in texture, massive to fissile, thinly to thickly jointed and slightly to strongly fractured. Most outcrops are excellent candidates of crushing aggregate for base, wearing course and concrete work as well as masonry stones sources. As visually observed most of the road side quarries from Akaki to Dukem developed by Private developers for aggregate production are basalt (based on personal observation).

b) **Trachyte**

The trachyte is localized in Debrezeit area. Usually it forms outstanding ridges attracting and dominating the scene of their surroundings. The trachyte is light green in color, fresh to slightly weathered and massive to widely joint. It could be one of the potential sources of paving stone and masonry stone.

Table 4.4: simplified Geology and Geomorphology (visual observation)

| Location | Route Geology and Geomorphology |
|---|---|
| 0.0-20 | Hill forming fresh to moderately weathered Alkaline Basalt, Ignimbrites, unwilled tuffs, ash flows, trachytes from Nazareth series Plateau Basalt |
| 20-50 | Hill forming fresh to moderately weathered Alkaline Basalt, Ignimbrites, un welded tuffs, ash flows, trachytes from Nazareth series. Plateau Basalt, Alluvial and Lucustrine deposit near Modjo |

Figure-4.2 Addis Ababa – Modjo Geological Map

### 4.1.6. Construction history of the Addis Ababa-Modjo road

The old Addis Ababa-Modjo road had been in use for decades. It was reinforced with a Telford during Italian Occupation and latter in 1962 surfaced with double surface treatment. In 1976 and 1981 the road was strengthened with first and second overlay using Asphalt.

A detailed assessment of the condition of pavement was conducted 1995 and maintenance measures were proposed [40]. The initial plan was to undertake maintenance and 40mm overlay, however, after award of the contract based on further pavement evaluation, the planned rehabilitation was changed and constructed as;

- The previous Asphalt Surface was milled, Reshaped, Compacted & used as Sub base layer

- 200mm crushed stone base was laid on top of the milled sub base
- 10cm Asphalt Concrete (in two separate layers, i.e.40mm Wearing and 60mm Binder Course) were applied on top of the Base Course.

The pavement was designed with pavement loading of $1.86 \times 10^7$ ESAL's for 15 years estimated pavement life.

Table 4.5: Summary of pavement materials requirements of the project (Source: Construction Specification by DHV and ACE 2000) [40]

| Layer | Project Material Specification | | | | | | | Project Field Density Requirements |
|---|---|---|---|---|---|---|---|---|
| | Grading by weight Passing % | | | | LA | WI | PI | |
| Subgrade | | | | | | | | ≥95% |
| Subbase | Sieve (mm) | A | B | C | ≤50 | ≤25 | ≤6 | ≥95% |
| | 75 | 100 | - | - | | | | |
| | 38 | 75.85 | 100 | - | | | | |
| | 25 | - | - | 100 | | | | |
| | 4.75 | 45-65 | 30-70 | 40-80 | | | | |
| | 0.8 | 15-40 | - | - | | | | |
| | 0.075 | 0-10 | 0-15 | 5-20 | | | | |
| Base | 75 | 100 | - | - | ≤50 | ≤25 | ≤6 | ≥98% |
| | 63 | - | 100 | - | | | | |
| | 50 | 70- | 80- | 100 | | | | |
| | 38 | 60-80 | 68-88 | 80-100 | | | | |
| | 25 | 50-70 | 53-73 | 60-80 | | | | |
| | 19 | 40-60 | 35-55 | 50-70 | | | | |
| | 9.5 | 25-45 | 29-49 | 30-50 | | | | |
| | 4.75 | 15-35 | 17-37 | 20-45 | | | | |
| | 2.07 | 5-25 | 8-28 | 5-30 | | | | |
| | 0.45 | 0-15 | 0-18 | 5-20 | | | | |
| | 0.075 | 0-10 | 0-13 | 0-10 | | | | |
| | Min CBR Subbase 30%, Base 80% | | | | | | | |

Table 4.6: Summary of Asphalt Wearing & Binder Course requirement (Source: Construction Specification by DHV and ACE, 2000)[40].

| **Layer** | **Asphalt Components** | | | | **Asphalt mixture** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Bitumen** | | **Aggregate Grading (%Pass)** | | **Marshal Stability (kN)** | **Flow (mm)** | **Voids** | **V.F.B** | **I.R.S** |
| Wearing | Type | 80/100 | 37.5 | 100 | Min 6 Max 13 | 02-05 | 03-05 | Max 80 | Min 75 |
| | | | 25 | 90-100 | | | | | |
| | | | 12.5 | 56-80 | | | | | |
| | | | 4.75 | 29-59 | | | | | |
| | Content | 3.5-7 | 2.36 | 19-45 | | | | | |
| | | | 0.3 | 5-17 | | | | | |
| | | | 0.075 | 1-7 | | | | | |
| Binder Course | Type | 80/100 | 37.5 | 100 | Min 7- Max 13 | 02-05 | 03-08 | Max 80 | Min 75 |
| | | | 25 | 90-100 | | | | | |
| | | | 12.5 | 56-80 | | | | | |
| | | | 4.75 | 29-59 | | | | | |
| | Content | 3.5-7 | 2.36 | 19-45 | | | | | |
| | | | 0.3 | 5-17 | | | | | |
| | | | 0.075 | 01-7 | | | | | |

Where VFB= voids filled with bitumen

IR.S= lndex of retained strength

Max bitumen variation was +0.3%

The materials used for the pavement construction includes (Source: Monthly Progress Report by DHV and ACE)

a) Cinder as Sub base meeting the project specification requirement
b) Crushed Stone Base Meeting the Project specification
c) The Asphalt & the Aggregate used for Asphalt Concrete were also satisfies the requirement of the Project Specification.

### 4.1.7. Comparison of Project Materials Specification against ERA's(2002)

The quality of materials required at different layers of pavement is specified in different specification based on the traffic, climate and nature of materials. Most projects including ERA's Specification specify maximum PI of six percent and minimum CBR 80% for base while PI between 6% and 12% and minimum CBR 30% for subbase. The quality of subgrade required specified by different specification varies however, most of the specifications specifies CBR greater than 3% percent and PI less than 30%.

**Subgrade Layer:** The project specification and ERA's specification requires the field density to be 95% of MDD. The ERA specification requires the Maximum PI to be 30%. However, no requirement is set in the project specification. This might be due to the project construction has started by milling the previous layer and it had been difficult to set requirement for already existing layer.

**Sub Base Layer:** The project specification and ERA's specification requires the field density to be 95% of MDD. The ERA specification requires the Maximum PI to be between 6-12%. However, the project requirement is maximum 6% that is the lowest boundary of ERA's specification requirement for PI.

**Base Layer:** The project specification and ERA's specification requires 80% CBR at 98%of MDD & field density of 98%of MDD and the PI to be maximum 6%.

**AC Surface Layer:** The stability required by project specification is minimum 7 and maximum 13 whereas; the Stability required by ERA's specification is minimum 9kN. However, the stability achieved during construction has reached up to 18kN, which has exceeded the minimum requirement at higher range. [40]

## 4.2. Visual Pavement condition survey

The Pavement condition evaluation has been done from July to August 2012. The main objectives of the condition survey was to evaluate and record the type of pavement distress and formulate the causes of the distresses by relating with previous researches made on distress type and causes.

The entire road was visually surveyed; the type of failures and extent was recorded. The road is divided in to three homogeneous sections based on the degree of distresses i.e minor distressed sections, Intermediate distress sections and severely distressed sections as presented in Table 4.7. Finally the possible causes of the distress are determined after evaluation of type of distress and its extent.

The following pavement failures were noted and recorded,

- Cracks/Crazing
- Ruts/Deformation
- Raveling
- Potholes/Patches

Table 4.7 Uniform sections

| Road Section | Chainage | | Remark |
|---|---|---|---|
| | From | To | |
| Uniform Section 1 | 22+000 | 32+000 | Minor distresses [Severity–level-1) |
| Uniform Section 2 | 13+000 | 17+000 | Intermediate Distress (Severity- level 2) |
| Uniform Section 3 | 0+000<br>17+000-<br>28+000- | 13+000<br>22+000<br>50+000 | Severely Distressed areas ( Severity –level-3) |

The visual survey of predominant soil type that the road is built show that Black Cotton soil prevails in most part of the road. The residue of decomposed Basalts and Trachyte gives Expansive clay (Montmorillonite clay). Table 4.8 presents the predominant soil type.

Table 4.8 Sub grade type

| Insitu Subgrade material | Chainage | |
|---|---|---|
| Black Cotton Soil | 0+000<br>32+000 | 28+000<br>48+500 |
| Bed Rock | 28+000 | 32+000 |
| Silty Clay | 48+500 | 49+500 |

The distresses type noted, extent and severity are presented in Appendix-I. The severity levels of distresses are identified as sited in, [17] :-

Severity 1. - Rut depth <2cm
- Cracks –Hair Line cracks
- Pothole Diameter <30cm

Severity 2. - Rut Depth between 2 and 4 cm
- Cracks open or branching cracks, crazing
- Pothole Diameter less than 100 cm

Severity 3. - Rut Depth between above 4 cm
- Cracks open or branching cracks, crazing edges damaged
- Pothole Diameter above 100 cm

The condition survey was conducted at every 1km interval for failure types of Rutting, Longitudinal cracking, transverse cracking, crazing, potholes, patching and repairing, stripping, raveling. The extent and severity of failure were summarized as shown in the following Figures and Tables. The variations of extent of different failure types in respect with the stations of the project road are plotted using charts.

The extent of rutting failure varies along the stations of the project road as shown in Figure 4.3 below. From station 21km to station 28km, rutting were not observed. In most of the stations from 29km to the end of the project road, the severity of rutting is more than 60%. The severity of the rutting at 32-33km, 45-46km and 47-48km is observed about 30%. The stations from 0-21km experience mostly a rutting severity of above 60%. In some stations of this section, severity varies from 10%-30% as shown in Figure 4.3 below.

Similarly the maximum rut depth was observed ranging from 2-6cm in most of the project road. The maximum rut depths from station 48-50km were observed about 10cm as shown in Figure 4-4 below.

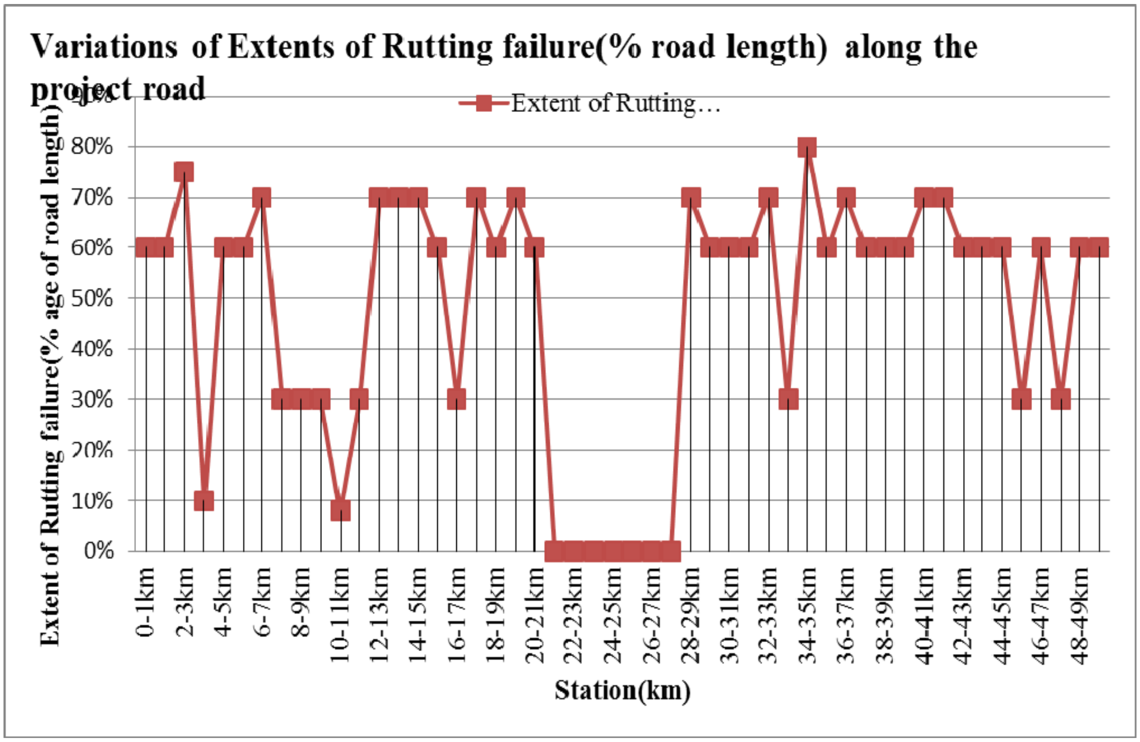


Figure 4-3. Variations of extents of rutting failure(% road length) along the project Road.

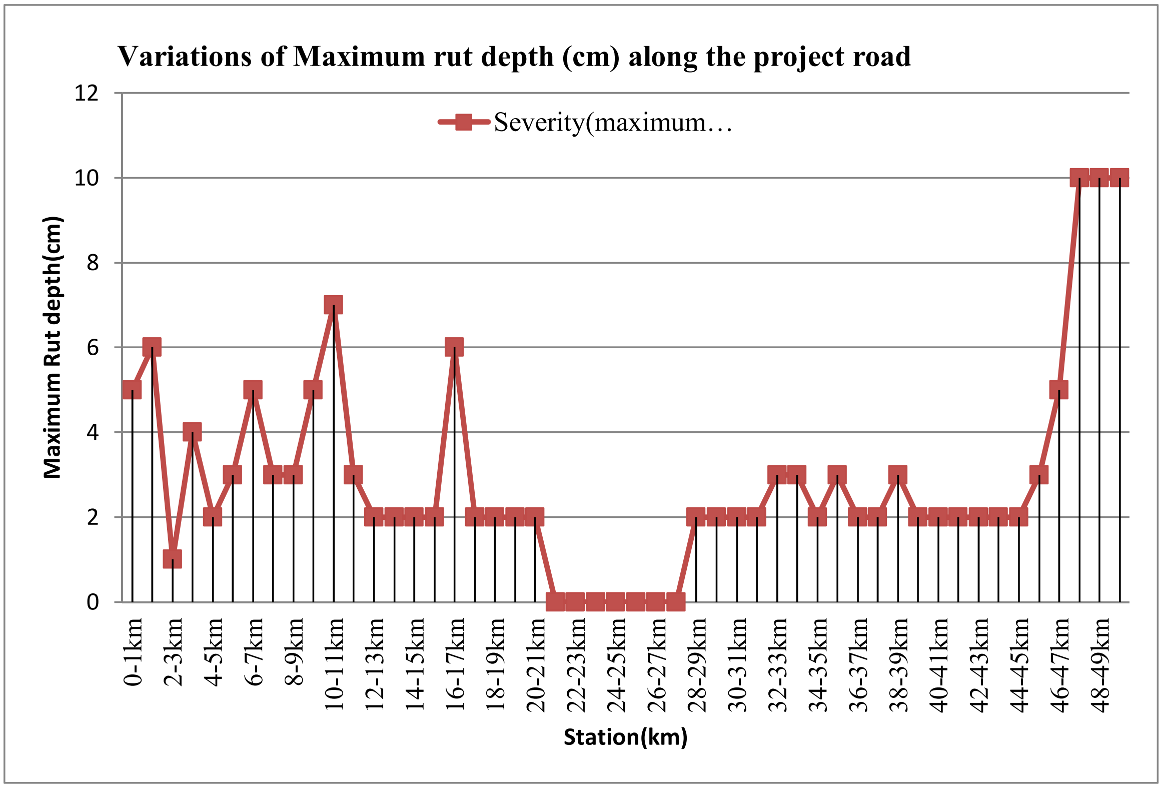


Figure 4-4: Variations of maximum Rut depth (cm) along the project road

Extent of crazing failure varies along the project road as shown Figure 4-5 below. In most of the stations from 29km to the end of the project, the extents of crazing failure were observed more than 60%. In the rest of the project section, the extent varies from 0-70% as shown in Figure 4-5.

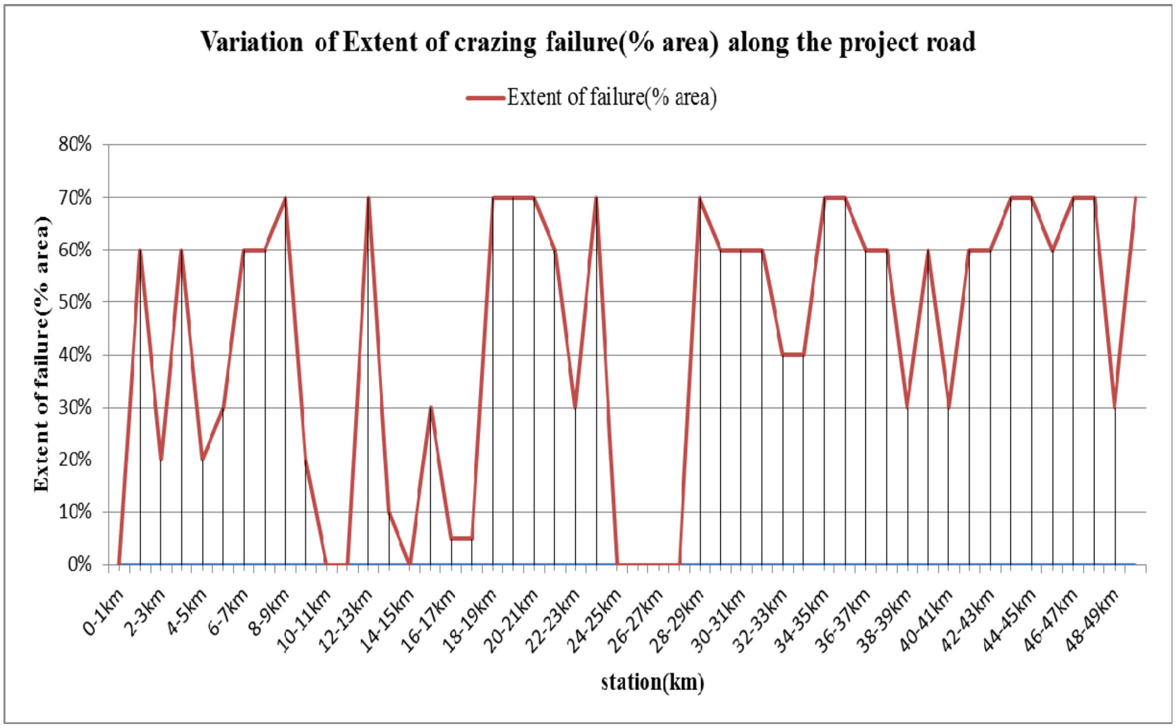


Figure 4-5: Variations of extent of crazing failure (% area) along the project road.

Similarly, the severity of crazing failure ranges from 0 to 70 cm cracking mesh width as presented in figure 4-6 below. In sections from 4-10km, the severity of crazing failure is higher mostly about 70cm. in addition most of the sections 38 to the end of the road project experiences a severity of more 60cm. The sections from 10-38km have faced relatively lower severity level ranging from 0-30%.

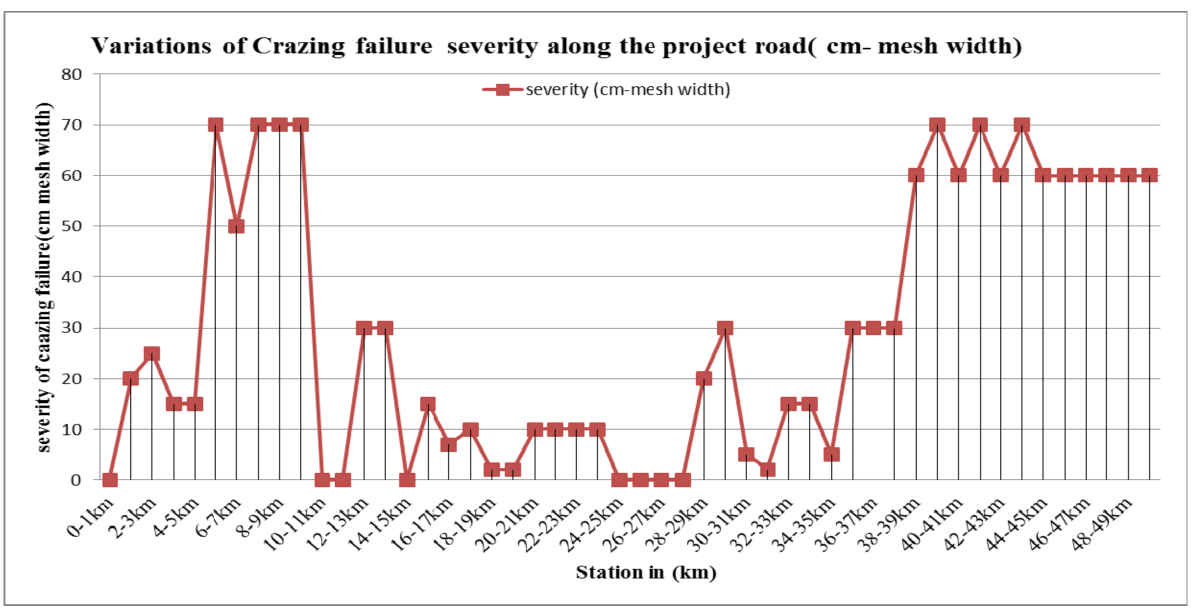


Figure 4-6: Variations of crazing failure severity along the project road (cm-mesh width)

Longitudinal cracking were observed along the project road as shown in Table 4-9 below. The extent of severity in those sections were mostly 10% relatively lower than stations 13-14km& 36-37km which is of 70% and 50%, respectively. However, the severity of cracking between 13-14 km is 2mm which is lower than other locations. The maximum severity level observed at stations 0-1km and 14-15km which were 20mm and 15mm respectively as shown in the Table.

**Table 4-9: Extent and severity of Longitudinal Cracking failure**

| Extent and severity of Longitudinal cracking failure | | |
|---|---|---|
| Station(km) | Extent of failure(% length ) | Severity(mm width of crack) |
| 0-1km | 10% | 20mm |
| 2-3km | 10% | 8mm |
| 10-11km | 10% | 8mm |
| 11-12km | 10% | 7mm |
| 13-14km | 70% | 2mm |
| 14-15km | 10% | 15mm |
| 15-16km | 10% | 5mm |
| 36-37km | 50% | 8mm |

Patching and repair were observed in the project road. Variation of extent of patching and repairing (% age area covered) were summarized as shown in Figure 4-7 below. The extent of patching and repairing failure were ranging from 0 to 30% in most of the stations of the project road. In stations from 15-35km the extent of patching and repairing failure is 0% except at 25-26km which is more than 60%.

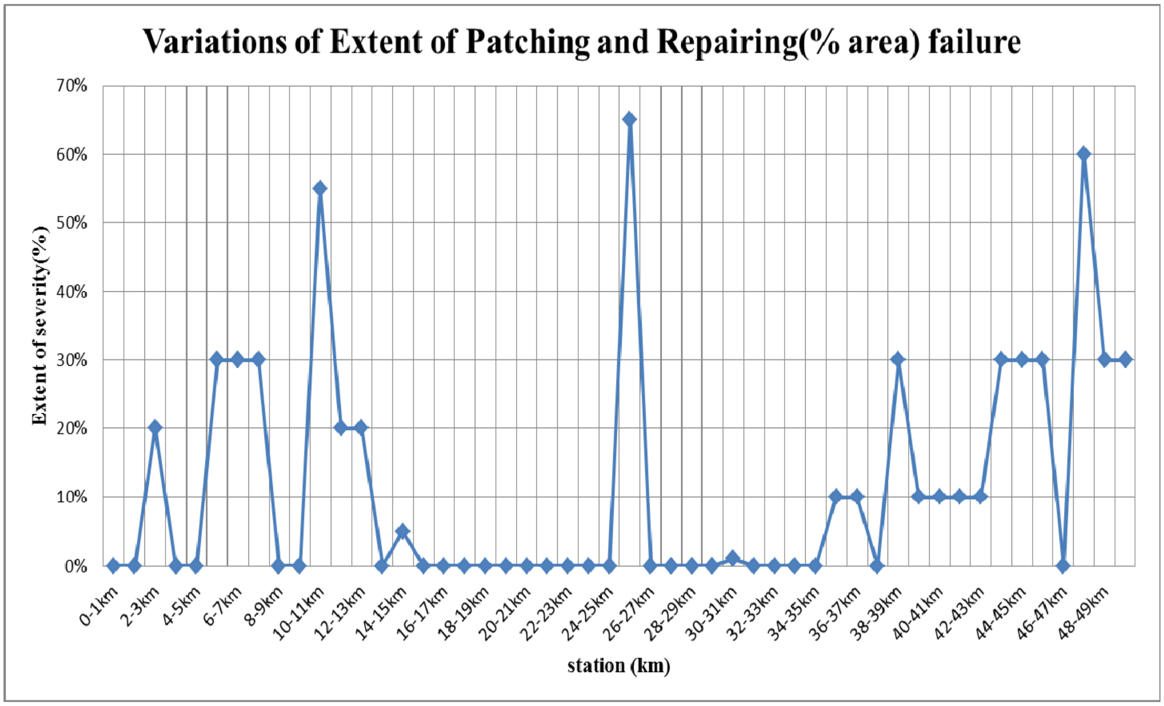


Figure 4-8: Variations of extent of patching and repairing (% area) failure along the project road.

Stripping and raveling were observed along the project road and the variations of failure along the project road were presented as shown in Figure 4-9 below. In most of the project road the extent of stripping and raveling was more than 60%. The station from 18-33km have faced relatively lower stripping and raveling failure as shown in Figure 4-9.

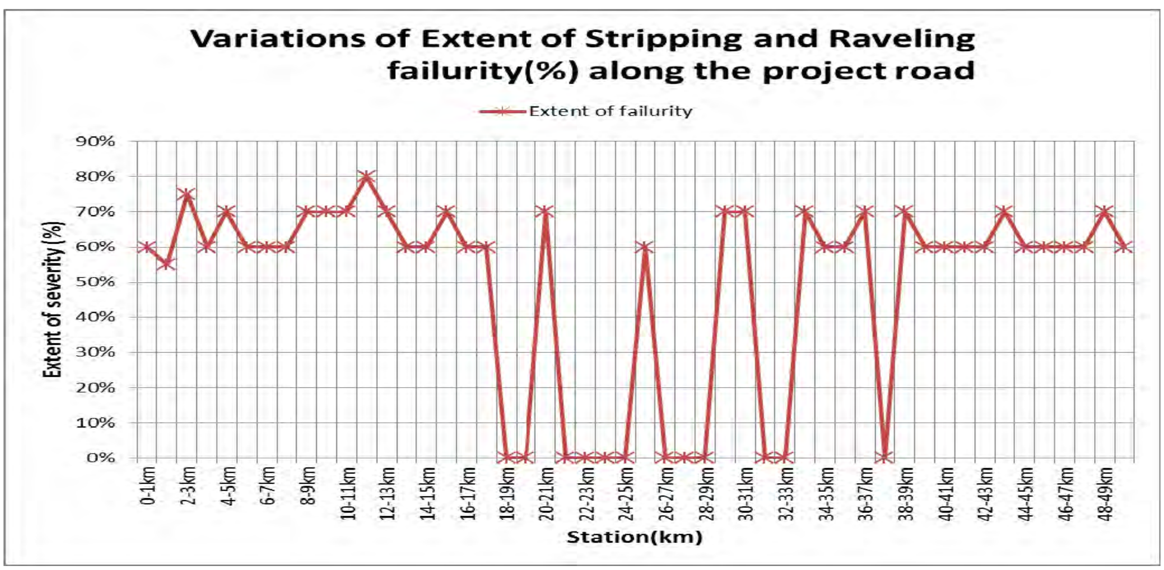


Figure 4-9: Variations of extent of stripping and raveling along the Project Road

The different types of pavement failure along the project road were observed as in the following photos.

The following photos show the pavement conditions recorded during visual condition survey

a) Dry and Brittle Surface

b) Ruts associated with cracks

c) Rut at outer wheel path

d) Side Drain Problem

e) Potholes

f) Repaired Section

g) Raveling h) Crazing

Photo 4.1: Pavement Distresses Photo (Photo along Addis Ababa-Modjo Road) August/September 2012)

### 4.3. Pavement Deflection Tests

In order to investigate structural conditions and complement the research (to mainly investigate the structural failure of the pavement), deflection test using Benkelman Beam has been performed.

Figure 4-10: Benkelman Beam Deflection Measurement

The magnitude of the rebound pavement deflection is recorded using Benkelman Beam at interval of 100 meter throughout each road sections using a truck loaded with 10 tone & load equally distributed on the two dual wheel of the rear axle. The twice recorded pavement rebound deflections are used to determine a Representative Rebound Deformation for the design. The Representative Rebound Deflection is the mean of the rebound deflection which have been corrected/ adjustment for reference to 21 $^{0}$C and critical period / season adjustment factor. The mean pavement temperature (which is an average of the temperature at the surface, mid-depth, and bottom of the asphalt-bound portion of the pavement) is used to find a temperature adjustment factor, required for adjusting pavement deflection values to the standard temperature of $21^0$C.

In light of this the maximum and minimum air temperature needed for each of the five days before the date of deflection test at each section is collected from National Meteorological Agency. The average of maximum and minimum air temperature for five days preceding the test date and the pavement surface temperature added up to find the adjusted surface temperature. This adjusted surface temperature with the thickness of the Asphalt pavement & mid depth entered in to predict pavement temperature graph and the temperature at mid depth and bottom of the asphalt pavement estimated. Finally the sum of surface temperature, mid depth temperature & temperature at bottom of Asphalt pavement estimated and the average of the three readings computed.

Based on the results of deflection, the road section is divided in to three homogenous sections where the representative rebound is less than 60, between 60 & 80 and greater than 80. Table 4.10 presents summary of the representative rebound deflection (RRD) value.

Table 4.10: Road Sections & its RR deflection Range

| RR Range | Sections |
|---|---|
| < 60 | 22+000-28+000, |
| 60-80 | 13+000-17+000 |
| >80 | 0+000-13+000, 17+000+22+000, 28+000-50+000 |

The RRD measured in September 2012 exceeds the previous existing data collected by Metaferial/Omega Consulting Engineers in 2008 as shown in Figure 4.11. This shows that the pavement structure has deteriorated more than anticipated with in the project life (i.e terminating deflection **20mm**).

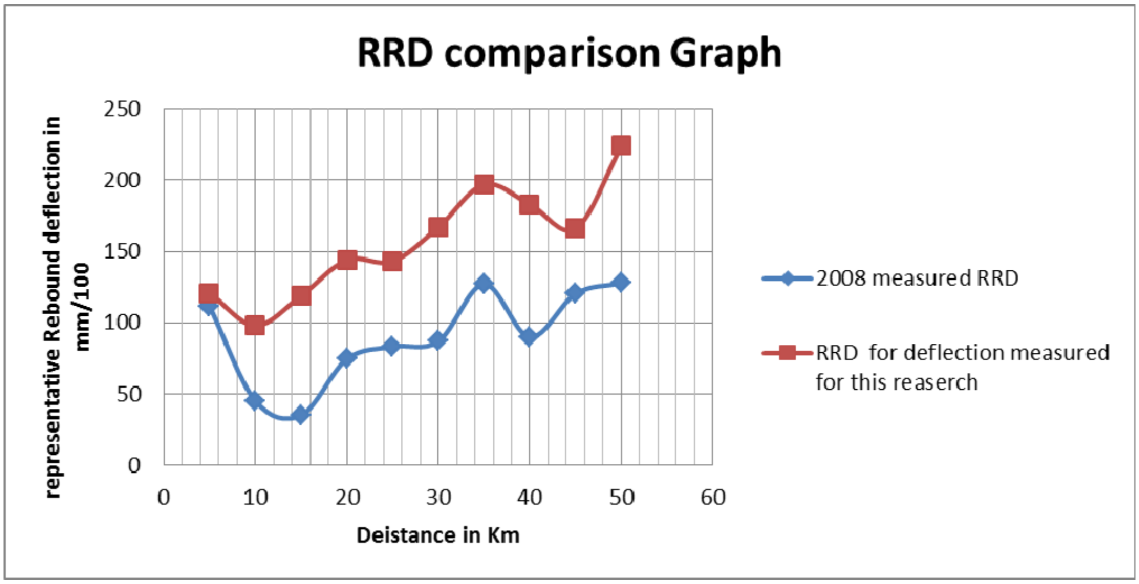


Fig. 4.11 Rebound deflection (RRD) graph

### 4.4. Experimental Evaluation

#### 4.4.1. Test Pit excavation and Pavement Thickness

Three test pits were dug at each uniform section at points that represent the uniform section. A total of nine test pits were excavated and from each layer of pavement 80 kg to 100 kg samples were collected for laboratory tests. Test pit were dug to depth of insitu or native materials, i.e up to 1m at most places as shown in Figure 4.12 below.

a)

b)

Figure 4.12: Existing pavement structure (Test pit on the Pavement) August/Sept 2012)

In most of the test pits layer, the thicknesses of asphalt concrete surfacing, base course and sub base layers full filled the designed thicknesses as shown in Table 4-11 below. The material property for base course is crushed aggregate in all the test pits. The property of sub base is milled asphalt, scoria and scoria mixed with milled asphalt. Capping layer materials used are scoria, black clay soil as presented in the Table below.

Table 4.11. Pavement layer thickness and materials description

| Chainage Km | Asphalt Concrete surfacing | Base | Sub Base | | Capping | |
|---|---|---|---|---|---|---|
| | Thickness (cm) | Thickness (cm) | Thickness (cm) | Material Description | Thickness (cm) | Material Description |
| 0 | 10 | 20 | 18 | Scoria | 30 | Scoria |
| 13 | 11 | 21 | 20 | Milled Asphalt | 30 | Scoria |
| 15 | 12 | 18 | 20 | Mixed with scoria | 30 | Scoria |
| 16 | 10 | 20 | 20 | Mixed with scoria | 30 | Scoria |
| 22 | 12 | 20 | | | Insitu material | |
| 28 | 9 | 20 | 20 | Milled Asphalt | Insitu material | Black clay soil |
| 31 | 10 | 20 | 20 | Milled Asphalt | Insitu material | Black clay soil |
| 43 | 10.5 | 20 | 20 | Milled Asphalt | Insitu material | Black clay soil |
| 48.5 | 10 | 20 | 20 | Milled Asphalt | Insitu material | Yellow Silty clay soil |

### 4.4.2. Insitu Density Survey

An in-situ density measurement has been carried out inside selected test pits where samples have been recovered for CBR tests. It was conducted by the sand replacement method in accordance with AASHTO T- 191 (1993). Such in – situ tests were performed on sub grade, sub base and Base layers, where the material thickness is 100 mm or more and without oversized stone or gravel.

The subgrade density was conducted with in depths of about 52cm to 90 cm below the road surface depending on the thickness of base, Subbase and granular capping layer. In each location the surface of the material layer to be tested was trimmed and smoothed to form a suitable seat for the measuring apparatus. Then, a hole was excavated through the guide of the base plate. The material from the hole to a depth of 52cm – 90cm was carefully collected in a polyethylene bag, and then weighed tightly sealed, and labeled for subsequent natural moisture content determination. Dry free – flowing sand of known density was then poured into the hole from the sanded sand cone. From the weight of sand required to fill the excavated space the volume of hole was determined.

The bulk density was computed upon completion of each test. The field dry densities were later computed based on the results of natural moisture content determined in the laboratory. Generally, the average field density computed for Base is 98%, for sub bases level regulating layer is 94% & capping layer is, 93%. The summary of the insitu Density were presented in Table 4.12 below.

**Table 4.12: Summary of Insitu Density**

| **Chainage** | **Insitu density(FDD)( gm/cm3)** | | |
|---|---|---|---|
| | **Base layer** | **Subbase Layer** | **Subgrade Layer** |
| 0+000 | 2.14 | 1.9 | 1.85 |
| 13+000 | 2.14 | 1.95 | |
| 15+000 | 2.13 | 1.82 | 1.43 |
| 16+000 | 2.23 | 1.86 | 1.46 |
| 22+000 | 2.35 | 2.15 | 1.45 |
| 28+000 | | 2.09 | |
| 31+000 | 2.06 | 2.10 | 1.55 |
| 43+000 | 2 | 2.01 | 1.37 |
| 48+500 | | 1.87 | |

### 4.4.3. Laboratory Tests

Enough representative samples were collected from each test pit and each layer of Pavement. Samples were collected, labeled and transported to the laboratory for tests. A total of twenty seven samples, nine samples from each layer (i.e nine from base layer, nine from subbase layer and nine from subgrade layer) were collected to determine the material characteristics of the base, sub base, capping layer and subgrade. The samples were collected from the edge of carriage way. The tests were conducted according to AASHTO Material Testing Manual and the lab results are attached in Appendix II.

**Base Material**: - the existing pavement is made up of crushed stone base (basalt) with average thickness of 200mm. A total of nine samples were collected from the test pits for test. Sieve analysis, Atterberg limits, gradation, 3-point CBR, ACV, TFV, specific gravity, water absorption and in situ density tests were performed, the test result summary is presented in Table 4.13.

Table 4.13: Summary of base material test results

| Chainage (km) | ACV (%) | TFV (kN) | PI (%) | CBR at 98 % of MDD | Specific gravity | MDD (gm/cm3) | OMC (%) | NMC (%) | FDD (gm/cm 3) | Insitu CBR (%) | Relative Density (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 11.3 | 242 | 8 | 89 | 2.8 | 2.18 | 7.8 | 4.3 | 2.14 | 85 | 97.3 |
| 13 | 19.9 | 230 | 9 | 82 | 2.6 | 2.13 | 7.4 | 5.4 | 2.14 | 89 | 100 |
| 15 | 16.5 | 265 | 8 | 95 | 2.6 | 2.21 | 6.9 | 5.1 | 2.13 | 93 | 97 |
| 16 | 21 | | 11 | 93 | 2.6 | 2.25 | 7.2 | 5.2 | 2.23 | 95 | 99 |
| 22 | 13.7 | | 8 | 89 | | 2.2 | 7.4 | 6 | 2.35 | 95 | 106 |
| 28 | 21 | | 9 | 87 | | 2.16 | 7.8 | | | | |
| 31 | | | 9 | 84 | 2.6 | 2.1 | 8.2 | 3.6 | 2.06 | 83.5 | 98 |
| 43 | | | 10 | 83 | | 2.05 | 8.1 | 5.2 | 2 | 80 | 97 |
| 48.5 | 16 | | 10 | 84 | | 2.12 | 8.9 | | | | |

The ACV values of base course material ranges from 11.3% to 21% which is within the specification. Ten percent fine values (TFV) KN are above 230KN which is more than 110KN which is the standard values. The Plasticity index (%) of base course varies from 8-11% which is more than the specified <6%. CBR values of the base course material at 98%

of MDD ranges from 82-95% which is above 80%. The specific gravity ranges from 2.6-2.8. The insitu CBR of base course varies from 80-95%.

The gradation of base course material lays with in a specification for all of the test pits as shown in Figure 4.13 and Table 4.14.

Table 4.14 Base materials sieve analysis result

| Sieve Size mm | Percent Pass | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test pit1 | Test Pit-2 | Test Pit-3 | Test Pit-4 | Test Pit-5 | Test Pit-6 | Test Pit-7 | Test Pit-8 | Test Pit-9 |
| 37.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 20 | 75 | 65 | 79 | 77 | 68 | 77 | 65 | 72 | 74 |
| 10 | 53 | 50 | 59 | 48 | 56 | 59 | 44 | 57 | 53 |
| 5 | 37 | 32 | 38 | 28 | 36 | 38 | 26 | 38 | 40 |
| 2.36 | 28 | 25 | 23 | 18 | 28 | 26 | 19 | 22 | 18 |
| 0.425 | 14 | 12 | 18 | 8 | 16 | 14 | 11 | 12 | 17 |
| 0.075 | 9 | 6 | 13 | 4 | 7 | 9 | 8 | 7 | 8 |

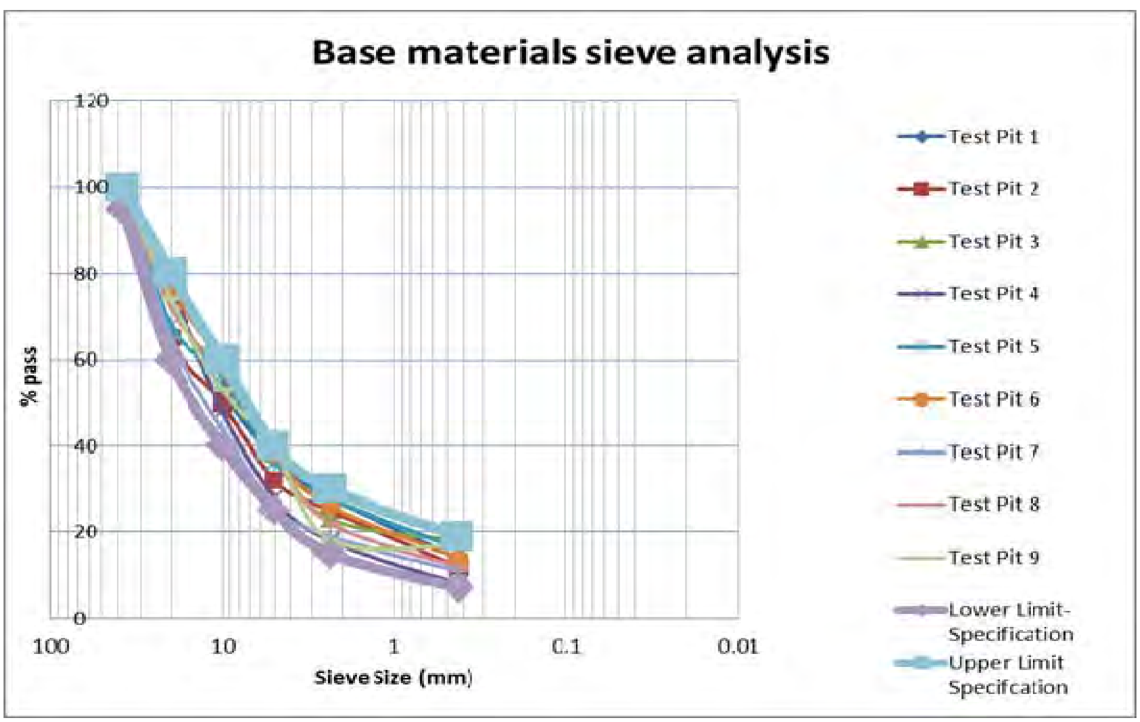

**Figure 4.13. Base course material gradation analysis**

**Sub Base Material**:-The materials with in sub base horizon consist of a regulating layer made up of cinder and milled asphalt with cinder or milled asphalt only. A total of nine samples were sampled and tested. Grading, Atterberg limit, 3-point CBR and field density tests were performed. Test result summary is presented in Table 4.15.

Table 4.15: Summary of sub base materials test results

| **Chainage** | **Material Description** | **PI (%)** | **CBR at 95 % of MDD** | **MDD (gm/cm3)** | **OMC (%)** | **NMC (%)** | **Insitu density FDD (gm/Cm3)** | **Initu CBR (%)** | **Relative Density (%)** |
|---|---|---|---|---|---|---|---|---|---|
| 0+000 | Cinder | NP | 64 | 2.148 | 10.2 | 3.7 | 1.898 | 33 | 88 |
| 13+000 | Cinder | 13 | 25 | 1.996 | 9.5 | 8.3 | 1.952 | 22 | 98 |
| 15+000 | Cinder | NP | 67 | 2.11 | 8.9 | 5.2 | 1.821 | 34 | 86 |
| 16+000 | Milled | 16 | 69 | 1.961 | 9.1 | 5.8 | 1.861 | 42 | 94 |
| 22+000 | Milled | 18 | 53 | 2.168 | 9.4 | 6 | 2.145 | 43 | 88 |
| 28+000 | Milled | 13 | 50 | 2.114 | 9.5 | 6.4 | 2.089 | 43 | 93 |
| 31+000 | Milled | 12 | 61 | 2.168 | 9.4 | 6 | 2.102 | 48 | 89 |
| 43+000 | Milled | 11 | 45 | 2.108 | 9.4 | 7.2 | 2.013 | 38 | 93 |
| 48+500 | Cinder | 8 | 54 | 2.019 | 8.4 | 6.7 | 1.867 | 18 | 92 |

The plasticity index of sub base ranges from non-plastic (NP) to 18 %. Most Cinder material shows lower plasticity index as compared with milled materials. The CBR values at 95% of MDD for sub base ranges from 25-69%. The lowest CBR at 95% of MDD obtained at station 13+000 of 25% which is below the standard 30%. Other CBR values are greater than 45% which satisfies the specification. The insitu CBR (%) ranges from 18-48%. Only at two stations of 13+000 and 48+500, the insitu CBR values lay below the specified 30%. This may have a contribution in rutting of pavements at those stations.

The gradation of sub base materials for all test pits lays with in the specification in all sieve size as shown in Figure 4.14 and Table 4.16.

Table 4.16 Sub-Base materials sieve analysis result

| Sieve Size | Percent Pass(%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Pit-1 | Test Pit-2 | Test Pit-3 | Test Pit-4 | Test Pit-5 | Test Pit-6 | Test Pit-7 | Test Pit-8 | Test Pit-9 |
| 50 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 37.5 | 90 | 89 | 83 | 86 | 82 | 96 | 95 | 92 | 81 |
| 20 | 75 | 81 | 74 | 77 | 67 | 78 | 84 | 86 | 72 |
| 5 | 45 | 56 | 57 | 65 | 53 | 52 | 74 | 72 | 61 |
| 1.18 | 35 | 42 | 45 | 51 | 38 | 39 | 47 | 52 | 50 |
| 0.3 | 28 | 31 | 36 | 37 | 28 | 26 | 32 | 39 | 38 |
| 0.07 | 7 | 9 | 6 | 10 | 12 | 8 | 9 | 7 | 6 |

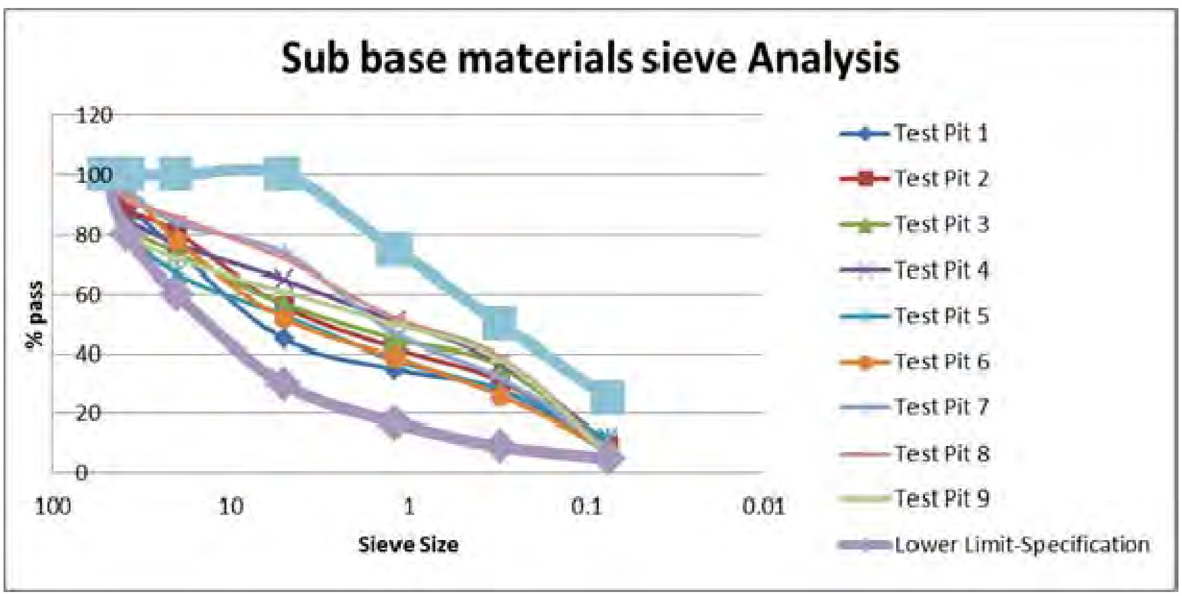


**Figure 4.14. Gradation of subbase materials**

**Capping layer and insitu subgrade material:**-The material with in sub grade horizon consists of a cinder capping layer (in most sections) and insitu subgrade (Predominantly black cotton). A total of nine samples were sampled and tested. Grading, Atterberg limit, 3-point CBR, shrinkage, classification, Swell and field density test were performed. Test result summary presented in Table 4.17.

**Table 4.17: Summary of sub grade test result**

| Chainage (km) | LL (%) | PI (%) | CBR at 95 % of MDD | CBR Swell | Linear Shrinkage (%) | MDD (gm/cm3) | OMC (%) | NMC (%) | FDD (gm/cm3) | Insitu CBR (%) | Relative density (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 18 | 3 | 42 | 0.1 | 2 | 1.995 | 8.2 | 7.2 | 1.854 | 18 | 93 |
| 13 | 80 | 34 | 2 | 10.8 | 16 | 1.416 | 21.2 | 6.9 | | | |
| 15 | 72 | 35 | 2.5 | 10.3 | 17 | 1.676 | 22.8 | | 1.43 | 2 | 85 |
| 16 | 64 | 35 | 1.5 | 5.1 | 15 | 1.495 | 21.5 | 7.9 | 1.46 | | 98 |
| 22 | 69 | 38 | 1.5 | 6.87 | 17 | 1.65 | 20.3 | 12 | 1.45 | | 89 |
| 28 | 67 | 37 | 2.6 | 5.1 | 14 | 1.529 | 19.9 | | | 2 | |
| 31 | 60 | 32 | 2.8 | 3.94 | 15 | 1.687 | 21.8 | 10.3 | 1.545 | 2 | 92 |
| 43 | 66 | 34 | 3.1 | 4.1 | 16 | 1.498 | 21.8 | 11.4 | 1.367 | 2 | 91 |
| 48.5 | 54 | 25 | 2.8 | 5.38 | 12 | 1.798 | 18 | | | | |

Note: material at station 0 km (capping/cinder) and at station 48.5km (yellowish silty clay) and the rest stations (Dark brown silty clay).

The results of the liquid limit (LL), plastic limit (PL) and plastic index (PI) for the subgrade soils are presented in tables 4.16 above. The liquid limits of capping layer and insitu subgrade are observed above 50% except at 0+000 station which is 18%. The plasticity index values of the subgrade lays above 30% except at station 0+000(3%) and station 48+500(18%). These results indicate that the samples contain more fine particles such as clay and they have more affinity for water and high compressibility. Most of Plasticity index values more than 30% are not within the acceptable requirements for soil sample that can be used as subgrade or fill during construction of highway.

Therefore, the rutting failures may be due to infiltration of water into the subgrade layer. Most subgrade CBR values at 95% MDD lays below 3%. This value shows that the samples are not suitable as subgrade because their CBR is less than 3%; High quality subgrade material at station 0+000 with CBR value of 42% is observed.

The gradation of subgrade materials for test pits is summarized as shown in Figure 4.15 and Table 4.18.

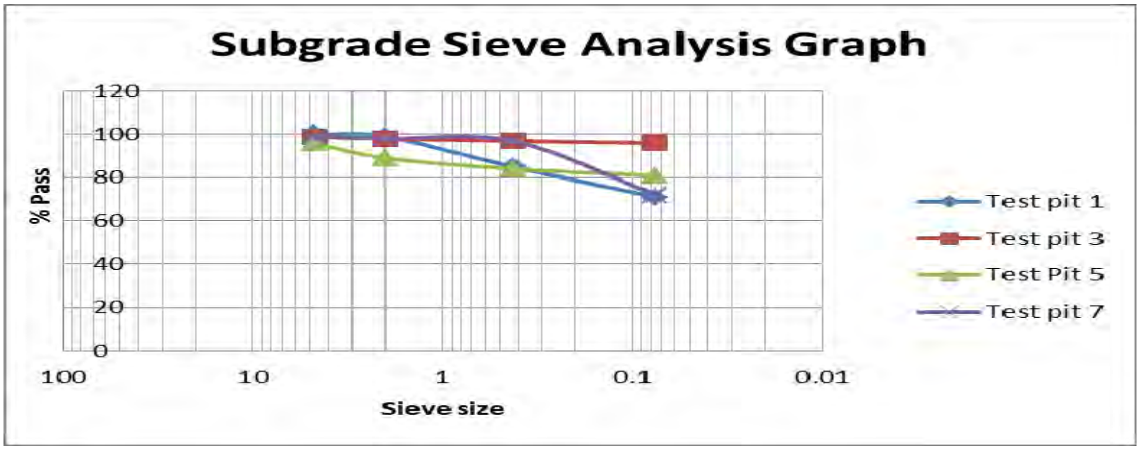


**Figure 4.15 Subgrade Sieve analyses**

Table 4.18. Sub-grade materials sieve analysis result

| Sieve Size | Percent Pass | | | |
|---|---|---|---|---|
| | Test Pit-2 | Test Pit-3 | Test Pit-5 | Test Pit-7 |
| 4.75 | 100 | 99 | 96 | 99 |
| 2 | 99 | 98 | 89 | 98 |
| .425 | 85 | 97 | 84 | 97 |
| 0.075 | 71 | 96 | 81 | 72 |

### 4.5. Traffic Analysis

#### 4.4.1. Traffic volume

Traffic analysis was made based on the data obtained from ERA Road asset management. Historical traffic counts were obtained at two sections which have different traffic volume. The road sections from Akaki-Debreziet have heavier traffic compared with the road section from Debreziet-Mojo as shown in Table 4.19 and Table 4.20. The historical traffic data were obtained from 1998-2013 for different traffic category as shown in Table 4.19.

Table 4.19 Akaki-Debrezeit 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 |
|---|---|---|---|---|---|---|---|---|---|
| 1998 | 593 | 727 | 426 | 430 | 542 | 474 | 463 | 574 | 4229 |
| 1999 | 721 | 1086 | 858 | 705 | 729 | 756 | 852 | 890 | 6597 |
| 2000 | 721 | 1096 | 958 | 905 | 749 | 756 | 945 | 945 | 7075 |
| 2001 | 792 | 1134 | 998 | 997 | 834 | 667 | 998 | 1025 | 7445 |
| 2002 | 979 | 1349 | 1024 | 1024 | 894 | 1067 | 1283 | 1068 | 8688 |
| 2003 | 1310 | 1733 | 1097 | 1089 | 956 | 1374 | 1339 | 1098 | 9996 |
| 2004 | 1418 | 1849 | 1122 | 1100 | 1024 | 1531 | 1413 | 1245 | 10702 |
| 2005 | 1512 | 1909 | 1338 | 1149 | 1081 | 1847 | 1665 | 1737 | 12238 |
| 2006 | 1738 | 2164 | 1592 | 1289 | 1367 | 1480 | 1744 | 1840 | 13214 |
| 2007 | 1964 | 2262 | 2159 | 1511 | 1456 | 2184 | 1844 | 1983 | 15363 |
| 2008 | 2007 | 2305 | 2268 | 1598 | 1987 | 2658 | 1971 | 2375 | 17169 |
| 2009 | 2118 | 2569 | 2287 | 1687 | 356 | 2876 | 1998 | 2426 | 16317 |
| 2010 | 2218 | 2862 | 2530 | 1769 | 394 | 2984 | 2135 | 2483 | 17375 |
| 2011 | 2256 | 3168 | 2781 | 1823 | 433 | 3126 | 2241 | 2545 | 18373 |
| 2012 | 2292 | 3453 | 3032 | 1893 | 472 | 3189 | 2287 | 2578 | 19196 |
| 2013 | 2433 | 3764 | 3305 | 1945 | 514 | 3290 | 2295 | 2612 | 20158 |

Table 4.20 Debreziet-Mojo 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 |
|---|---|---|---|---|---|---|---|---|---|
| 1998 | 420 | 640 | 523 | 253 | 355 | 358 | 413 | 465 | 3427 |
| 1999 | 368 | 673 | 550 | 343 | 392 | 598 | 546 | 713 | 4183 |
| 2000 | 544 | 712 | 659 | 481 | 671 | 723 | 707 | 771 | 5268 |
| 2001 | 440 | 863 | 731 | 574 | 701 | 729 | 787 | 781 | 5606 |
| 2002 | 519 | 1069 | 820 | 749 | 867 | 801 | 1101 | 892 | 6818 |
| 2003 | 590 | 1103 | 927 | 879 | 881 | 961 | 1270 | 981 | 7592 |
| 2004 | 629 | 1165 | 989 | 938 | 920 | 999 | 1307 | 996 | 7943 |
| 2005 | 762 | 1203 | 1059 | 989 | 933 | 1120 | 1381 | 1018 | 8465 |
| 2006 | 769 | 1218 | 1091 | 815 | 999 | 1162 | 1396 | 1055 | 8505 |
| 2007 | 793 | 1499 | 1187 | 1041 | 1160 | 1348 | 2039 | 1095 | 10162 |
| 2008 | 813 | 1718 | 1357 | 1401 | 1184 | 1391 | 2089 | 2149 | 12102 |
| 2009 | 913 | 1914 | 1501 | 1443 | 1204 | 1402 | 2134 | 2183 | 12694 |
| 2010 | 1025 | 2133 | 1660 | 1490 | 1226 | 1415 | 2189 | 2221 | 13359 |
| 2011 | 1142 | 2361 | 1825 | 1539 | 1248 | 1429 | 2196 | 2262 | 14002 |
| 2012 | 1245 | 2574 | 1990 | 1587 | 1270 | 1438 | 2209 | 2283 | 14596 |
| 2013 | 1357 | 2805 | 2169 | 1640 | 1295 | 1447 | 2289 | 2306 | 15308 |

### 4.5.2. Total Equivalent Axle Load

Total Equivalent axle load was determined for both traffic volume sections using Vehicle Damaging Factor (VDF) as shown in Table 4.20 and 4.21 below. The Total equivalent axle load from 2000 to 2013 year is calculated to **97,217,459.83** (Akaki-Debreziet section) and **76,827,713.03** **(Debreziet-Mojo section)**. The design traffic load is lower than the actual traffic for two traffic load sections. The total traffic load from Akaki-Debreziet section is higher than Debreziet-Mojo section.

Table 4.21 ESAL Table for Akaki-Debrezeit section

| VDF | 0.03 | 0.66 | 2.09 | 0.18 | 1.74 | 4.75 | 11.2 | |
|---|---|---|---|---|---|---|---|---|
| Year | L/Rover | S/Bus | L/Bus | S/Truck | H/Truck | M/Truck | TT | ESAL -one direction |
| 2000 | 32.9 | 632.3 | 1891.5 | 134.8 | 1644.3 | 3591.0 | 10584.0 | 3378208.2 |
| 2001 | 34.0 | 658.7 | 2083.7 | 150.1 | 1736.5 | 3168.3 | 11480.0 | 3524315.9 |
| 2002 | 40.5 | 675.8 | 2140.2 | 160.9 | 2232.4 | 5068.3 | 11961.6 | 4066038.0 |
| 2003 | 52.0 | 724.0 | 2276.0 | 172.1 | 2329.9 | 6526.5 | 12297.6 | 4448996.0 |
| 2004 | 55.5 | 740.5 | 2299.0 | 184.3 | 2458.6 | 7272.3 | 13944.0 | 4919137.9 |
| 2005 | 57.3 | 883.1 | 2401.4 | 194.6 | 2897.1 | 8773.3 | 19454.4 | 6325648.9 |
| 2006 | 64.9 | 1050.7 | 2694.0 | 246.1 | 3034.6 | 7030.0 | 20608.0 | 6337909.3 |
| 2007 | 67.9 | 1424.9 | 3158.0 | 262.1 | 3208.6 | 10374.0 | 22209.6 | 7428668.0 |
| 2008 | 69.2 | 1496.9 | 3339.8 | 357.7 | 3429.5 | 12625.5 | 26600.0 | 8745135.4 |
| 2009 | 77.1 | 1509.4 | 3525.8 | 64.1 | 3476.5 | 13661.0 | 27171.2 | 9031034.4 |
| 2010 | 85.9 | 1669.8 | 3697.2 | 70.9 | 3714.9 | 14174.0 | 27809.6 | 9348067.9 |
| 2011 | 95.0 | 1835.5 | 3810.1 | 77.9 | 3899.3 | 14848.5 | 28504.0 | 9685338.9 |
| 2012 | 103.6 | 2001.1 | 3956.4 | 85.0 | 3979.4 | 15147.8 | 28873.6 | 9881785.5 |
| 2013 | 112.9 | 2181.3 | 4065.1 | 92.5 | 3993.3 | 15627.5 | 29254.4 | 10097175.7 |
| **Total One Direction Loading** | | | | | | | | **97,217,459.83** |

Table 4.22 ESAL Table for Debrezeit-Mojo section

| VDF | 0.03 | 0.66 | 2.09 | 0.18 | 1.74 | 4.75 | 11.2 | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | L/Rover | S/Bus | L/Bus | S/Truck | M/Truck | H/Truck | TT | | ESAL -one direction |
| 2000 | 21.4 | 434.9 | 1005.3 | 120.8 | 1258.0 | 3358.3 | 8635.2 | 14833.8 | 2707175.8 |
| 2001 | 25.9 | 482.5 | 1199.7 | 126.2 | 1268.5 | 3738.3 | 8747.2 | 15588.1 | 2844828.3 |
| 2002 | 32.1 | 541.2 | 1565.4 | 156.1 | 1393.7 | 5229.8 | 9990.4 | 18908.6 | 3450825.0 |
| 2003 | 33.1 | 611.8 | 1837.1 | 158.6 | 1672.1 | 6032.5 | 10987.2 | 21332.4 | 3893170.3 |
| 2004 | 35.0 | 652.7 | 1960.4 | 165.6 | 1738.3 | 6208.3 | 11155.2 | 21915.4 | 3999564.2 |
| 2005 | 36.1 | 698.9 | 2067.0 | 167.9 | 1948.8 | 6559.8 | 11401.6 | 22880.1 | 4175623.7 |
| 2006 | 36.5 | 720.1 | 1703.4 | 179.8 | 2021.9 | 6631.0 | 11816.0 | 23108.7 | 4217328.6 |
| 2007 | 45.0 | 783.4 | 2175.7 | 208.8 | 2345.5 | 9685.3 | 12264.0 | 27507.7 | 5020146.1 |
| 2008 | 51.5 | 895.6 | 2928.1 | 213.1 | 2420.3 | 9922.8 | 24068.8 | 40500.3 | 7391297.5 |
| 2009 | 57.4 | 990.7 | 3015.9 | 216.7 | 2439.5 | 10136.5 | 24449.6 | 41306.3 | 7538390.6 |
| 2010 | 64.0 | 1095.6 | 3114.1 | 220.7 | 2462.1 | 10397.8 | 24875.2 | 42229.4 | 7706869.2 |
| 2011 | 70.8 | 1204.5 | 3216.5 | 224.6 | 2486.5 | 10431.0 | 25334.4 | 42968.3 | 7841722.1 |
| 2012 | 77.2 | 1313.4 | 3316.8 | 228.6 | 2502.1 | 10492.8 | 25569.6 | 43500.5 | 7938844.9 |
| 2013 | 84.2 | 1431.5 | 3427.6 | 233.1 | 2517.8 | 10872.8 | 25827.2 | 44394.1 | 8101926.9 |
| **Total One Direction Loading** | | | | | | | | | **76,827,713.03** |

# 5. Discussion of Results

## 5.1. Visual Road Condition Survey

Types of pavement distresses indicate the possible cause of the pavement failure. This has helped to relate the pavement distress noticed on the surface with possible causes and also to relates which distress are caused by the effect of geotechnical problems like subgrade materials. Different distresses are recorded during visual condition survey including: Rutting and deformation, potholes/patches, raveling, cracks/crazing, etc.

**Rutting Failure:**

The severity analysis indicates that about 22% of the road section shows severity 3 (i.e measured ruts are above 4cm) 62% of the rut depth fall in severity-2 (i.e the rut depth is between 2cm and 4cm), the remaining 14% of the rut depth are between 0 to 2cm depth. It is also noted that the rutting are associated with cracks and appeared on the left hand side of the road (on lane carrying traffic from Modjo side to Addis Ababa). The failure extent shows that about 49% of the road fall under severity-3, 30% of the road exhibit Severity 2 and 21% of the road falls under Severity -1. It can be concluded that about 49% of the road section severely affected by rutting. This failure type is mainly due to the low quality subgrade materials as and mostly due to excessive traffic loading above the design values.

**Pothole failure:**

20% of pothole failures show severity-2 and 80% shows severity 1. The extent of pavement failure with potholes indicates that 5% of the road shows Severity 2 and 95% of the road shows Sverity-1.

Minimum numbers of Potholes were observed due to already maintained roads.. However, the appearance of Potholes shows failure on base or subgrade due to poor drainage or due to structural deficient pavement as presented in deflection test. Moreover, the intrusion of water to the pavement through the cracking or ponding of water on the rutting of pavement may cause pothole creation.

**Cracking failure**

The severity of cracking failure shows that about 45% of the crack width fall under Severety-3 i.e (below 20cm), 35% fall in Severety-2 (20cm and 50 cm) and 20% fall in Severety-1 (above 50 cm width).

The extent of cracking failure shows that about 55% of the road fall under severity-3, 32% of the road exhibit Severity 2 and 13% of the road fall under Severity -1.

In Addis –Modjo road small number of transverse cracks has been exhibited. From Visual condition survey it had been observed that joints at repaired section are not filled properly. In addition the Asphalt surface is very dry and brittle. Therefore from visual condition survey the transverse cracks are caused by aging related shrinkage and unfilled joint related cracks on the repaired/patched section of the road.

In Addis Ababa-Modjo road the longitudinal cracks are associated with ruts hence it is a load induced crack. Some locations exhibit longitudinal cracks at right and left side of carriage way including shoulders. It is noted that the subgrade in this section is black cotton and located at shallow depth beneath the base and sub base. This shows that the swelling effect of the expansive soil has attributed to the longitudinal cracks.

Some sections of Addis Ababa-Modjo road exhibited Block cracking and shoulder uplifting. This is probably due to the effect of black cotton soil and shrinkage due to ageing. The section between 12+400-12+700 LHS has exhibited such cracks and uplifting of shoulder. The pavement thickness over the insitu subgrade varies between 0.6m to 0.8m as it is measures during trial pit excavation. This shows that no enough cover is provided to overcome the swell effect of the expansive soil.

The Addis-Modjo road exhibits cracks with severity varying from 1 to 3 most of the cracks are associated with rutting. The Whole road is exhibiting woven hair crack which will probably change to alligator crack with time. The main cause of this alligator cracks may be due to traffic over loading or weak subgrade.

### 5.2. Deflection Test

The Representative Rebound deflection value is greater than 80mm/100. The result also shows that deflection has increased when compared with the 2008 deflection result hence this RR measures shows there is structural problem (Support failure).

### 5.3. Field Density result

Field density result shows

- Subgrade layer 85 to 92 % some section
- Subbase layer 88% to 94% most section
- Base layer 97% and above

The density of the pavement layer is expected to increase due to secondary compaction by traffic. However, the field density result show that the subgrade and subbase layer density is below the requirement set in ERA's specifications. This may contribute pavement failure in rutting and deformation.

### 5.4. Pavement Layer Profiling

It has been recorded that 105mm, 200mm and 200mm average thickness for Asphalt concrete, Base and Subbase. The Asphalt surface thickness is not affected by traffic load and hence the failure noted on the surface of the AC layer may be related with weak subgrade.

### 5.5. Actual Traffic pavement Loading to-date and design loading.

The ESAL carried by the road since 2000 to 2013 is above 97.2 $X10^6$ ESAL for the section from Akaki-Debrezeit and $76.8*10^6$ for the section Debreziet-Mojo. The road was designed and constructed to carry $18.6x10^6$ ESAL's with a design period of 15 years until 2015.

This indicates that the current traffic exceeds the allowable traffic and hence the existing pavement has been carrying traffic load more than the design ESAL. This shows traffic load was not properly forecasted during design. The actual total equivalent axle load is more than four times the proposed design traffic load for the section Debreziet-Mojo and more than five times for Akaki-Debreziet section. This indicates rutting and cracking failures may be greatly attributed due to this higher traffic loading. Rutting and cracking failures are related with traffic overloading exponentially with the principles of the fourth power rule. That means if the axle load level doubles, the damage of the load with relative to the standard axle load would become more than sixteen times based on the fourth power rule.

In order to accommodate the traffic load from the opening date (2000 to 2013), the pavement thickness should have been designed to accommodate the correct traffic loading for safely distributing stress to the subgrade. The thickness of the existing road consists of Asphalt Concrete 100mm, Crushed stone base of 200mm and Subbase about 200mm thick milled or Cinder.

This deficit in thickness has caused the insitu subgrade to carry repeated loads, which is subsequently resulting fatigue cracking and rutting.

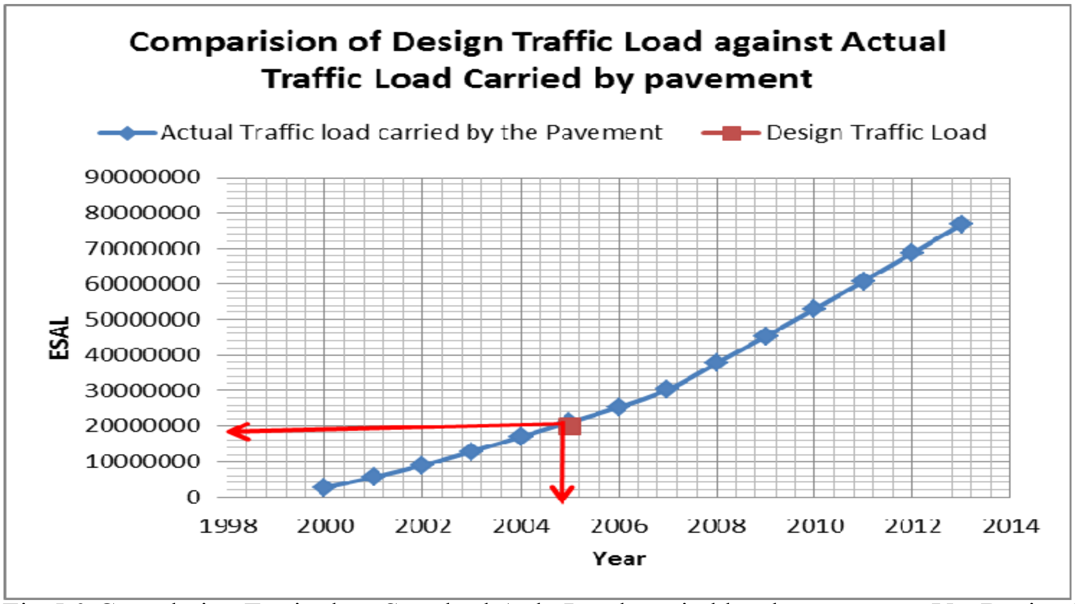


Fig 5.0 Cumulative Equivalent Standard Axle Load carried by the pavement Vs. Design Load (Debreziet-Mojo section)

## 5.6. Discussion of Laboratory Test Results

### 5.6.1. Summary of base laboratory test results

The quality of material used as base course of existing pavement has meet the project specification and ERA specification except the PI which is above 6%. Most specification including ERA specification requires a maximum of 6% PI for crushed stone Base. This increase in PI may have been caused due to abrasion and crushing of the Basaltic base materials by excessive repeated traffic load. This increase in PI reduces the aggregate strength (load carrying capacity) by reducing grain to grain contact friction hence it may cause ruts in base layer.

The insitu density is above 98% (minimum 98% is specified by different specifications). The grading result shows base material tends to be finer when evaluated with ERA grading envelop for base materials.

### 5.6.2. Subbase laboratory Test Result

The sections with cinder regulating layers exhibit lower field density & low insitu CBR. The relative compaction for this section is below 90% of MDD. The milled sub base has a higher PI. Section with milled sub base has a PI ranging from 11% to 14%. The cinder regulating layer has insitu CBR less than 30% and the material passing sieve size 0.075mm is about 26% for grade C grading envelop. Therefore, the quality test of subbase material shows that high plasticity Index and low CBR.

### 5.6.3. Subgrade Test Result

Field density of the capping layer and insitu subgrade is below 95% of MDD. The plasticity index of the capping layer ranges from non-plastic to 18%. The insitu subgrade has a higher PI and swell. The CBR of the insitu subgrade is very low at 95% of MDD/ 100% of standard compaction.

# 6. Conclusions and Recommendations

## 6.1. Conclusion

This thesis aimed at investigation of the cause of pavement failure on Addis Ababa- Modjo Road. The study has been achieved through analysis of;

i. type and extent of pavement failure,

ii. traffic loading analysis,

iii. Pavement materials testing and Evaluation.

The overall analysis in the study is based on the road condition at the time of testing. In the analysis, pavement failure was assumed to be associated with excess traffic loading, poor workmanship, expansive subgrade and use of poor quality materials.

The road from Addis Ababa to Modjo has been in repeated maintenance; however the maintenance did not work. Detail field and laboratory investigation which consists of, visual condition survey, Benkleman deflection measurement, test pitting and pavement layer profiling, material sampling and testing have been conducted in order to investigate the causes of failure.

Finally based on the investigation;

1. The visual condition survey indicates that;
   a. 49% of the road shows severity-3 (i.e the rut depth greater than 4cm), 30% of the road shows Sevrity-2 ruts (Ruts depth between 2 and 4 cm). From the literature review Ruts on road surface are caused by insufficient structural strength and excessive traffic loading.
   b. 52% of the road exhibit cracks with severity-3 and 32% of the road exhibit cracks of severity -2. According literature review Cracks on road surface are load induced cracks
   c. Block cracks between 12+400-12+700 LHS accompanied by shoulder uplifts and hence is due to black cotton soil (volumetric change) as the subgrade is expansive soil at 0.6m to 0.8m below the surface of the road.

   **The Visual condition survey indicates the distresses manifested on the surface of the pavement are results of structural failure that may be resulted from excessive traffic loading and poor subgrade.**
2. Filed investigations indicates that;
   a. Field density of capping layer is below the standard requirement.

b. Expansive subgrades at some location are between 0.6meter and 0.8 meter below the top surface this has caused block cracks and shoulder uplifting and rutting.
c. 80% of the road pavement shows deflection above the maximum tolerance which implies structural failure of the pavement as mentioned in the literatures.

3. The laboratory tests shows that;
   a. Subgrade materials have high Plasticity Index, high swell and very low CBR.
   b. Cinder regulating layers have low insitu density, Materials passing sieve size 0.075mm is above 26% and low insitu CBR.
   c. Base materials tend to the finer side of the specification and higher Plasticity index as compared to the specification.

**The pavement materials qualities are substandard.**

4. Traffic data analysis shows that the design traffic ESAL has been exceeded before 2004 which only about 4 years only; hence, the road has been carrying traffic more than design for over 10 years. High stress induced to the subgrade due to high traffic load and hence deformation to subgrade in addition it is the major causes of cracking.

From the overall analysis of the data it is concluded

i. The existence of the expansive subgrade soil shows failure on the Pavement in section with expansive subgrade, Pavement Materials are substandard; Traffic has exceeded the design loading within four years opening to Traffic.
ii. The overloading of Pavement for more than ten years above the design traffic loading has caused the pavement structural failure which cannot be easily maintained by overlying.

Therefore, in order to improve the quality of existing pavement reconstruction shall be done considering future traffic and the residual strength of the existing pavement.

## 6.2. 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.
- ✓ When heavy traffic is expected materials like cinder which lacks plasticity and which does not stand lateral pressures or susceptible to crushing under repeated load should be avoided.

- ✓ Effect of level of ground water table on the expansive subgrade material needs to be further investigated
- ✓ Acceptable method for determination of bearing capacity of expansive soil need to be further investigated
- ✓ Accurate traffic prediction models need to be devised throughout the country so that traffic forecasting errors would be minimized
- ✓ Relevant pavement structure need to be proposed for such heavy traffic important road section by thinking rigid pavement which have long standing resistance of heavy stresses.

# 7. References


- [1] AASHTO Guide for Design of Pavement Structures-2002. American Association of State Highway and Transportation Officials, 444N.Capitol Street, NW., Suite 249 Washington, D.C. 2001.

- [2] C.P. Van der Merwe, M. Ahronovitz (2005). The Behaviour of Flexible Pavement on Expansive Soil, Rhodesia Publication No 187.

- [3] Draft Standard Specification for Road and Bridge Works (2001). Division of Roads and Transport Technology, CSIR

- [4] LNEC for European Road Federation (2006), Evaluation of the cause of distress of Addis Ababa-Modjo-Awassa Road Pavement

- [5] N. Okigbo, "Road maintenance in Nigeria, the way forward," International journal of research in engineering science, Pan African journal series, Accra, Ghana, 2012.

- [6] O. G. Omer, A. M. Elsharief and A. E. Mohamed, "Failure Investigation for Recently Constructed Road in Khartoum State," Journal of Geological Resource and Engineering 2, David Publishing Press, 2014, pp 20-31.

- [7] M. Sargious, Pavement and Surfacing for Highways and Airports. London: Applied Science Publishers Ltd, 1975.

- [8] D.Y. Patil Abhijit, Y. B. Patil Prathisthan's, and A. Patil Polytechnic, "Effects of Bad Drainage on Roads," Civil and Environmental Research, Vol. 1, No.1, 2011.

- [9] D. N. Little, T. Scullion, P. Kota, and J. Bhuiyan, "Identification of the Structural Benefits of Base and Subgrade Stabilization," Research Report 1287-2F, Texas Transportation Institute, Texas A&M University, College Station, Texas, 1995.

- [10] S. Sebesta, "Reworking Base, "Presented at Statewide Maintenance," Conference, San Antonio, TX, April 16, 2002.

- [11] P. Croney, and D. Croney, The Design and Performance of Road Pavements. New York City: McGraw-Hill Professional, 1998.

- 

- [12] T. M. Oguara, A management model for road infrastructure maintenance. Book of proceedings, 19th engineering assembly, Council for the regulation of engineering in Nigeria, 2010.

- [13]. Haung. Pavement design and analysis, 2004

- [14] Investigating Causes of Pavement Deterioration in Khartoum State, Sudan , Magdi M. E. Zumrawi International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:9, No:11, 2015

- [15] S. Y. Wee, R. B. Chan, and H. W. Teo, "Potential modeling of pavement deterioration rate due to cracking," UNIMAS E-Journal of Civil Engineering, Vol 1, issue 1, August 2009.

- [16] N. P. Khosla, G. B. Birdsall, and S. Kawaguchi, "An In-Depth Evaluation of Moisture Sensitivity of Asphalt Mixtures," NCDOT Research Project 1998-08 FHWA/NC/2002-102, 1999.

- [17] K. D. Stuart, "Moisture Damage in Asphalt Mixtures- A State-of-ArtvReport, FHWARD-90-019, Federal Highway Administration, U.S Department of Transportation, Washington, D.C., 20001., 1990.

- [18] R.S. Rollings, "Marginal Materials for Pavement Construction," Final Report, Department of the Army Waterways Experiment Station Corps of Engineers, US. Vicksburg Mississippi 39180-0631, 1988.

- [19] O. M. Osuolale, A. A. Oseni, and I. A. Sanni, "Investigation of Highway Pavement Failure Along Ibadan - Iseyin Road, Oyo State, Nigeria," International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 8, October – 2012.

- [20] D. N. Little, and R. Graves, "Upgrading Marginal Aggregate Bases And High-Fines Bases With Low Levels of Stabilizers," Texas Transportation Institute, Texas A&M University and Vulcan Materials Company, 1999.

- [21] S. Sebesta, "Reworking Base, "Presented at Statewide Maintenance," Conference, San Antonio, TX, April 16, 2002.

- [22] Hagos Gebretsadik (2006), Assessment of Road Failure constructed on Red Clay soils of Western Ethiopia and their Remedial Measures. Thesis for the fulfilment of MSC degree, Addis Ababa University.

- [23]. M.D.Gidigasu/A.A. Hamond (1980), Soil mechanics and foundation Engineering. Seventh Regional Conference for Africa

- [24] S. Sebesta, "Investigation of Maintenance of Base Repairs over Expansive Soil," FHWA/TX-03/0-4395-1, 2005.

- [25] W. Charlie, M. Osman and E. Ali, "Construction on Expansive Soils in Sudan," Journal of Construction Engineering Management, American Society of Civil Engineers, Construction Division. Vol. 110 No. 3, pp. 359–374, 1984.

- [26] ERA, Pavement Rehabilitation and Overlay Design Manual (2002)

- [27] Metaferia Consultants in Joint venture with Omega Consulting Engineer (2009), Materials Report for Design of periodic maintenance of Addis Ababa-Modjo road.

- [28] Overseas Road Note 31(1993) A guide to the structural design of bitumen-surfaced road in tropical and sub-tropical countries, Fourth Edition. Overseas centre: Transport Research Laboratory, Crowthorne, Berkshire, United Kingdom.

- [29] Patrick G. Lavin (2003), Asphalt pavement, a practical guide to design, production, and maintenance for Engineers and Architects, Second Edition. ISBN-10:0415247330

- [31] P. Kumar, A. Gupta, "Cases studies of bituminous pavements," Compendium of Papers from the First International Conference on Pavement Preservation. Chapter 7, paper 52, pp 505 – 518, 2010.

- [32] W. Woods, A. Adcox, "A General Characterization of Pavement System Failures, with Emphasis on a Method for Selecting a Repair Process," Journal of Construction Education, Vol. 7, No. 1, pp. 58 – 62, 2004.

- [33] Caltrans, Flexible Pavement Rehabilitation Manual, California Department of Transportation, Sacramento, CA, June, 2001.

- [34] S. Jain, P. Kumar, "Report on Causes of Cracks Occurrence in Ramghat - Aligarh Road in U.P.," Report Submitted to PWD, Aligarh. 1998.

- [35] A. Ahmed, Pavement Distresses Study: Identification and Maintenance (case study), M.Sc. thesis, University of Sudan, 2008.

- [36] P. Sikdar, S. Jain, S. Bose, P. Kumar, (1999). "Premature Cracking of Flexible Pavements," Journal of Indian Roads Congress, Paper No. 461, Volume 60,Issue 3, pp. 355 – 398. 1999.

- [37] Queensland Transport, Pavement Rehabilitation Manual, Pavement, Materials, Geotechnical Branch, State of Queensland, April 2012.

- [38] M. Zumrawi, "The impacts of poor drainage on road performance in Khartoum," Research Article, International Journal of Multidisciplinary and

Scientific Emerging Research (IJMSER), available online, Vol. 3, No. 1, pp. 901 – 907, Oct. 2014.

- [39]. Standard Technical Specification (2002), Ethiopian Roads Authority.
- [40] Progress & Final Acceptance Report (1999). DHV in association with AEC

# 8. Appendix