ACKNOWLEDGEMENTS

Above all, I would like to say thank you to creator and governor of the world, the almighty God and Saints for their invaluable gifts to me that guiding and allowed to accomplish the MSc thesis.
I am very grateful to the Ethiopian Road Authority and Jimma University, JIT, Faculty of Civil and Environmental Engineering for allowing me to take part in the Master Program in Highway Engineering.

I would like to express my sincere thankfulness to Federal Democratic Republic of Ethiopia, Ethiopian Road Authority, Jimma Road Network and Safety Management Branch Directorate for their assistance to conduct condition survey of the project within the required manner and permitting to take representative samples along the road and providing me service car to transport samples. Additionally, grateful thanks forwarded for ERA Own Force Road Maintenance District of Jimma for their entire support of doing DCP Test on the required locations and their openness to guide and support for conducting essential laboratory tests.

I would also like to thank you to my Main Advisor, Eng'r. Elmer C. Agon (Asso. Prof) for giving me encouragement, critical comment and helpful guidance with friendly approach throughout this thesis work. I am also indebted to my Co - Advisor, Mr. Bishurilkerim Owmer for his support and encouragement.

At last but not least, I would like to provide deepest gratitude to my father, Mr. Getaye Lulie (Priest) and my mother, Mrs. Aguaba Mitiku and Friends for their love and unconditional support during my study.

ABSTRACT

Transportation system is one of the most important factors affecting the national and public economy/development of any country. A premature road defect is a critical situation for road sector because of the high cost for construction of new roads and maintenance of existing roads and routes.

One of these roads failed before serving the design period is the Bedele - Metu road upgrading project, Lot - II (50.659 km) trunk road with 20 years design life. However, premature pavement failures have been manifested since the year 2017. The objective of this study is to assess the Causes of the premature pavement failures and also propose its alternative treatments. Hence, a desk study, field visual inspection and in-depth field and laboratory investigations have been undertaken.

The thesis comprises the tasks of visual pavement condition survey, dynamic cone penetrometer test, test pitting and pavement layer profiling, materials sampling and laboratory testing have been conducted. Moreover, the past traffic data was obtained and analyzed. Following to condition survey result, ideal locations of 4 in number for dynamic cone penetrometer, 1 from failed and other 1 as control sample with a total of 16 samples were identified for essential laboratory tests. Those of samples were transported to Ethiopian Road Authority, Own Force District of Jimma laboratory center for determination of laboratory test.

The road condition survey indicates the existence of different types of distresses such as: potholes/patch failure, cracking, rutting, depression/failure, raveling/fretting and others. Field and laboratory investigation have been carried out and it shown that low air voids with void in mix result in a wearing course material <3%, such as 1%, that indicates the possible factor for occurrence premature pavement deformation. Also, insufficient surfacing layer thickness, such as 11.34 mm thickness difference would be the possible causes for the formation of surface deformation and workmanship problem of the asphalt concrete works along the joint of the separate lanes are also the observed potential causes for surface defects and cracking. Accordingly, proper treatment types were suggested that tend to be enhancing the design life of the pavement. In conclusion, the individual pavement layer thickness difference from the measured to design and also their cumulative effect could be the possible causes for occurrence of premature defects such as: surface deformations. Therefore, to avoid further road damages; traffic count, more detailed analysis of traffic volume and axle load survey should be made and also further comprehensive tests on the structural capacity of the pavement would be done. Based on the result of those analyses, right remedial measures should be made urgently.

***Key Word**: Asphalt Concrete, Failure, Road Condition Survey, Traffic Loading and Type, Extent and Severity level of distress.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AADT - Average Annual Daily Traffic

AASHTO - American Association of State Highway and Transportation Officials'

AC - Asphalt concrete

ACV - Aggregate Crushing Value

AFDB - African Development Bank

ASTM - American Society for Testing and Materials

CBR - California Bearing Ratio

CL - Center Line

Cm^3 - Cubic Centimeter

DC - Corrugation Deformation

DD - Depression Deformation

DR - Rutting Deformation

DS - Shoving Deformation

DS - Design Standard

EF - Equivalency Factor

ERA - Ethiopia Roads Authority

DCP - Dynamic cone penetrometer

GB1 - Graded Crushed Stone

Gmm - Maximum Theoretical Density

Gm - Gram

GPS - Global Positioning System

HMA - Hot Mix Asphalt

JIT - Jimma Institute of Technology

JRNSMBD - Jimma Road Network and Safety Management Branch Directorate

JU - Jimma University

KG - Kilogram

Km - Kilo meter

KN - Kilo Newton

LAA - Los Angeles Abrasion Value

LHS - Left Hand Side

LL - Liquid limit

MDD - Maximum Dry Density

mm^2 - Square Millimeter

MSc - Master of Science

OMC - Optimum Moisture Content

PI - Plasticity Index

PL - Plasticity Limit

RHS - Right Hand Side

SD - Surface Delamination

SF - Surface Flushing

SP - Surface Polishing

SR - Surface Raveling

SS - Surface Stripping

SSD - Specific Gravity in Air

T - Traffic Volume

TPV - Ten Percent Fines Value

TRL - Transport Research Laboratory, UK (formerly TRRL)

VIM - Void in Mix

CHAPTER ONE

INTRODUCTION

1.1 Background

Transportation system is one of the most important factors affecting the national and public economy/development of any country. The better transportation system is the necessity for developing the nation and public economically. From this, asphalt concrete road is one part of the largest infrastructure components in civil construction works and complex system that involves multiple layers of different material types that subjected to various combinations of traffic loadings and varying environmental conditions. It provides the road - user a smooth, quiet and skid - resistant riding surface, maximizes tire contact by providing more traction, and saves wear and tear on vehicles. AC pavements are safe, economical and most long - lasting roads that can be built very quickly thereby reducing costs due to traffic delays and save the traveling time.

Road deterioration is a critical situation for road sector because of the high cost for construction of new roads and maintenance of existing roads and routes. Restoring serviceability of bituminous pavements has significant economic and societal benefits as the pavements plays an important role in our daily life thereby providing safe and a convenient means of transportation which is one of the major aspect of our life. However, insufficient funding often limits the timely repairs and rehabilitation of the pavements [1].

Maintenance of a road network involves a variety of operations, which are, identification of deficiencies and planning, programming and scheduling for actual implementation in the field and monitoring. The essential objective should be to keep the road surface and appurtenances in good condition and to extend the life of the road assets to its design life. Broadly, the activities include identification of defects and the possible cause there off, determination of appropriate remedial measures; implement these in the field and monitoring of the results. This will involve several subsystems of identification, evaluation, planning, scheduling, management of material and machinery and then performance evaluation [2].

Each of these pavement types has specific failure mechanisms and each failure mechanism is caused by specific factors. Example of such failure mechanisms include: fatigue damage and roughness of rigid and flexible pavement, faulting of rigid pavement, and rutting of flexible pavement. These failure mechanisms are caused by the following factors: heavy vehicle loading, climate, drainage, material properties, and inadequate layer thicknesses [3].

The road network in Ethiopia provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the country. The network comprises a huge national asset that requires adherence to appropriate standards for design, construction and maintenance in order to provide a high level of service. As the length of the road network is increasing, appropriate choice of methods to preserve this investment becomes increasingly important. All roads deteriorate with time as a result of traffic and environmental effects. The deterioration may be relatively easy to correct or may require major works, depending on the causes and extent of deterioration. The works processes for keeping roads in good condition are often subdivided into the following categories: routine maintenance, emergency maintenance, periodic maintenance, rehabilitation, reconstruction and upgrading [4].

Besides, the increasing traffic intensity, high tire pressure, increasing axle loads and others… are causing early signs of distress to bituminous pavements throughout the world. The deterioration of the paved roads in tropical and subtropical countries differs from those in the more temperate regions of the world. This can be due to the harsh climatic conditions and sometimes due to the lack of good pavement materials and construction practices [5].

In addition, moisture damage is deteriorates pavement structure that is induced by the loss of bond between the asphalt cement or the mastic (asphalt cement, the mineral filler and small aggregates) and the fine and coarse aggregate. Moisture damage accelerates as moisture permeates and weakens the mastic, making it more susceptible to moisture during cyclic loading [7].

Among these factor, heavy vehicle load are the major source for pavement damage. Magnitude and configuration of vehicular loads together with environment have significant effect on induced tensile stress within flexible pavement [3].

In reality, flexible pavements are subjected to dynamic loading caused by truck traffic. The mechanical damage to the pavements due to such loading cannot be estimated without the laboratory characterization of AC for a range of loading of various durations that pavements experience in service. In general, laboratory test results in conjunction with the theoretical predictions will permit comparison with actual pavement performance available from field measurements. The findings from such studies will ultimately lead to adoption and use of new or improved materials based on satisfactory performance.

From these of early deteriorated road in Ethiopia, Bedele - Metu Road Upgrading Project Lot –II is the one of which occurrence of premature defects become the main concern. The upgrading works of the at hand trunk road was then substantially completed and opened to traffic in two sections before one year defect liability period of September 2017 and July 2018 for station 66+000 to Km 111+659 and for station 61+000 to 66+000 respectively. The design pavement life was estimated to be 20 years and its entire project length is 50.659Km. However; pavement failure had been manifested while of serving a maximum of 6 months. Existence of these surface and structural defects such as stripping/fretting, cracking, potholes/patching, depression/failure, rutting and those of adjacent road side drainage problems become the reason for deficit of functional importance (reduced riding quality and poor skid resistance) and also resulted in structural failure (unable to carry the design traffic load) on some locations owing to late of taking maintenance interventions. On this research, it is intended to identify critical parameters contributing to AC damage and develop a remedial for asphalt concrete pavement that predicts the damage accumulation and serves the highway community to design a pavement for extended period of time.

1.2 Statement of the Problem

Pavement is an engineering structure placed on natural soils and designed to withstand the traffic loading and the action of the climate with minimal deterioration and in the most economical way. Asphalt pavement roads are designed and constructed to serve the upcoming traffic that reveal during the service life of the road. Different factors taken in to account in the design and construction of pavements include the characteristics of the traffic, climatic conditions, material as well as structural properties and other elements which have significant impact on the overall performance of the road [42].

Most of the pavement structures are deteriorated prior to serve the expected design periods. In connection with this, Bedele - Metu Lot –II Road Upgrading Project (50.659Km) is the one significantly represent the early failed road projects of Ethiopia that leads to deterioration after a while of serving 6 months of completion of the construction. Nonetheless, the design period of the project is 20 years. In relation with this, the upgrading project completion date was accomplished in to two sections. Firstly, he project length from Km 66+000 to Km 111+659 (Total length of 45.659 Km) was substantially completed on 13th of September 2017. Secondly, the project length from Km 61+000 to Km 66+000 (Total length of 5.00 Km) was substantially completed on 12th of July 2018. The defect notification period for both of the above stretches was 12 extended months for each of respective sections. Conversely, the project is exposed to premature defects with varying severity ratings from 0/good to 3/poor such as stripping/fretting, cracking, potholes/patching, depression/failure, rutting and those of adjacent road side drainage problems prior to serve the intended design period while of the Contractor was provided the required maintenances in the stipulated defect liability period.

The premature failure of the pavement structures on most of the asphalt concrete roads are mainly related to but not limited with; lack of updated design inputs (including traffic volume), workmanship errors, poor construction materials, inadequate treatment of the available poor subgrade soil, surface and sub - surface water and lack of proper adopting the given design data’s during implementation stage.

Various numerical, experimental and automated defect inspection system studies have been carried out to evaluate the different types of defects and its respective remedial measures with respect to field and laboratory analysis. Nonetheless, still now there is limited experience about implementing those of findings on the failure section with variable circumstances of the local study area through weather condition, soil type, traffic condition and others.

When considering the case of Metu – Bedele road pavement, it has the following scenarios:

- The road is characterized by heavy deformation with extreme stripping/fretting, potholes/patching, depression/failure and rutting. These causes traffic accident, travel time for road users become increased, affecting economic, industrial and cultural growth of the country. The accessibility, users comfort and national/ social development of country and increasing vehicle operating cost are directly and indirectly affected owning to occurrence of premature road defects.

- The road is part of Djibouti – Juba – Kampala Road Corridor with the aim to promote trade and alleviate poverty through highway infrastructure development and the management of road-based trade corridors.

- The road is famous for coffee trade, surrounding forest and its wildlife. Also, the population of Illubabor zone and Glabella region will have to travel less by following Metu - Bedele - Nekemte - Addis Ababa route in lieu of Metu - Bedele - Jimma - Addis Ababa route.
- The route is accessible for three regions of the country; Oromia, South Nation Nationality and Peoples Glabella that control over by different vehicle types of several in numbers.

Therefore, this research was important in order to evaluate the pavement condition and its performance on the basis of the field, laboratory and traffic volume assessments so as to forwarding the appropriate treatment types.

1.3 Research Questions

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

1. Which sections of the road are affected by deterioration?
2. What types and patterns of pavement distress exist in the study area?
3. What are the factors or parameters that cause premature failures along the study area?
4. What are the possible treatment types to meet its design life?

1.4 Objectives of the Study

1.4.1 General Objective

The purpose of the study is to investigate the causes leading to premature failure of the pavement structure and recommend alternative treatments to improve the current situation in Bedele - Metu road upgrading project.

1.4.2 Specific Objectives

The specific objectives of the study are:

- To identify sites/road sections those are affected by deterioration before serving the anticipated design life.
- To determine the types and patterns of the available road defects along the study area.
- To analyze and fix the factors/parameters for the cause of the deterioration.
- To recommend possible treatments to meet its design service life.

1.5 Significance of the Study

The findings of this research will help:

- To create a way to assess the gaps behind for the cause of the premature pavement failures with variable natures and propose its remedies in line with the project specifications and general manuals.
- To avoid and/or reduce Maintenance cost, road user cost, accident cost and travel time irredeemable.
- To provide access as reference material for different government and private organization that open away to preserve road assets and create viable usage of government's budget.
- The research paper will give a clue for those who are interested in conducting research on pavement premature failures.

1.6 Scope of the Study

The focus area of the study is detecting the causes of premature pavement deterioration on Bedele - Metu Road Upgrading Project, Lot 2: Km 61+000 - Km 111+659 (50.659Km) by considering the identified distress type along with their severity level on the basis of pavement condition survey output. After a while, numerical values of field observation and on-site tests of DCP and laboratory test (i.e. surfacing layer percentage compaction, sieve analysis, Atterberg limit, proctor test, CBR) results were used on the representative sample units of the purposive selected sections. Consequently, remedial measures of the road failures would be proposed by reviewing with project documents and ERA 2013 manual. Thickness of each pavement layers were checked and traffic volume of the study area was also analyzed.

But the study was limited to investigation of few failed and one control sample unit of the study project so as to exhaustively analyze the study with in the allotted budget and time frame. The sample units were taken by considering only of the variety of distress type and higher severity level.

CHAPTER TWO

RELATED LITERATURE REVIEW

Pavement is an engineering structure placed on natural soils and designed to withstand the traffic loading and the action of the climate/environment with minimal deterioration and in the most economical way [9].

The majority of modern pavement structures may be classified as flexible or rigid pavement structures. A flexible pavement consists of a surface layer constructed of flexible materials typically asphalt concrete over granular base and sub base layers placed on the existing, natural soil. Rigid pavement is a pavement structure that deflects very little under loading because of the high stiffness of the Portland cement concrete used in the construction of surface layer [10].

Flexible pavements are considered here to be pavements that consist of an asphaltic top layers on a bound or unbound base layer which in turn rests on a subgrade. In the design of pavements, the layer thicknesses and the materials are selected in such a way that the pavement can resist the heavy axle loads without severe cracking of the bound layers and excessive deformation of the subgrade. Furthermore, the pavement should not deteriorate excessively because of environmental effects. Finally the pavement surface should have sufficient durability. Any structure will fail when the stresses induced are higher than the strength of the material from which the structure is built [11].

2.1 Characteristics of Pavement Structure

Asphalt concrete:- Asphalt concrete (AC) pavement is one of the most important infrastructures that involve multiple layers of different materials subjected to non-uniform traffic loadings and varying environmental conditions. Pavement structures components are: asphalt surfacing, base course, sub base, capping layer (optional) and subgrade.

2.1.1 Asphalt Surfacing

Surface course: is a layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC).

Binder course: This layer provides the bulk of the asphalt concrete structure. Its purpose is to distribute load to the base course. The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course.

2.1.2 Base-Course (Road base)

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slug and other untreated or stabilized materials.

2.1.3 Sub-Base Course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage and to reduce the intrusion of fines from the sub-grade in the pavement structure. A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

2.1.4 Sub-grade

The subgrade is the underlying or foundation component of the total roadway pavement structure. It is usually constructed with native soil sometimes in combination with soil imported from local borrow sources. Subgrade soils can be used as earth borrow to construct embankment fills or to replace existing unsuitable soils. The objective of the subgrade construction is to provide a uniform foundation for the pavement structure. Non uniform subgrades lead to differential pavement performance [20].

The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. Direct assessment of the likely strength or CBR of the subgrade soil under the completed road pavement is often difficult to make. Its value, however, can be inferred from an estimate of the density and equilibrium or ultimate moisture content of the subgrade together with knowledge of the relationship between strength, density and moisture content for the soil in question. This relationship must be determined in the laboratory. The density of the subgrade soil can be controlled within limits by compaction at suitable moisture content at the time of construction [8].

2.2 Road Deterioration and It's Treatment Types

Pavement failure is defined in terms of decreasing serviceability caused by the development of surface distresses such as cracks, potholes and ruts [18].

Mainly, Condition survey is highly helpful to evaluate the functional and structural aspects of the road right after construction or during rehabilitation and reconstruction. Functional evaluations are used to identify the capability of the pavement structure to provide a comfortable and safe service. In a newly constructed road, the primary parameters determined in functional evaluations are the riding quality and skid resistance. For rehabilitation and reconstruction, this may include the evaluation of aspects such as potholes, cracks, and deformations. Structural evaluations are needed to determine whether the pavement will carry the traffic it has been designed for [28]. The evaluation methods for those of functional and structural aspects are as below,

- **Functional aspect**

Functional evaluation is usually performed by visual inspection. Visual inspection requires the rating of the degree and extent of the various distresses. Typical pavement conditions evaluated visually includes surface conditions (roughness), potholes, deformations (ruts), cracks, edge - breaks, raveling, bleeding (flushing), and patching.

- **Structural aspect**

The structural aspect of pavement can be evaluated using different ways. The most common methods involve probing the pavement (by DCP or any similar method), measurement of the surface deflection and shape of the deflection bowl under loading and evaluation of trial pits, measure layer thickness and obtain laboratory data.

Pavement failures of bituminous pavements are caused due to many reasons or combination of reasons. From these, the most common pavement distress and its possible causes are discussed below [18].

Table 2.1: The most common pavement distress and its possible causes [18]

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

In many pavement failures, excess moisture is the main cause of failure or a contributing cause. Hence, the effect of moisture content changes on the strength and stiffness of pavement materials [19]. They found that excess moisture reduces the strength and stiffness of pavement materials, being worse for the subgrade material, than for the sub-base 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 [19]. It can be seen that for nearly all types of pavement failure, moisture is often the primary or a contributing cause of failure.

2.2.1 Different Types of Road Deterioration

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions. The four major categories of common asphalt pavement surface distresses are [26]:

- Cracking
- Surface deformation
- Disintegration
- Surface defects

2.2.2 Distresses in Asphalt Pavement

2.2.2.1 Deformation

Description

Deformation is the change in a road surface from the constructed (intended) profile. Deformation may occur after construction due to trafficking (load associated) or environmental (non-load associated) influences. In some cases, deformation may be built in to a new pavement owing to inadequate control. Deformation may lead to cracking of the surface layer. Several types of deformation may occur, the foremost of which are: Corrugations (DC), Depressions (DD), Rutting (DR) and Shoving (DS) [12].

Severity and Extent

Their severity and extent of road defects under this category that mostly available on AC pavements are described below [17].

Failures

Severity	Extent
1 Less than 1 minor depression in the section	1 Less than 20% of the section affected
2 Between 2 and 5 depressions or areas of Movement/structural cracking in the section	2 Between 20% and 50% of the area affected
3 Greater than 5 depressions or areas of Movement/structural cracking in the section	3 Greater than 50% of the area affected

Corrugations

Severity	Extent
1 Maximum corrugation depth between 10mm and 20mm	1 Less than 20% of the section affected
2 Maximum corrugation depth between 20mm and 50mm	2 Between 20% and 50% of the section affected
3 Maximum corrugation depth greater than 50mm	3 Greater than 50% of the section affected

Note: the corrugation depth should be measured at selected locations within the 500m sections and the maximum recorded.

2.2.2.2 Cracking

Severity and Extent

Severity	Extent
1 Any	1 Less than 10% area cracked (wheel Path) or less than 10% area cracked transverse or longitudinal
	2 Between 10% and 20% area cracked
	3 Greater than 20% area cracked

2.2.2.3 Potholes and Patching

Description

Potholes are structural failures which include both the surfacing and road base layer. They are usually caused by water penetrating a cracked surfacing and weakening the road base. Further trafficking causes the surfacing to break up and a pothole develops. Because of the obvious hazard to the road user, potholes are usually patched as a matter of priority. Although patches are not necessarily defects, they do indicate the previous condition of the road and are included in the assessment [4].

Severity and Extent

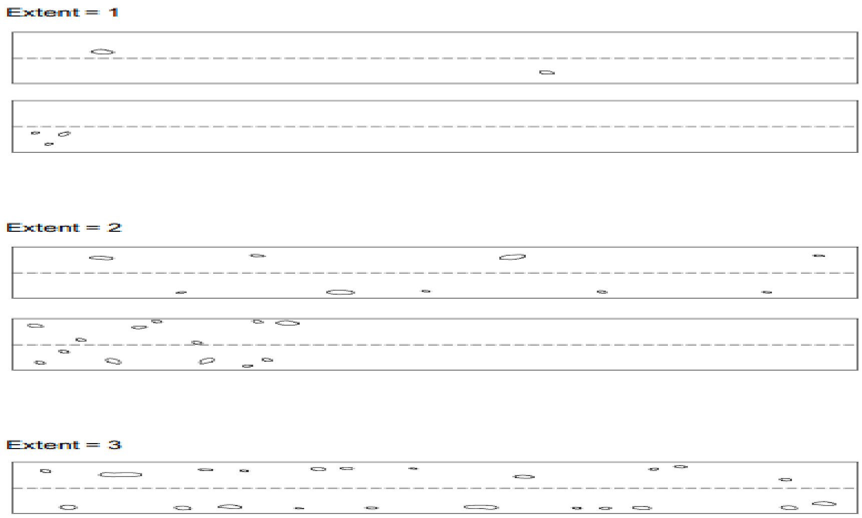


Figure 2.1: Extent of potholes and patching [4]

The severity of potholes and patching are given below [17].

1 Pothole depth only in the surfacing

2 2 or more potholes greater than 0.5m2 in surface area or depth of pothole into base course

3 2 or more potholes greater than 1m2 in surface area or depth of pothole into sub base

2.2.2.4 Edge Defects and Shoulder Condition

Description

Edge failures are caused by poor shoulder maintenance that leaves the surface of the road pavement higher than the adjacent shoulder. This unsupported edge can then be broken away by traffic, narrowing the running surface of the road [4].

Severity and Extent

Shoulder - Deformation

Severity	Extent
1 Shoulder profile less than design 5%, Drainage becoming impaired	1 Less than 20% of the section affected
2 Shoulder slightly deformed, some rutting and potholes, drainage impaired	2 Between 20% and 50% of the section affected
3 Shoulder heavily deformed, rutting, Potholes, water ponding in shoulder	3 Greater than 50% of the section affected

Vegetation

Severity	Extent
1 Less than 5 shrubs/trees (dia <37.5mm) or Vegetation less than 300mm in height	1 Less than 20% of the section affected
2 Between 5 and 10 shrubs/trees (dia <37.5mm) or vegetation between 300mm and 1m in height	2 Between 20% and 50% of the section affected
3 Greater than 10 shrubs/trees (dia <37.5mm) or vegetation greater than 1m in height	3 Greater than 50% of the section affected

2.2.2.5 Surface Texture Deficiencies

Severity and Extent

Raveling

Severity	Extent
1 Less than 10% area raveled	1 Less than 20% of the section affected
2 Between 10% and 20% area raveled	2 Between 20% and 50% of the section affected
3 Greater than 20% of the area raveled	3 Greater than 50% of the section affected\

Safety

Safety as a defect has a severity but no extent, if there is a safety issue such as an eroded culvert headwall or moving embankment that is putting the road user or the road at risk then it has to be addressed immediately. All reports of safety must be brought to the attention of the DED Manager as soon as they are recorded.

Severity	Extent
1 Minor safety issue i.e. not Immediate danger to the road user or the road structure	1 Any
2 A safety issue that is becoming a danger to the road user or the road structure.	
3 A major safety issue that is a danger to the road user or the road structure.	

In the case of severity ‘3’ it is important that all attempts are made to either rectify the situation or to make it safe or to place signs to warn road users of the danger.

2.2.2.6 Side Drain Siltation and Scour

Silt and scour are the defects to be recorded against the side drains and turnouts. The detail description and its severity Vs. Extent are given below [17].

Severity and Extent

Side Drain - Silt

Severity	Extent
1 Ditch invert between 600mm and 1m Below road shoulder edge	1 Less than 20% of the section affected
2 Ditch invert between 300mm and 600mm Below road shoulder edge	2 Between 20% and 50% of the section affected
3 Ditch invert less than 300mm below shoulder edge	3 Greater than 50% of the section affected

Should be measured with a straight edge and spirit level where possible.

Side Drain - Scour

Severity	*Extent*
1 ditch invert scoured less than 500mm Below effective invert	1 Less than 20% of the section affected
2 ditch invert scoured between 500mm and 1m below effective invert	2 Between 20% and 50% of the section affected
3 ditch invert scoured greater than 1m below effective invert	3 Greater than 50% of the section affected

Note: where the scour is excessive the inspector should note the number of scour checks (check dams) required and the quantity of material required repairing the scour erosion.

2.2.2.7 Safety Problem

Safety

Severity and Extent

Severity	Extent
1 minor safety issue i.e. not an immediate danger to the Road user or the road structure	1 Any
2 A safety issue that is becoming a danger to the road user or the road structure.	
3 A major safety issue that is a danger to the road user or the road structure.	

2.2.3 Causes of Pavement Premature Failures

Pavement deterioration is the process by which distress or defects develop in the pavement under the combined effects of traffic loading and environmental conditions [14].

Pavement deterioration can be expressed in terms of a damage function or as the development and progression of the actual distresses. A damage function "expresses the performance of the pavement in relation to two standards, the quality of the original construction or initial condition and the 'terminal' level of distress at which maintenance or rehabilitation is necessary". Thus, damage functions rely upon prescribed standards which vary often significantly between countries, and even areas within the same country. Structural deterioration is defined as any condition that reduced the load carrying capacity of the pavement [5].

Roads are subjected to traffic loads and varying climate conditions that eventually lead to different types of damage. Moisture in asphalt is one of the major causes of premature failure in asphalt pavements [38].

For design purposes it is usually necessary to carry out additional non-destructive testing to be certain of any diagnosis and to ensure that any other potential problems are identified at an early stage. Finally, destructive testing (test pits and samples collected for laboratory testing) may be necessary, if only for confirmation of the interpretation of the data collected non-destructively [4].

- **Destructive sampling and material testing**

When the results of the condition survey indicate that the properties of the asphalt surfacing could be the cause of differential performance between sub-sections then this should be confirmed by further testing. Sufficient 150mm diameter core samples need to be taken from each subsection to ensure that representative values for the composition and properties of the asphalt surfacing are obtained. Prior to testing, the cores must be examined to establish the following: thickness of each bound layer, degree of bonding between asphalt layers, occurrence of any stripping and depth of cracking (if required) [4].

- **Road condition data from non-destructive testing and measurement**

These data include road roughness, deflection, deformation, details of cracking, potholes, rutting, gullies, and others [4].

2.2.3.1 Poor Drainage

Localized pavement failures are often caused by the poor design or maintenance of side and cut-off drains and cross drainage structures. When side drains and culverts silt up, water ponds against the road embankment, eventually weaken the lower pavement layers. Conversely, if the water velocity in the side drain is too high it erodes the road embankment and shoulders. More general failures occur when there is no drainage within the pavement layers themselves. Paved roads do not remain waterproof throughout their lives and, if water is not able to drain quickly, it weakens the lower pavement layers and results in rapid road failure. However, pavement deterioration as a result of poor drainage may not be obvious in the dry season hence discussions with local people may be necessary to establish the situation in the wet season [4].

2.2.3.2 Traffic and Operational Conditions

The deterioration of paved roads caused by traffic as a result of the magnitude of the individual wheel loads and the number of times these loads are applied. It is necessary to Consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles. Equivalency factors are used to convert traffic volumes into cumulative standard axle loads. Classes are defined for paved roads, for pavement design purposes, by ranges of cumulative Traffic number of equivalent standard axle's load [22].

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. It is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles. Equivalency factors are used to convert traffic volumes into cumulative standard axle loads and this is discussed in this section. For paved roads, traffic classes are defined by ranges of cumulative number of equivalent standard axles (ESAs) [8].

Countrywide traffic data should, preferably, be collected on a systematic basis to enable seasonal trends in traffic volumes to be quantified. The frequency of counting shown in the following Table is recommended [8].

Table 2.2: Frequency of traffic counts [8]

Road Classification	7-Day Traffic Counts
Trunk Road	Quarterly
Link Road	Quarterly
Main Access Road	Every 6 Months
Others Road	Every 3 Years

- ***Determination of cumulative traffic volumes***

In order to determine the cumulative number of vehicles over the design period of the road, the following procedure should be followed [8]:

1. Determine the initial traffic volume, $AADT(m)_0$, of each traffic class (m) using the results of the traffic survey and any other recent traffic count information that is available.
2. Estimate the annual growth rate "i" expressed as a decimal fraction, and the anticipated number of years "n" between the traffic survey and the opening of the road.
3. For each vehicle class, estimate the traffic in the first year that the road is opened to traffic. For normal traffic this is given by

$$AADT(m)_1 = AADT(m)_0 \, (1+i)^n$$

4. For each vehicle class, add the estimate for diverted traffic and for generated traffic if any are anticipated.

For structural pavement design the cumulative traffic loading of each of the motorized vehicle classes over the design life of the road in one direction is required. For a given class, m, this is given by the following equation:

$$T(m) = 0.5 \times 365 \times AADT(m)_0 \, [(1+i/100)^N - 1]/(i/100)$$

Where;

$T(m)$ = the cumulative traffic of traffic class m

$AADT(m)_1$ = The AADT of traffic class m in the first year

N = the design period in years

i = the annual growth rate of traffic in percent

The cumulative traffic for each class of vehicle is multiplied by the average number of equivalent standard axles of vehicles in that class to calculate the cumulative total number of equivalent standard axles over the life of the road [8].

- ***Axle load surveys***

Countrywide axle load data should, preferably, be collected on a systematic basis to enable trends to be quantified and to provide data for road design purposes. The following method of analysis is recommended [8]:

1. Determine the equivalency factors for each of the wheel loads measured during the axle load survey, in order to obtain the equivalency factors for vehicle axles. The factors for the axles are added together to obtain the equivalency factor for each of the vehicles.
2. For vehicles with multiple axles (tandems, triples and others.), each axle in the multiple group is considered separately. Although the exact ESA values for multiple axles have been shown to differ from this, the differences are dependent on road structure and axle spacing but are relatively small compared with the problem of uneven distribution of load between the axles in the multiple sets. Thus treating the axles separately provides the most reliable estimate of road damage.
3. Determine the mean equivalency factor for each class of heavy vehicle travelling in each direction. It is customary to assume that the axle load distribution of the heavy vehicles will remain unchanged for the design period of the pavement.

This method of determining the mean equivalency factors must always be used; calculating the equivalency factor for the average axle load is incorrect and leads to very large errors.

The number of equivalent standard axles (ef) of an axle is related to the axle load

as follows: $ef = (L/8160)^n$ (for loads in kg)

Or $ef = (L/80)^n$ (for loads in kN)

Where:

ef = Number of equivalent standard axles (ESAs)

L = Axle load (in kg or kN)

n = Damage exponent (n = 4.5).

To a reasonable extent, however, pavement thickness design is not very sensitive to cumulative axle loads and the method recommended in this manual provides fixed structures of paved roads for ranges of traffic as tabulated below [8].

Table 2.3: Traffic classes for flexible pavement design [8]

Traffic Classes	Range of ESAs (Millions)
LV1	<0.01
LV2	0.01 - 0.1
T1/LV3 (See note)	0.1 - 0.3
T2/LV4 (See note)	0.3 - 0.5
T3/LV5 (See note)	0.5 - 0.7
T3/LV5 (See note)	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0
T6	6.0 - 10
T7	10 - 17
T8	17 - 30
T9	30 - 50
T10*	50 - 80
T11	>80

As long as the estimate of cumulative equivalent standard axles is close to the center of one of the ranges, any errors are unlikely to affect the choice of pavement design. However, if estimates of cumulative traffic are close to the boundaries of the traffic ranges, then the basic traffic data and forecasts should be re-evaluated and sensitivity analyses carried out to ensure that the choice of traffic class is appropriate. Depending on the degree of accuracy achieved, if in doubt, selecting the next higher traffic class may be appropriate [8].

2.2.3.3 Environmental Factors

Environmental factor affect the performance of the pavement material and causes various damage. Environmental factor that affect pavement are two type temperature and Precipitation. Also the presence of water in the sub-base or subgrade soil underlying the pavement layers frost heaves.

2.2.3.4 Temperature

The effect of temperature on asphalt pavement is different from that of concrete pavement. Temperature affect the resilient modulus of asphalt layer, while it induces curling of concrete slab in rigid pavement, due to difference in temperature of top and bottom slab ,temperature stresses or fractional stress are developed .while in flexible pavement dynamic modulus of asphalt concrete various with temperature.

2.2.3.5 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 sub - base and poor subgrade soil of low bearing strength [13].

2.2.4 Treatment Types of Defects

2.2.4.1 Introduction

All roads deteriorate with time as a result of traffic and environmental effects. The deterioration may be relatively easy to correct or may require major works, depending on the causes and extent of deterioration. The works processes for keeping roads in good condition are often subdivided into the following categories: (i). Routine maintenance – maintenance that needs to be done at relatively short intervals such as cutting grass and cleaning drainage ditches. (ii). Emergency maintenance - maintenance that has to be done immediately as a result of an unexpected problem e.g. clearing a rock fall. (iii). Periodic maintenance – maintenance that needs to be done at longer intervals of, say, 5-10 years e.g. surface dressing. Usually this category excludes structural strengthening. (iv). Rehabilitation – this term is commonly used when structural strengthening is required and includes overlaying. (v). Reconstruction – this usually means that at least one layer of the pavement needs to be reprocessed. (vi). Upgrading – this usually means that strengthening and some realignment are required. The graphical representation of the structural condition along with their service age or traffic is as follow [4].

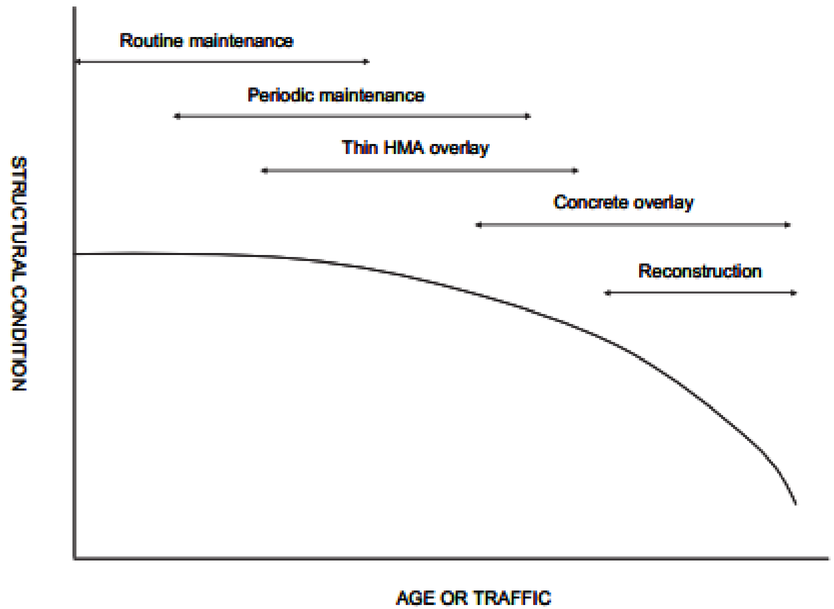


Figure 2.2: Timing for the maintenance and rehabilitation of concrete roads [4]

The selection of appropriate rehabilitation or maintenance is based on a number of considerations. Firstly, the cause of deterioration in the existing pavement must be correctly identified and its importance assessed. Secondly, attention should be given to the nature, extent and severity of the deterioration to check what effect it will have on the treatments that are being considered. Finally, the strategy must be economically viable taking into consideration both the costs of maintenance and the vehicle operating costs over a number of years [4].

Avoidance is usually cheaper than treatment and investment in identifying and dealing with potential problems early on would probably lead to savings in the medium and long term. This is particularly the case with respect to the control of side ditch/drain runoff and the control of erosion beneath culverts. Low cost measures using local materials wherever possible could be usefully adopted [16].

2.2.4.2 Selection of Type of Treatment

- **Surface defects -** There are some surfacing defects which, if localized, can be treated at this stage without the need for further testing. Suggested treatments for these types of pavement distress are summarized as below.

Table 2.4: Surfacing defects - roads with asphalt surfacing [4]

Defect	Extent	Maintenance treatment	Notes
Fretting or stripping	<10%	Local patching	Application of a proprietary rejuvenator may prevent further fretting.
	>10%	Patching followed by surface dressing or slurry seal	
Bleeding or fatting-up	<10%	No action	Local application of heated fine aggregate may be required if poor skid resistance is a problem.
	>10%	Additional tests required	A new surfacing may be required
Loss of texture and/or polishing of aggregate	<10%	No Action	
	>10%	Additional tests required	A new surfacing may be required
Potholes	Any	Patching	Potholes are the result of other failures such as cracking and deformation and additional tests will usually be necessary
Edge failures	Any	Patch road and reconstruct the shoulder	

- **Structural defects -** Deflection measurements and Dynamic Cone Penetrometer (DCP) tests are used to obtain important information about the structural properties of the road pavement, to identify the cause of differential performance between sub-sections and to provide information for the maintenance or rehabilitation of the section [4].

Also, laboratory tests are used to obtain the engineering properties of materials of pavement layers and enable to identify the respective causes.

2.2.4.3 Construction considerations

The careful and correct preparation of the existing pavement prior to the construction of an overlay is essential to optimize overlay performance. Much of the deterioration that occurs in overlays results from deterioration that was not repaired adequately in the existing pavements. The condition of the existing pavement consists of three basic types namely [4];

- Deep structural weakness.
- Surfacing defects that are structural in nature.
- Relatively superficial surface defects that are not themselves structurally critical but can affect the behavior of the overlay.

2.3 Perpetual Design Life

Determining an appropriate design period is the first step towards pavement design. Many factors may influence this decision, including budget constraints. However, the designer should follow certain guidelines in choosing an appropriate design period, taking into account the conditions governing the project. Some of the points to consider include functional importance of the road, traffic volume, location and terrain of the project, financial constraints and difficulty in forecasting traffic. Usually it is economical to construct roads with longer design periods for important roads and for roads with high traffic volume. Where rehabilitation would cause major inconvenience to road users, a longer period may be used. For roads in difficult locations and terrain where regular maintenance proves to be costly and time consuming because of poor access and non-availability of nearby construction material sources, a longer design period is also appropriate [8].

2.4 Shoulder

Shoulders participate in the structural function of a road pavement, providing lateral support for the pavement layers. They should help in removing surface water from the road surface and facilitate the internal drainage of the pavement. They are especially important when unbound materials are used in the pavement. It is also recommended that shoulders on paved roads having a width less than 1m should be paved. Shoulders give additional width for emergency and temporary parking [8].

2.5 Drainage Structure

Water is the main contributor to the failure and damage to roads. Water can be in the form of ground water, surface water (streams and rivers) or rain, as runoff from the surrounding areas. Also, water may flow laterally from the pavement edges, or it may seep upward from a high ground water table. The water flow can damage the road in several ways. Water-related damage to pavement can cause one or more of the following forms of deteriorations:

reduction of base, sub base, and sub grade strength, differential swelling in expansive sub-grade soils, stripping of asphalt in flexible pavements, and movement of fine particles into base or sub base materials resulting in a reduction of hydraulic conductivity considerably. The damage to the road can be reduced if the flow of water is controlled. Minor damages can easily be repaired as part of the regular maintenance provided to the road and its structures. If the flow of water is not properly managed, the deterioration of the road will be more serious and occur more rapidly. This will lead to higher maintenance demands and in the worst cases result in serious damage [21].

Drainage quality is an important parameter which affects the highway pavement performance. The excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement. Drainage is the most important aspect of road design. Proper design of drainage is necessary for the satisfactory and prolonged performance of the pavement. In designing drainage, the primary objective is to properly accommodate water flow along and across the road and conveniently transport and deposit the water o the downstream without any obstruction in the flow [22].

2.6 Design Subgrade Strength

To determine the subgrade strength to use for the design of the road pavement, it is apparent that it is necessary to ascertain the density-moisture content strength relationships specific to the subgrade soils encountered along the road under study. It is also necessary to select the density which will be representative of the subgrade once compacted. Estimating the subgrade moisture content that will ultimately govern the design, i.e. the moisture content following the construction, is also required. It is recommended to determine the moisture content as a first step in the process, as this could influence the subsequent ones [8].

2.7 Moisture Content

It is well known in pavement engineering that moisture can have a significant detrimental effect on the performance and bearing capacity of pavement structures. Excess moisture presence in pavement structures usually results in accelerated pavement distresses, particularly when combined with heavy axle loads. Both field observations and laboratory based research studies have shown that proper drainage can greatly improve pavement performance and increase its service life. Then, understanding moisture variation and movement in pavement structures and moisture-related distresses have become of great interest among the pavement research community. This has resulted in development of non-destructive techniques for in situ real-time measurement of moisture content within the pavement systems. The moisture related deterioration mechanisms greatly depend on the type of pavement structure, the material, the topography of the section, the climate and the condition of the pavement surface. In thin flexible pavement structures, unbound granular layers and subgrade soils undergo higher traffic load stresses. Since unbound pavement materials are generally sensitive to moisture content, thin pavement structures show higher sensitivity to moisture variations. Thus, their performance is highly dependent on their moisture condition and prolonged exposure to high moisture content can result in pavement instability and large resilient and accumulated permanent deformations. This highlights the significant role of maintaining an intact surface course with a functional drainage system [23].

Moisture can enter pavements by means of: a) capillary action, b) infiltration from the surface, and c) seepage from surrounding areas. Moisture can occupy pavements as liquid water or moisture vapor above the capillary fringe [37].

2.8 Dynamic Cone Penetrometer

2.8.1 Introduction

Soil penetration testing devices like the DCP have a long, but subdued history. Perhaps the earliest penetration testing devices were driven piles. On a project requiring piles, a builder would install "test" piles to determine their required length. These "test" piles would be driven until a certain rate of penetration was achieved. Once that rate was reached, it was assumed that future installation of the same length piles would be satisfactory. The earliest record of a subsoil penetration testing device similar to the DCP is a "ram penetrometer," developed in Germany at the end of 17th century by Nicholas Goldman. The next major development again came from Germany, when Künzel in 1936 developed what was known as a "Prüfstab". This device was later used by Paproth in 1943, and eventually become standardized in 1964 as the "Light Penetrometer", German Standard DIN 4094 [25].

The dynamic cone penetrometer test (DCP) has been widely used for field exploration and quality assessment of sub-soil layers. DCP device is distinguished by its economy and simplicity to operate and its superiority to provide repeatable results and rapid property assessment [32]. In addition; the important feature of the dynamic cone penetration could be drawn in the following:

- Its capability to provide a continuous record of relative soil strength with depth
- It is simple to operate and is conducted in very confined spaces without the need for trucks of heavy machinery that may not have an easy access to the site or may damage existing installations
- DCP test can be used in the sandy soil where it is difficult to obtain undisturbed samples, especially when loose or submerged sandy soil is encountered.

DCP is a practical device to evaluate the base and subgrade during construction which can greatly develop the quality monitoring of pavement unbound materials. In addition, the required time to run one test was reduced to one-fifth using an automated DCP. However, very small penetration rates were observed in some of the tests, which they related to the non-homogenous nature of subgrade soil and presence of small rocks [33].

CBR can be fairly estimated from DCP; hence, CBR test can be replaced by DCP for preliminary design purposes in roads construction to assess the relative strength of road subgrade [34].

2.8.2 Test Procedure

The standard DCP uses an 8kg hammer dropping through a height of 575mm and a 60° cone having a maximum diameter of 20mm. The instrument is assembled as shown in Figure 2.3. It is supplied with two spanners and a tommy bar to ensure that the screwed joints are kept tight at all times. To assist in this the following joints should be secured with a non-hardening thread locking compound prior to use: i) Handle/hammer shaft ii) Coupling/hammer shaft iii) Standard shaft/cone. The instrument is usually split at the joint between the standard shaft and the coupling for carriage and storage and therefore it is not usual to use locking compound at this joint. However it is important that this joint is checked regularly during use to ensure that it does not become loose. Operating the DCP with any loose joints will significantly reduce the life of the instrument [4].

2.8.3 Interpretation of Results

Relationships between DCP readings and CBR have been obtained by several research authorities. Agreement is generally good over most of the range but differences are apparent at low values of CBR in fine grained materials. It is expected that for such materials the relationship between DCP and CBR will depend on material state and therefore, if more precise values are needed it is advisable to calibrate the DCP for the material being evaluated [4].

2.8.4 Benefits and Limitations

The DCP offers many benefits compared to other similar hand-held testing devices. Its benefits make the device not only inexpensive, portable and easy to operate and understand but also the most versatile among other similar equipment.

The dynamic cone penetrometer has its own limitations; some of these are caused by the equipment operator. One should not be surprised to find out that the result of two DCP tests done on the same site only a few meters apart is not the same. These errors include tilting of the equipment, falling height of the hammer, etc. It is also difficult to penetrate hard and granular materials and as in most dynamic tests, the DCP test does not give reliable result in saturated fine graded soils. This is because the dynamic load from the equipment is carried by a developed pore water pressure rather than the soil grains in these types of soils.

CHAPTER THREE

RESEARCH MEHODOLOGY

3.1 Description of The Study area

3.1.1 Background and Accessibility

The Government of the Federal Democratic Republic of Ethiopia was secured a loan from the African Development Bank (AFDB) towards the cost of rehabilitation of existing Bedele - Metu Road Project, Lot -II: km 61+000-111+659 (50.659 km) asphalt road. The starting station is from the town of Bedele. Bedele – Metu road is a part of 208 Km long Nekemte - Bedele - Metu Road projects under Oromia Region, which was built several 30 years ago with asphalt surfaced and currently serves moderate level of traffic. The project road forms part of the major Trunk road in the region which connects Addis Ababa to Jima to Gambela town passing through the major towns in the project section Bedele - Metu. It is part of Djibouti – Juba road corridor connecting Addis Ababa - Nekemte - Gambela up to South Sudan Border. Project aims to promote trade and alleviate poverty through highway infrastructure development and the management of road-based trade corridors and regional integration between different cities by improving transport communication. The upgrading will providing socio-economic benefits like increased social services, reduced transport cost, access to remote villages, immediate access to exports thereby leading to increase in the yield of agricultural products especially coffee being one of the major crops. The road is upgraded to 7.0 m carriageway with Asphalt Concrete course with 0.5/1.5 m width Bituminous Macadam on either side. The functional classification of the road is Trunk road with geometrical classification of DS4 standard Asphalt concrete road. Bedele - Metu road was constructed to a paved road about 20 years ago [6].

The road map with their starting and ending detailed GPS locations are shown below.

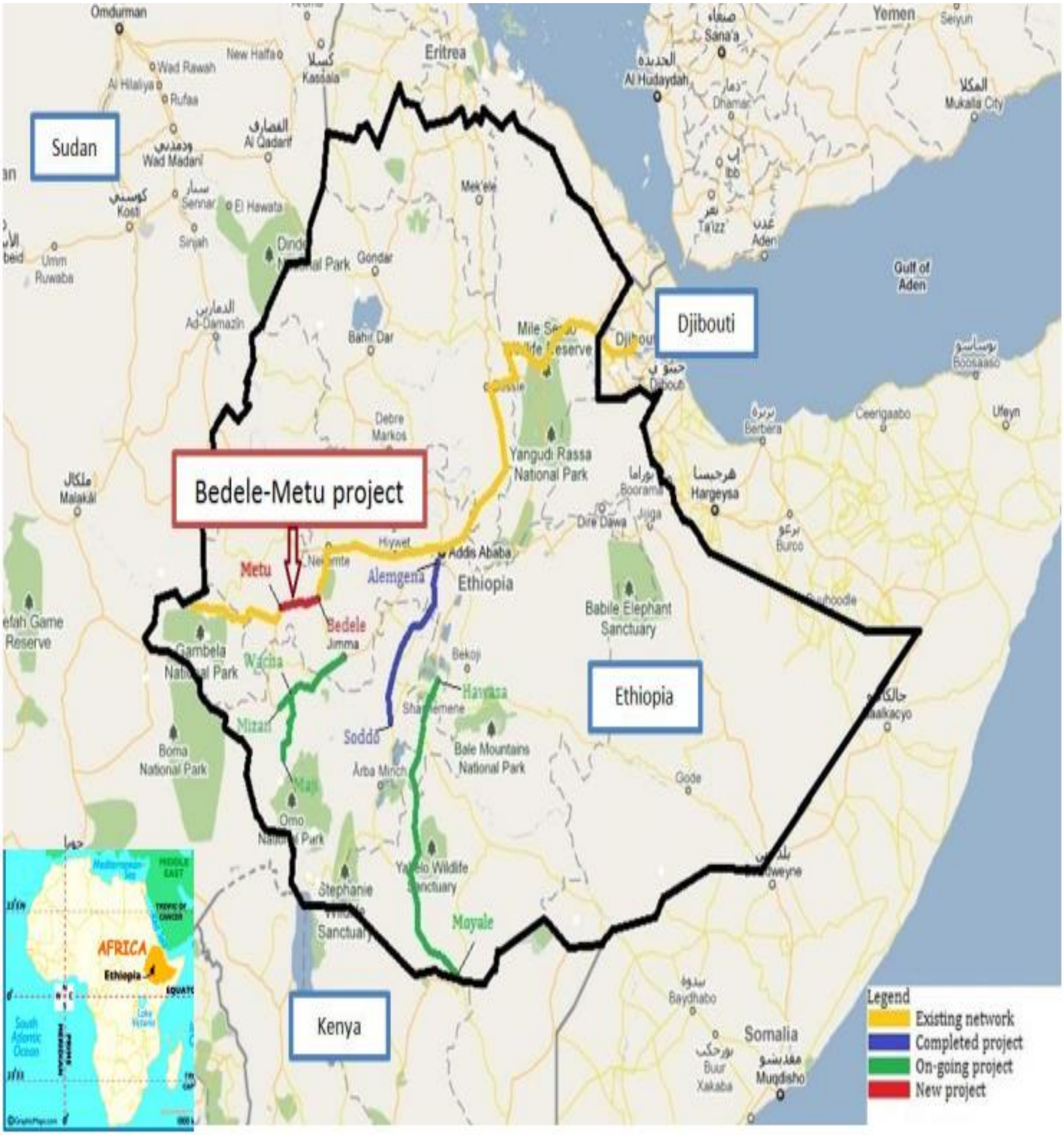


Figure 3.1: Road map of the study area (Google Image)

Table 3.1: Project starting and ending GPS location (Google map)

<table>
<tr><th>Station</th><th colspan="2">Project Location</th><th colspan="2">Reference/0+000/Bedele Town</th></tr>
<tr><td rowspan="2">Starting/61+000</td><td>Longitude</td><td>Latitude</td><td>Longitude</td><td>Latitude</td></tr>
<tr><td>35.946117</td><td>8.375310</td><td rowspan="3">36.352220</td><td rowspan="3">8.455961</td></tr>
<tr><td rowspan="2">Ending/111+659</td><td>Longitude</td><td>Latitude</td></tr>
<tr><td>35.598489</td><td>8.311617</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

3.1.2 Topography

The Project road traverses mainly through rolling and mountainous and short escarpment. Rolling comprises 54%, mountainous 37% and the remaining 9% is escarpment terrain of the total terrain classification. There are four deep gorges in the whole stretch of the road. The rolling sections are mainly located ahead and past the gorges and most of the mountainous and escarpment section are contained in sides of the gorges. The detail descriptions are tabulated as Table 3.2 [6].

Table 3.2: Terrain classification [6]

Station		Length (Km)	Terrain	Percentage (%)
From	**To**			
61+000	63+750	2.750	Rolling	**54**
68+700	72+200	3.500		
73+800	76+100	2.300		
76+100	77+800	1.700		
77+800	80+200	2.400		
90+300	98+450	8.150		
101+450	107+000	5.550		
109+000	109+800	0.800		
Total -1		**27.150**		
63+750	68+700	5.050	Mountainous	**37**
72+200	73+800	1.600		
80+200	81+700	1.500		
84+350	86+700	2.350		
89+050	90+300	1.250		
98+450	101+450	3.000		
107+000	109+000	2.000		
109+800	111+659	1.859		
Total -2		**18.609**		
81+700	84+350	2.650	Escarpment	**9**
86+700	89+050	2.350		
Total -3		**5.000**		
Total		**50.759**		**100**

3.1.3 Geology

The project is found in South West part of the country at the Western plateau. The plateau is formed due by enormous in suit weathering of ignimbrite rock and fresh basaltic rock. This rocks are found massive, boulders and in fragment form. The Bedele- Metu road section area comprises of four types of geological formations. Most part of the geology of the project area lays in-situ weathering of Ignimbrite rock and a volcanic regime [24].

3.1.4 Road Works and Pavement Layers

The functional classification of the road is trunk road with geometrical classification of DC5 asphalt concrete road. The project detail description of project works is shown refer to table as Table 3.3 [6].

Table 3.3: Descriptions of project road works [6]

Section	Carriageway	Crust
Rural	7.0 m wide with 0.5 to 1.5 m Shoulders	50 mm AC, 200 mm Base Course, 350 mm Sub Base Layer
Town	7.0 m wide undivided Carriageway with 3.5 m Parking Lane and 2.5 m wide Pedestrian Walkway on both sides	50 mm AC, 200 mm Base Course, 350 mm Sub Base Layer
Village	7.0 m wide undivided Carriageway with 2.5 m wide Pedestrian Walkway and RCC Drain on both sides having 0.90m width	50 mm AC, 200 mm Base Course, 350 mm Sub Base Layer
Expansive Soil Stretch (Fill Sections)	7.0 m undivided Carriageway with1.50/0.50 m wide Shoulders on both sides	50 mm AC, 200 mm Base Courses, 350 mm Sub Base Layer. The top 600 mm Problematic Soil should be excavated and replaced with Selected Borrow Material having CBR value of greater than 5% and Swell Index<2%.
One side fill- One side deep cut in mountainous (for cut> 10m)	7.0 m undivided Carriageway with1.50/0.50 m wide Shoulders on both sides with 0.90 m RCC ditch on cutting side	50 mm AC, 200 mm Base Course, 350 mm Sub Base Layer
One side fill- One side cut (for cut<10m)	7.0 m undivided Carriageway with1.50/0.50 m wide Shoulders on both sides with 0.90 m RCC ditch on cutting side	50 mm AC, 200 mm Base Course, 350 mm Sub Base Layer

3.2 Study Design

For this study; experimental, descriptive, quantitative and qualitative types of research approach were adopted directly or indirectly. Calling of experimental and descriptive types of research are telling the fact for experimental identification of the problem, practical cause, numerical analysis and their solution. Whereas, qualitative study gives impression of the findings and quantitative study was used to describe the numerical aspects of the research finding.

3.3 Research Procedure

The procedures utilized throughout the conduct of this research study are as follows:

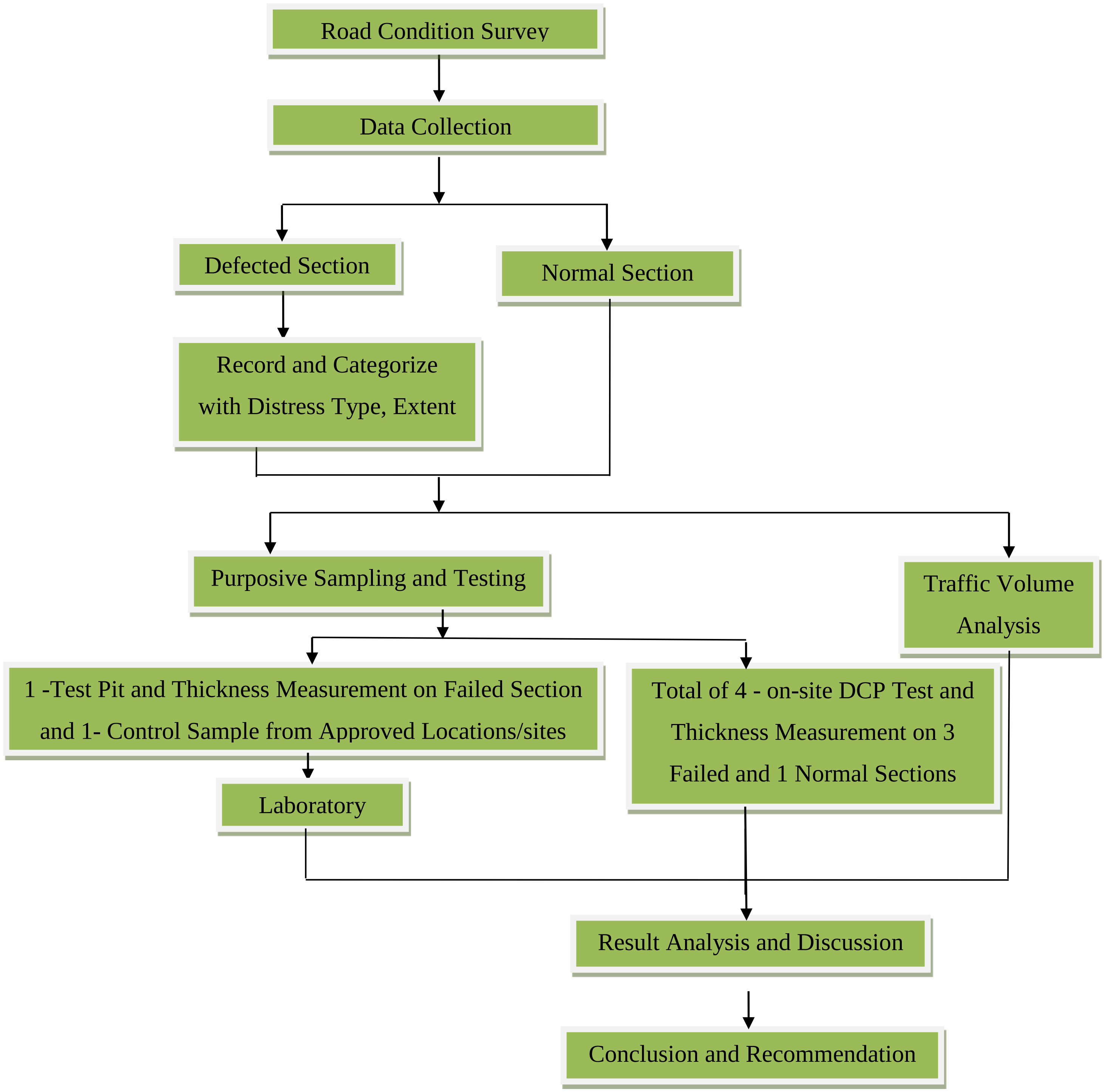


Figure 3.2: Research procedure

3.4 Population

The research populations were enclosed from station 61+000 to 111+659 section of the roads. The references of the station are from the town of Bedele, Oromia National Regional State. But, the target populations were assessed and result obtained for the genuine causes of the premature failure sections. The vital materials that were tended to be tested/measured are from each of the pavement layers.

3.5 Sampling Size and Procedure

Purposive sampling technique was adopted for conducting destructive and non-destructive testing and measurement. Destructive sampling and material testing was carried out on 1 failed section and 1 representative control sample from the respective locations of AC-normal section and the underneath materials were from the nearby material locations.

In order to achieve the objectives of the research, the following procedures were followed;

- The pavement was divided into sections and/or sample units on the basis of preliminary site visit program of the study project on the date of 20/09/2020 with visual observations and few measurement tools. Also, desk assessment was conducted using project data’s.
- In consideration of current pavement condition, length coverage and available time, resource, money, and manpower; road condition survey was conducted on the date of 24/09/2020 and 25/09/2020.
- One representative sample was taken on defected sections on the basis of defect type and severity level that badly deteriorated locations which enable to block traffic movements. Also, one representative sample from AC layer (on verge side and wheel path) was taken on normal sections of the project to use as control sample and for the underlying layers the sample were taken from approved locations/sites through systematic and appropriate techniques. Subsequently, subsequent laboratory tests were conducted to evaluate the causes of the failures on ERA, Jimma Road Network and Safety Management directorate laboratory room.
- Also, four on site DCP tests were conducted on the basis of defect type and severity level along the study area.

Hence, the test results were analyzed in reference with the control sample, project specification and manuals of ERA, ASTM and AASHTO.

3.6 Study Variables

3.6.1 Dependent Variable

- Premature pavement failures and its respective treatments

3.6.2 Independent Variables

- Defect type
- Road Layer Thickness
- Traffic Volume
- Surface and sub - surface water
- Gradation
- Atterberg limit value
- Moisture content
- Proctor/Density
- CBR

3.7 Adopted Methods and Supportive Equipment and/or Tool

The main supportive equipment's employed for road condition assessment, samplings and testing operations are as follows;

- Vehicle Equipped With Odometer
- Distance Measuring Wheels (100000 m)
- Condition Survey Manual
- Wedge
- Straight Edge
- 5 m Measuring Tape
- Scientific Calculator
- Asphalt Cutter
- Asphalt Core Cutter
- Laboratory Equipment's

- Digital Camera
- DCP Machine
- Traffic Cone
- Water Bag
- Printed Forms
- Clip Boards
- Ballpoint Pens
- Paint
- Shovel, Brush, Sack and Other Tools

In addition, the survey vehicle was used as a shield against traffic, a safety barrier. The vehicle continued to be used as a measuring device unless there were sufficient kilometer posts to aid location referencing.

3.8 Data Collection Process

Data collection process was performed using both primary and secondary data collection techniques as soon as getting the required information.

3.8.1 Primary Data Collection

In order to attain the purpose of this research work, ethical considerations was concentrating on the context of my research work.

Before starting any data collection, formal letter was taken from JIT and an official permission was obtained from Ethiopian Road Authority, Jimma Road Network and Safety Management Directorate for both of road condition assessment, DCP/field and laboratory works. Then the data collection process was started with including;

- Preliminary site visit on the date of 20/09/2020
- Field visual inspection on the date of 24/09/2020 and 25/09/2020
- Detail pavement condition survey with DCP, field measurements and sampling on the date of 30/10/2020 and 31/10/2020.
- Laboratory tests were conducted on the date from 02/11/2020 to 21/11/2020.

Four on site DCP test, one sample unit on failed section and also one control sample were took over as per the required procedures. Quantitative as well as qualitative data types were been collected and analyzed to determine the existing pavement condition and to measure the level of pavement failures quantitatively. Road condition survey, DCP test, direct field measurement, determining of the engineering properties of pavement layers (due to laboratory tests) and some of secondary data were been the main sources for quantitative data and the preliminary survey was also a source for qualitative data. Those all the laboratory-tested data‘s were utilized based on the necessary input parameters for the analysis by comparing with project specification and ERA manuals.

While conducting road condition survey over the study area, the following important parameters were included as far as possible.

Table 3.4: Data and Common Surface Defects to be Recorded [4]

S/No.	Item	Description
1	Road Number	The nationally accepted route number
2	Form Number	Numbers to run consecutively
3	Date	Day/month/year
4	Inspector/Data Collector	Name of inspector/data collector
5	Start Location	If an established marker is available is should be used. If not, permanent markers such as junctions should be used
6	Direction	The direction towards a permanent feature, preferably a large town
7	Road Width	Road width should be recorded at the beginning of each form
8	Surfacing	Type (Asphalt/bituminous seal)
9	Shoulder	Type (gravel/sealed) and width
10	Chainage	Chainage 61+000 is at the start point and continued adding
11	Crack Type	Letters Longitudinal, Transverse, Block, Crocodile or Parabolic
12	Crack Intensity	Defined by Six levels (Rating from 0 to 5)
13	Crack Position	Letters Verge side, Offside or Carriageway
14	Crack Width	Measurable using appropriate gauge

15	Crack Extent	Measurable using appropriate gauge
16	Potholes and Patching	Measurable using appropriate gauge
17	Edge Failures	Edge step (S) and edge damage (F), measured using calibrated wedge
18	Rut Depth	Maximum values recorded in either the verge side or offside wheel path. If shoving is occurring the value should be recorded
19	Depressions	Defects with short wavelengths where severity can be measured by the use of a simple 2-metre straight-edge and calibrated wedge. defects with longer wavelengths that are best quantified by the use of more sophisticated road profiling instruments (Roughness Measurements)

N.B.: The remaining exclusive items are governed by the recommended manuals of ERA.

3.8.2 Secondary Data Collection

The secondary data are found from written document through literature review, AADT from ERA, Road Asset Management, report and different as-built data of the study area, and previous research done in the area. Secondary data are collected during the research period to support the primary data.

3.9 Data Processing and Analysis

The preliminary and final pavement condition assessment, traffic data analysis, thickness measurement, DCP test and laboratory data was processed and analyzed using Microsoft office which using table, graph, figure and necessary formats to achieve the objectives

3.9.1 Pavement Condition Data Analysis

Project condition survey was performed in line with ERA condition survey manual. The pavement was divided into sections. Each section was divided into sample units. The type and respective quantities of the study project were assessed starting from the beginning of the project up to destination. After that, desk study were conducted by reviewing the site collected data’s with the project records and categorize by severity and extent matrices. The supportive manual for grouping of those of collected pavement defects in to severity and extent matrices is again ERA condition survey manual.

After finishing of the pavement condition survey, four onsite DCP tests from different road conditions, one sample unit from severely failed section and one another sample unit from normal section surfacing layer and the underlying materials from the approved nearby material locations were collected on the date of 30/10/2020 and 31/10/2020. The base for selection of the separate sample units were from severity and extent matrices with different defect type through higher percentage of severely damaged portions. While, budget constraint bounds the number of sample units.

3.9.2 DCP Test

After desk study stage, DCP tests were took over through the date of 30/10/2020 and 31/10/2020 on three severely deteriorated locations with various defect types and also on one normal section using standard data recording sheet from ERA manual. The equipment and Vehicle were supported by ERA, Jimma Road Network and Safety Management Directorate.

3.9.3 Traffic Volume, Coring, Sampling and Laboratory Test

In order to achieve the objectives of this research, it was first necessary to analyze different data‘s such as pavement condition data. Therefore, on the date of 30/10/2020 and 31/10/2020 adequate samples were collected and labeled immediately from each station for every pavement layers. The representative samples collected from more distressed portion (one in number) and one control sample, which were also from the AC surfacing, base course, sub base and subgrade filling/capping layer. Re-instating the 10cm cored and an area of (1.5*0.5) m locations was held using locally available material and C-30 concrete finishes. Immediately after extracting samples, these were transported to ERA, Jimma District laboratory center and the following measurement/tests were undertaken. Layer thickness measurement, determination of percentage of compacted bituminous mixtures, grain size analysis, Atterberg limit, compaction tests and California Bearing Ratio (CBR) Tests were made to understand the general behavior of the road materials and to checking whether it effects on the pavement distresses or not. The necessary tests were conducted for all the samples and the summary of the results are presented and discussed in **Chapter 4** of this research. The tests were processed and analyzed according to AASHTO, ASTM and ERA specification. The laboratory data analyses with their results are attached under appendices.

Traffic load analysis and layer thickness measurement were also part of the research that thoroughly evaluated and comparatively assessed with the existing project data's.

3.10 Ethical Considerations

The permission of Jimma University, Jimma Institute of Technology, concerned local administrative and Ethiopian Roads Authority were obtained for conducting this research study. Also ethical considerations will insure;

- Confidentiality of the data that were wanted to obtain
- Assuring that the results are accurately represent on what observed and/or grasped

The letters in which permission were obtained from the concerned body that enable to successfully accomplish my research work are attached refer as **Appendix H**.

3.11 Quality Assurance

Pre - test of the available instruments were done before the main data collection period begin and the data were collected after gaining an awareness on how to collect relevant data by principal investigator. Samples were collected from appropriate sources. Standard formats are used for data collecting and recording of test results to prevent loss of data. The collected data was also checked for reliability and accuracy.

CHAPTER FOUR

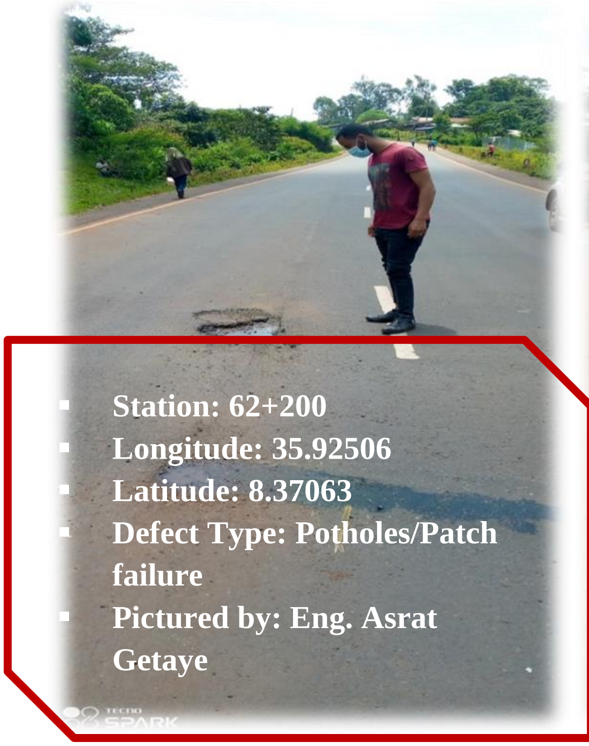
RESULT AND DISCUSSION

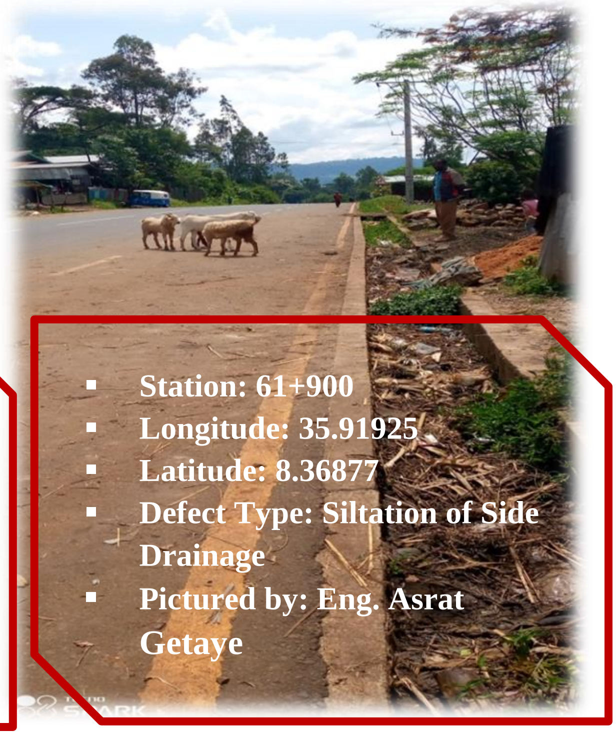
4.1 Pavement condition survey

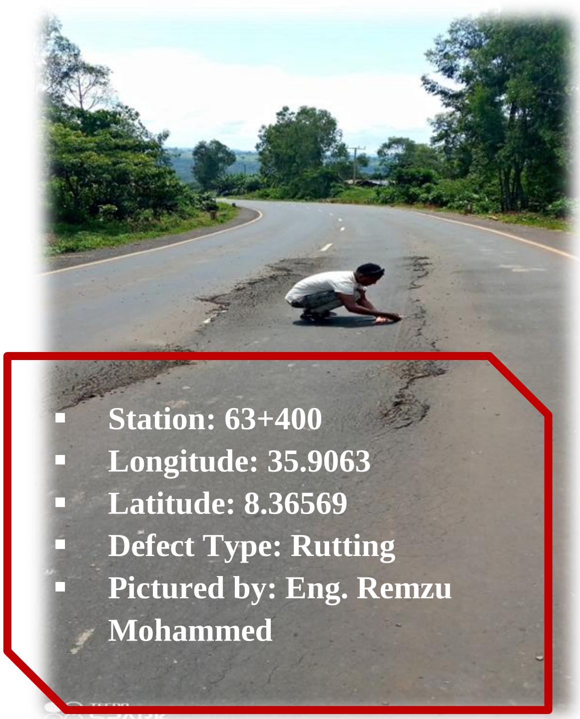
The road condition survey is an important part of maintenance management. The condition survey was conducted for the whole sections of the study project from 61+000 to 111+659. Technicians drive the roads in a vehicle equipped with a calibrated odometer. The driver was responsible for reading the odometer if it is not clear to the recording technicians. The survey vehicle was driven at an average speed of 15 kph by stopping as required to record data and inspect by walking on the features.

4.1.1 Survey Results

Preliminary site visit was made on the date of 20/09/2020 that enables to fix the homogeneity characteristics of the pavement structure of the project in abide with project documents and highly helping for efficient schedule of the detailed condition survey works. The Pavement condition survey has been done on the date of 24/09/2020 and 25/09/2020. The main objectives of the road condition survey was by recording to identify sites/road sections those are affected by deterioration, to determine the types and patterns of the available road defects to recommend the possible treatments of the distresses on the basis of previous related literatures. The whole project length from 61+000 to 111+659 was visually surveyed by recording the defect type with their dimensions and pictures using a Distance Measuring Wheels (100000 m) and steel measurement tape (5 m). The overall collected field survey data for entire carriageway, shoulder, side drainage and remaining ancillary works along with their details are annexed refer as **Appendix A**. Also, variable representative photographs from failed and normal sections of the study area are attached below.

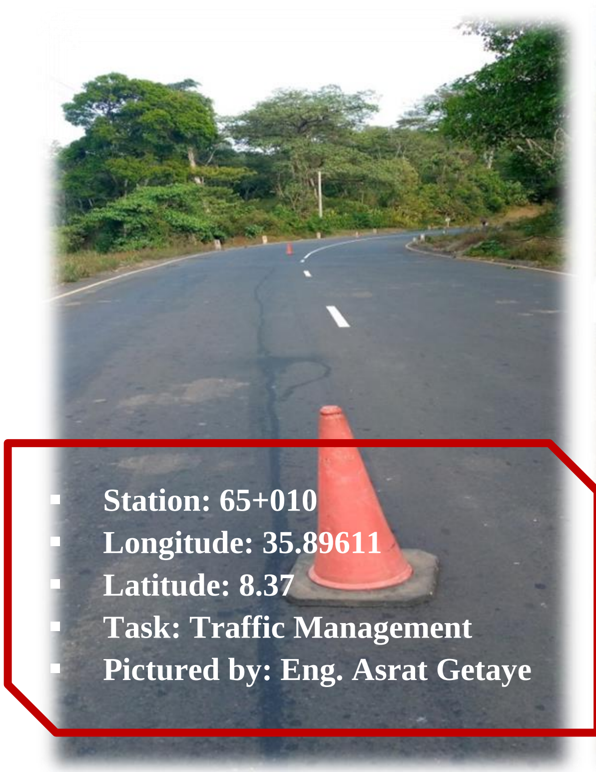

Station: 62+200
Longitude: 35.92506
Latitude: 8.37063
Defect Type: Potholes/Patch failure
Pictured by: Eng. Asrat Getaye


Station: 61+900
Longitude: 35.91925
Latitude: 8.36877
Defect Type: Siltation of Side Drainage
Pictured by: Eng. Asrat Getaye


Station: 63+400
Longitude: 35.9063
Latitude: 8.36569
Defect Type: Rutting
Pictured by: Eng. Remzu Mohammed


Station: 63+900
Longitude: 35.90181
Latitude: 8.36538
Defect Type: Stripping
Pictured by: Eng. Asrat Getaye


▪ Station: 65+200
▪ Longitude: 35.89481
▪ Latitude: 8.37009
▪ Defect Type: Rutting
▪ Pictured by: Eng. Remzu Mohammed


▪ Station: 65+010
▪ Longitude: 35.89611
▪ Latitude: 8.37
▪ Task: Traffic Management
▪ Pictured by: Eng. Asrat Getaye

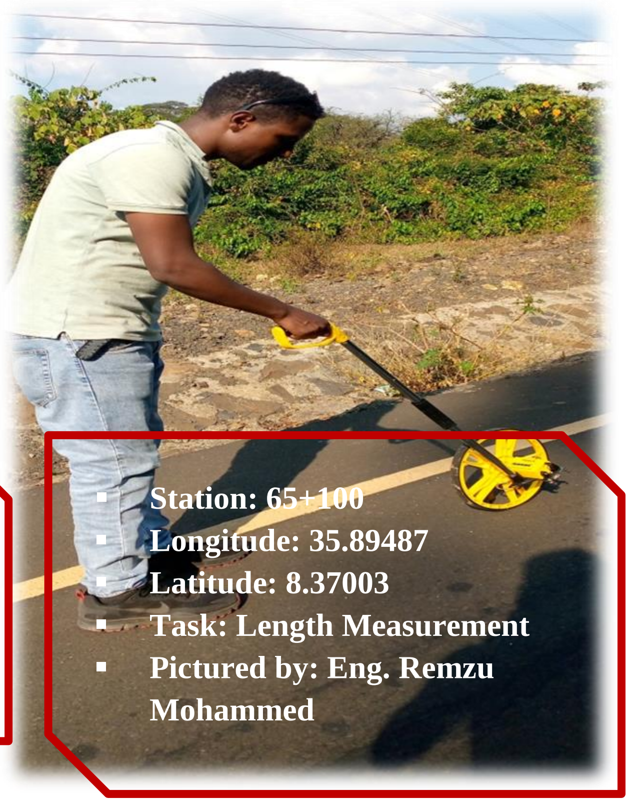

▪ Station: 65+100
▪ Longitude: 35.89487
▪ Latitude: 8.37003
▪ Task: Length Measurement
▪ Pictured by: Eng. Remzu Mohammed

Figure 4.1: Selected road defects along Bedele – Metu upgrading road project

Figure 4.2: Selected normal road sections along Bedele – Metu road upgrading project

The following pictures show the major defect types and their extent along Bedele - Metu road upgrading project.

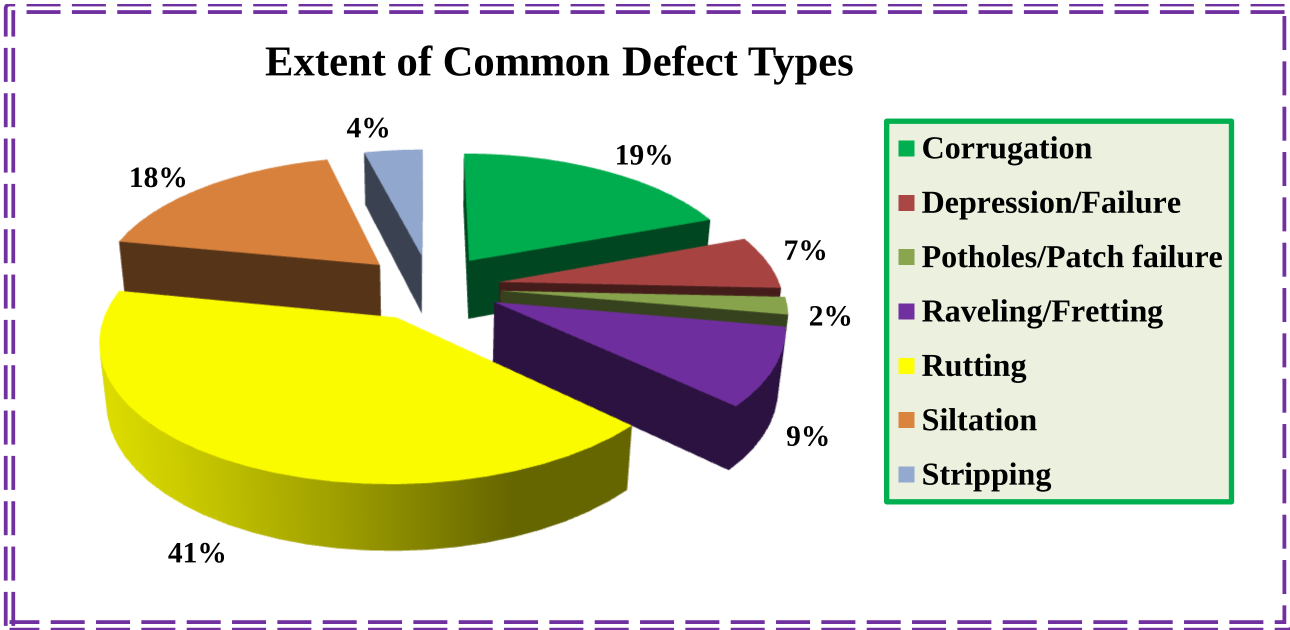


Figure 4.3: The percentage of common defects types with their extent along Bedele – Metu road upgrading project

Consequently, by considering the homogeneity characteristics of the project and for good accuracy level, the road was divided in to sections of 500 m length to evaluate the extent and severity levels. Finally, locations of test pit were determined by consideration of varying type of distress and its severity levels with high rating. Refer to appendix as **Appendix -B** the summary of Severity and extent of road defects on selected road portions.

4.2 Experimental Evaluation

4.2.1 Field Assessment and/or Test

The field assessment was carried out on the basis of the condition survey output. This task was aimed at assessing the cause which leads to premature failures of the pavement structure by practically working along the defected portion of the project by equipping with essential resources.

Based on field observation and measurement and project data's, the road has the following components.

- **Rural section and expansive soil stretch (fill section)** have 7 m wide undivided carriageway with 1.5/0.5 m wide shoulders on both sides.
- **Town section** has 7.0 m wide undivided Carriageway with 3.5 m Parking Lane, 2.5 m wide Pedestrian Walkway on both sides and 0.90 m width RCC Drain on both sides.
- **Village section** has 7.0 m wide undivided Carriageway with 2.5 m wide Pedestrian Walkway and 0.90 m width RCC Drain on both sides.
- **One side fill - One side cut section** 7.0 m wide undivided Carriageway with 1.5/0.50 m wide Shoulders on both sides with 0.90 m RCC ditch on cutting side.
- **Road side drainage** with channel type of unlined open drain in flat and rolling area for grade <5% and lined open drain in rolling area with grade >5% were adopted.

Hence, the project's cross sectional elements of Carriage way width and shoulder width for sections of rural, town and village are fulfilling the minimum requirements of ERA manual 2013 with geometrid design category of DC5. In addition, the project V-shaped ditch have fulfills the minimum requirements stipulated under ERA manual 2013 with width 500 mm and depth of 600mm. Unlined and lined open drain detail (including ditch slope) of the project are above the minimum requirements of ERA manual 2013 in accordance with the gradient level of less than 5% and greater than 5% respectively.

4.2.1.1 Pavement Layer Thickness

Thickness measurements for a given project were conducted in in two parts. The thickness for the AC - surfacing layer can be computed from the sample cores obtained from the required defected location on both verge side and along wheel path. While, the thickness measurement for the underlying layers takes placed in apparent with on - site CBR measurement (DCP) equipment. Hence, pavement layers with different strengths, the boundaries between them can be identified and the thickness of each layer can be identified.

The thickness of the top AC/surfacing layer was handled by 10cm core machine and asphalt cutter machine with the detail recorded data is attached under **Appendix J**.

The thickness of the underlying layers of Base course, sub-base and capping were identified by the DCP machine. The material property for base course, sub base and capping layer/subgrade fill/embankment are crushed aggregate, natural gravel from the approved borrow areas mixed with crushed rock aggregates in proportion of 65:35/ or 70:30 and selected fill from the approved borrow areas respectively. The summary of average thickness for surfacing layer and for each underlying layers are presented in the Table 4.1.

Table 4.1: Summary of pavement layer thickness with their material description

Pavement Layer Thickness				
Station	**Description**	**Layer Type**	**Estimated/Average Measured Layer Thickness, mm**	**Visual/Project Material Description**
63+400	Finished Road Elevation			
		AC/Surfacing	**47.87**	AC
	Base-course Elevation			
		Base-course	**198.00**	Crushed basaltic rock aggregate
	Sub-base Elevation			
		Sub-base Course	**349.25**	Crushed basaltic rock aggregate with light brown sandy soil
	Sub-grade Elevation			
		Sub-grade Fill/Capping		light brown sandy soil with gravel soil
	Existing Ground Condition			
64+015	Finished Road Elevation			
		AC/Surfacing	**45.25**	AC
	Base-course Elevation			
		Base-course	**198.70**	Crushed basaltic rock aggregate
	Sub-base Elevation			
		Sub-base Course	**349.40**	Crushed basaltic rock aggregate with light brown sandy soil
	Sub-grade Elevation			
		Sub-grade Fill/Capping		light brown sandy soil with gravel soil
	Existing Ground Condition			
78+900	Finished Road Elevation			
		AC/Surfacing	**38.66**	AC
	Base-course Elevation			

		Base-course	**198.50**	Crushed basaltic rock aggregate
	Sub-base Elevation			
		Sub-base Course	**349.00**	Crushed basaltic rock aggregate with Gravel soil
	Sub-grade Elevation			
		Sub-grade Fill/Capping		Gravel soil
	Existing Ground Condition			
85+490	Finished Road Elevation			
		AC/Surfacing	**39.88**	AC
	Base-course Elevation			
		Base-course	**199.50**	Crushed basaltic rock aggregate
	Sub-base Elevation			
		Sub-base Course	**350.00**	Crushed basaltic rock aggregate with Gravel soil
	Sub-grade Elevation			
		Sub-grade Fill/Capping		Gravel soil
	Existing Ground Condition			

4.2.1.2 *Dynamic Cone Penetrometer (DCP) Test*

In order to investigate structural conditions in rapid measurement of the in situ strength of existing pavements constructed with unbound materials along structural failure zones and complement the research, Dynamic Cone Penetrometer (DCP) was adopted for identifying the cause of defects along the project.

DCP tests are particularly useful for identifying the cause of road deterioration when it is associated with one of the unbound pavement layers, e.g. shear failure of the road base or sub-base. A comparison between DCP test results from sub-sections that are just beginning to fail and those that are sound will quickly identify the pavement layer which is the cause of the problem. Where pavement layers have different strengths, the boundaries between them can be identified and the thickness of each layer estimated [4].

The employed DCP equipment has a standard with 8kg hammer dropping through a height of 575 mm and a 60° cone having a maximum diameter of 20mm. Three DCP test were conducted on the date 30/10/2020 and 31/10/2020 by considering the severity level and its variety type of road deterioration. Also, one DCP test was conducted on the same mentioned date at normal section of the road. By viewing and analyzing the field survey evaluation sheet for enabling to select the DCP test locations as of the following.

- Station 63+400 – Rutting defect type, severity and extent matrices are 3:1 respectively.
- Station 64+015 – Normal (no deteriorated) section.
- Station 78+900 – Potholes/Patching defect type, severity and extent matrices are 2:1 respectively.
- Station 85+490 – Depression/Failure defect type, severity and extent matrices are 3:1 respectively.

On - site recorded data with some computation at station 63+400 is refer to the table as Table 4.2 and the remaining recorded data in each of the stations are attached refer as **Appendix K.**

Table 4.2: DCP collected data @ station 63+400

Dynamic Cone Penetrometer (DCP) Test Field Sheet											
Site/Road				Bedele - Metu Lot - II (61+000 - 111+659)							
Test No.				DCP01							
Section No./Chainage			63+400		**Date**			30/10/2020			
Direction		Bedele - Metu			**Ave. Zero Reading of DCP, mm**			47.87			
Wheel Path		RHS			**Test Started**			9:30 AM			
No. of Blows	**Sum of Blows**	**Penetr. Depth, mm**	**Cum. Penetr., mm**	**No. of Blows**	**Sum of Blows**	**Penetr. Depth, mm**	**Cum. Penetr., mm**	**No. of Blows**	**Sum of Blows**	**Penetr. Depth, mm**	**Cum. Penetr., mm**
0	0		47.87	1	29	3.00	120.62	1	56	2.00	182.87
1	1	2.00	49.87	1	30	3.00	123.62	1	57	2.00	184.87
1	2	2.00	51.87	1	31	2.50	126.12	1	58	3.50	188.37

1	3	2.75	54.62	1	32	2.50	128.62	1	59	3.00	191.37
2	5	3.50	58.12	1	33	2.00	130.62	1	60	3.00	194.37
1	6	2.00	60.12	1	34	2.00	132.62	1	61	2.00	196.37
1	7	2.00	62.12	1	35	3.00	135.62	1	62	2.00	198.37
1	8	2.50	64.62	2	37	2.50	138.12	1	63	3.00	201.37
1	9	3.00	67.62	1	38	3.00	141.12	1	64	3.00	204.37
1	10	3.00	70.62	1	39	3.50	144.62	1	65	2.00	206.37
2	12	3.00	73.62	1	40	2.00	146.62	1	66	2.00	208.37
1	13	2.00	75.62	1	41	2.00	148.62	1	67	2.50	210.87
1	14	2.50	78.12	1	42	3.00	151.62	1	68	2.00	212.87
1	15	3.00	81.12	1	43	3.00	154.62	1	69	2.50	215.37
1	16	3.00	84.12	1	44	3.00	157.62	1	70	2.00	217.37
1	17	3.00	87.12	1	45	2.50	160.12	1	71	2.50	219.87
1	18	3.50	90.62	1	46	3.00	163.12	1	72	3.00	222.87
2	20	3.00	93.62	1	47	1.50	164.62	1	73	3.00	225.87
1	21	5.00	98.62	1	48	2.00	166.62	1	74	3.00	228.87
1	22	5.00	103.62	1	49	2.50	169.12	1	75	2.00	230.87
1	23	3.50	107.12	1	50	2.50	171.62	1	76	2.00	232.87
1	24	3.00	110.12	1	51	2.75	174.37	1	77	2.50	235.37
1	25	3.50	113.62	1	52	3.00	177.37	1	78	2.00	237.37
1	26	2.00	115.62	1	53	2.00	179.37	1	79	2.00	239.37
2	28	2.00	117.62	2	55	1.50	180.87	1	80	3.00	242.37
1	81	2.00	244.37	1	106	5.00	355.62	1	132	6.00	481.12
1	82	1.50	245.87	1	107	4.50	360.12	1	133	6.00	487.12
1	83	3.00	248.87	1	108	5.00	365.12	1	134	5.00	492.12
1	84	3.00	251.87	1	109	5.00	370.12	1	135	4.00	496.12
1	85	4.00	255.87	1	110	4.00	374.12	1	136	5.00	501.12
1	86	4.50	260.37	1	111	5.00	379.12	1	137	5.00	506.12
1	87	4.00	264.37	1	112	4.00	383.12	1	138	5.50	511.62

1	88	5.00	269.37	1	113	3.00	386.12	1	139	7.00	518.62
1	89	5.00	274.37	1	114	4.00	390.12	1	140	7.00	525.62
1	90	4.00	278.37	1	115	6.00	396.12	1	141	8.00	533.62
1	91	6.00	284.37	2	117	6.00	402.12	1	142	7.00	540.62
1	92	6.00	290.37	1	118	6.00	408.12	1	143	7.00	547.62
1	93	5.00	295.37	1	119	6.00	414.12	1	144	5.00	552.62
1	94	3.00	298.37	1	120	4.00	418.12	1	145	4.00	556.62
1	95	4.00	302.37	1	121	4.00	422.12	1	146	4.50	561.12
1	96	4.00	306.37	1	122	5.00	427.12	1	147	5.00	566.12
1	97	4.75	311.12	1	123	5.00	432.12	1	148	5.00	571.12
1	98	5.00	316.12	1	124	6.00	438.12	1	149	4.00	575.12
1	99	6.00	322.12	1	125	6.00	444.12	1	150	6.00	581.12
1	100	6.00	328.12	1	126	2.00	446.12	1	151	5.00	586.12
1	101	7.00	335.12	1	127	3.00	449.12	1	152	5.00	591.12
1	102	4.00	339.12	1	128	6.00	455.12	1	153	4.00	595.12
1	103	3.50	342.62	1	129	6.00	461.12	1	154	6.00	601.12
1	104	3.00	345.62	1	130	7.00	468.12	1	155	7.00	608.12
1	105	5.00	350.62	1	131	7.00	475.12	1	156	8.00	616.12
1	157	9.00	625.12								
1	158	9.00	634.12								
1	159	12.00	646.12								
1	160	11.00	657.12								
1	161	10.00	667.12								
1	162	12.00	679.12								
1	163	11.00	690.12								
1	164	9.00	699.12								
1	165	10.00	709.12								
1	166	11.00	720.12								
1	167	8.50	728.62								

1	168	9.00	737.62								
1	169	9.00	746.62								
1	170	9.00	755.62								

After a while, desk assessments were done by choosing from the several research authorities by the TRL instrument that has been designed for strong materials.

Since, from the different suggested methods below, the at hand instrument and suggested method forces for choosing the fourth option for quantifying the CBR values to unbound pavement layer of Base-course up to Sub-grade fill/ capping level. The calculated CBR values are summarized below and the detail results for the same are attached refer as **Appendix C**.

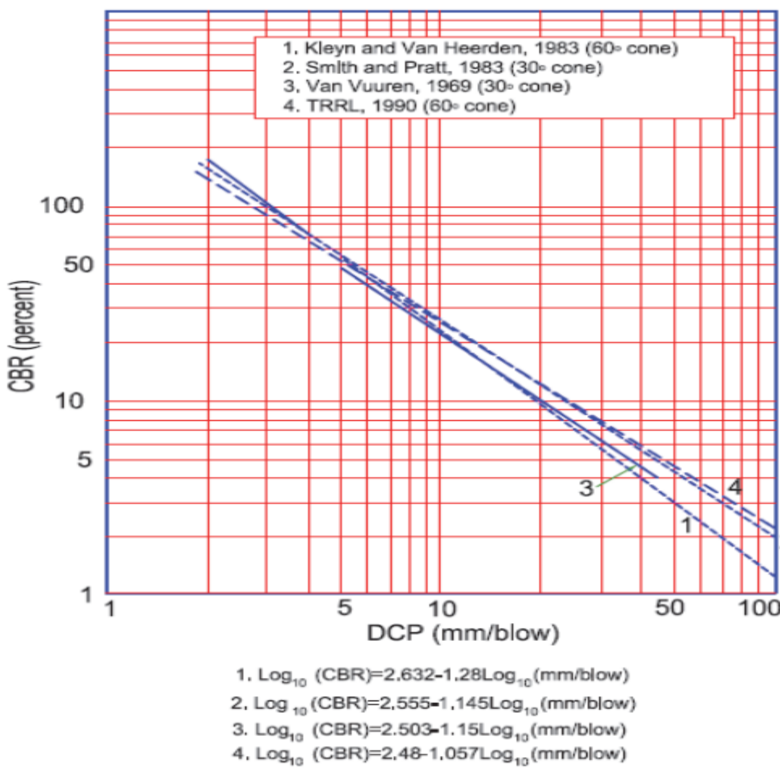


Figure 4.4: DCP - CBR relationships [4]

Table 4.3: Summary of DCP test results for sub-grade fill/capping, sub-base material and base-course materials

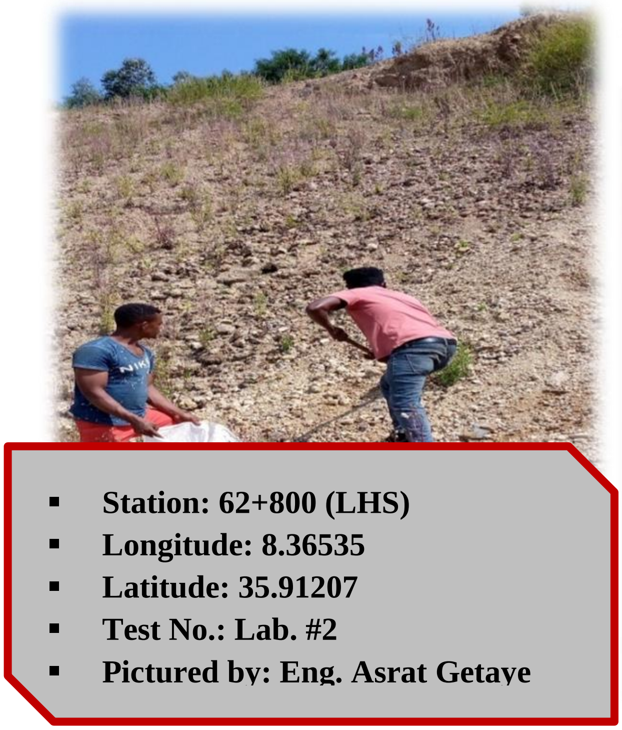
DCP Test			TRRL, 1990 (60^0 Cone)	
Station	**Layer Type**	**Estimated/Measured Layer Thickness, mm**	**Avr. Penetration Index (N), (mm/blow)**	**Calculated CBR, %**
63+400	AC/Surfacing	**47.87**		
	Base-course	**198.00**	2.503	114.492
	Sub-base	**349.25**	4.946	55.736
	Sub-grade Filling/Capping @	**160.50**	9.441	28.145
64+015	AC/Surfacing	**45.25**		
	Base-course	**199.50**	2.239	128.853
	Sub-base	**349.75**	5.054	54.479
	Sub-grade Filling/Capping @	**169.00**	9.941	26.651
78+900	AC/Surfacing	**38.66**		
	Base-course	**198.50**	2.500	114.651
	Sub-base	**349.00**	4.576	60.520
	Sub-grade Filling/Capping @	**169.00**	8.895	29.975
85+490	AC/Surfacing	**39.88**		
	Base-course	**199.50**	2.111	137.065
	Sub-base	**350.00**	5.392	50.876
	Sub-grade Filling/Capping @	**166.50**	9.794	27.074

Furthermore, herein below on-site pictures that illustrate location, defect type and test number for DCP tests.

Figure 4.5: Conducting on-site DCP test

4.2.2 Laboratory Assessment and/or Test

One test pit was dug at each at severely failed section of uniform section and one another sample was taken on nearby approved quarry/borrow areas and crusher plant locations. A total of two samples were taken from each layer of the pavement structure for about 75 kg to 115 kg to conduct essential laboratory tests. In addition, samples were taken from AC/surfacing layer using core cutter machine for checking thickness and percentage of compaction. In addition, primary works of the thesis including test pit excavation, sampling operations and others are show below.



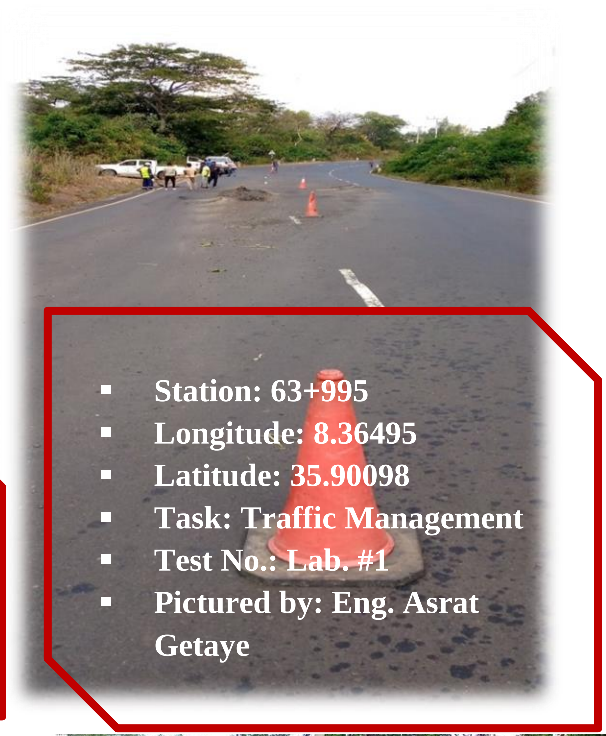


Figure 4.6: Summary of on-site test pit excavation and sampling operations

4.2.2.1 Pavement Layer Thickness

The thicknesses of asphalt concrete/surfacing layer, base course, sub base layer and subgrade fill/capping layer are measured from direct measurement on the test pit excavation. The results are tabulated as Table 4.4. The material property for base course, sub base, subgrade fill/capping layer materials used are Crushed basaltic rock aggregate, Crushed basaltic rock aggregate with light brown sandy soil and light brown sandy soil with gravel soil respectively as presented in the Table 4.4. Also, the detail recorded thicknesses for surfacing layer is attached refer as **Appendix J**.

Table 4.4: Measured Pavement layer thickness with their material description

Summary of Pavement Layer Thickness				
Station	**Description**	**Layer Type**	**Estimated/Average Measured Layer Thickness, mm**	**Visual/Project Material Description**
63+995	Finished Road Elevation			
		AC/Surfacing	**40.57**	AC
	Base-course Elevation			
		Base-course	**199.50**	Crushed basaltic rock aggregate
	Sub-base Elevation			
		Sub-base Course	**349.75**	Crushed basaltic rock aggregate with light brown sandy soil
	Sub-grade Elevation			
		Sub-grade Fill/Capping		light brown sandy soil with gravel soil
	Existing Ground Condition			

Since, the project design thickness from ERA catalogue with sub-grade strength class, S3 and traffic class, T6 are 5 mm, 20 mm, 350 mm and as required of AC, base-course, sub-base and sub-grade fill/capping respectively. The estimated/measured thicknesses of each layer are lightly departed from the design thickness or else from ERA manual thickness requirements with varying extents as discussed below and refer to the table as Table 4.16.

4.2.2.2 Required Laboratory Tests

Enough representative samples were collected from each test pit and/or appropriate source for each layer of Pavement structures. Samples were collected, labeled and transported to the laboratory center located at Jimma Road Network and Safety Management Directorate, Own Force Road Maintenance District of Jimma. A total of eleven samples (which are; Ten from AC/surfacing layer, two samples base-course material, two samples sub-base material and two samples sub-grade fill/capping layer) were collected to determine the material characteristics of the surfacing, road-base, sub-base and subgrade fill/capping. The samples were collected adjacent to the failed section, normal section and at locations where abundant material stocks are availing. The tests were conducted according to AASHTO and ASTM test method and the lab results are attached from **Appendix D** to **Appendix G**. Also, a few pictures showing laboratory works for some testing procedures are shown below and the comprehensive are attached under **Appendix L**.

- **AC/surfacing layer Density Test**

Asphalt density measurement has been carried on surfacing layer at four failed sections on verge side and along wheel path and one normal section on same locations with total of (10) ten samples. The sample locations are obtained from the formerly identified defected sections that enable for identifying the causes. Hence, the samples are acquired using 10cm core cutter machine. It was conducted by AASHTO test method T 166-93. The surfacing layer density test result and pictures are summarized below.

Table 4.5: Percentage of compaction for surfacing layer

Core No.	Location	Core Height (mm)	Wt. of Speci. in air (Dry) (gm)	Wt. of Speci. in air (SSD) (gm)	Wt. of Speci. in water (gm)	Vol. of Specimen (Cm^3)	Cor. factor for 25°C	Bulk Density of Core in (gm/Cm^3)	Max. Theo. Density of Mix (G_{mm}) (gm/Cm^3)	Mix spec. gravity (G_{mb})	% Compaction Spec. = min. 93%
			(A)	(B)	(C)	(D = B - C)	(k)	(E = k(A / D))	(F)	(G)	(G)=E /F*100)
Km 61+000 - 111+659											
1	63+400 RHS - Verge Side	47.85	869.5	870.0	531.5	338.5	1.00000	2.569	2.607	2.508	99
2	63+400 RHS - Wheel Path	47.89	874.4	875.2	532.7	342.5		2.553			98
3	63+995 LHS - Verge Side	40.70	703.5	704.4	421.7	282.7	1.0000	2.489	2.607	2.508	95
4	63+995 LHS - Wheel Path	40.44	696.2	696.8	418.5	278.3		2.502			96
5	64+015 CL - Verge Side	40.24	672.0	672.5	401.5	271.0	1.0000	2.480	2.607	2.508	95
6	64+015 CL - Wheel Path	40.26	672.6	673.3	399.4	273.9		2.456			94
7	78+900 RHS - Verge Side	38.00	687.4	691.6	423.6	268.0	1.0000	2.565	2.607	2.508	98
8	78+900 RHS - Wheel Path	38.72	685.1	693.4	421.7	271.7		2.522			97
9	85+490 RHS -	39.85	718.9	722.3	436.2	286.1	1.0000	2.513	2.607	2.508	96

	Verge Side										
10	85+490 RHS - Wheel Path	39.91	720.3	720.4	439.6	280.8		2.565			98

From the different mix design parameters of continuously graded AC wearing courses stipulated under ERA manual 2013, Critical Values of VIM (after Secondary Compaction) is the one tend to be sensitive to variations in composition. Hence, most of the above test result showed that secondary compactions are achieved early by departing from the target VIM 3 - 5 % limits. Hence, ERA manual declares the durable and stable mixes are within the range of 3 - 5 %. Rapid increment or decrement from the recommended range becomes one possible factor for early pavement failure. Pictures showing the test are attached under appendix.

- **Grain Size Analysis**

The project data confirmed that varying type of materials was used for constructing the pavement layers that locally found and fulfill the stipulated requirements. From those, two tests with each contained of two trials grain size analysis were conducted on locations range from 61+000 – 75+050. The reasons behind for selecting the stated section are due to occurrence of much severely and dispersed deterioration types. Also, the adopted test method is **AASHTO T- 27.** The detail tabular results with their drawn charts are attached in **Appendix D.**

Sub-grade fill/capping and sub-base material: The results of grain size analysis for the respective materials are summarized in the table below, while the detail analysis data are attached in same appendices.

Table 4.6: Results of grain size analysis for Sub-grade fill/capping and sub-base material

Average Cumulative % Passing					
Sieve Sizes	***Sub-grade fill/Capping***		***Sub-base***		**Specification Limits For Sub-grade**
	63+995	**62+800**	**63+995**	**62+800 &**	

				75+050	fill/Capping and Sub-base
50.000	100	100	100	100	**100**
37.500	90	85	93	83	**80 - 100**
20.000	76	68	82	69	**60 - 100**
5.000	62	55	64	56	**30 - 100**
1.180	45	42	50	40	**17 - 75**
0.300	24	21	23	23	**9 - 50**
0.075	9.1	6.7	7.8	8.2	**5 - 25**
Pan	0.0	0.0	0.0	0.0	

Base-course material: The results of grain size analysis for base-course material are summarized in the table below, while the detail analysis data are attached in appendix.

Table 4.7: Results of grain size analysis for base-course material

Average Cumulative % Passing			
Sieve Sizes	***Base-course***		**Specification Limits For Base-course**
	63+995	**75+050**	
37.500	100	100	**100.00**
20.000	80	75	**70 - 85**
10.000	56	53	**50 - 65**
5.000	44	40	**35 - 55**
2.360	33	30	**25 - 40**
0.425	20	16	**12 - 24**
0.075	12	5.7	**5 - 12**
Pan	0.0	0.0	

The sub-base material type stipulated for the project is natural gravel mixed with crushed basaltic rock aggregates in proportion of 65:35/ or 70:30 to achieve the required grading requirements. Grain size analysis result for base-course, sub-base and sub-grade fill/capping layer are in compliance with ERA manual minimum requirements in either of satisfying specification limits and fulfilling the necessary particle size dimension of the materials as dictated on discussion heading's below. In addition, pictures showing laboratory works of the at hand test are attached under appendix.

- **Atterberg limit Test**

The Atterberg limit tests were given the properties on the fine-grained material based on the moisture content in percent that named as LL and PL. It is aimed to determine the plastic and liquid limits of a fine grained soil in accordance with **AASHTO** test method of **T89 & T90).** Based on their mode of formation and composition, different materials may respond differently for the same moisture content. The summarized Plasticity index of sub-grade fill/capping, sub base and base course materials are tabulated below. The detail laboratory data analyses with their drawn charts of number of blows versus moisture content are attached in **Appendix E**.

Table 4.8: Results of Atterberg limit tests for sub-grade fill/capping, sub base and base course materials

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)											
Sub-grade fill/capping				**Sub-base**				**Base-course**			
Location	**LL**	**PL**	**PI**	**Location**	**LL**	**PL**	**PI**	**Location**	**LL**	**PL**	**PI**
63+995	32	11	20	63+995	26	19	7	63+995	8	12	Non - PI
62+800	31	13	19	62+800 & 75+050	28	20	8	75+050	9	11	Non - PI

ERA's manual 2013 specify Atterberg limit of non-plastic for Graded Crushed stone (GB1) while PI not exceeding 12% in seasonally wet tropical climate condition for Natural Gravel Sub-bases. The quality of subgrade fill required specified by different specification varies however, ERA manual 2013 specifies PI not exceeding 30%. However, the project specification for most of the above materials alongside with ERA specification are higher in little amount. The materials quality requirements of base-course and sub-base are the same for PI. The material quality of subgrade fill or embankment construction specified under project specification declares PI not exceeding 25%. Whereas, material quality of capping layer specified under project specification declares PI not exceeding 25%.

The test result refer to the table as Table 4.8 for seasonally wet tropical climate condition of the project are satisfying the minimum requirements of ERA manual 2013 including plasticity index of <30, <12 and non-PI for sub-grade fill/capping layers, sub-base and base-course respectively. In addition, pictures showing laboratory works of the at hand test are attached under appendix.

- **Proctor Test**

The most common measure of compaction of soil is its density. Soils maximum dry density and its corresponding optimum moisture content should be determined according to **AASHTO T180.** Optimal engineering properties such as shear strength for a soil type occur near its maximum dry density (MDD) and optimum moisture content (OMC). At this level; soils void ratio, potential to shrink and swell is minimized. The summary of the test result is tabulated below and the laboratory test analysis and plots of moisture content versus dry density are attached in **Appendix F**.

Table 4.9: Results of laboratory compaction tests for sub-grade fill/capping, sub base and base course materials

MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D & ASTM D 1557)								
Sub-grade fill/capping (AASHTO T-180)			**Sub-base (AASHTO T-180)**			**Base-course (ASTM D 1557))**		
Location	**OMC, %**	**MDD, g/cc**	**Location**	**OMC, %**	**MDD, g/cc**	**Location**	**OMC, %**	**MDD , g/cc**
63+995	17.40	1.86	63+995	12.65	1.97	63+995	5.25	2.16
62+800	16.82	1.86	62+800 & 75+050	11.24	1.94	75+050	5.65	2.17

Hence, the above test result have done in compliance with ERA manual 2013 in which, the placed material with minimum of 93% or 95%, 95% and 98% of the maximum dry density obtained for sub-grade fill/capping layers, sub-base and base-course respectively. Those are, 95% - sub-grade fill/capping, 97% - sub-base and at 102% - base-courses. In addition, pictures showing laboratory works of the at hand test are attached under appendix.

- **California Bearing Ratio**

The CBR is the most widely used methods for designing road pavement structures. The test method is based on **AASHTO T193.** The summary of the test result is tabulated below and the laboratory test analyses with their plots are attached in **Appendix G**.

Table 4.10: Results of laboratory CBR tests for sub-grade fill/capping, sub base and base course materials

CALIFORNIA BEARING RATIO TEST (TEST METHOD AASHTO T-193)											
Sub-grade fill/capping				**Sub-base**				**Base-course**			
Location	**95% of MDD (g/cc)**	**CBR, %**	**Swell, %**	**Location**	**95% of MDD (g/cc)**	**CBR, %**	**Swell, %**	**Location**	**95% of MDD (g/cc)**	**CBR, %**	**Swell, %**
63+995	1.76	29	1.29	63+995	1.91	52	0.87	63+995	2.20	116	0.31
62+800	1.76	20	1.13	62+800 & 75+050	1.88	55	0.88	75+050	2.21	119	0.50

ERA's manual 2013 specify CBR values in excess of 100% for Graded Crushed stone (GB1) CBR 30% for Natural Gravel Sub-bases. The quality of subgrade fill required specified by different specification varies however, ERA manual specifies CBR not less than 5%, swell value of not more than 2%.

However, the project specification for most of the above materials alongside with ERA manual 2013 are higher in little amount. The materials quality requirements of base-course and sub-base are the same for CBR. While, material quality of CBR-swell shall not exceed 1% for sub-base layer. The material quality of subgrade fill or embankment construction specified under project specification declares CBR not less than 15% and swells not more than 2%. Whereas, material quality of capping layer specified under project specification declares CBR not less than 5%, and swell not more than 1.5%.

The project specification for CBR parameter of all unbound materials refers the table as Table 4.10 fulfills the minimum requirements of ERA manual 2013. Meanwhile, the above test result is within the acceptable limit of the project specification, the material strength is good of standing the applied pressure. The minimum soaked Californian Bearing Ratio (CBR) stated under ERA manual shall be 8%, 30% and 100% for sub-grade fill/capping layers, sub-base and base-course respectively. The project test results for swell value also conform to the minimum requirements of ERA manual. In addition, pictures showing laboratory works of the at hand test are attached under appendix.

4.3 Traffic Analysis

4.3.1 Traffic volume

Traffic analysis was made based on the data obtained since the year of 2002 to 2019 from the office of ERA, Road Asset Management. Historical traffic counts were obtained at road section from Bedele - Metu road with road number and route number nomination of 43 and 3 respectively [31].

The salient features of the project road are outlined below [6].

- Length – 50.659 Km
- Class of road – Trunk
- Region(s) / Zone(s) – Illu Abba Bora zone
- Carriageway width – variable (refer the field assessment result)
- Base year traffic count - detailed DPR Consultant and design review Consultant are 2009 and 2013 respectively
- ESAL (in million) - (6 - 10 ESA)
- Traffic class - T6
- Year of commencement - 2013
- Completion year - 2016
- Opening year of traffic - 2017
- Expected end of design life of the project road - 2036

In addition, some of the assumptions and/or essential data’s for traffic analysis are;

- Normal traffic - as attached below
- Diverted traffic - Similar with previous Design Consultant

- Generated traffic - Similar with previous Design Consultant
- Design period (N = 20 years)

The calculated total AADT by talking 2016 base year traffic count data from ERA, Road Asset Management as shown in the table below and the detail are attached below under appendix. Since the revised project completion date of the project is on the year of 2016 that guided for choosing the base year traffic count data.

Table 4.11: AADT data for Bedele - Metu (61+000 – 111+659) road upgrading project

Traffic Analysis - AADT									
Year	**Car**	**4 WD**	**S/ Bus**	**L/ Bus**	**S/ Truck**	**M/ Truck**	**H/ Truck**	**T & T**	**TOTAL**
Normal +Diverted + Generated									
2016	1	110	118	19	67	98	120	83	616
2017	1	119	128	20	73	106	131	90	669
2018	1	129	138	22	80	116	142	98	726
2019	1	139	149	24	87	126	155	107	789
2020	1	150	161	25	95	138	169	117	856
2021	2	162	174	27	103	150	184	127	930
2022	2	175	188	30	113	164	201	139	1010
2023	2	189	203	32	123	178	219	151	1097
2024	2	203	217	34	133	193	237	164	1182
2025	2	217	232	37	143	208	256	177	1272
2026	2	232	249	39	155	225	276	191	1369
2027	2	248	266	42	167	243	298	206	1473
2028	2	266	285	45	181	262	322	222	1586
2029	3	284	304	48	195	283	348	240	1706
2030	3	304	326	51	211	306	376	259	1837
2031	3	326	349	55	228	331	406	280	1977
2032	3	348	373	59	246	357	438	303	2127
2033	3	373	399	63	266	386	473	327	2290
2034	4	399	427	67	287	417	511	353	2465

2035	4	427	457	72	310	450	552	381	2653
2036	4	457	489	77	335	486	596	412	2855

4.3.2 Cumulative Equivalent Standard Axles over the Design Period

The cumulative ESAs over the design period for each vehicle class is obtained by multiplying $EF_{(m)}$ by the cumulative traffic, $T_{(m)}$. The total number of cumulative standard axles for all vehicle classes is then obtained by adding together the values of $EF_{(m)}$ x $T_{(m)}$ for all the classes [8].

The Total calculated equivalent standard axle loads from 2017 to 2036 years are calculated to **5,351,297.412** (Bedele – Metu: 61+000 – 111+659). The result showing that the calculated cumulative ESA over a given design period is below the project design value as shown.

Table 4.12: Cumulative ESAs for Bedelle - Metu (61+000 – 111+659) road upgrading project

Calculation of CMSAL with Weighed Average Truck Factor								
Vehicle Type	S/Bus	L/Bus	S/Truck	M/Truck	H/Truck	T & T	Directional Distribution Factor	0.500
Ave. AADT	118	19	67	98	120	83	Lane Distribution Factor	0.600
WA Truck Fac.	0.228	1,23	0.089	1.275	1.960	6.300		

Year	m	Total AADT						Total Traffic in ESA	Total Cum. Traffic in ESA	Traffic in MSA	Rem.
		S/Bus	**L/Bus**	**S/Truck**	**M/Truck**	**H/Truck**	**T & T**				
2017	1	128	20	73	106	131	90	111,601.41	111,601.415	0.11	The Upgraded Road was Open to Traffic
2018	2	138	22	80	116	142	98	121,464.41	233,065.823	0.23	
2019	3	149	24	87	126	155	107	132471.4575	365,537.280	0.37	
2020	4	161	25	95	138	169	117	144562.2285	510,099.509	0.51	
2021	5	174	27	103	150	184	127	157027.2705	667,126.779	0.67	

2022	6	188	30	113	164	201	139	171759.6195	838,886.399	0.84	on the
2023	7	203	32	123	178	219	151	186596.8695	1,025,483.268	1.03	year
2024	8	217	34	133	193	237	164	202238.616	1,227,721.884	1.23	2017
2025	9	232	37	143	208	256	177	218254.6335	1,445,976.518	1.45	
2026	10	249	39	155	225	276	191	235389.084	1,681,365.602	1.68	
2027	11	266	42	167	243	298	206	253916.922	1,935,282.524	1.94	
2028	12	285	45	181	262	322	222	273772.8855	2,209,055.409	2.21	
2029	13	304	48	195	283	348	240	295717.014	2,504,772.423	2.50	
2030	14	326	51	211	306	376	259	319153.8465	2,823,926.270	2.82	
2031	15	349	55	228	331	406	280	344848.2405	3,168,774.510	3.17	
2032	16	373	59	246	357	438	303	372525.8985	3,541,300.409	3.54	
2033	17	399	63	266	386	473	327	402025.527	3,943,325.936	3.94	
2034	18	427	67	287	417	511	353	433887.618	4,377,213.554	4.38	
2035	19	457	72	310	450	552	381	468256.602	4,845,470.156	4.85	
2036	20	489	77	335	486	596	412	505827.2565	5,351,297.412	5.35	

Notes. *The cumulative equivalent standard axle over the period of 20 years (from 2017 to 2036) is equal to5.35 MSA which is grouped in to the traffic class of 3 to 6 million vehicles, T5.*

The assumption for taking base year traffic count data as 2016 from ERA, RAM in the reason that the practical completion date of the upgrading project was 2017.

Since the project is Trunk road, the traffic analyses are going to be done from 2017 up to the year of 2036 for an about 20 years design period.

The adopted basic assumptions of traffic growth rates and average equivalency factors of the project are attached under ***Appendix I.***

4.4 Discussion

The following comparisons and discussions are based on the interpretation of all data gathered from the study sections that had been obtained at Bedele - Metu road upgrading project.

4.4.1 Visual Pavement Condition Survey Output

Types of pavement distresses will indicate the possible cause of the pavement failure. This has

helped to relate the pavement distress noticed on the surface with alternative and possible causes. The different types of deterioration observed in the study area are presented below under **Appendix A.** In addition, summary of severity and extent of road defects on severely deteriorated road portions are attached below under **Appendix B.** The observation results show that potholes/patch failure, cracking, lane marking fade-out, rutting, depression/failure, stripping, raveling/fretting, lane marking with few missing, corrugation, side drainage siltation, shoulder deform, guardrail damaged and vegetation cover types of road defects were recognized along the selected sections. The causes of road defects related to vegetation cover are owing to seasonal rain.

The causes of the observed deterioration could be moisture fluctuation, poor drainage facilities, and poor method of compaction as described by [30].

From the observed defects, the severity level Percentage for common deterioration types and in each respective severity level is shown below.

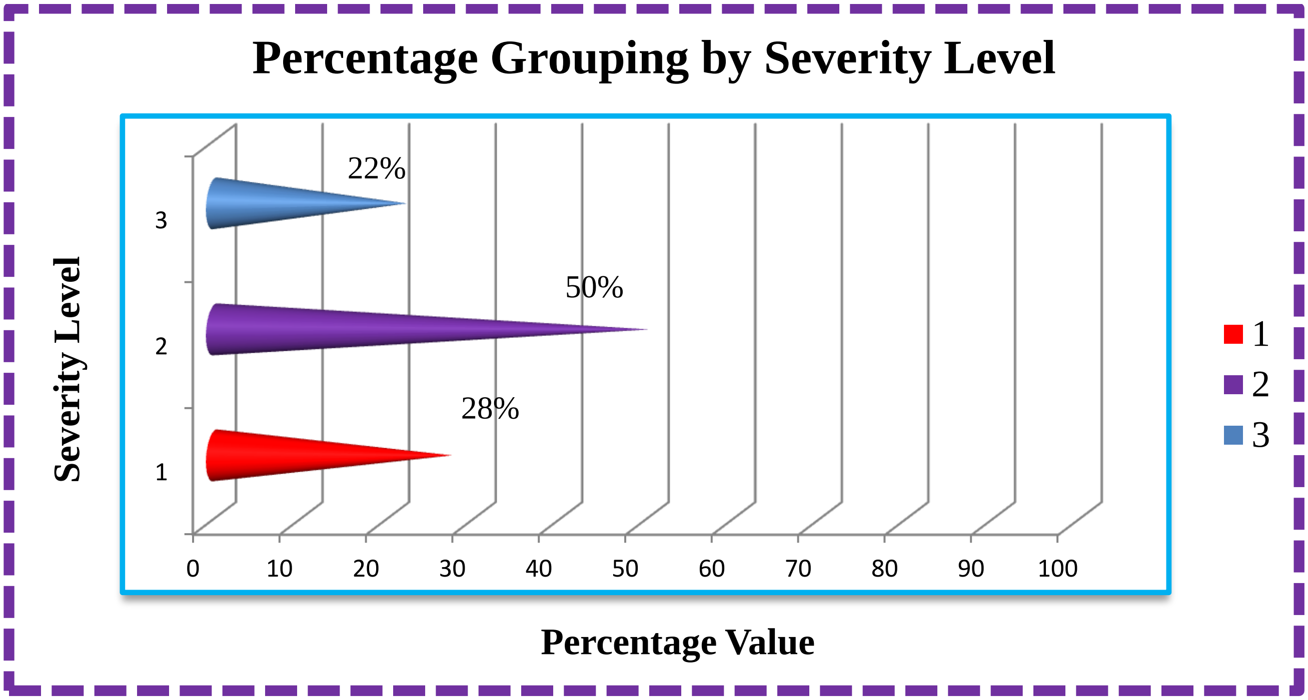


Figure 4.7: Percentage of defects based on severity level

Note: The Legend above dictates severity level of distresses; which are: 1-low, 2-medium and 3-high.

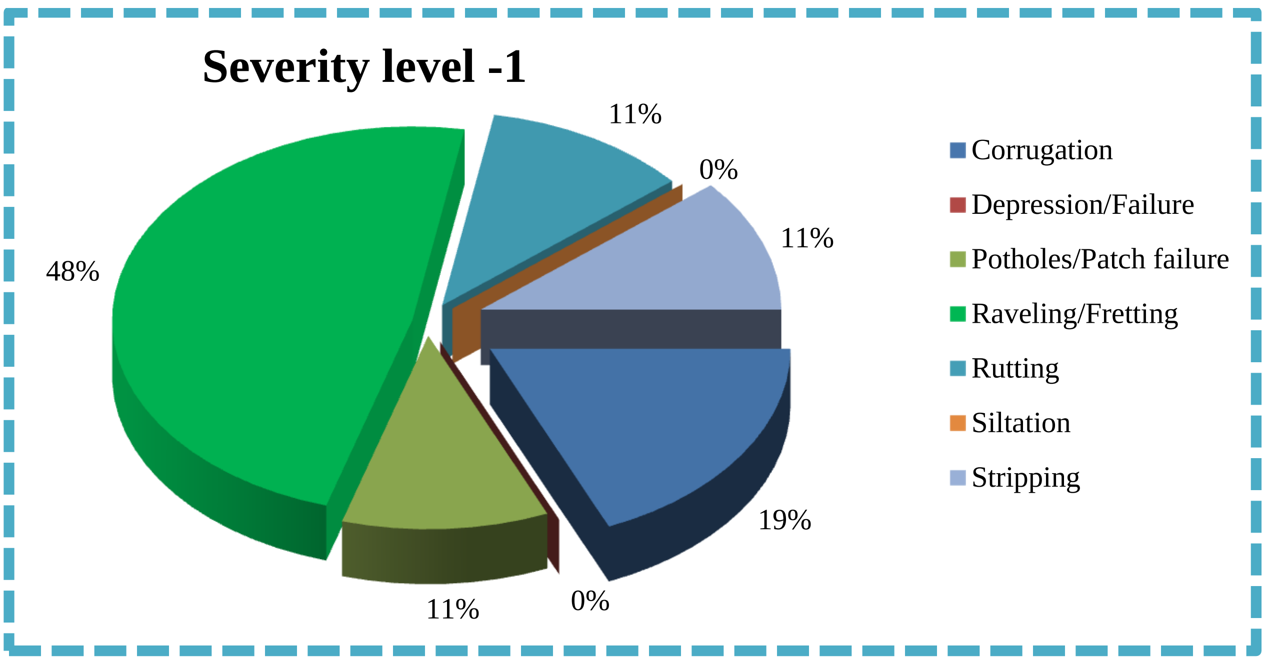


Figure 4.8: Percentage of defects grouped under severity level -1

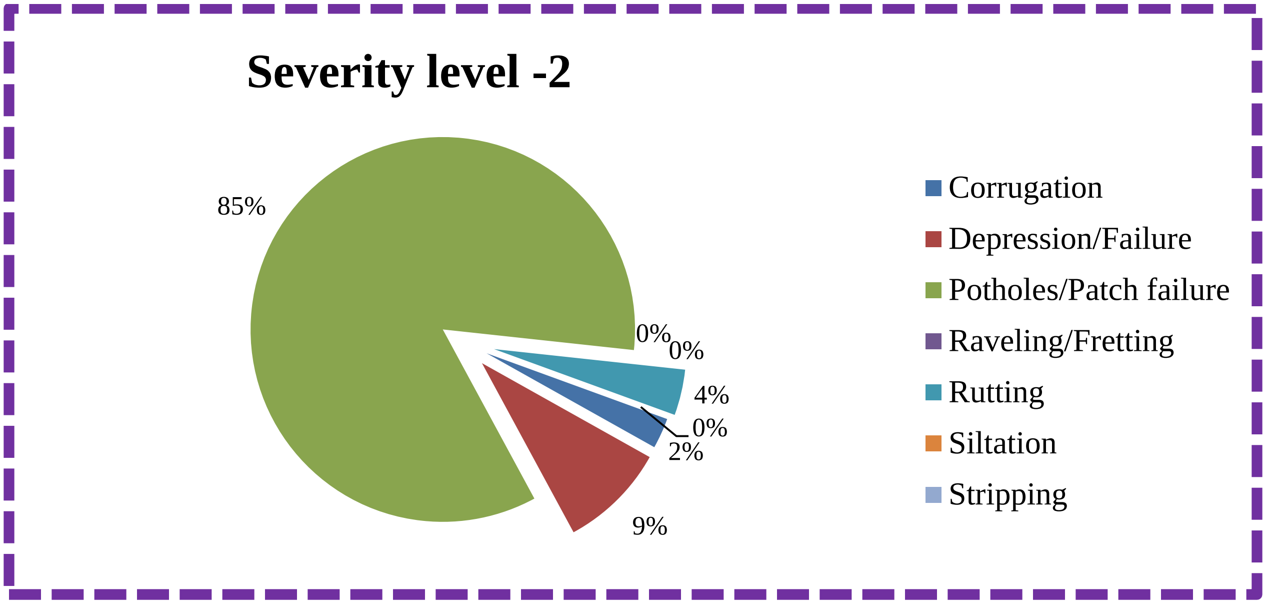


Figure 4.9: Percentage of defects grouped under severity level -2

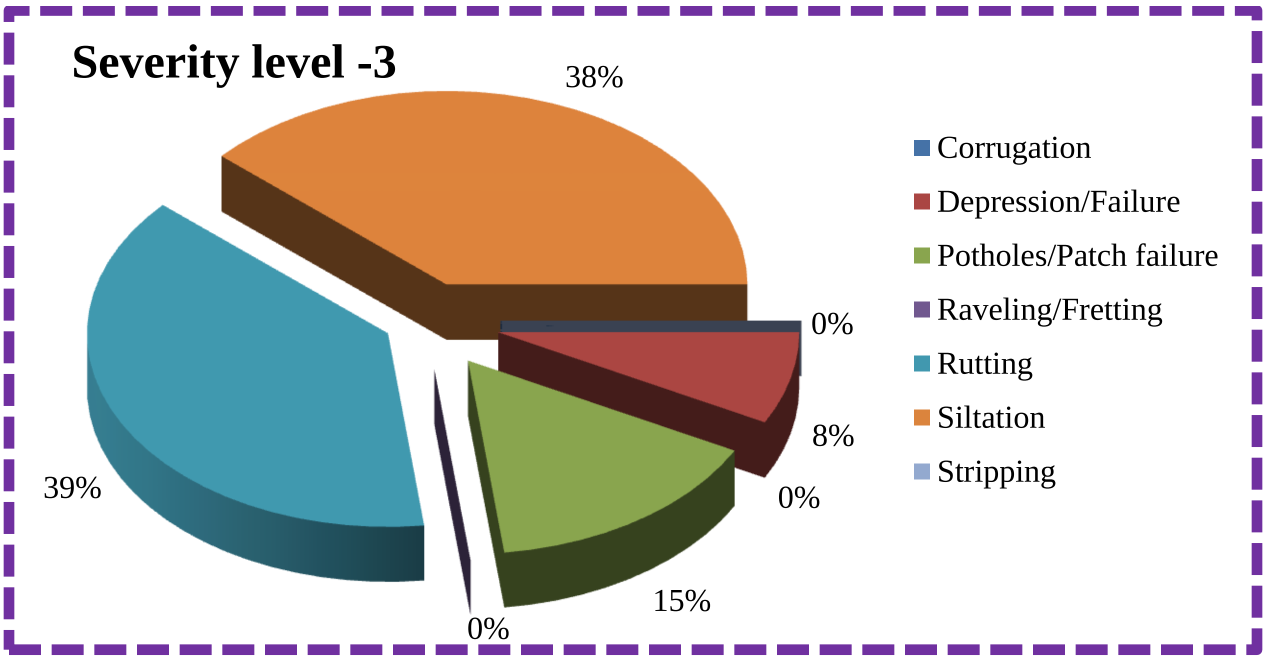


Figure 4.10: Percentage of defects grouped under severity level -3

Rutting (41%) and potholes/patch failure (2%) defect type are categorized under first and last based on their extent of which the defects are availing on the study area as indicated in figure 4.3. In addition, the severity level of those road defects have a ranking half percentage are grouped under severity level -2 (50%) with potholes/patch failure defect type (85%) as displayed above.

The occurrence of potholes/patch failure defect type are mainly on previously correction works during defect liability period by the former Contractor due to poor work methodology and workmanship problem.

4.4.2 Experimental Result Evaluation for Pavement Structures

The representative samples collected during detailed field investigation were carried to ERA, Own Force Road Maintenance District of Jimma laboratory center and the following tests were undertaken. These tests are Atterberg limit, compaction, sieves analysis, and CBR test of each pavement layers (i.e. sub-grade fill/capping, sub-base and base-course) to understand the general behavior of the road materials and to check whether the laboratory test results are the possible causes of the observed pavement distresses. The quality of materials required for each pavement layers are different characteristics based on the project specific design requirements (i.e. traffic, climate condition and nature of materials).

Hence, the laboratory CBR test result found a little bit difference with that of field DCP final computed values. The average laboratory CBR outputs for pavement layers are lesser with some extent than that of DCP-CBR values.

4.4.2.1 Asphalt Surfacing

Asphalt density measurement has been carried for surfacing layer. The result for the same showing percent of compaction a range from 94 to 99 on behalf of selected four failed section and one more normal section. While, the design and control sample have percent of compaction 96 and 95 respectively. Hence, all of the listed test results are above the specified project minimum percentage, which is 93%. The control sample is an average result in relation with the rest. But, the maximum test result, such as 99%, indicating that, the VIM result in a wearing course material <3%, such as 1%, that indicates the possible factor for occurrence pavement deformation under heavy loading. The requirement of ERA manual 2013 under this scope is also complemented with the project specifications. Those early achieved percent of compaction perhaps one factor for premature failure type of rutting, cracking and depression/failure along wheel path.

Table 4.13: Summary Critical Values of VIM/after Secondary Compaction [41]

VIM in wearing course material (percent)	Effect
>8	Extremely permeable to air and water. Oxidation of the bitumen very rapid in hot climates
>5	Increasingly permeable to air and prone to oxidation of the bitumen
4 or 5	Target for design
3 - 5	For a durable and stale mix
<3	Prone to plastic deformation under heavy loading

4.4.2.2 Base-course/Road-Base Layer

The implemented base-course material is a product of stone Crusher Plant with a category of Graded crushed basaltic rock (GB1) aggregate from approved quarry areas.

The Sieve Analysis (Test Method AASHTO T- 27) test output for both of the control sample and the remaining test result has found within the specification limits but with a few different on the percent passing proportions. Since the test result for the first sample located at km 63+995 are falling towards the upper sieve limit. Whereas, the test result for the control sample indicated that the gradation limit are categorized under the lower sieve. This indicates the grading proportion lacks adequate proportion or does not have a good representation of all sizes particles that have impact on engineering properties of shear strength, hydraulic conductivity and compressibility.

The Atterberg limit test result for both of the control sample and remaining sample unit from failed section are categorized under non-PI. Hence, the material is good that fulfills the requirements stipulated on the ERA manual 2013.

The calculated CBR from both of the DCP machine and 102% of MDD laboratory test result are good and categorized within the required range of ERA manual 2013, which is in excess of 100 per cent. The result confirmed that the CBR values using DCP machine at station of 64+015 is 129%. Whereas, the laboratory CBR test result for the control sample is 119%. Similarly, the DCP-CBR results for the remaining sample units have higher percentage with some amount than laboratory CBR result. The swell in % is also within the allowable limit of ERA manual 2013.

4.4.2.3 Sub-base Course Layer

Since the project technical specification are allowing a proportion of Crushed basaltic rock aggregate with materials from approved quarry/borrow locations of 65:35 or 70:30 respectively. Hence, for this project, 70:30 proportion were adopting for the analysis of their Engineering properties.

Likewise to base-course material, the Sieve Analysis (Test Method AASHTO T- 27) test computation for sub-base material to the control sample and remaining test result are within the required range of ERA manual 2013. Since, average cumulative % passing for each of them is good. However, the test result for the first sample located at km 63+995 is falling towards the upper sieve limit. Conversely, the particles sizes in relation with the stipulated project specification (control sample) limit are grouped towards lower limit. This indicates the grading proportion lacks adequate proportion or does not have a good representation of all sizes particles that have impact on the important engineering properties of shear strength, hydraulic conductivity and compressibility.

The Atterberg limit test result for both of the control sample and remaining sample unit from failed section are nearly similar and within the required range of ERA manual 2013. Hence, the plasticity index for the control sample and remaining sample unit are good enough with values of 8 and 7 respectively.

The calculated CBR from both of the DCP machine and 97% of MDD laboratory test result are good and considered within the range of ERA manual 2013 requirements, which is in excess of 30 per cent. The result confirmed that the CBR values using DCP machine at station of 64+015 is 55%. Whereas, the laboratory CBR test result for the control sample is 54%. Similarly, the DCP-CBR results for the remaining sample units have higher percentage with some amount than laboratory CBR result. The swell in % is good that grouped within the required allowable limit of ERA manual 2013.

4.4.2.4 Sub-grade Fill/Capping Layer

The implemented sub-grade fill/capping layer material is natural gravel from approved borrow locations.

The Sieve Analysis (Test Method AASHTO T- 27) test computation for sub-grade fill/capping material to the control sample and remaining test result are within the required range of ERA manual 2013. Since, average cumulative % passing for each of them is good with slight grading differences. This indicates the grading proportion are fulfills the important engineering properties of shear strength, hydraulic conductivity and compressibility.

The Atterberg limit test result for both of the control sample and remaining sample unit from failed section are nearly similar and within the required range of ERA manual 2013. Hence, the plasticity index for the control sample and remaining sample unit are good enough with values of 19 and 20 respectively.

The calculated CBR from both of the DCP machine and 95% of MDD laboratory test result are good and considered within the range of ERA manual 2013 requirements, which is CBR of both 7% for lower capping layer and 15% for upper capping layers. The result confirmed that the CBR values using DCP machine at station of 64+015 is 27%. Whereas, the laboratory CBR test result for the control sample is 20%. Similarly, the DCP-CBR results for the remaining sample units have nearly the same and a little higher percentage with some amount than laboratory CBR result. The swell, % is good that falling within the allowable limit of ERA manual 2013.

4.4.3 Evaluation of Pavement Traffic loading

The cumulative equivalent standard axle over the period of 20 years (from 2017 to 2036) is equal to **5.35 MSA** which is grouped in to the traffic class of **3 - 6** million vehicles, **T5**.

The road was designed and constructed to carry **7.7 MSA** with a design period of 20 years starting from 2015 to 2034 by the Supervision/design review Consultant as attached under **Appendix I,** that grouped in the traffic class of **6 - 10** million vehicles, **T6** [35]. Also, the traffic class category by the design Consultant is the same with the Supervision/design review Consultant. Hence, this indicates that the design traffic loading by the design

Consultant or Supervision/design Consultant is conservative design in comparing with the current traffic analysis result. Hereafter, the respective design thickness **(i.e. AC - 5 mm, base-course – 20 mm and sub-base - 350 mm)** of the pavement structure becomes higher and enabling to withstand the traffic loading beyond the expected one.

Furthermore, the archived AADT data from ERA, Road Asset Management indicated that the uncertainties belongs to representing the actual value become higher during counting period and also analysis stage. Hence, attached below the table showing 5 year (2012 - 2016) previous AADT data from ERA, Road Asset Management which support the uncertainties made so far by evaluating the traffic data for previous years decreases for some vehicle types and others also the growth rate become little alongside the recent years.

Accurate estimates of cumulative traffic are difficult to achieve due to errors in the surveys and uncertainties with regard to traffic growth, axle loads and axle equivalencies.

Table 4.14: Summary of previous AADT data for Bedele - Metu road [31]

Traffic Count (AADT) data from 2012 up to 2016									
Year	**Car**	**4 WD**	**S/ Bus**	**L/ Bus**	**S/ Truck**	**M/ Truck**	**H/ Truck**	**T & T**	**Total**
2012	1	81	101	22	48	100	73	29	455
2013	0	84	105	12	49	103	68	29	450
2014	1	47	77	12	47	88	56	26	354
2015	1	52	81	14	55	75	93	40	411
2016	1	85	99	15	49	77	95	54	475
Average	**1**	**70**	**93**	**15**	**50**	**89**	**77**	**36**	**429**

Nonetheless, in view of the project data belong to the terrain classification of the study area (i.e. rolling 54%, mountainous 37% and the remaining 9% is escarpment) and the current heavy loading traffic flow in relation with availability of nearly upgrading projects significantly affecting service life of the project. Hence, during mobilization stage of the contractor resources to the required projects (i.e. Gore – Diri Junction – Tepi Road Upgrading Project) become the possible cause for premature failures in general and that mainly affecting the Metu direction lane of the project.

4.4.4 Pavement Layer Profiling

The design thickness from the project record declares that 5 mm, 200 mm and 350 mm thickness for AC, base-course and sub-base layer respectively. The estimated/measured for base-course and sub-base is nearly the same with the design thickness or below the construction tolerance stipulated under ERA 2013 manual. Also, the estimated/measured thickness for some stretches of the AC layer is nearly the same with the design thickness or below the construction tolerance stipulated under ERA 2013 manual. Whereas, the estimated/measured thickness for some sections of the AC layer are reduced from the design thickness or above the allowed construction tolerance stipulated under ERA 2013 manual.

Table 4.15: Summary of pavement layer thickness

Summary of Pavement Layer Thickness								
Station	**Description**	**Layer Type**	**Measured Coordinate, m**		**Design Layer Thickness, mm**	**Estimated/Average Measured Layer Thickness, mm**	**Diffe., mm**	**Visual Project Material Description**
			X	**Y**				
63+400	Finished Road Elevation		0.000	1,546.671				
		AC		**0.050**	**50.00**	**47.87**	-2.13	AC
	Base-course Elevation		0.000	1,546.621				
		Base-course		**0.200**	**200.00**	198.00	-2.00	Crushed basaltic rock aggregate
	Sub-base Elevation		0.000	1,546.421				
		Sub-base Course		**0.350**	**350.00**	349.25	-0.75	Crushed basaltic rock aggregate with light brown sandy soil

	Sub-grade Elevation		0.000	1,546.071				
		Sub-grade Fill/Capping		**1.262**	**1,262.00**			light brown sandy soil with gravel soil
	Existing Ground Condition		-0.007	1,547.333				
63+995	Finished Road Elevation		0.000	1,507.089				
		AC		**0.050**	**50.00**	40.87	-9.43	AC
	Base-course Elevation		0.000	1,507.039				
		Base-course		**0.200**	**200.00**	**199.50**	-0.50	Crushed basaltic rock aggregate
	Sub-base Elevation		0.000	1,506.839				
		Sub-base Course		**0.350**	**350.00**	**349.75**	-0.25	Crushed basaltic rock aggregate with light brown sandy soil
	Sub-grade Elevation		0.000	1,506.489				
		Sub-grade Fill/Capping		**1.425**	**1,425.00**			light brown sandy soil with gravel soil
	Existing Ground Condition		0.000	1,507.914				
64+015	Finished Road Elevation		0.000	1,505.149				
		AC		**0.050**	**50.00**	45.25	-4.75	AC
	Base-course Elevation		0.000	1,505.099				

		Base-course		**0.200**	**200.00**	**198.70**	-1.30	Crushed basaltic rock aggregate
	Sub-base Elevation		0.000	1,504.899				
		Sub-base Course		**0.350**	**350.00**	**349.40**	-0.60	Crushed basaltic rock aggregate with light brown sandy soil
	Sub-grade Elevation		0.000	1,504.549				
		Sub-grade Fill/Capping		**1.588**	**1,588.00**			light brown sandy soil with gravel soil
	Existing Ground Condition		0.000	1,506.137				
78+900	Finished Road Elevation		0.000	1,549.219				
		AC		**0.050**	**50.00**	**38.66**	-11.34	AC
	Base-course Elevation		0.000	1,549.169				
		Base-course		**0.200**	**200.00**	**198.50**	-1.50	Crushed basaltic rock aggregate
	Sub-base Elevation		0.000	1,548.969				
		Sub-base Course		**0.350**	**350.00**	**349.00**	-1.00	Crushed basaltic rock aggregate with Gravel soil
	Sub-grade Elevation		0.000	1,548.619				
		Sub-grade Fill/Capping		**1.062**	**1,062.00**			Gravel soil

	Existing Ground Condition		0.000	1,549.681				
85+490	Finished Road Elevation		0.000	1,496.439				
		AC		**0.050**	**50.00**	**39.88**	-10.12	AC
	Base-course Elevation		0.000	1,496.389				
		Base-course		**0.201**	**201.00**	**199.50**	-1.50	Crushed basaltic rock aggregate
	Sub-base Elevation		0.000	1,496.188				
		Sub-base Course		**0.350**	**350.00**	**350.00**	0.00	Crushed basaltic rock aggregate with Gravel soil
	Sub-grade Elevation		0.000	1,495.838				
		Sub-grade Fill/Capping		**1.144**	**1,144.00**			Gravel soil
	Existing Ground Condition		0.000	1,496.982				

The construction tolerances for sub-base and base course lot will be considered to comply with the requirements for layer thicknesses if [8]:

- At least 90 % of all the thickness measurements taken before any thickness repairs are made equal to or greater than the specified thickness minus 27 mm, and the mean layer thickness of the lot is not less than the specified thickness minus 5 mm.
- Construction tolerances for thickness of asphalt base and surfacing shall be at least equal to that shown on the table below [8].

Table 4.16: Thickness tolerances for asphalt base and surfacing [8]

	Base (mm)	Surfacing (mm)
D_{90}	15	5
D_{max}	20	8
D_{ave}	5	2

Therefore, the separate and its cumulative effect of the thickness difference for pavement layers; such as, at station 78+900 (AC-11.34 mm, Base-course-1.5 mm and Sub-base Course-1 mm) possibly the factor for the premature failure of the study project.

4.5 Observations and Alternative Treatment Types

Based on the findings and observation of the study by evaluating the current pavement condition, project historical data, field and laboratory samples along the study area, the possible causes and their respective treatment types of the premature failures are known to be determined.

A walk-over inspection was made over the section that had been identified for investigation, noting the extent of the problem in an effort to select positions that would give as much information as possible regarding the pavement distress problem but also take into account safety for those involved with excavation and inspection of the trenches [39].

Among the existing road defects, rutting covering a greater extent of all with 41% and their occurrences are mostly on curved sections. As of station 63+400, in which DCP01 test have been conducting and the possible cause for the same would be insufficient AC layer design thickness, it's complex geometry and the rapid achievement of its secondary compaction in line with their service life spans.

Proper compaction of hot mix asphalt (HMA) mixture is vital to ensuring that a stable and durable pavement is constructed. For typical dense-graded HMA mixes, numerous studies have shown that initial in-place air voids should not be below approximately 3 percent or above approximately 8 percent. Low in-place air voids can result in rutting and/or shoving, while high in-place air voids allow water and air to penetrate into the pavement leading to an increased potential for water damage, oxidation, raveling, and/or cracking [40].

Corrugation and siltation of side drainage grouped in second with 19% and third with 18% conditions based on which the measured extent of road defects along the study area. The possible causes of corrugation are related with insufficient AC layer design thickness, provision of incorrect asphalt grade in line with their terrain type and low air voids of the AC layer propagates the at hand failure type. Also, the potential causes of side drainage siltation are missing out of crossing structures along crossing road from the main road and absence critical follow-up and cleaning of side draining by the ERA, district of Jimma using the suggested recurrent activities of ditch cleaning (manual and machine) basis.

Raveling/fretting surface defect are occupying the fourth rank with 9% based on their extent of available defects along the study project. The causes of surface defects including of stripping defect are AC poor quality mixture and workmanship problem of the AC works along the joint of the separate lanes. From observed facts from field work, the joints in the pavement were excessively porous and that propagates to the adjacent pavement sections. Existence of moisture and moisture vapor along road sides and in pavement structure are possibly the causes for stripping.

The term “stripping” is applied to hot mix asphalt (HMA) mixtures that generally exhibit separation and removal of asphalt binder film from aggregate surfaces due primarily to the action of moisture and/or moisture vapor [36].

Depression/failure type of defect is the other one that extensively available along the study project. The field and laboratory assessment is also concerning on this defect type at station 63+995 and 85+490. Improper construction technique, complex road geometry, untreated underground and surface water continued deterioration of another type of distress.

The part of assessment that located in station 89+900 with defect type of pothole/patch failure is also the existing defect on the study project. The causes for the failure are related with deterioration that was not repaired adequately in the existing pavements during DLP, weak spots in the base or sub-grade owing to poor compaction or spring and continued deterioration of another type of distress, such as raveling, cracking, failed patch after pieces of the original pavement surface has been dislodged. Moisture is also the main factor for different types of defects along pavement structure.

Damage due to moisture in pavements usually initiates at or near the bottom of the asphalt bound layers or at interfaces between layers. Advanced moisture damage in HMA pavements can lead to rutting, shoving, corrugations, fatigue cracking, raveling, flushing, and pot holes [37].

In general, the temperature and moisture content have yielded significant contributions towards explaining the strain at the bottom of AC layers. The observed facts are supporting that, usage of uniform bitumen grade for a given complex terrain type is significantly affecting the service life of the pavement structure. The analyzed possible causes of the available defects are presented below.

The treatment types of the different available defect types are categorized under routine and periodic maintenances. The suggested treatment types of existing defects on the basis of the investigation results and essential references from national, international manuals and literatures are tabulated below.

Table 4.17: Summary of causes of defects and their alternative treatment types of deterioration which are common along the road section

S/No.	Defect Category		Possible Causes	Recommended Alternative Treatment Measures
1	Surface defects	Raveling/Fretting	AC poor quality mixture and workmanship problem of the AC works along the joint of the separate lanes.	Refer ERA manual 2013, maintenance treatments of surfacing defects - roads with asphalt surfacing
		Stripping	Including of the same causes as Raveling/Fretting and existence of moisture and/or moisture vapor	
2	Cracking			
		Longitudinal	Workmanship problem in relation with longitudinal segregation caused by the improper operation of the paver and poorly constructed paving joint crack	Crack seal/fill or fill with light grade of asphalt mixed with fine sand and provide safe and clean side drainage ditches

3	Surface deformation	Corrugations	Insufficient AC layer design thickness, provision of incorrect asphalt grade in line with their terrain type, low air voids and wrong work methodology (including compaction of base in wave form)	Patch with appropriate depth of higher strength pavement material with correct bituminous grade
		Rutting	Insufficient AC layer design thickness, it's complex geometry and the rapid achievement of its secondary compaction	Redesign pavement, considering the economy of total reconstruction against the required thickness of asphalt overlay or thin surface patch
		Shoving	Low air voids, insufficient AC layer design thickness and incorrect bituminous grade	Patch with appropriate depth of higher strength pavement material with correct bituminous grade
4	Disintegration	Potholes/Patch failure	Deterioration that was not repaired adequately in the existing pavements during DLP, weak spots in the base or sub-grade owing to poor compaction or spring and continued deterioration of another type of distress, such as raveling, cracking, failed patch after pieces of the original pavement surface has been dislodged. Moisture/surface water is also the main factor that enter through the void thereof and reasons for occurrence of different types of defects along pavement structure	Crack seal along the edges of the patch failure, cut out an area greater than the affected area to a depth of 50mm minimum, tack coat all surfaces and lift patching with better quality material, provision of subsoil drainage
5	Other	Side drainage siltation	Missing out of crossing structures along crossing road from the main road and absence critical follow-up and cleaning of side draining by the ERA, district of Jimma using the suggested recurrent activities of ditch cleaning (Manual and Machine)	Close follow up and implementation ditch cleaning by manual and machine for paved and earthen side ditches respectively
		Vegetation Cover	Seasonal growth of different sizes and types of grasses and trees with absence of close-follow up by ERA, district of Jimma and clearing of the existing vegetation using suggested activity of brush clearing	Close follow up and implementation of bush clearing activity

In addition, provision of the required sub-surface drainage system would also arrest the occurrence of some of the road defects as like pothole formation on station **83+300** of the study area.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Detailed field and laboratory investigation which consists of, visual condition survey, DCP, test pitting and pavement layer measurement, material sampling and testing have been conducted in order to investigate the causes of the premature pavement failures.

Depending on the observation and investigation of pavement condition survey, the field measurements/tests, laboratory tests and traffic analysis results the following conclusions are drawn.

1. Pavement condition survey:

The road condition survey along the whole route revealed that different types and degree of deteriorations have been observed along the study area. The terrain complexities of the study area alongside with the heavy vehicles that use the road are paramount factor for formations of different defects along the route. The observed defects are; potholes/patch failure, cracking, lane marking fade-out, rutting, depression/failure, stripping, raveling/fretting, lane marking with few missing, corrugation, side drainage siltation, shoulder deform, guardrail damaged and vegetation cover. Accordingly, from the common observed defect types, Rutting and potholes/patch failure are ranked based on their extent of coverage laid first and last with values of 41% and 2% respectively. Moreover, the half percentages of severity level for those existing road defects are grouped under severity level -2 that weighting of 50%. Severity level -1 and severity level -3 are ranked second and third with 22% and 27% respectively. From those; Severity level -2: Potholes/patch failure takes the larger portion with 85%, severity level -1: Raveling/fretting takes the larger portion with 48% and severity level -3: rutting takes the larger portion with 39%.

2. Field investigations:

Field thickness measurements for pavement layers were made. Hence, the thickness difference from the design thickness for the underneath layers of base-course and sub-base are below the accepted construction tolerance of ERA manual 2013. Whereas, the thickness difference such as: 11.34 mm for AC layer are above the accepted tolerance of ERA manual 2013. All of the DCP-CBR test result for base-course and sub-base are good that fulfills the minimum requirements under ERA manual 2013.

The field investigation confirmed that the DCP-CBR result for the respective materials have good quality that conform to the control sample and required specifications. But, the individual thickness difference and their cumulative effect may result for occurrence of premature defects such as: surface deformations.

3. Laboratory tests:

Asphalt density measurement has been carried for surfacing layer. The result for the same dictates the percent of compaction ranging from 94% to 99%. That showed us the percentage increment from the minimal project requirements of 93% is faster and which results the VIM in a wearing course material <3%, such as 1%, that indicates the possible factor for occurrence pavement deformation under heavy loading. The requirement of ERA manual 2013 under this scope is also complemented with the project specifications.

All of the laboratory CBR test result for base-course, sub-base and sub-grade fill/capping layer are good that fulfills the minimum requirements under ERA manual 2013.

The laboratory CBR result confirmed that the materials have good quality that conform to the control sample and required specifications. Also, the output verified that the DCP-CBR values with laboratory CBR values are nearly similar. However, the early achievement of the percentage compaction for AC layer probably resulting for occurrence of certain defects such as: rutting.

4. Traffic data analysis:

The calculated design traffic ESAL has been categorized under traffic class T5 with **5.35 MSA**. But, the project design traffic analysis showed us the traffic category under traffic lass T6 with **7.7 MSA**. This difference tells us whether the data sources from ERA, RAM are lacks an accuracy or the design consultant traffic assessment becoming conservative.

Perhaps, the usage of heavy trucks in relation with availability of in front upgrading projects and complexity of their terrain types assisting in formation of some defect types and accelerate the increment of rate of deteriorations for existing ones.

In addition, the road condition survey output revealed the distresses manifested on the surface of the pavement are resulted for occurrence of additional surface defects and also reasons for failure of structural defects that possibly owing to its complex geometry and poor method of construction (i.e. construction of pavement layers during rainy season).

The treatment types of the different available defect types are categorized under routine and periodic maintenances. The suggested treatment types of existing defects on the basis of the investigation results and essential references from national, international manuals and literatures are tabulated below. From those, the treatment types of surface defects are refer on ERA manual 2013, maintenance treatments of surfacing defects - roads with asphalt surfacing.

5.2 Recommendation

Lastly, the following recommendations may be considered:

Adoption of new technology developments will help for quick inspection of roads and streets by using automated inspection equipment. The automated system has the ability to assess the condition of the pavement and use the resulting data to create and archive a database. This can be conducted at the same cost or less than manual survey procedures and the surveys become safer and less labor intensive.

It is also advisable to perform some additional non-destructive survey such as roughness survey and deflection survey and the destructive survey includes other laboratory tests for each of pavement layers below AC such as; LAA, ACV, TPF, flakiness index and for asphalt concrete such as; bitumen content, ductility, marshal test, and others to further check of the structural capacity of the pavement.

Separate bituminous grade should adopt for those of different and complex terrain categories.

Conducting on-site traffic count through the recommended forms of ERA manual 2013, more detailed analysis of traffic volume and axle load survey shall be essential to arrest the uncertainties during traffic class selection.

Accurate traffic prediction models need to be devised throughout the country so that traffic forecasting errors would be minimized.

Routine and scheduled field inspection and modern data encoding system should be developed for useful evaluation and reference. It is recommended that ratings be updated every periodically and routine pavement maintenance practices should be employed to reduce the rate of deterioration of existing premature defects.

The required urgent maintenances interventions should be made by the ERA, JRNSMD through usage of effective maintenance technics and provision of necessary maintenance resources to scale up the adopted maintenance conditions that enabling to increase the level of services.

Relevant pavement structures need to be proposed at critical sections for such heavy traffic important road section by thinking rigid pavement which has long standing resistance of heavy stresses.

REFERENCES

[1] Surajo Abubakar WadaInt. Bituminous Pavement Failures, Journal of Engineering Research and Applications. 2016; 6(2):PP. 94-100.

[2] Zulufqar Bin Rashid and Dr. Rakesh Gupta. Study of Defects in Flexible Pavement and its Maintenance. International Journal of Recent Engineering Research and Development. 2017; 2 (6):PP. 30-37.

[3] Michael H.C. Analysis of Highway Noise. Journal of Soil, Air and Water Pollution, Springer Verlag Publishing. 1973; 2(3).

[4] ERA. Pavement Rehabilitation and Asphalt Overlay Design Manual. Ethiopian Roads Authority. 2013.

[5] AASHTO. Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials. Washington DC; 1993.

[6] ERA. Completion Report of Bedele - Metu Road upgrading Project; Lot 2: Km 61+000 to Km 111+659. Ethiopian Roads Authority. 2018.

[7] Altan Yilmaz and Şebnem Sardin. Water Effect on Deteriorations of Asphalt Pavements. The Online Journal of Science and Technology. 2012; 2(1).

[8] ERA. Pavement Design Manual Volume -I: flexible Pavements. Ethiopian Roads Authority. 2013.

[9] Hodges, J. A Guide to the Structural Design of Bitumen Surfaced Roads in Tropical and Sub-Tropical Countries. Overseas Centre, Transport Research Laboratory (TRL). 4th ed. London. 1993.

[10] Paise-Green. The Structural Design, Construction Maintenance of Unpaved Roads. Pretoria, South Africa. 1990.

[11] Molenaar P. A. Structural Design of Pavements part -III: Design of Flexible Pavements. 2006.

[12] Australian Asphalt Pavement Association. Flexible Pavement Maintenance and Rehabilitation. 2010.

[13] 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.

[14] G. Kollaros, A., Athanasopoulou & A. Kokkalis. Perpetual Flexible Pavement Design Life. https://www.researchgate.net/publication/318857804. 2017.

[15] ERA. Pavement Design Manual: Volume -I: Flexible Pavements and Gravel Roads. Ethiopian Roads Authority. 2002.

[16] ERA. Technical Specification for Road Maintenance Works. 2nd Edition. Ethiopian Roads Authority. 2003.

[17] ERA. Highway Management System: Road Condition Survey Manual. Ethiopian Roads Authority. 2005.

[18] P. Kumar & A. Gupta. Cases studies of bituminous pavements. Compendium of Papers from the First International Conference on Pavement Preservation. 2010; pp. 505 – 518.

[19] Queensland Transport. Pavement Rehabilitation Manual. Pavement, Materials, Geotechnical Branch, State of Queensland. 2012.

[20] Toronto, Ontario M5H 2N2. Pavement Design and Rehabilitation Guideline. 2nd ed. City of Toronto: City of Toronto Infrastructure Asset Management & Programming Transportation Services Division; 2019.

[21] Fekadu Zeleke Ayele. Analysis of Storm Water Runoff Drainages in Addis Abeba City. 2018.

[22] Tiza, Michael Toryila, Iorver, Vitalis Terpase and Iortyom, Enoch Terlumun. The Effects of Poor Drainage System on Road Pavement. International Journal for Innovative Research in Multidisciplinary Field. 2016; 2(8).

[23] Farhad Salour. Moisture Influence on Structural Behavior of Pavements Field and Laboratory Investigations. Stockholm: KTH, Royal Institute of Technology; 2015.

[24] Geological Map of Ethiopia 1996 Edition.

[25] Kleyn, E., Maree, J., and Savage, P. The Application of a Portable Pavement Dynamic Cone Penetrometer to Determine In Situ Bearing Properties of Road Pavement Layers and Subgrades in South Africa," Proc. of the Second European Symposium on Penetration Testing, Amsterdam. 1982.

[26] ASTM D 6433-07. Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. American Society for Testing and Materials. 2007.

[27] Gupta, K.A. & Adlinge, S.S. Pavement Deterioration and its Causes. Shivaji University, India: Journal of Mechanical & Civil Engineering; 1998.

[28] ERA. Site Investigation Manual. Ethiopian Roads Authority. 2013.

[29] ERA. Best Practice Manual for Thin Bituminous Surfacing's. Ethiopian Roads Authority. 2013.

[30] Keith RK. Northwest pavement Management Systems Users Group and Washington State Department of Transportation. 1992.

[31] ERA. Annual Average Daily Traffic by Road Section and Vehicle Kilometer of Travel from Year 2002 To 2019. Ethiopian Roads Authority.

[32] Abdulrahaman M. Hamid. The dynamic Cone Penetration Test: a Review of its Correlation and its Applications. International Conference of Advances in Civil and Environmental Engineering. Saudi Arabia: Dhahran-31261; 2015.

[33] Wu, S. & Sargand, S.M. Use of Dynamic Cone Penetrometer in Subgrade and Base Acceptance. Ohio Department of Transportation, Report No. FHWA/ODOT-2007/01. 2007.

[34] Jemal J. Muhammed & Murad M. Abdella. Evaluation of Subgrade Capacity of Jimma Soils Using Dcp Test: A Correlation of CBR And DCPI Malaysian Journal of Civil Engineering. 2018; 30(3): pp. 441-451.

[35] ERA. Design Review Report of Bedele - Metu Road upgrading Project; Lot 2: Km 61+000 to Km 111+659. Ethiopian Roads Authority. 2013.

[36] Kandahl PS, & Richards IJ. Premature Failure of Asphalt Overlays from Stripping: Case Histories. National Center for Asphalt Technology (US). 2001.

[37] Scholz TV & Rajendran S. Investigating premature pavement failure due to moisture. Oregon. Department of Transportation. Research Section. 2009.

[38] Sulejmani P. Climate Impact on the Durability of Asphalt Concrete. Bulletin. 2020.

[39] Mgangira MB. Characterization of pavement distress from test pit observation. In-Road Pavement Material Characterization and Rehabilitation: Selected Papers Geo-Hunan International Conference. 2009; pp. 74-80.

[40] Cooley LA & Williams KL. Evaluation of hot mix asphalt (HMA) lift thickness. Mississippi. Dept. of Transportation; 2009.

[41] ERA. Standard Technical Specifications and Methods of Measurement for Road works. Ethiopian Roads Authority. 2013.

[42]. Berhanu A. Analysis and Modeling of Rutting for Long Life Asphalt Concrete pavement. A PhD.Thesis,Technische Universität Darmstadt. 2009.

APPENDIX

Appendix A: Field survey data for entire carriageway and shoulder, side drainage and remaining ancillary works

Field Survey Data Collection Sheet for Entire Carriageway											
Paved Road Condition Survey			Date	24/09/20	Inspector	Asrat G.	District	JRNS MBD	Section	Bedele	Page 1 of 2
Road No.	A5-7	Start Km	61+000	End Km	111+659	Direction	From	Wutete Village		To	Metu
S/No.	Station		Type of Defect	Defect Side			Dimension in M/No.			Measurement	
	From	To		Verge side (V)	Offside /wheel path (O)	Entire Carriageway (C/W)	Length	Width	Depth	Unit	Quantity
1	61+200	61+240	Potholes/Patch failure		√		1.50	1.00	0.07	M3	0.11
							0.30	0.20	0.03	M3	0.00
2	61+200	61+250	Cracking			√	40.00	3.50		M2	140.00
3	61+400		Raveling/Fretting	√			3.50	3.00		M2	10.50
4	61+900		Lane Marking Fade-out			√	Slight fade - out of the yellow marking				
5	63+400		Rutting		√		17.00	3.50	0.13	M3	7.74
6			Rutting		√		45.00	3.50	0.10	M3	14.96
7	63+760		Depression/Failure		√		5.00	3.00	0.40	M3	6.00
8	63+770		Rutting		√		4.00	2.50	0.18	M3	1.80
9	63+880		Stripping		√		22.00	2.50		M2	55.00

10	64+000		Depression/Failure			√	21.00	7.00	0.21	M3	30.87
11	64+030	64+100	Rutting		√		70.00	2.00	0.07	M3	9.80
12	64+170	64+200	Rutting		√		30.00	1.50	0.10	M3	4.50
13	64+170	64+180	Raveling/Fretting		√		10.00	2.30		M2	23.00
14	63+910	64+285	Rutting		√		370.00	2.00	0.07	M3	51.80
15	64+285	64+300	Depression/Failure		√		10.00	2.00	0.20	M3	4.00
16	64+500		Stripping		√		14.00	4.00		M2	56.00
17	64+700	64+760	Rutting		√		60.00	1.50	0.05	M3	4.05
18	64+860	64+950	Lane Marking with Few Missing			√	Lane marking is visible with few missing sections				
19	64+900	64+960	Stripping		√		60.00	0.80		M2	48.00
20	65+080	65+200	Rutting		√		150.00	1.40	0.06	M3	12.60
21	65+400	65+500	Raveling/Fretting		√		100.00	1.80		M2	180.00
22	65+700	65+780	Raveling/Fretting		√		6.00	2.60		M2	15.60
23	66+300	66+380	Raveling/Fretting	√			12.00	2.00		M2	24.00
24	67+000		Raveling/Fretting		√		6.00	1.30		M2	7.80

25	67+100		Potholes/Patch failure		√		0.60	0.60	0.06	M3	0.02
26	67+300		Raveling/Fretting		√		4.50	1.40		M2	6.30
27	68+200	68+300	Raveling/Fretting		√		20.00	3.00		M2	60.00
28	68+493	68+500	Rutting		√		7.00	2.30	0.11	M3	1.77
29	68+560		Depression/Failure		√		3.00	2.00	0.15	M3	0.90
30	68+600		Potholes/Patch failure		√		1.00	0.80	0.04	M3	0.03
31	70+600	70+700	Corrugation	√			80.00	0.60	0.02	M3	0.72
32	70+700		Potholes/Patch failure			√	12.00	3.00	0.90	M3	32.40
33	77+900		Depression/Failure	√			4.00	2.00	0.16	M3	1.28
34	78+900		Potholes/Patch failure			√	6.90	2.90	0.09	M3	1.80

Field Survey Data Collection Sheet for Entire Carriageway												
Paved Road Condition Survey			**Date**	**25/09/2020**	**Inspector**	**Asrat G.**	**District**	**JRNS MBD**	**Section**	**Bedele**	**Page 2 of 2**	
Road No.	**A5-7**	**Start Km**	**61+000**	**End Km**	**111+659**	**Direction**	**From**	**Wutete Village**		**To**	**Metu**	

S/No.	Station		Type of Defect	Defect Side			Dimension in M/No.			Measurement	
	From	To		Verge side (V)	Offside /wheel path (O)	Entire Carriageway (C/W)	Length	Width	Depth	Unit	Quantity
1	80+100		Raveling/Fretting		√		12.00	2.00		M2	24.00
2	80+300		Potholes/Patch failure			√	4.00	3.00	0.08	M3	0.96
3	80+800		Raveling/Fretting		√		2.00	1.50		M2	3.00
4	81+100		Depression/Failure		√		3.00	4.00	0.08	M3	0.96
5	81+800		Corrugation		√		6.00	2.00	0.03	M3	0.30
6	83+000		Corrugation			√	7.00	2.50	0.01	M3	0.18
7	83+300		Potholes/Patch failure			√	0.40	0.45	0.06	M3	0.03
8	83+350	83+390	Corrugation		√		40.00	0.80	0.01	M3	0.45
9	83+390	83+410	Corrugation		√		18.00	1.30	0.01	M3	0.23
10	83+410	83+500	Corrugation	√			70.00	0.30	0.01	M3	0.27
11	83+500	83+600	Corrugation	√			90.00	0.25	0.01	M3	0.32
12	83+800	83+900	Raveling/Fretting		√		3.00	2.00		M2	6.00
13	84+900		Rutting		√		2.50	1.50	0.04	M3	0.15
14	85+050		Potholes/Patch failure		√		1.50	1.00	0.14	M3	0.21
15	85+060		Potholes/Patch		√		9.00	2.70	0.26	M3	6.32

			failure								
16	85+050		Cracking		√		9.00			M	9.00
17	85+100		Raveling/Fretting			√	6.00	2.00		M2	12.00
18	85+300	85+370	Depression/Failure			√	70.00	6.80	0.30	M3	142.80
19	85+490	85+510	Depression/Failure			√	20.00	7.00	0.28	M3	39.20
20	85+700		Rutting	√			2.00	3.00	0.08	M3	0.48
21	86+500	86+650	Corrugation	√			150.00	0.80	0.02	M3	2.04
22	86+670	86+690	Rutting		√		20.00	1.50	0.09	M3	2.55
23	87+700	87+750	Rutting		√		50.00	1.40	0.06	M3	4.20
24	87+700	87+730	Raveling/Fretting		√		30.00	4.00		M2	120.00
25	87+724		Potholes/Patch failure		√		0.80	0.70	0.06	M3	0.03
26	87+900	87+950	Rutting		√		40.00	1.60	0.08	M3	5.12
27	88+100	88+130	Rutting		√		130.00	1.80	0.06	M3	14.04
28	88+500		Potholes/Patch failure		√		4.00	3.00	0.06	M3	0.72
29	88+700		Potholes/Patch failure		√		4.20	5.00	0.16	M3	3.36
30	88+715		Potholes/Patch failure		√		4.40	7.00	0.15	M3	4.62
31	88+800		Depression/Failur		√		3.00	2.00	0.11	M3	0.66

			e								
32	89+900		Raveling/Fretting		√		3.00	7.00		M2	21.00
33	90+200		Raveling/Fretting		√		3.00	1.50		M2	4.50
34	90+500		Raveling/Fretting		√		2.00	1.00		M2	2.00
35	99+270		Corrugation	√			7.00	1.50	0.01	M3	0.12
36	111+642	111+659	Depression/Failure			√	17.00	3.80	0.17	M3	10.98

Field Survey Data Collection Sheet for Shoulder, Side Drainage and Remaining Ancillary Works											
Paved Road Condition Survey			**Date**	**24/09/20**	**Inspector**	**Asrat G.**	**District**	**JRNS MBD**	**Section**	**Bedele**	**Page 1 of 1**
Road No.	**A5-7**	**Start Km**	**61+000**	**End Km**	**111+659**	**Direction**	**From**	**Wutete Village**		**To**	**Metu**
S/No.	**Station**		**Type of Defect**	**Defect Side**			**Dimension**			**Measurement**	
	From	**To**		**LHS**	**BHS**	**RHS**	**Length**	**Width**	**Depth**	**Unit**	**Quantity**
1	61+270		Siltation	√			12.00	1.7	0.6	M3	12.24
2	61+800	62+000	Siltation		√		400.00	0.6	0.4		96.00
3	63+910		Shoulder Deform			√	13.000	0.4	0.05		0.26
4	65+190	65+200	Shoulder Deform			√	10.00	0.5	0.09		0.45
5	66+400		Guardrail Damaged			√					0.00
6	75+100		Siltation	√			7.00	1.7	0.60		7.14
7	77+400		Siltation			√	9.00	0.6	0.80		4.32
8	79+500		Siltation			√	7.00	1.7	0.60		7.14

Condition Survey Date: 24/09/2020 and 25/09/2020											
9	63+000	105+000	Vegetation		√		31,000.	3.0		M2	186,000.00

Appendix B: Summary of severity and extent of road defects on severely deteriorated road portions

Paved Road Condition Survey					Date	30/09/20	Inspector	Asrat G.	District	JRN SM BD	Section	Bedele	Page 1 of 4
Road No.	A5-7	Start Km	61+000	End Km	111+659	Direction	From	Wutete Village		To		Metu	
Station in Km			61+000 - 61+500		61+500 - 62+000		62+000 - 62+500		62+500 - 63+000		63+000 - 63+500		Comment/Actions
			Severity	Extent	Severity	Extent	Severity	Extent	Severity	Extent	Severity	Extent	
Left	Side Drain	Silt	3	1	3	2							
		Scour											
	Shoulder	Deform											
		Erosion											
		Vegetation									2	2	
	Edge Step												
	Edge Damage												
Carriageway	Rutting										3	1	
	Corrugations												
	Cracking		1	1									
	Potholes/Patching		2	2									
	Bleeding												
	Stripping/Fretting		1	1									
	Surface Texture												
	Depression/Failure												
	Safety												
	Lane Marking				2	1							
Right	Side Drain	Silt											
		Scour											

Shoulder	Deform											
	Erosion											
	Vegetation									2	2	
Edge Step												
Edge Damage												

Paved Road Condition Survey					**Date**	**30/09/20**	**Inspector**	**Asrat G.**	**District**	**JRNS MBD**	**Section**	**Bedele**	**Page 2 of 4**
Road No.	**A5-7**	**Start Km**	**61+000**	**End Km**	**111+659**	**Direction**	**From**	**Bedele/Wutete Village**			**To**	**Metu**	
Station in Km			**63+500 - 64+000**		**64+000 - 64+500**		**64+500 - 65+000**		**65+000 - 65+500**		**65+500 - 66+000**		**Comment/ Actions**
			Severity	**Extent**	**Severity**	**Extent**	**Severity**	**Extent**	**Severity**	**Extent**	**Severity**	**Extent**	
Left	Side Drain	Silt											
		Scour											
	Shoulder	Deform	1	1					2	1			
		Erosion											
		Vegetation	3	2	1	2	2	2	3	1	2	2	
	Edge Step												
	Edge Damage												
Carriageway	Rutting		3	1	3	3	2	1	3	2			
	Corrugations												
	Cracking												
	Potholes/Patching												
	Bleeding												
	Stripping/ Fretting		1	1	1	2	1	1	1	2	1	1	
	Surface Texture												

	Depression/Failure		2	1	2	1							
	Safety											
	Lane Marking						1	2					
Right	Side Drain	Silt											
		Scour											
	Shoulder	Deform											
		Erosion											
		Vegetation	3	2	2	2	2	2	1	3	2	1	
	Edge Step												
	Edge Damage												

Paved Road Condition Survey					Date	30/09/20	Inspector	Asrat G.	District	JRNS MBD	Section	Bedele	Page 3 of 4
Road No.	A5-7	Start Km	61+000	End Km	111+659	Direction	From	Bedele/Wutete Village		To	Metu		

Station in Km			78+500 - 79+000		79+000 - 79+500		79+500 - 80+000		80+000 - 80+500		80+500 - 81+000		Comment/ Actions
			Severity	Extent	Severity	Extent	Severity	Extent	Severity	Extent	Severity	Extent	
Left	Side Drain	Silt			3	1							
		Scour											
	Shoulder	Deform											
		Erosion											
		Vegetation	1	1	1	1	2	2	2	1	3	3	
	Edge Step												
	Edge Damage												
Carriageway	Rutting												
	Corrugatio												

	ns												
	Cracking												
	Potholes/Patching		2	1					2	1			
	Bleeding												
	Stripping/ Fretting								1	1	1	1	
	Surface Texture												
	Depression/Failure												
	Safety												
	Lane Marking												
Right	Side Drain	Silt											
		Scour											
	Shoulder	Deform											
		Erosion											
		Vegetation	1	1	1	1	2	2	2	1	3	3	
	Edge Step												
	Edge Damage												

Paved Road Condition Survey					**Date**	**30/09/20**	**Inspector**	**Asrat G.**	**District**	**JRN SMBD**	**Section**	**Bedele**	**Page 4 of 4**
Road No.	**A5-7**	**Start Km**	**61+000**	**End Km**	**111+659**	**Direction**	**From**	**Bedele/Wutete Village**			**To**	**Metu**	

Station in Km			**83+500 - 84+000**		**84+000 - 84+500**		**84+500 - 85+000**		**85+000 - 85+500**		**85+500 - 86+000**		**Comment/ Actions**
			Severity	**Extent**	**Severity**	**Extent**	**Severity**	**Extent**	**Severity**	**Extent**	**Severity**	**Extent**	
Left	Side Drain	Silt											
		Scour											
	Shoulder	Deform											

		Erosion											
		Vegetation	2	2	2	3	2	2	1	1	1	1	
	Edge Step												
	Edge Damage												
Carriageway	Rutting						2	1			3	1	
	Corrugations		1	1									
	Cracking								1	1			
	Potholes/Patching								3	2			
	Bleeding												
	Stripping/Fretting		1	1					1	1			
	Surface Texture												
	Depression/Failure								3	1			
	Safety												
	Lane Marking												
Right	Side Drain	Silt											
		Scour											
	Shoulder	Deform											
		Erosion											
		Vegetation	2	2	2	3	2	2	1	1	1	1	
	Edge Step												
	Edge Damage												

Appendix C: DCP test results

Dynamic Cone Penetrometer (DCP) Test Field Sheet			
Site/Road	Bedelle - Metu Lot - II (61+000 - 111+659)		
Test No.	DCP01		
Section No./Chainage	63+400	**Analysis Date**	02/11/2020 - 06/11/2020
Direction	Bedele - Metu	**Ave. Zero Reading of DCP in mm**	47.87
Wheel Path	RHS	**Test Started**	9:30 AM

DCP Test				**TRRL, 1990 (60^0 Cone)**			
No. of Blows	**Sum of Blows**	**Penetration Depth, mm**	**Cumulative Penetration, mm**	**Penetration Index (N), (mm/blow)**	**$Log_{10}N$**	**Log_{10} (CBR) = 2.48-1.057Log_{10}(mm/blow)**	**Calculated CBR, %**
0	0		47.87				
AC/Surfacing Layer End							
1	1	2.00	2.00	2.00	0.30	2.16	145.15
1	2	2.00	4.00	2.00	0.30	2.16	145.15
1	3	2.75	6.75	2.75	0.44	2.02	103.66
2	5	3.50	10.25	1.75	0.24	2.22	167.15
1	6	2.00	12.25	2.00	0.30	2.16	145.15
1	7	2.00	14.25	2.00	0.30	2.16	145.15
1	8	2.50	16.75	2.50	0.40	2.06	114.65
1	9	3.00	19.75	3.00	0.48	1.98	94.55
1	10	3.00	22.75	3.00	0.48	1.98	94.55
2	12	3.00	25.75	1.50	0.18	2.29	196.73
1	13	2.00	27.75	2.00	0.30	2.16	145.15
1	14	2.50	30.25	2.50	0.40	2.06	114.65
1	15	3.00	33.25	3.00	0.48	1.98	94.55
1	16	3.00	36.25	3.00	0.48	1.98	94.55
1	17	3.00	39.25	3.00	0.48	1.98	94.55
1	18	3.50	42.75	3.50	0.54	1.90	80.34
2	20	3.00	45.75	1.50	0.18	2.29	196.73
1	21	5.00	50.75	5.00	0.70	1.74	55.10
1	22	5.00	55.75	5.00	0.70	1.74	55.10
1	23	3.50	59.25	3.50	0.54	1.90	80.34
1	24	3.00	62.25	3.00	0.48	1.98	94.55

1	25	3.50	65.75	3.50	0.54	1.90	80.34
1	26	2.00	67.75	2.00	0.30	2.16	145.15
2	28	2.00	69.75	1.00	0.00	2.48	302.00
1	29	3.00	72.75	3.00	0.48	1.98	94.55
1	30	3.00	75.75	3.00	0.48	1.98	94.55
1	31	2.50	78.25	2.50	0.40	2.06	114.65
1	32	2.50	80.75	2.50	0.40	2.06	114.65
1	33	2.00	82.75	2.00	0.30	2.16	145.15
1	34	2.00	84.75	2.00	0.30	2.16	145.15
1	35	3.00	87.75	3.00	0.48	1.98	94.55
2	37	2.50	90.25	1.25	0.10	2.38	238.54
1	38	3.00	93.25	3.00	0.48	1.98	94.55
1	39	3.50	96.75	3.50	0.54	1.90	80.34
1	40	2.00	98.75	2.00	0.30	2.16	145.15
1	41	2.00	100.75	2.00	0.30	2.16	145.15
1	42	3.00	103.75	3.00	0.48	1.98	94.55
1	43	3.00	106.75	3.00	0.48	1.98	94.55
1	44	3.00	109.75	3.00	0.48	1.98	94.55
1	45	2.50	112.25	2.50	0.40	2.06	114.65
1	46	3.00	115.25	3.00	0.48	1.98	94.55
1	47	1.50	116.75	1.50	0.18	2.29	196.73
1	48	2.00	118.75	2.00	0.30	2.16	145.15
1	49	2.50	121.25	2.50	0.40	2.06	114.65
1	50	2.50	123.75	2.50	0.40	2.06	114.65
1	51	2.75	126.50	2.75	0.44	2.02	103.66
1	52	3.00	129.50	3.00	0.48	1.98	94.55
1	53	2.00	131.50	2.00	0.30	2.16	145.15
2	55	1.50	133.00	0.75	-0.12	2.61	409.32
1	56	2.00	135.00	2.00	0.30	2.16	145.15
1	57	2.00	137.00	2.00	0.30	2.16	145.15
1	58	3.50	140.50	3.50	0.54	1.90	80.34
1	59	3.00	143.50	3.00	0.48	1.98	94.55
1	60	3.00	146.50	3.00	0.48	1.98	94.55
1	61	2.00	148.50	2.00	0.30	2.16	145.15
1	62	2.00	150.50	2.00	0.30	2.16	145.15
1	63	3.00	153.50	3.00	0.48	1.98	94.55
1	64	3.00	156.50	3.00	0.48	1.98	94.55
1	65	2.00	158.50	2.00	0.30	2.16	145.15

1	66	2.00	160.50	2.00	0.30	2.16	145.15
1	67	2.50	163.00	2.50	0.40	2.06	114.65
1	68	2.00	165.00	2.00	0.30	2.16	145.15
1	69	2.50	167.50	2.50	0.40	2.06	114.65
1	70	2.00	169.50	2.00	0.30	2.16	145.15
1	71	2.50	172.00	2.50	0.40	2.06	114.65
1	72	3.00	175.00	3.00	0.48	1.98	94.55
1	73	3.00	178.00	3.00	0.48	1.98	94.55
1	74	3.00	181.00	3.00	0.48	1.98	94.55
1	75	2.00	183.00	2.00	0.30	2.16	145.15
1	76	2.00	185.00	2.00	0.30	2.16	145.15
1	77	2.50	187.50	2.50	0.40	2.06	114.65
1	78	2.00	189.50	2.00	0.30	2.16	145.15
1	79	2.00	191.50	2.00	0.30	2.16	145.15
1	80	3.00	194.50	3.00	0.48	1.98	94.55
1	81	2.00	196.50	2.00	0.30	2.16	145.15
1	82	1.50	198.00	1.50	0.18	2.29	196.73
Base-course Layer End							
1	1	3.00	3.00	3.00	0.48	1.98	94.55
1	2	3.00	6.00	3.00	0.48	1.98	94.55
1	3	4.00	10.00	4.00	0.60	1.84	69.76
1	4	4.50	14.50	4.50	0.65	1.79	61.60
1	5	4.00	18.50	4.00	0.60	1.84	69.76
1	6	5.00	23.50	5.00	0.70	1.74	55.10
1	7	5.00	28.50	5.00	0.70	1.74	55.10
1	8	4.00	32.50	4.00	0.60	1.84	69.76
1	9	6.00	38.50	6.00	0.78	1.66	45.45
1	10	6.00	44.50	6.00	0.78	1.66	45.45
1	11	5.00	49.50	5.00	0.70	1.74	55.10
1	12	3.00	52.50	3.00	0.48	1.98	94.55
1	13	4.00	56.50	4.00	0.60	1.84	69.76
1	14	4.00	60.50	4.00	0.60	1.84	69.76
1	15	4.75	65.25	4.75	0.68	1.76	58.17
1	16	5.00	70.25	5.00	0.70	1.74	55.10
1	17	6.00	76.25	6.00	0.78	1.66	45.45
1	18	6.00	82.25	6.00	0.78	1.66	45.45
1	19	7.00	89.25	7.00	0.85	1.59	38.61
1	20	4.00	93.25	4.00	0.60	1.84	69.76

1	21	3.50	96.75	3.50	0.54	1.90	80.34
1	22	3.00	99.75	3.00	0.48	1.98	94.55
1	23	5.00	104.75	5.00	0.70	1.74	55.10
1	24	5.00	109.75	5.00	0.70	1.74	55.10
1	25	4.50	114.25	4.50	0.65	1.79	61.60
1	26	5.00	119.25	5.00	0.70	1.74	55.10
1	27	5.00	124.25	5.00	0.70	1.74	55.10
1	28	4.00	128.25	4.00	0.60	1.84	69.76
1	29	5.00	133.25	5.00	0.70	1.74	55.10
1	30	4.00	137.25	4.00	0.60	1.84	69.76
1	31	3.00	140.25	3.00	0.48	1.98	94.55
1	32	4.00	144.25	4.00	0.60	1.84	69.76
1	33	6.00	150.25	6.00	0.78	1.66	45.45
2	35	6.00	156.25	3.00	0.48	1.98	94.55
1	36	6.00	162.25	6.00	0.78	1.66	45.45
1	37	6.00	168.25	6.00	0.78	1.66	45.45
1	38	4.00	172.25	4.00	0.60	1.84	69.76
1	39	4.00	176.25	4.00	0.60	1.84	69.76
1	40	5.00	181.25	5.00	0.70	1.74	55.10
1	41	5.00	186.25	5.00	0.70	1.74	55.10
1	42	6.00	192.25	6.00	0.78	1.66	45.45
1	43	6.00	198.25	6.00	0.78	1.66	45.45
1	44	2.00	200.25	2.00	0.30	2.16	145.15
1	45	3.00	203.25	3.00	0.48	1.98	94.55
1	46	6.00	209.25	6.00	0.78	1.66	45.45
1	47	6.00	215.25	6.00	0.78	1.66	45.45
1	48	7.00	222.25	7.00	0.85	1.59	38.61
1	49	7.00	229.25	7.00	0.85	1.59	38.61
1	50	6.00	235.25	6.00	0.78	1.66	45.45
1	51	6.00	241.25	6.00	0.78	1.66	45.45
1	52	5.00	246.25	5.00	0.70	1.74	55.10
1	53	4.00	250.25	4.00	0.60	1.84	69.76
1	54	5.00	255.25	5.00	0.70	1.74	55.10
1	55	5.00	260.25	5.00	0.70	1.74	55.10
1	56	5.50	265.75	5.50	0.74	1.70	49.82
1	57	7.00	272.75	7.00	0.85	1.59	38.61
1	58	7.00	279.75	7.00	0.85	1.59	38.61
1	59	8.00	287.75	8.00	0.90	1.53	33.53

1	60	7.00	294.75	7.00	0.85	1.59	38.61
1	61	7.00	301.75	7.00	0.85	1.59	38.61
1	62	5.00	306.75	5.00	0.70	1.74	55.10
1	63	4.00	310.75	4.00	0.60	1.84	69.76
1	64	4.50	315.25	4.50	0.65	1.79	61.60
1	65	5.00	320.25	5.00	0.70	1.74	55.10
1	66	5.00	325.25	5.00	0.70	1.74	55.10
1	67	4.00	329.25	4.00	0.60	1.84	69.76
1	68	6.00	335.25	6.00	0.78	1.66	45.45
1	69	5.00	340.25	5.00	0.70	1.74	55.10
1	70	5.00	345.25	5.00	0.70	1.74	55.10
1	71	4.00	349.25	4.00	0.60	1.84	69.76
Sub-base course Layer End							
1	1	6.00	6.00	6.00	0.78	1.66	45.45
1	2	7.00	13.00	7.00	0.85	1.59	38.61
1	3	8.00	21.00	8.00	0.90	1.53	33.53
1	4	9.00	30.00	9.00	0.95	1.47	29.61
1	5	9.00	39.00	9.00	0.95	1.47	29.61
1	6	12.00	51.00	12.00	1.08	1.34	21.84
1	7	11.00	62.00	11.00	1.04	1.38	23.95
1	8	10.00	72.00	10.00	1.00	1.42	26.49
1	9	12.00	84.00	12.00	1.08	1.34	21.84
1	10	11.00	95.00	11.00	1.04	1.38	23.95
1	11	9.00	104.00	9.00	0.95	1.47	29.61
1	12	10.00	114.00	10.00	1.00	1.42	26.49
1	13	11.00	125.00	11.00	1.04	1.38	23.95
1	14	8.50	133.50	8.50	0.93	1.50	31.45
1	15	9.00	142.50	9.00	0.95	1.47	29.61
1	16	9.00	151.50	9.00	0.95	1.47	29.61
1	17	9.00	160.50	9.00	0.95	1.47	29.61
Sub-grade Layer @160.50 mm							

Dynamic Cone Penetrometer (DCP) Test Field Sheet							
Site/Road			Bedele - Metu Lot - II (61+000 - 111+659)				
Test No.			DCP02				
Section No./Chainage			64+015	**Analysis Date**		02/11/2020 - 06/11/2020	
Direction		Bedele - Metu		**Ave. Zero Reading of DCP in mm**		45.25	
Wheel Path		Center		**Test Started**		11:30 AM	
DCP Test				**TRRL, 1990 (60^0 Cone)**			
No. of Blows	**Sum of Blows**	**Penetration Depth, mm**	**Cumulative Penetration, mm**	**Penetration Index (N), (mm/blow)**	**$Log_{10}N$**	**Log_{10} (CBR) = 2.48-1.057Log_{10}(mm/blow)**	**Calculated CBR, %**
0	0		45.25				
AC/Surfacing Layer End							
1	1	1.00	1.00	1.00	0.00	2.48	302.00
1	2	1.50	2.50	1.50	0.18	2.29	196.73
1	3	2.00	4.50	2.00	0.30	2.16	145.15
2	5	2.00	6.50	1.00	0.00	2.48	302.00
1	6	2.00	8.50	2.00	0.30	2.16	145.15
1	7	2.50	11.00	2.50	0.40	2.06	114.65
1	8	1.00	12.00	1.00	0.00	2.48	302.00
1	9	2.00	14.00	2.00	0.30	2.16	145.15
1	10	2.00	16.00	2.00	0.30	2.16	145.15
2	12	1.50	17.50	0.75	-0.12	2.61	409.32
1	13	2.50	20.00	2.50	0.40	2.06	114.65
1	14	2.00	22.00	2.00	0.30	2.16	145.15
1	15	2.00	24.00	2.00	0.30	2.16	145.15
1	16	2.00	26.00	2.00	0.30	2.16	145.15
1	17	1.50	27.50	1.50	0.18	2.29	196.73
1	18	2.00	29.50	2.00	0.30	2.16	145.15
2	20	2.00	31.50	1.00	0.00	2.48	302.00
1	21	2.00	33.50	2.00	0.30	2.16	145.15
1	22	1.50	35.00	1.50	0.18	2.29	196.73
1	23	3.00	38.00	3.00	0.48	1.98	94.55
1	24	3.00	41.00	3.00	0.48	1.98	94.55
1	25	3.00	44.00	3.00	0.48	1.98	94.55
2	27	2.00	46.00	1.00	0.00	2.48	302.00

1	28	2.00	48.00	2.00	0.30	2.16	145.15
1	29	2.50	50.50	2.50	0.40	2.06	114.65
1	30	1.50	52.00	1.50	0.18	2.29	196.73
1	31	3.00	55.00	3.00	0.48	1.98	94.55
1	32	3.50	58.50	3.50	0.54	1.90	80.34
1	33	2.50	61.00	2.50	0.40	2.06	114.65
2	35	2.00	63.00	1.00	0.00	2.48	302.00
1	36	2.00	65.00	2.00	0.30	2.16	145.15
1	37	2.00	67.00	2.00	0.30	2.16	145.15
1	38	3.00	70.00	3.00	0.48	1.98	94.55
1	39	3.00	73.00	3.00	0.48	1.98	94.55
1	40	2.50	75.50	2.50	0.40	2.06	114.65
1	41	3.00	78.50	3.00	0.48	1.98	94.55
1	42	3.00	81.50	3.00	0.48	1.98	94.55
1	43	3.00	84.50	3.00	0.48	1.98	94.55
1	44	2.00	86.50	2.00	0.30	2.16	145.15
1	45	2.00	88.50	2.00	0.30	2.16	145.15
1	46	2.00	90.50	2.00	0.30	2.16	145.15
1	47	1.00	91.50	1.00	0.00	2.48	302.00
1	48	3.00	94.50	3.00	0.48	1.98	94.55
1	49	3.00	97.50	3.00	0.48	1.98	94.55
1	50	2.00	99.50	2.00	0.30	2.16	145.15
1	51	3.00	102.50	3.00	0.48	1.98	94.55
1	52	2.00	104.50	2.00	0.30	2.16	145.15
1	53	2.50	107.00	2.50	0.40	2.06	114.65
1	54	2.00	109.00	2.00	0.30	2.16	145.15
1	55	2.00	111.00	2.00	0.30	2.16	145.15
1	56	2.00	113.00	2.00	0.30	2.16	145.15
1	57	1.00	114.00	1.00	0.00	2.48	302.00
1	58	0.50	114.50	0.50	-0.30	2.80	628.33
1	59	2.00	116.50	2.00	0.30	2.16	145.15
1	60	2.00	118.50	2.00	0.30	2.16	145.15
1	61	1.50	120.00	1.50	0.18	2.29	196.73
1	62	1.50	121.50	1.50	0.18	2.29	196.73
1	63	2.00	123.50	2.00	0.30	2.16	145.15
1	64	2.50	126.00	2.50	0.40	2.06	114.65
1	65	2.00	128.00	2.00	0.30	2.16	145.15
1	66	2.00	130.00	2.00	0.30	2.16	145.15

1	67	3.00	133.00	3.00	0.48	1.98	94.55
1	68	2.00	135.00	2.00	0.30	2.16	145.15
1	69	2.00	137.00	2.00	0.30	2.16	145.15
1	70	3.50	140.50	3.50	0.54	1.90	80.34
1	71	3.00	143.50	3.00	0.48	1.98	94.55
1	72	3.00	146.50	3.00	0.48	1.98	94.55
1	73	2.50	149.00	2.50	0.40	2.06	114.65
1	74	2.00	151.00	2.00	0.30	2.16	145.15
1	75	3.00	154.00	3.00	0.48	1.98	94.55
1	76	3.00	157.00	3.00	0.48	1.98	94.55
1	77	3.50	160.50	3.50	0.54	1.90	80.34
1	78	3.00	163.50	3.00	0.48	1.98	94.55
1	79	3.00	166.50	3.00	0.48	1.98	94.55
1	80	3.00	169.50	3.00	0.48	1.98	94.55
1	81	3.00	172.50	3.00	0.48	1.98	94.55
1	82	3.00	175.50	3.00	0.48	1.98	94.55
1	83	2.00	177.50	2.00	0.30	2.16	145.15
1	84	3.00	180.50	3.00	0.48	1.98	94.55
1	85	2.00	182.50	2.00	0.30	2.16	145.15
1	86	2.00	184.50	2.00	0.30	2.16	145.15
1	87	2.00	186.50	2.00	0.30	2.16	145.15
1	88	3.00	189.50	3.00	0.48	1.98	94.55
1	89	3.00	192.50	3.00	0.48	1.98	94.55
1	90	3.00	195.50	3.00	0.48	1.98	94.55
1	91	2.00	197.50	2.00	0.30	2.16	145.15
1	92	2.00	199.50	2.00	0.30	2.16	145.15
Base-course Layer End							
1	1	4.00	4.00	4.00	0.60	1.84	69.76
1	2	3.00	7.00	3.00	0.48	1.98	94.55
1	3	4.00	11.00	4.00	0.60	1.84	69.76
1	4	3.50	14.50	3.50	0.54	1.90	80.34
1	5	4.50	19.00	4.50	0.65	1.79	61.60
1	6	5.00	24.00	5.00	0.70	1.74	55.10
1	7	4.50	28.50	4.50	0.65	1.79	61.60
1	8	5.00	33.50	5.00	0.70	1.74	55.10
1	9	5.00	38.50	5.00	0.70	1.74	55.10
1	10	6.00	44.50	6.00	0.78	1.66	45.45
1	11	5.00	49.50	5.00	0.70	1.74	55.10

1	12	5.00	54.50	5.00	0.70	1.74	55.10
1	13	3.00	57.50	3.00	0.48	1.98	94.55
1	14	4.00	61.50	4.00	0.60	1.84	69.76
1	15	4.50	66.00	4.50	0.65	1.79	61.60
1	16	5.50	71.50	5.50	0.74	1.70	49.82
1	17	5.00	76.50	5.00	0.70	1.74	55.10
1	18	5.00	81.50	5.00	0.70	1.74	55.10
1	19	6.00	87.50	6.00	0.78	1.66	45.45
1	20	6.00	93.50	6.00	0.78	1.66	45.45
1	21	4.50	98.00	4.50	0.65	1.79	61.60
1	22	4.00	102.00	4.00	0.60	1.84	69.76
1	23	4.50	106.50	4.50	0.65	1.79	61.60
1	24	4.50	111.00	4.50	0.65	1.79	61.60
1	25	5.00	116.00	5.00	0.70	1.74	55.10
1	26	6.00	122.00	6.00	0.78	1.66	45.45
1	27	5.00	127.00	5.00	0.70	1.74	55.10
1	28	4.00	131.00	4.00	0.60	1.84	69.76
1	29	4.00	135.00	4.00	0.60	1.84	69.76
1	30	4.00	139.00	4.00	0.60	1.84	69.76
2	32	2.00	141.00	1.00	0.00	2.48	302.00
1	33	3.00	144.00	3.00	0.48	1.98	94.55
1	34	4.00	148.00	4.00	0.60	1.84	69.76
1	35	4.00	152.00	4.00	0.60	1.84	69.76
1	36	5.00	157.00	5.00	0.70	1.74	55.10
1	37	5.00	162.00	5.00	0.70	1.74	55.10
1	38	6.00	168.00	6.00	0.78	1.66	45.45
1	39	7.00	175.00	7.00	0.85	1.59	38.61
1	40	6.00	181.00	6.00	0.78	1.66	45.45
1	41	6.00	187.00	6.00	0.78	1.66	45.45
1	42	7.00	194.00	7.00	0.85	1.59	38.61
1	43	7.00	201.00	7.00	0.85	1.59	38.61
1	44	6.00	207.00	6.00	0.78	1.66	45.45
1	45	6.00	213.00	6.00	0.78	1.66	45.45
1	46	5.00	218.00	5.00	0.70	1.74	55.10
1	47	5.00	223.00	5.00	0.70	1.74	55.10
1	48	5.00	228.00	5.00	0.70	1.74	55.10
1	49	4.00	232.00	4.00	0.60	1.84	69.76
1	50	5.00	237.00	5.00	0.70	1.74	55.10

1	51	4.00	241.00	4.00	0.60	1.84	69.76
1	52	5.00	246.00	5.00	0.70	1.74	55.10
1	53	4.00	250.00	4.00	0.60	1.84	69.76
1	54	4.00	254.00	4.00	0.60	1.84	69.76
1	55	4.75	258.75	4.75	0.68	1.76	58.17
1	56	6.00	264.75	6.00	0.78	1.66	45.45
1	57	6.00	270.75	6.00	0.78	1.66	45.45
1	58	6.50	277.25	6.50	0.81	1.62	41.76
1	59	5.00	282.25	5.00	0.70	1.74	55.10
1	60	5.00	287.25	5.00	0.70	1.74	55.10
1	61	7.00	294.25	7.00	0.85	1.59	38.61
1	62	6.00	300.25	6.00	0.78	1.66	45.45
1	63	6.00	306.25	6.00	0.78	1.66	45.45
1	64	6.50	312.75	6.50	0.81	1.62	41.76
1	65	6.00	318.75	6.00	0.78	1.66	45.45
1	66	7.00	325.75	7.00	0.85	1.59	38.61
1	67	6.50	332.25	6.50	0.81	1.62	41.76
1	68	5.00	337.25	5.00	0.70	1.74	55.10
1	69	6.00	343.25	6.00	0.78	1.66	45.45
1	70	6.50	349.75	6.50	0.81	1.62	41.76
Sub-base course Layer End							
1	1	7.00	7.00	7.00	0.85	1.59	38.61
1	2	7.50	14.50	7.50	0.88	1.56	35.90
1	3	6.00	20.50	6.00	0.78	1.66	45.45
1	4	8.00	28.50	8.00	0.90	1.53	33.53
1	5	11.00	39.50	11.00	1.04	1.38	23.95
1	6	10.00	49.50	10.00	1.00	1.42	26.49
1	7	12.00	61.50	12.00	1.08	1.34	21.84
1	8	13.00	74.50	13.00	1.11	1.30	20.07
1	9	12.00	86.50	12.00	1.08	1.34	21.84
1	10	14.00	100.50	14.00	1.15	1.27	18.56
1	11	9.00	109.50	9.00	0.95	1.47	29.61
1	12	9.00	118.50	9.00	0.95	1.47	29.61
1	13	8.00	126.50	8.00	0.90	1.53	33.53
1	14	9.50	136.00	9.50	0.98	1.45	27.96
1	15	11.00	147.00	11.00	1.04	1.38	23.95
1	17	12.00	169.00	12.00	1.08	1.34	21.84
Sub-grade Layer @169.00 mm							

Dynamic Cone Penetrometer (DCP) Test Field Sheet							
Site/Road			Bedele - Metu Lot - II (61+000 - 111+659)				
Test No.			DCP03				
Section No./Chainage			78+900	**Analysis Date**		02/11/2020 - 06/11/2020	
Direction		Bedele - Metu		**Ave. Zero Reading of DCP in mm**		38.66	
Wheel Path		RHS		**Test Started**		11:30 AM	
DCP Test				**TRRL, 1990 (60^0 Cone)**			
No. of Blows	**Sum of Blows**	**Penetration Depth, mm**	**Cumulative Penetration, mm**	**Penetration Index (N), (mm/blow)**	**Log_{10} N**	**Log_{10} (CBR) = 2.48-1.057Log_{10}(mm/blow)**	**Calculated CBR, %**
0	0		38.66				
AC/Surfacing Layer End							
2	2	2.00	2.00	1.00	0.00	2.48	302.00
1	3	2.00	4.00	2.00	0.30	2.16	145.15
1	4	1.50	5.50	1.50	0.18	2.29	196.73
1	5	1.50	7.00	1.50	0.18	2.29	196.73
1	6	2.00	9.00	2.00	0.30	2.16	145.15
1	7	2.00	11.00	2.00	0.30	2.16	145.15
1	8	2.50	13.50	2.50	0.40	2.06	114.65
1	9	3.00	16.50	3.00	0.48	1.98	94.55
1	10	3.00	19.50	3.00	0.48	1.98	94.55
1	11	3.50	23.00	3.50	0.54	1.90	80.34
1	12	3.00	26.00	3.00	0.48	1.98	94.55
1	13	3.00	29.00	3.00	0.48	1.98	94.55
1	14	5.00	34.00	5.00	0.70	1.74	55.10
1	15	2.50	36.50	2.50	0.40	2.06	114.65
1	16	3.00	39.50	3.00	0.48	1.98	94.55
1	17	3.00	42.50	3.00	0.48	1.98	94.55
1	18	3.00	45.50	3.00	0.48	1.98	94.55
1	19	2.50	48.00	2.50	0.40	2.06	114.65
1	20	2.50	50.50	2.50	0.40	2.06	114.65
1	21	3.00	53.50	3.00	0.48	1.98	94.55
1	22	3.00	56.50	3.00	0.48	1.98	94.55
1	23	2.00	58.50	2.00	0.30	2.16	145.15

1	24	2.00	60.50	2.00	0.30	2.16	145.15
1	25	2.00	62.50	2.00	0.30	2.16	145.15
1	26	2.00	64.50	2.00	0.30	2.16	145.15
1	27	2.00	66.50	2.00	0.30	2.16	145.15
1	28	2.50	69.00	2.50	0.40	2.06	114.65
1	29	4.00	73.00	4.00	0.60	1.84	69.76
1	30	3.00	76.00	3.00	0.48	1.98	94.55
1	31	2.00	78.00	2.00	0.30	2.16	145.15
1	32	2.00	80.00	2.00	0.30	2.16	145.15
1	33	2.00	82.00	2.00	0.30	2.16	145.15
1	34	3.00	85.00	3.00	0.48	1.98	94.55
1	35	2.00	87.00	2.00	0.30	2.16	145.15
1	36	2.00	89.00	2.00	0.30	2.16	145.15
1	37	2.00	91.00	2.00	0.30	2.16	145.15
1	38	3.00	94.00	3.00	0.48	1.98	94.55
1	39	2.00	96.00	2.00	0.30	2.16	145.15
1	40	2.00	98.00	2.00	0.30	2.16	145.15
1	41	2.00	100.00	2.00	0.30	2.16	145.15
1	42	2.50	102.50	2.50	0.40	2.06	114.65
1	43	2.00	104.50	2.00	0.30	2.16	145.15
1	44	2.00	106.50	2.00	0.30	2.16	145.15
1	45	2.50	109.00	2.50	0.40	2.06	114.65
1	46	2.00	111.00	2.00	0.30	2.16	145.15
1	47	2.00	113.00	2.00	0.30	2.16	145.15
1	48	2.00	115.00	2.00	0.30	2.16	145.15
1	49	2.00	117.00	2.00	0.30	2.16	145.15
1	50	2.00	119.00	2.00	0.30	2.16	145.15
1	51	2.00	121.00	2.00	0.30	2.16	145.15
1	52	1.50	122.50	1.50	0.18	2.29	196.73
1	53	2.00	124.50	2.00	0.30	2.16	145.15
1	54	3.00	127.50	3.00	0.48	1.98	94.55
1	55	3.00	130.50	3.00	0.48	1.98	94.55
1	56	3.00	133.50	3.00	0.48	1.98	94.55
1	57	3.00	136.50	3.00	0.48	1.98	94.55
1	58	2.00	138.50	2.00	0.30	2.16	145.15
1	59	3.00	141.50	3.00	0.48	1.98	94.55
1	60	3.50	145.00	3.50	0.54	1.90	80.34
1	61	2.00	147.00	2.00	0.30	2.16	145.15

1	62	1.50	148.50	1.50	0.18	2.29	196.73
1	63	2.00	150.50	2.00	0.30	2.16	145.15
1	64	2.00	152.50	2.00	0.30	2.16	145.15
1	65	2.50	155.00	2.50	0.40	2.06	114.65
1	66	3.00	158.00	3.00	0.48	1.98	94.55
1	67	3.00	161.00	3.00	0.48	1.98	94.55
1	68	3.00	164.00	3.00	0.48	1.98	94.55
1	69	3.00	167.00	3.00	0.48	1.98	94.55
1	70	2.50	169.50	2.50	0.40	2.06	114.65
1	71	3.00	172.50	3.00	0.48	1.98	94.55
1	72	3.00	175.50	3.00	0.48	1.98	94.55
1	73	2.50	178.00	2.50	0.40	2.06	114.65
1	74	3.00	181.00	3.00	0.48	1.98	94.55
1	75	3.00	184.00	3.00	0.48	1.98	94.55
1	76	3.00	187.00	3.00	0.48	1.98	94.55
1	77	3.00	190.00	3.00	0.48	1.98	94.55
1	78	3.00	193.00	3.00	0.48	1.98	94.55
1	79	2.50	195.50	2.50	0.40	2.06	114.65
1	80	3.00	198.50	3.00	0.48	1.98	94.55
Base-course Layer End							
1	1	3.50	3.50	3.50	0.54	1.90	80.34
1	2	4.00	7.50	4.00	0.60	1.84	69.76
1	3	4.00	11.50	4.00	0.60	1.84	69.76
1	4	5.00	16.50	5.00	0.70	1.74	55.10
1	5	5.00	21.50	5.00	0.70	1.74	55.10
1	6	5.00	26.50	5.00	0.70	1.74	55.10
1	7	4.00	30.50	4.00	0.60	1.84	69.76
1	8	4.00	34.50	4.00	0.60	1.84	69.76
1	9	3.50	38.00	3.50	0.54	1.90	80.34
1	10	3.50	41.50	3.50	0.54	1.90	80.34
1	11	4.00	45.50	4.00	0.60	1.84	69.76
1	12	3.50	49.00	3.50	0.54	1.90	80.34
1	13	4.00	53.00	4.00	0.60	1.84	69.76
1	14	4.00	57.00	4.00	0.60	1.84	69.76
1	15	3.50	60.50	3.50	0.54	1.90	80.34
1	16	3.50	64.00	3.50	0.54	1.90	80.34
1	17	6.00	70.00	6.00	0.78	1.66	45.45
1	18	5.00	75.00	5.00	0.70	1.74	55.10

1	19	6.00	81.00	6.00	0.78	1.66	45.45
1	20	6.00	87.00	6.00	0.78	1.66	45.45
1	21	4.00	91.00	4.00	0.60	1.84	69.76
1	22	4.00	95.00	4.00	0.60	1.84	69.76
1	23	4.50	99.50	4.50	0.65	1.79	61.60
1	24	4.00	103.50	4.00	0.60	1.84	69.76
1	25	4.00	107.50	4.00	0.60	1.84	69.76
1	26	5.00	112.50	5.00	0.70	1.74	55.10
1	27	4.00	116.50	4.00	0.60	1.84	69.76
1	28	3.00	119.50	3.00	0.48	1.98	94.55
1	29	4.50	124.00	4.50	0.65	1.79	61.60
1	30	4.00	128.00	4.00	0.60	1.84	69.76
1	31	5.00	133.00	5.00	0.70	1.74	55.10
2	33	2.50	135.50	1.25	0.10	2.38	238.54
1	34	3.00	138.50	3.00	0.48	1.98	94.55
1	35	3.50	142.00	3.50	0.54	1.90	80.34
1	36	4.00	146.00	4.00	0.60	1.84	69.76
1	37	4.00	150.00	4.00	0.60	1.84	69.76
1	38	6.00	156.00	6.00	0.78	1.66	45.45
1	39	6.00	162.00	6.00	0.78	1.66	45.45
1	40	6.00	168.00	6.00	0.78	1.66	45.45
1	41	7.00	175.00	7.00	0.85	1.59	38.61
1	42	7.00	182.00	7.00	0.85	1.59	38.61
1	43	8.00	190.00	8.00	0.90	1.53	33.53
1	44	7.00	197.00	7.00	0.85	1.59	38.61
1	45	6.00	203.00	6.00	0.78	1.66	45.45
1	46	6.00	209.00	6.00	0.78	1.66	45.45
1	47	6.00	215.00	6.00	0.78	1.66	45.45
1	48	4.00	219.00	4.00	0.60	1.84	69.76
1	49	4.00	223.00	4.00	0.60	1.84	69.76
1	50	4.00	227.00	4.00	0.60	1.84	69.76
1	51	5.00	232.00	5.00	0.70	1.74	55.10
1	52	4.00	236.00	4.00	0.60	1.84	69.76
1	53	5.00	241.00	5.00	0.70	1.74	55.10
1	54	5.00	246.00	5.00	0.70	1.74	55.10
1	55	4.00	250.00	4.00	0.60	1.84	69.76
1	56	5.00	255.00	5.00	0.70	1.74	55.10
1	57	6.00	261.00	6.00	0.78	1.66	45.45

1	58	6.00	267.00	6.00	0.78	1.66	45.45
1	59	4.00	271.00	4.00	0.60	1.84	69.76
1	60	4.00	275.00	4.00	0.60	1.84	69.76
1	61	3.00	278.00	3.00	0.48	1.98	94.55
1	62	4.00	282.00	4.00	0.60	1.84	69.76
1	63	5.00	287.00	5.00	0.70	1.74	55.10
1	64	5.00	292.00	5.00	0.70	1.74	55.10
1	65	5.50	297.50	5.50	0.74	1.70	49.82
1	66	5.00	302.50	5.00	0.70	1.74	55.10
1	67	4.00	306.50	4.00	0.60	1.84	69.76
1	68	4.50	311.00	4.50	0.65	1.79	61.60
1	69	4.00	315.00	4.00	0.60	1.84	69.76
1	70	2.00	317.00	2.00	0.30	2.16	145.15
1	71	3.00	320.00	3.00	0.48	1.98	94.55
1	72	3.00	323.00	3.00	0.48	1.98	94.55
1	73	3.00	326.00	3.00	0.48	1.98	94.55
1	74	4.00	330.00	4.00	0.60	1.84	69.76
1	75	6.00	336.00	6.00	0.78	1.66	45.45
1	76	6.00	342.00	6.00	0.78	1.66	45.45
1	77	7.00	349.00	7.00	0.85	1.59	38.61
Sub-base course Layer End							
1	1	8.00	8.00	8.00	0.90	1.53	33.53
1	2	9.00	17.00	9.00	0.95	1.47	29.61
1	3	12.00	29.00	12.00	1.08	1.34	21.84
1	4	10.00	39.00	10.00	1.00	1.42	26.49
1	5	11.00	50.00	11.00	1.04	1.38	23.95
1	6	8.00	58.00	8.00	0.90	1.53	33.53
1	7	7.00	65.00	7.00	0.85	1.59	38.61
1	8	6.50	71.50	6.50	0.81	1.62	41.76
1	9	5.50	77.00	5.50	0.74	1.70	49.82
1	10	7.00	84.00	7.00	0.85	1.59	38.61
1	11	7.00	91.00	7.00	0.85	1.59	38.61
1	12	9.00	100.00	9.00	0.95	1.47	29.61
1	13	9.00	109.00	9.00	0.95	1.47	29.61
1	14	13.00	122.00	13.00	1.11	1.30	20.07
1	15	10.00	132.00	10.00	1.00	1.42	26.49
1	16	9.00	141.00	9.00	0.95	1.47	29.61
1	17	11.00	152.00	11.00	1.04	1.38	23.95

1	18	7.00	159.00	7.00	0.85	1.59	38.61
1	19	10.00	169.00	10.00	1.00	1.42	26.49
Sub-grade Layer @169.00 mm							

Dynamic Cone Penetrometer (DCP) Test Field Sheet							
Site/Road			Bedele - Metu Lot - II (61+000 - 111+659)				
Test No.			DCP04				
Section No./Chainage			85+490	**Analysis Date**		02/11/2020 - 06/11/2020	
Direction		Bedele - Metu		**Ave. Zero Reading of DCP in mm**		39.88	
Wheel Path		RHS		**Test Started**		9:30 AM	
DCP Test				**TRRL, 1990 (60^0 Cone)**			
No. of Blows	**Sum of Blows**	**Penetration Depth, mm**	**Cumulative Penetration, mm**	**Penetration Index (N), (mm/blow)**	**Log_{10} N**	**Log_{10} (CBR) = 2.48-1.057Log_{10}(mm/blow)**	**Calculated CBR, %**
0	0		39.88				
AC/Surfacing Layer End							
1	1	1.00	1.00	1.00	0.00	2.48	302.00
1	2	2.00	3.00	2.00	0.30	2.16	145.15
1	3	1.00	4.00	1.00	0.00	2.48	302.00
1	4	2.50	6.50	2.50	0.40	2.06	114.65
1	5	2.00	8.50	2.00	0.30	2.16	145.15
2	7	2.00	10.50	1.00	0.00	2.48	302.00
1	8	2.00	12.50	2.00	0.30	2.16	145.15
1	9	2.50	15.00	2.50	0.40	2.06	114.65
1	10	2.00	17.00	2.00	0.30	2.16	145.15
1	11	2.00	19.00	2.00	0.30	2.16	145.15
1	12	2.00	21.00	2.00	0.30	2.16	145.15
1	13	2.00	23.00	2.00	0.30	2.16	145.15
1	14	2.00	25.00	2.00	0.30	2.16	145.15
1	15	2.00	27.00	2.00	0.30	2.16	145.15
2	17	2.00	29.00	1.00	0.00	2.48	302.00
2	19	2.00	31.00	1.00	0.00	2.48	302.00
2	21	1.50	32.50	0.75	-0.12	2.61	409.32
2	23	3.00	35.50	1.50	0.18	2.29	196.73
1	24	1.50	37.00	1.50	0.18	2.29	196.73

1	25	2.00	39.00	2.00	0.30	2.16	145.15
1	26	3.00	42.00	3.00	0.48	1.98	94.55
1	27	3.00	45.00	3.00	0.48	1.98	94.55
1	28	4.00	49.00	4.00	0.60	1.84	69.76
1	29	2.00	51.00	2.00	0.30	2.16	145.15
1	30	3.50	54.50	3.50	0.54	1.90	80.34
1	31	2.00	56.50	2.00	0.30	2.16	145.15
1	32	3.50	60.00	3.50	0.54	1.90	80.34
1	33	3.00	63.00	3.00	0.48	1.98	94.55
1	34	3.00	66.00	3.00	0.48	1.98	94.55
1	35	3.00	69.00	3.00	0.48	1.98	94.55
1	36	2.00	71.00	2.00	0.30	2.16	145.15
1	37	3.00	74.00	3.00	0.48	1.98	94.55
1	38	3.00	77.00	3.00	0.48	1.98	94.55
1	39	3.00	80.00	3.00	0.48	1.98	94.55
1	40	2.00	82.00	2.00	0.30	2.16	145.15
1	41	3.50	85.50	3.50	0.54	1.90	80.34
1	42	3.00	88.50	3.00	0.48	1.98	94.55
1	43	1.00	89.50	1.00	0.00	2.48	302.00
1	44	2.00	91.50	2.00	0.30	2.16	145.15
1	45	2.00	93.50	2.00	0.30	2.16	145.15
1	46	2.00	95.50	2.00	0.30	2.16	145.15
1	47	1.00	96.50	1.00	0.00	2.48	302.00
1	48	3.00	99.50	3.00	0.48	1.98	94.55
1	49	3.00	102.50	3.00	0.48	1.98	94.55
1	50	2.00	104.50	2.00	0.30	2.16	145.15
1	51	3.00	107.50	3.00	0.48	1.98	94.55
1	52	2.00	109.50	2.00	0.30	2.16	145.15
1	53	2.50	112.00	2.50	0.40	2.06	114.65
1	54	2.00	114.00	2.00	0.30	2.16	145.15
1	55	1.00	115.00	1.00	0.00	2.48	302.00
1	56	1.00	116.00	1.00	0.00	2.48	302.00
1	57	1.00	117.00	1.00	0.00	2.48	302.00
1	58	0.50	117.50	0.50	-0.30	2.80	628.33
1	59	2.00	119.50	2.00	0.30	2.16	145.15
1	60	2.00	121.50	2.00	0.30	2.16	145.15
1	61	1.50	123.00	1.50	0.18	2.29	196.73
1	62	1.50	124.50	1.50	0.18	2.29	196.73

1	63	2.00	126.50	2.00	0.30	2.16	145.15
1	64	2.50	129.00	2.50	0.40	2.06	114.65
1	65	2.00	131.00	2.00	0.30	2.16	145.15
1	66	2.00	133.00	2.00	0.30	2.16	145.15
1	67	3.00	136.00	3.00	0.48	1.98	94.55
1	68	2.50	138.50	2.50	0.40	2.06	114.65
1	69	3.00	141.50	3.00	0.48	1.98	94.55
1	70	2.00	143.50	2.00	0.30	2.16	145.15
1	71	2.00	145.50	2.00	0.30	2.16	145.15
1	72	2.00	147.50	2.00	0.30	2.16	145.15
1	73	1.00	148.50	1.00	0.00	2.48	302.00
1	74	2.00	150.50	2.00	0.30	2.16	145.15
1	75	2.00	152.50	2.00	0.30	2.16	145.15
1	76	2.00	154.50	2.00	0.30	2.16	145.15
1	77	2.50	157.00	2.50	0.40	2.06	114.65
1	78	2.00	159.00	2.00	0.30	2.16	145.15
1	79	3.00	162.00	3.00	0.48	1.98	94.55
1	80	3.00	165.00	3.00	0.48	1.98	94.55
1	81	1.50	166.50	1.50	0.18	2.29	196.73
1	82	1.00	167.50	1.00	0.00	2.48	302.00
1	83	2.00	169.50	2.00	0.30	2.16	145.15
1	84	2.00	171.50	2.00	0.30	2.16	145.15
1	85	1.50	173.00	1.50	0.18	2.29	196.73
1	86	3.00	176.00	3.00	0.48	1.98	94.55
1	87	2.00	178.00	2.00	0.30	2.16	145.15
1	88	3.00	181.00	3.00	0.48	1.98	94.55
1	89	3.00	184.00	3.00	0.48	1.98	94.55
1	90	1.50	185.50	1.50	0.18	2.29	196.73
1	91	2.00	187.50	2.00	0.30	2.16	145.15
1	92	2.00	189.50	2.00	0.30	2.16	145.15
1	93	2.00	191.50	2.00	0.30	2.16	145.15
1	94	2.50	194.00	2.50	0.40	2.06	114.65
1	95	2.00	196.00	2.00	0.30	2.16	145.15
1	96	2.00	198.00	2.00	0.30	2.16	145.15
1	97	1.50	199.50	1.50	0.18	2.29	196.73
Base-course Layer End							
1	1	4.00	4.00	4.00	0.60	1.84	69.76
1	2	3.00	7.00	3.00	0.48	1.98	94.55

1	3	4.00	11.00	4.00	0.60	1.84	69.76
1	4	3.50	14.50	3.50	0.54	1.90	80.34
1	5	3.00	17.50	3.00	0.48	1.98	94.55
1	6	6.00	23.50	6.00	0.78	1.66	45.45
1	7	6.00	29.50	6.00	0.78	1.66	45.45
1	8	5.00	34.50	5.00	0.70	1.74	55.10
1	9	5.00	39.50	5.00	0.70	1.74	55.10
1	10	6.00	45.50	6.00	0.78	1.66	45.45
1	11	6.00	51.50	6.00	0.78	1.66	45.45
1	12	7.00	58.50	7.00	0.85	1.59	38.61
1	13	7.00	65.50	7.00	0.85	1.59	38.61
1	14	5.00	70.50	5.00	0.70	1.74	55.10
1	15	8.00	78.50	8.00	0.90	1.53	33.53
1	16	8.00	86.50	8.00	0.90	1.53	33.53
1	17	8.50	95.00	8.50	0.93	1.50	31.45
1	18	7.00	102.00	7.00	0.85	1.59	38.61
1	19	6.00	108.00	6.00	0.78	1.66	45.45
1	20	6.00	114.00	6.00	0.78	1.66	45.45
1	21	3.00	117.00	3.00	0.48	1.98	94.55
1	22	3.50	120.50	3.50	0.54	1.90	80.34
1	23	4.00	124.50	4.00	0.60	1.84	69.76
1	24	4.00	128.50	4.00	0.60	1.84	69.76
1	25	5.50	134.00	5.50	0.74	1.70	49.82
1	26	4.00	138.00	4.00	0.60	1.84	69.76
1	27	4.00	142.00	4.00	0.60	1.84	69.76
1	28	3.00	145.00	3.00	0.48	1.98	94.55
1	29	4.00	149.00	4.00	0.60	1.84	69.76
1	30	5.00	154.00	5.00	0.70	1.74	55.10
1	31	5.00	159.00	5.00	0.70	1.74	55.10
1	32	3.00	162.00	3.00	0.48	1.98	94.55
1	33	4.00	166.00	4.00	0.60	1.84	69.76
1	34	5.00	171.00	5.00	0.70	1.74	55.10
1	35	5.00	176.00	5.00	0.70	1.74	55.10
1	36	5.00	181.00	5.00	0.70	1.74	55.10
1	37	4.50	185.50	4.50	0.65	1.79	61.60
1	38	5.00	190.50	5.00	0.70	1.74	55.10
1	39	4.50	195.00	4.50	0.65	1.79	61.60
1	40	5.00	200.00	5.00	0.70	1.74	55.10

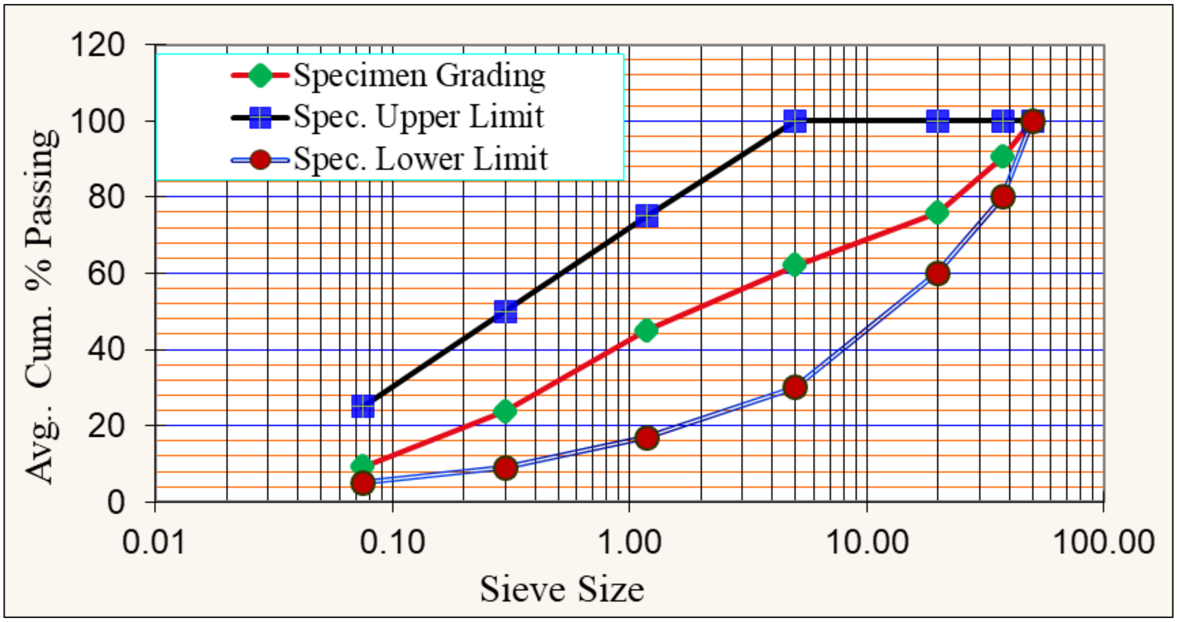
1	41	7.00	207.00	7.00	0.85	1.59	38.61
1	42	7.00	214.00	7.00	0.85	1.59	38.61
1	43	6.00	220.00	6.00	0.78	1.66	45.45
1	44	6.00	226.00	6.00	0.78	1.66	45.45
1	45	6.00	232.00	6.00	0.78	1.66	45.45
1	46	5.00	237.00	5.00	0.70	1.74	55.10
1	47	7.00	244.00	7.00	0.85	1.59	38.61
1	48	5.50	249.50	5.50	0.74	1.70	49.82
1	49	6.00	255.50	6.00	0.78	1.66	45.45
1	50	5.50	261.00	5.50	0.74	1.70	49.82
1	51	5.00	266.00	5.00	0.70	1.74	55.10
1	52	6.00	272.00	6.00	0.78	1.66	45.45
1	53	6.00	278.00	6.00	0.78	1.66	45.45
1	54	4.00	282.00	4.00	0.60	1.84	69.76
1	55	4.50	286.50	4.50	0.65	1.79	61.60
1	56	6.00	292.50	6.00	0.78	1.66	45.45
1	57	6.00	298.50	6.00	0.78	1.66	45.45
1	58	7.00	305.50	7.00	0.85	1.59	38.61
1	59	7.00	312.50	7.00	0.85	1.59	38.61
1	60	6.00	318.50	6.00	0.78	1.66	45.45
1	61	6.50	325.00	6.50	0.81	1.62	41.76
1	62	7.00	332.00	7.00	0.85	1.59	38.61
1	63	6.50	338.50	6.50	0.81	1.62	41.76
1	64	6.00	344.50	6.00	0.78	1.66	45.45
1	65	6.00	350.50	6.00	0.78	1.66	45.45
Sub-base course Layer End							
1	1	7.00	7.00	7.00	0.85	1.59	38.61
1	2	7.00	14.00	7.00	0.85	1.59	38.61
1	3	7.00	21.00	7.00	0.85	1.59	38.61
1	4	8.00	29.00	8.00	0.90	1.53	33.53
1	5	8.00	37.00	8.00	0.90	1.53	33.53
1	6	10.00	47.00	10.00	1.00	1.42	26.49
1	7	11.00	58.00	11.00	1.04	1.38	23.95
1	8	12.00	70.00	12.00	1.08	1.34	21.84
1	9	14.00	84.00	14.00	1.15	1.27	18.56
1	10	13.00	97.00	13.00	1.11	1.30	20.07
1	11	12.00	109.00	12.00	1.08	1.34	21.84
1	12	11.00	120.00	11.00	1.04	1.38	23.95

1	13	10.00	130.00	10.00	1.00	1.42	26.49
1	14	9.00	139.00	9.00	0.95	1.47	29.61
1	15	10.00	149.00	10.00	1.00	1.42	26.49
1	16	9.00	158.00	9.00	0.95	1.47	29.61
1	17	8.50	166.50	8.50	0.93	1.50	31.45
Sub-grade Layer @166.50 mm							

Appendix D: Sieve analysis data for sub-grade, sub-base and base-course sample

Sieve Analysis (Test Method AASHTO T- 27)			
Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade Fill/capping**
Sampled at	**63+995**	**Lab #**	**Lab.01**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**light brown sandy soil with gravel soil**	**Testing Date**	**02/11/20**

Sieve Sizes	**Trial -01**			**Trial -02**			**Average**	
	Weight Retained	**% Retained**	**Cum. % Passing**	**Weight Retained**	**% Retained**	**Cum. % Passing**	**Avr. Cum. % Passing**	**Specification Limits**
50.000	-	-	100	-	-	100	**100**	**100**
37.500	1244.6	10	90	1156.5	9	91	**90**	**80 - 100**
20.000	1861.2	15	76	1788.2	14	76	**76**	**60 - 100**
5.000	1766.5	14	62	1745.9	14	62	**62**	**30 - 100**
1.180	2134.4	17	45	2132.6	17	45	**45**	**17 - 75**
0.300	2687.6	21	24	2678.8	22	23	**24**	**9 - 50**
0.075	1876.3	15	9.6	1804.3	15	8.6	**9.1**	**5 - 25**
Pan	1232.1	9.6	0.0	1065.5	8.6	0.0	**0.0**	
Total	**12802.7**	**100.0**		**12371.80**	**100.0**			

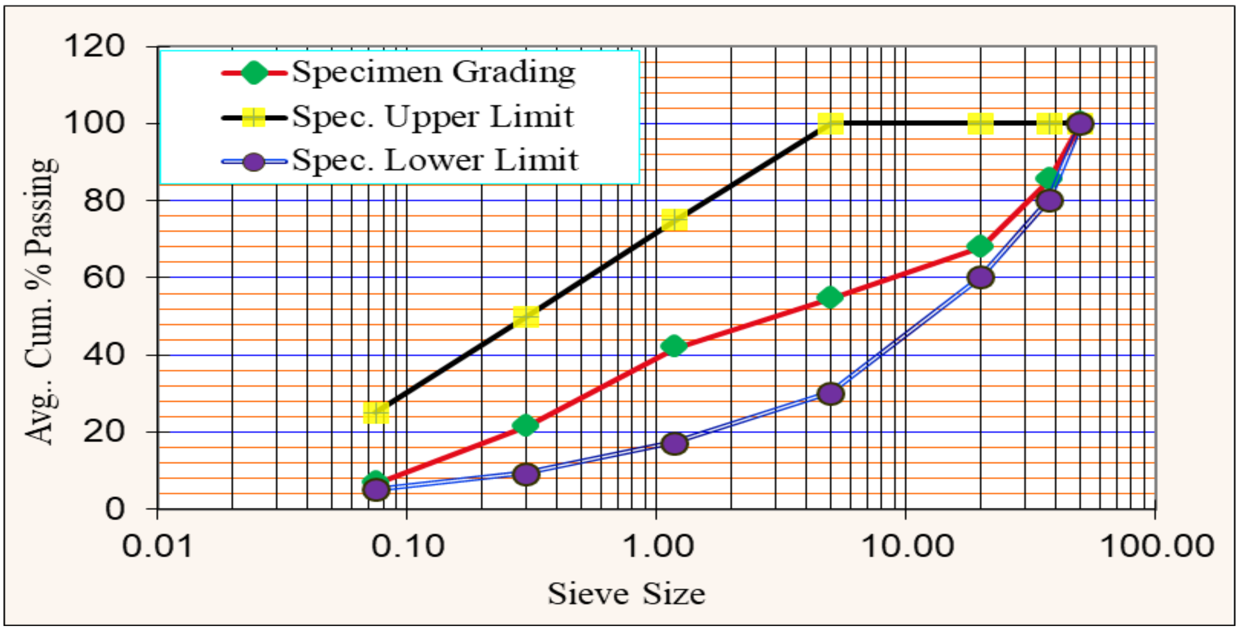


Sieve Analysis (Test Method AASHTO T- 27)			
Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade fill/capping**
Sampled at	**62+800**	**Lab #**	**Lab.02**
Source Type	**Approved subgrade borrow area**	**Sampling date**	**30/10/2020**
Visual Description	**Light brown sandy soil with gravel soil**	**Testing Date**	**04/11/20**

-

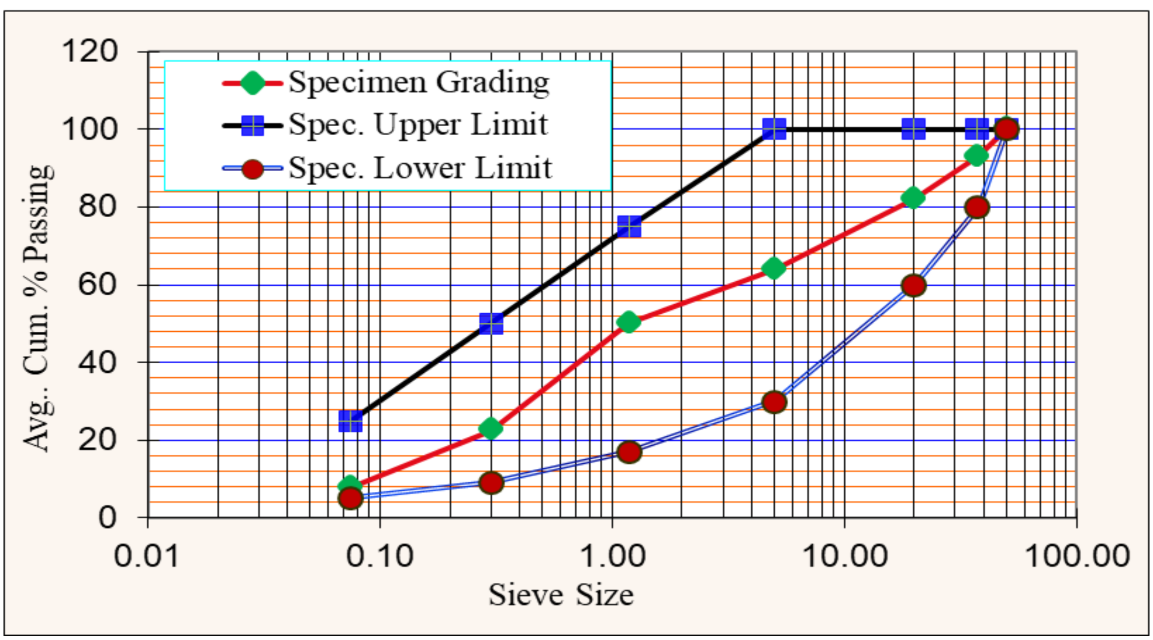
Sieve Sizes	**Trial -01**			**Trial -02**			**Average**	
	Weight Retained	**% Retained**	**Cum. % Passing**	**Weight Retained**	**% Retained**	**Cum. % Passing**	**Avr. Cum. % Passing**	**Specification Limits**
50.000	-	-	100	-	-	100	**100**	**100**
37.500	2012.4	16	84	1921.3	14	86	**85**	**80 - 100**
20.000	2256.5	17	67	2404.6	17	69	**68**	**60 - 100**
5.000	1761.1	14	53	1787.7	13	56	**55**	**30 - 100**

1.180	1656.6	13	40	1765.3	13	43	**42**	**17 - 75**
0.300	2567.2	20	21	2921.5	21	22	**21**	**9 - 50**
0.075	1811.3	14	6.5	2132.1	15	6.8	**6.7**	**5 - 25**
Pan	843.9	6.5	0.0	939.2	6.8	0.0	**0.0**	
Total	**12909.0**	**100.0**		**13871.70**	**100.0**			



Sieve Analysis (Test Method AASHTO T- 27)			
Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base Layer**
Sampled at	**63+995**	**Lab #**	**Lab.001**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed basaltic rock aggregate with light brown sandy soil**	**Testing Date**	**08/11/20**

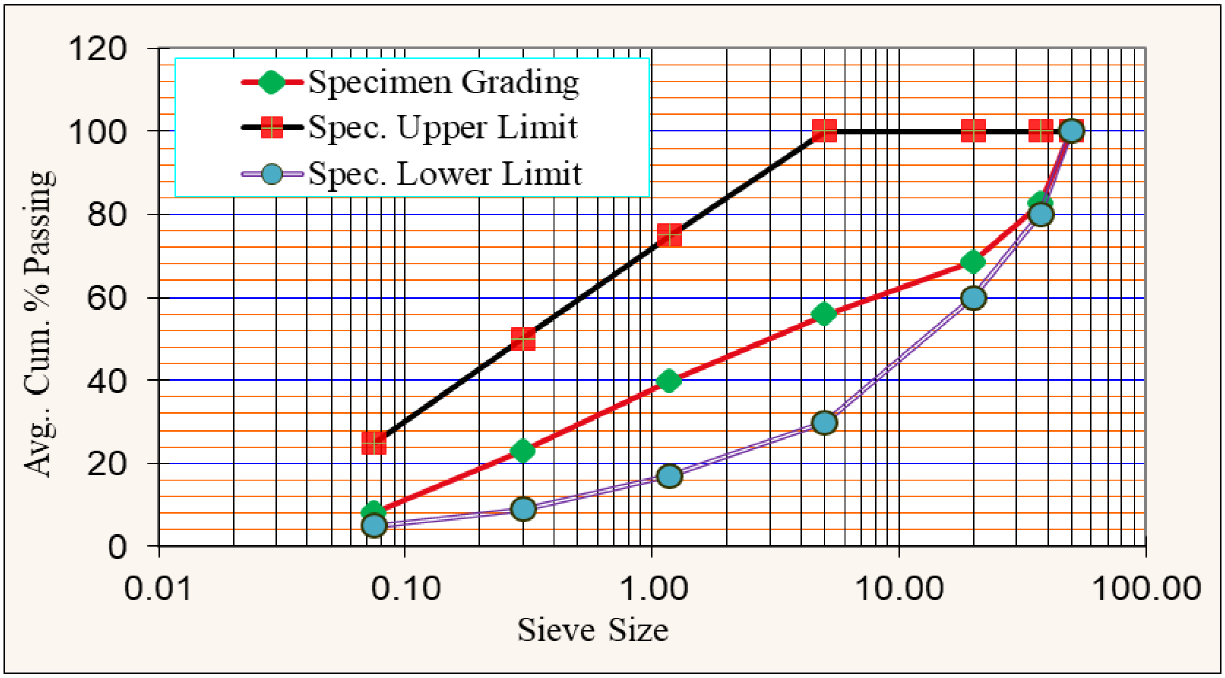
Sieve Sizes	Trial -01			Trial -02			Average	
	Weight Retained	% Retained	Cum. % Passing	Weight Retained	% Retained	Cum. % Passing	Avr. Cum. % Passing	Specification Limits
50.000	-	-	100	-	-	100	**100**	**100**
37.500	1143.2	9	91	1043.4	9	91	**91**	**80 - 100**
20.000	1776.6	14	76	1687.8	14	77	**77**	**60 - 100**
5.000	1801.1	15	62	1674.2	14	64	**63**	**30 - 100**
1.180	2233.3	18	44	2155.1	18	46	**45**	**17 - 75**
0.300	2544.5	21	23	2653.2	22	24	**24**	**9 - 50**
0.075	1767.6	14	9.1	1747.9	14	9.3	**9.2**	**5 - 25**
Pan	1133.2	9.1	0.0	1122.4	9.3	0.0	**0.0**	
Total	**12399.5**	**100.0**		**12084.0**	**100.0**			



Sieve Analysis (Test Method AASHTO T- 27)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base layer**
Sampled at	**62+800 & 75+050**	**Lab #**	**Lab.002**
Source Type	**Approved sub-base borrow area and crushed agg. stock (70:30)**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed rock aggregate with light brown sandy soil (70:30)**	**Testing Date**	**10/11/20**

Sieve Sizes	**Trial -01**			**Trial -02**			**Average**	
	Weight Retained	**% Retained**	**Cum. % Passing**	**Weight Retained**	**% Retained**	**Cum. % Passing**	**Avr. Cum. % Passing**	**Specification Limits**
50.000	-	-	100	-	-	100	**100**	**100**
37.500	2344.3	18	82	2186.7	17	83	**83**	**80 - 100**
20.000	1776.9	13	69	1856.6	15	68	**69**	**60 - 100**
5.000	1689.2	13	56	1609.8	13	55	**56**	**30 - 100**
1.180	2134.9	16	40	2043.3	16	39	**40**	**17 - 75**
0.300	2276.5	17	23	2112.4	17	23	**23**	**9 - 50**
0.075	1932.8	15	8.6	1912.2	15	7.7	**8.2**	**5 - 25**
Pan	1143.2	8.6	0.0	978.7	8	0.0	**0.0**	
Total	**13297.8**	**100.0**		**12699.70**	**100.0**			

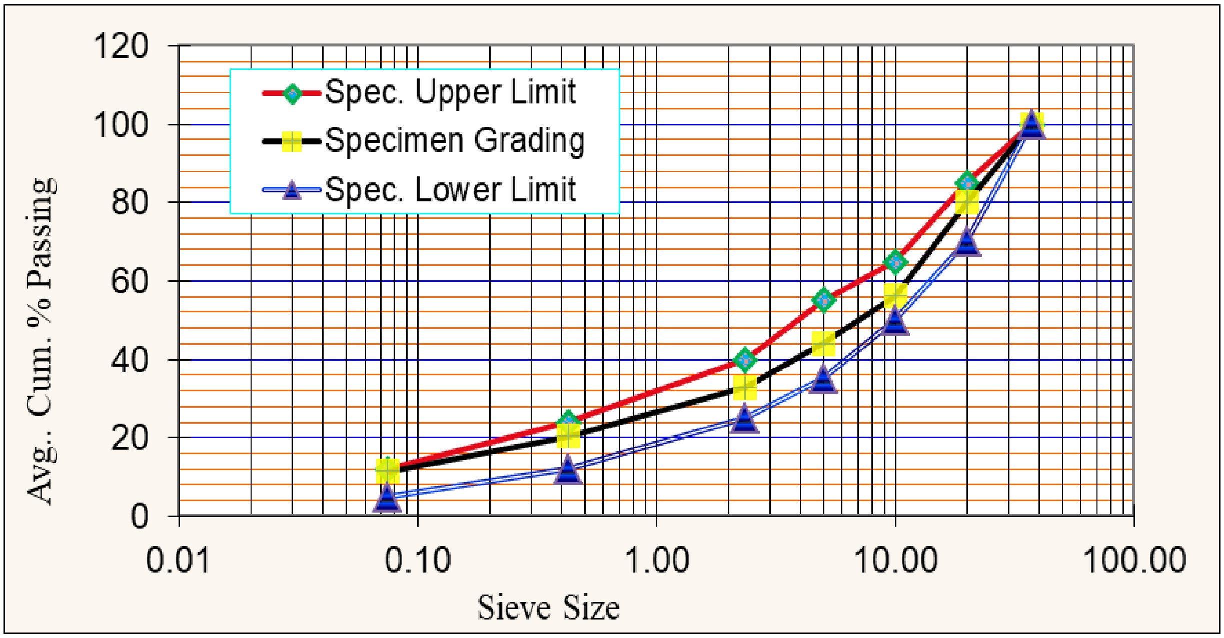


Sieve Analysis (Test Method AASHTO T- 27)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**63+995**	**Lab #**	**Lab.0001**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**10/11/20**

Sieve Sizes	**Trial -01**			**Trial -02**			**Average**	
	Weight Retained	**% Retained**	**Cum. % Passing**	**Weight Retained**	**% Retained**	**Cum. % Passing**	**Avr. Cum. % Passing**	**Specification Limits**
37.500	-	-	100	-	-	100	**100**	**100**
20.000	2989.9	20	80	2916.2	20	80	**80**	**70 - 85**
10.000	3707.1	25	55	3297.3	23	57	**56**	**50 - 65**
5.000	1405.5	9	46	2127.2	15	42	**44**	**35 - 55**
2.360	1876.2	13	33	1437.1	10	32	**33**	**25 - 40**

0.425	2070.3	14	20	1617.1	11	21	**20**	**12 - 24**
0.075	1321.4	8.8	11	1277.2	9	12	**12**	**5 - 12**
Pan	1613.8	11	0.0	1770.1	12.3	0.0	**0.0**	
Total	**14984.20**	**100.0**		**14442.20**	**100.0**			

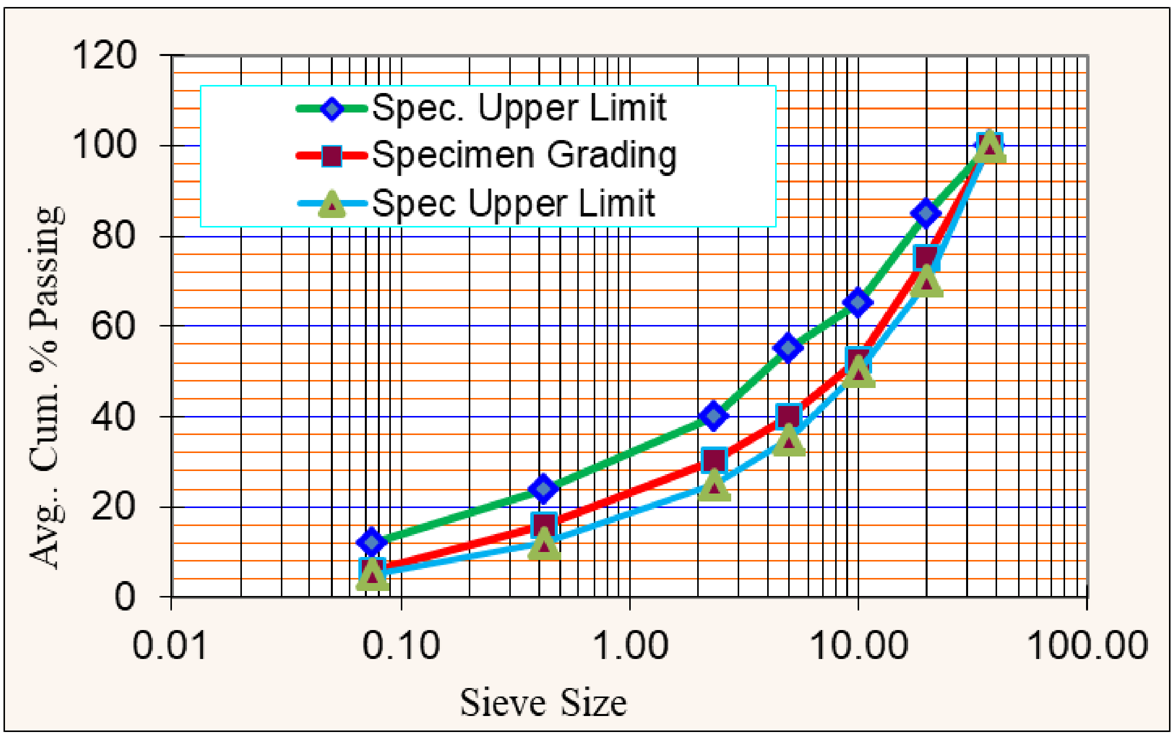


Sieve Analysis (Test Method AASHTO T- 27)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**75+050**	**Lab #**	**Lab.0002**
Source Type	**Approved stone quarry/crushed agg. Stock**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**12/11/20**

Sieve Sizes	**Trial -01**			**Trial -02**			**Average**	
	Weight Retained	**% Retained**	**Cum. % Passing**	**Weight Retained**	**% Retained**	**Cum. % Passing**	**Avr. Cum. % Passing**	**Specification Limits**

37.500	-	-	100	-	-	100	**100**	**100**
20.000	2885.2	24	76	2956.3	25	75	**75**	**70 - 85**
10.000	2612.8	22	53	2787.1	24	52	**53**	**50 - 65**
5.000	1566.8	13	40	1434.5	12	39	**40**	**35 - 55**
2.360	1091.9	9	31	1171.7	10	30	**30**	**25 - 40**
0.425	1701.4	14	17	1695.2	14	15	**16**	**12 - 24**
0.075	1231.5	10.4	6	1177.4	10	5.4	**5.7**	**5 - 12**
Pan	721.8	6.1	0.0	634.6	5.35	0.0	**0.00**	
Total	**11811.4**	**100.0**		**11856.8**	**100.0**			

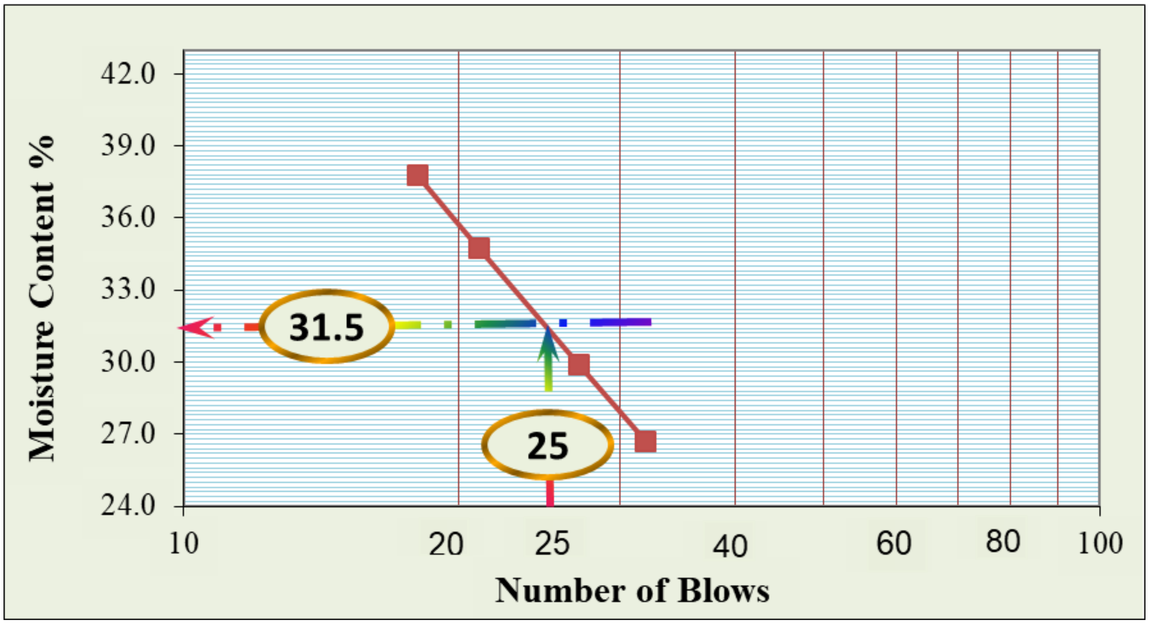


Appendix E: Atterberg limit determination data for sub-grade, sub-base and base-course sample

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade Fill/capping**
Sampled at	**63+995**	**Lab #**	**Lab.01**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**light brown sandy soil with gravel soil**	**Testing Date**	**03/11/20**

	Liquid Limit				**Plastic Limit**	
No. of Blows	32	27	21	18		
Container Number	LD	LC	LB	LA	PE	PF
Wt. of Container + Wet Soil (g) = (W_1)	47.81	48.70	49.49	50.72	14.23	14.60
Wt. of Container + Dry Soil (g) = (W_2)	41.34	41.31	41.24	41.31	13.89	14.42
Wt. of Container (g) = (W_3)	17.10	16.60	17.50	16.40	11.50	12.20
Weight of Moisture (g) = (W_1 - W_2) = A	6.47	7.39	8.25	9.41	0.34	0.18
Weight of Dry Soil (g) = (W_2 - W_3) = B	24.24	24.71	23.74	24.91	2.39	2.22
Moisture Content (%) = (A / B)x 100	26.69	29.91	34.75	37.78	14.23	8.11
				AV. Plas. Lim.	**11**	



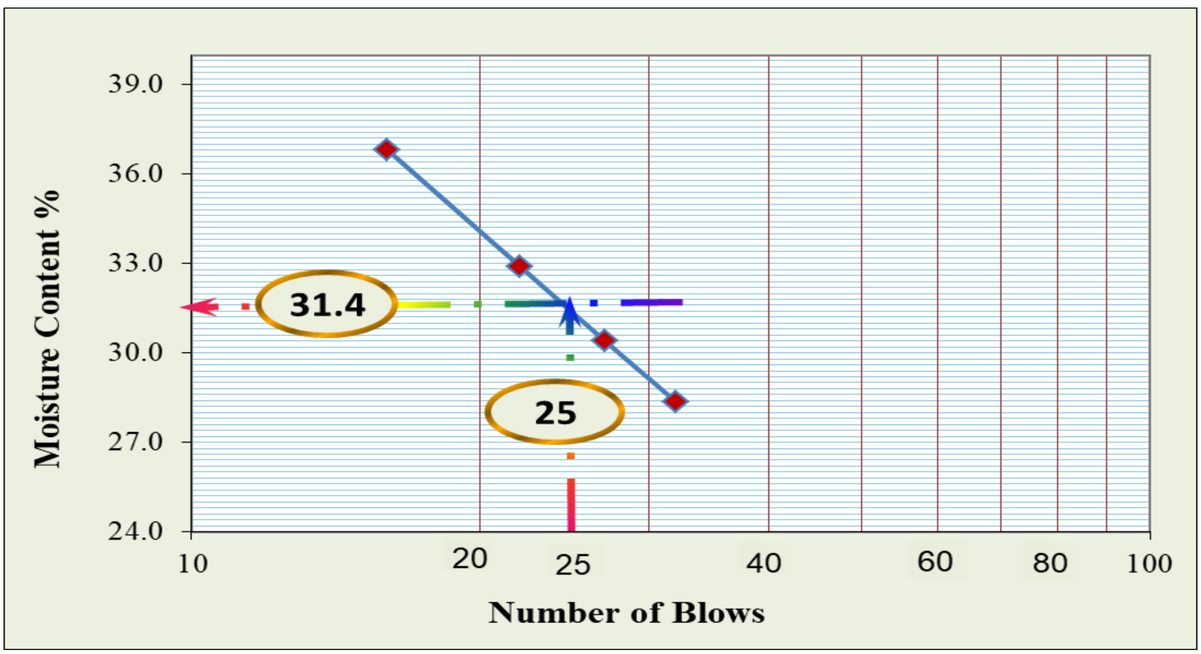
LIQUIDLIMIT	**LL**	**32**
PLASTIC LIMIT	**PL**	**11**
PLASTICITY INDEX	**LL - PL**	**20**

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade fill/capping**
Sampled at	**62+800**	**Lab #**	**Lab.02**
Source Type	**Approved Subgrade Borrow Area**	**Sampling date**	**30/10/2020**
Visual Description	**Light brown sandy soil with gravel soil**	**Testing Date**	**04/11/20**

	Liquid Limit				**Plastic Limit**	
No. of Blows	32	27	22	16		
Container Number	LD1	LC2	LB3	LA4	PE1	PF2
Wt. of Container + Wet Soil (g) = (W_1)	42.37	41.96	42.71	40.45	17.87	18.52

Wt. of Container + Dry Soil (g) = (W_2)	37.36	37.40	36.74	34.32	16.89	17.76
Wt. of Container (g) = (W_3)	19.70	22.40	18.60	17.67	10.20	10.70
Weight of Moisture (g) = (W_1 - W_2) = A	5.01	4.56	5.97	6.13	0.98	0.76
Weight of Dry Soil (g) = (W_2 - W_3) = B	17.66	15.00	18.14	16.65	6.69	7.06
Moisture Content (%) = (A / B)x 100	28.37	30.40	32.91	36.82	14.65	10.76
				AV. Plas. Lim.	**12.71**	



LIQUIDLIMIT	**LL**	**31**
PLASTIC LIMIT	**PL**	**13**
PLASTICITY INDEX	**LL - PL**	**19**

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base Layer**
Sampled at	**63+995**	**Lab #**	**Lab.001**
Source Type	**Test Pit#01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed rock aggregate with light brown sandy soil**	**Testing Date**	**09/11/20**

	Liquid Limit				**Plastic Limit**	
No. of Blows	34	23	21	17		
Container Number	L1	L2	L3	L4	P1	P2
Wt. of Container + Wet Soil (g) = (W_1)	41.06	40.85	41.98	39.02	18.78	17.22
Wt. of Container + Dry Soil (g) = (W_2)	36.98	36.71	36.87	33.82	17.38	16.23
Wt. of Container (g) = (W_3)	18.65	21.31	18.63	16.87	10.20	10.70
Weight of Moisture (g) = ($W_1 - W_2$) = A	4.08	4.14	5.11	5.20	1.40	0.99
Weight of Dry Soil (g) = ($W_2 - W_3$) = B	18.33	15.40	18.24	16.95	7.18	5.53
Moisture Content (%) = (A / B)x 100	22.26	26.88	28.02	30.68	19.50	17.90
				AV. Plas. Lim.	**19**	

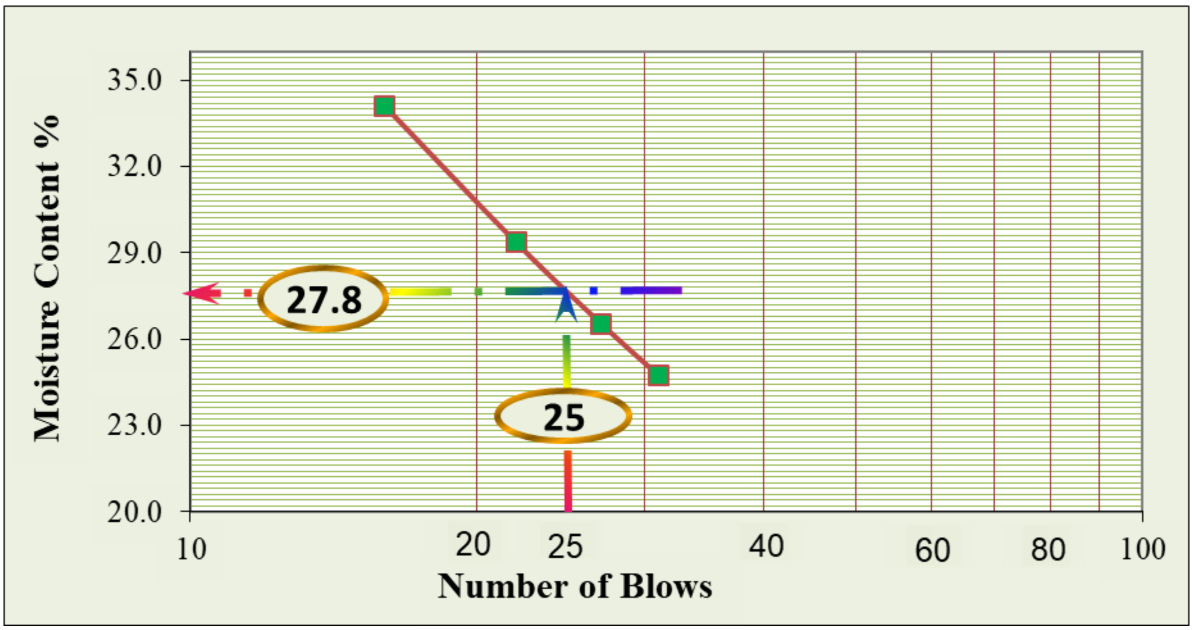
LIQUIDLIMIT	**LL**	**26**
PLASTIC LIMIT	**PL**	**19**
PLASTICITY INDEX	**LL - PL**	**7**

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base layer**
Sampled at	**62+800 & 75+050**	**Lab #**	**Lab.002**
Source Type	**Approved sub-base borrow area and crushed agg. stock (70:30)**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed rock aggregate with light brown sandy soil**	**Testing Date**	**11/11/20**

	Liquid Limit				**Plastic Limit**	
No. of Blows	31	27	22	16		
Container Number	L11	L22	L33	L44	P11	P22
Wt. of Container + Wet Soil (g) = (W_1)	43.57	42.76	42.74	41.49	18.75	19.31
Wt. of Container + Dry Soil (g) = (W_2)	38.58	38.31	37.27	35.24	17.38	17.78
Wt. of Container (g) = (W_3)	18.41	21.54	18.63	16.91	10.56	10.29

Weight of Moisture (g) = $(W_1 - W_2) = A$	4.99	4.45	5.47	6.25	1.37	1.53
Weight of Dry Soil (g) = $(W_2 - W_3) = B$	20.17	16.77	18.64	18.33	6.82	7.49
Moisture Content (%) = (A / B)x 100	24.74	26.54	29.35	34.10	20.09	20.43
				AV. Plas. Lim.	**20.26**	

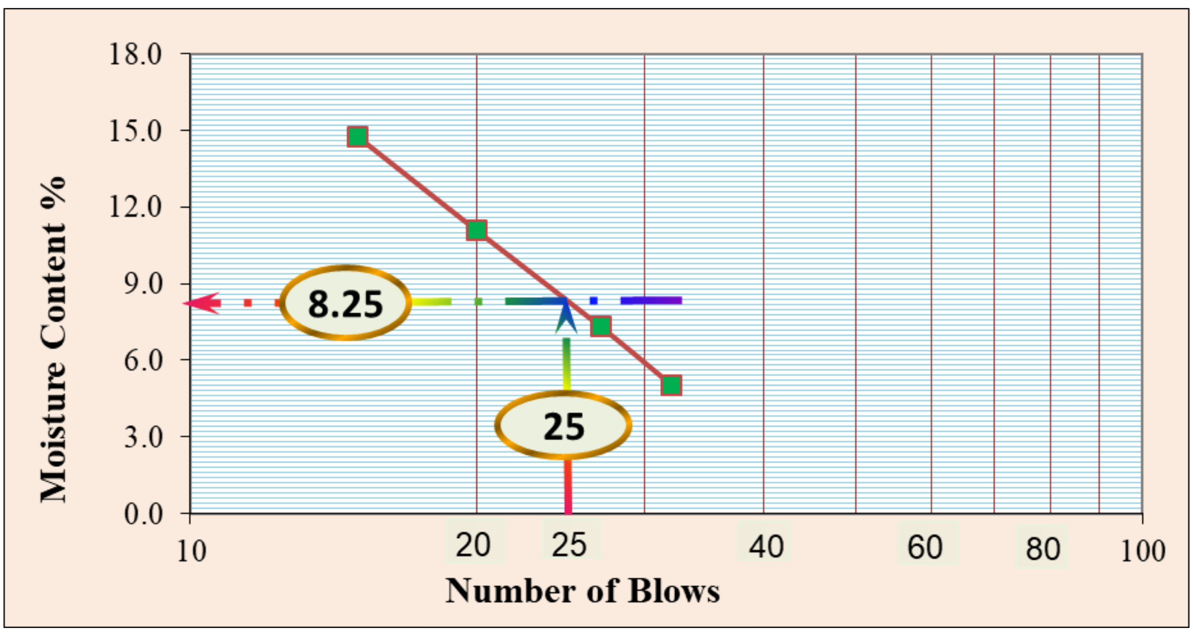


LIQUIDLIMIT	**LL**	**28**
PLASTIC LIMIT	**PL**	**20**
PLASTICITY INDEX	**LL - PL**	**8**

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course Layer**
Sampled at	**63+995**	**Lab #**	**Lab.0001**
Source Type	**Test Pit#01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed Basaltic Rock Agg.**	**Testing Date**	**11/11/20**

	Liquid Limit				Plastic Limit	
No. of Blows	32	27	20	15		
Container Number	LB1	LB2	LB3	LB4	PB1	PB2
Wt. of Container + Wet Soil (g) = (W_1)	34.16	35.34	34.58	35.18	17.71	18.24
Wt. of Container + Dry Soil (g) = (W_2)	33.42	34.27	32.94	32.97	16.98	17.38
Wt. of Container (g) = (W_3)	18.75	19.62	18.13	17.98	10.40	10.30
Weight of Moisture (g) = (W_1 - W_2) = A	0.74	1.07	1.64	2.21	0.73	0.86
Weight of Dry Soil (g) = (W_2 - W_3) = B	14.67	14.65	14.81	14.99	6.58	7.08
Moisture Content (%) = (A / B)x 100	5.04	7.30	11.07	14.74	11.09	12.15
				AV. Plas. Lim.	**12**	

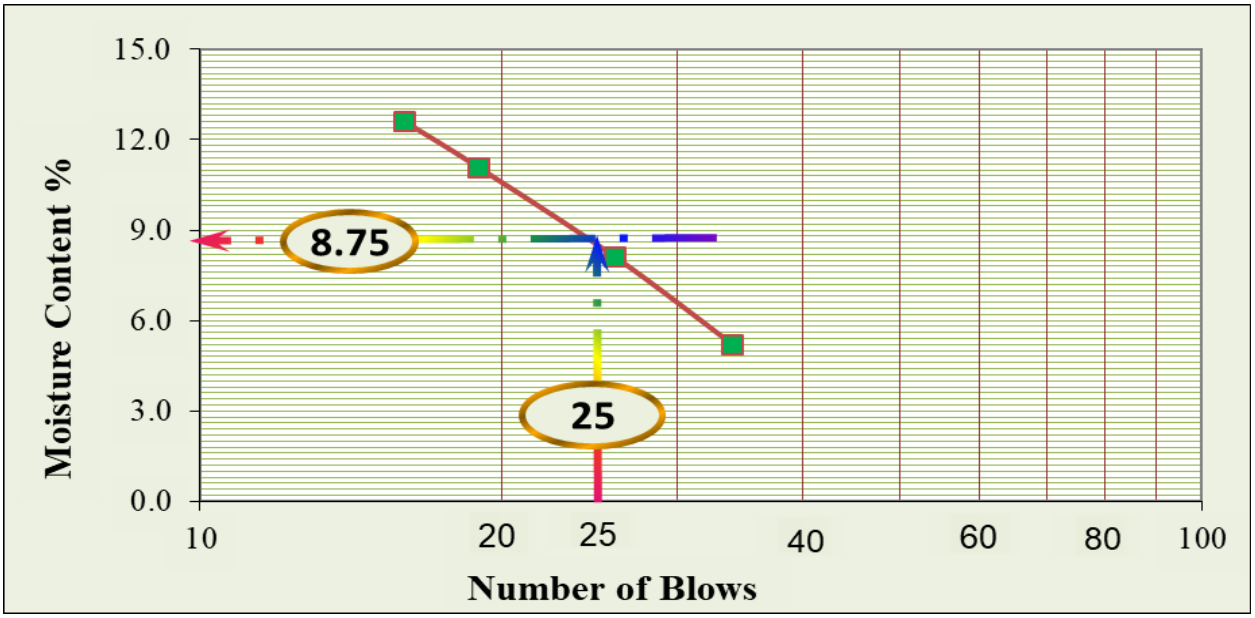


LIQUIDLIMIT	**LL**	**8**
PLASTIC LIMIT	**PL**	**12**
PLASTICITY INDEX	**LL - PL**	**Non - PI**

SOIL CONSISTENCY TEST RESULT (TEST METHOD : AASHTO T89 & T90)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**75+050**	**Lab #**	**Lab.0002**
Source Type	**Approved stone quarry/crushed agg. Stock**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**13/11/20**

	Liquid Limit				**Plastic Limit**	
No. of Blows	34	26	19	16		
Container Number	LB11	LB22	LB33	LB44	PB11	PB22
Wt. of Container + Wet Soil (g) = (W_1)	35.71	36.13	35.87	35.44	17.21	17.76
Wt. of Container + Dry Soil (g) = (W_2)	34.87	34.89	34.13	33.46	16.64	17.02
Wt. of Container (g) = (W_3)	18.76	19.58	18.41	17.76	10.82	10.51
Weight of Moisture (g) = ($W_1 - W_2$) = A	0.84	1.24	1.74	1.98	0.57	0.74
Weight of Dry Soil (g) = ($W_2 - W_3$) = B	16.11	15.31	15.72	15.70	5.82	6.51
Moisture Content (%) = (A / B)x 100	5.21	8.10	11.07	12.61	9.79	11.37
				AV. Plas. Lim.	**11**	



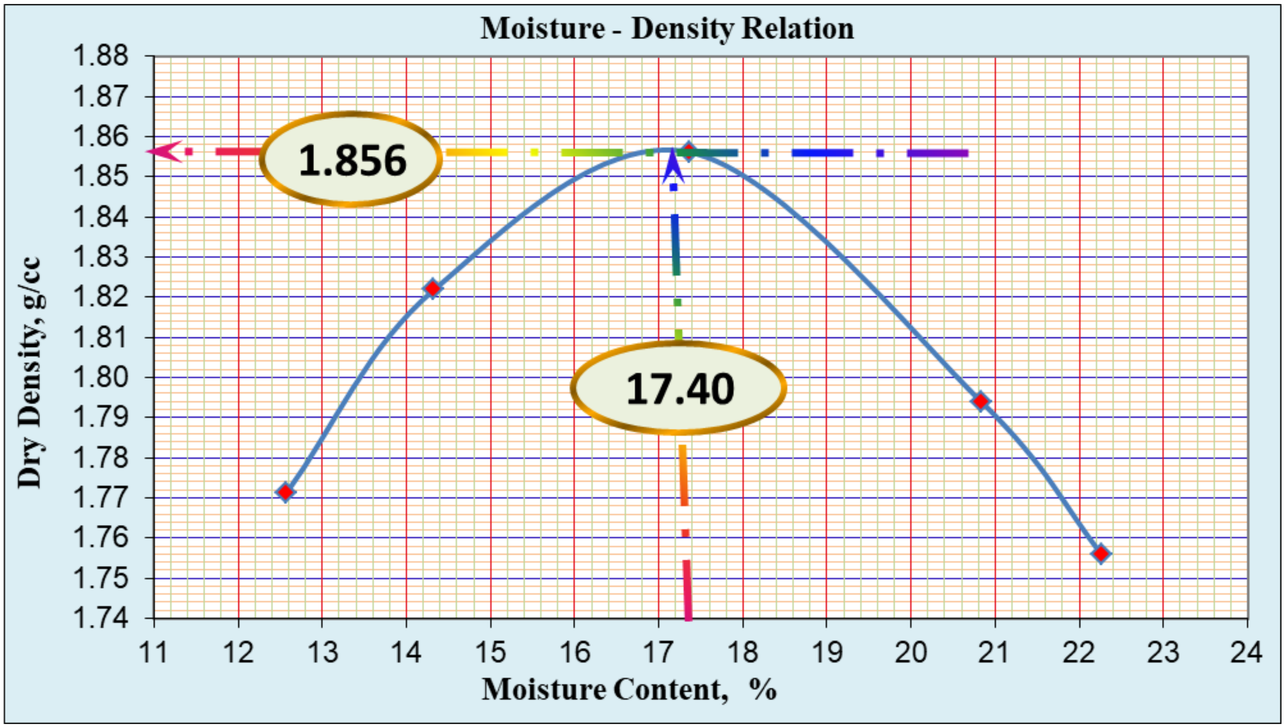
LIQUIDLIMIT	LL	9
PLASTIC LIMIT	PL	11
PLASTICITY INDEX	LL - PL	Non - PI

Appendix F: Moisture density relationship data for sub-grade, sub-base and base-course sample

MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade fill/capping**
Sampled at	**63+995**	**Lab #**	**Lab.01**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**light brown sandy soil with gravel soil**	**Testing Date**	**03/11/20**

			1	2	3	4	5
Density	Trial Number		1	2	3	4	5
	Weight of Soil + Mold, (g)	w_1	8,787	8,976	9,179	9,156	9,112
	Weight of Mold, (g)	w_2	4554.1	4554.1	4554.1	4554.1	4554.1
	Volume of Mold, (Cm^3)	v	2123	2123	2123	2123	2123
	Weight of Wet Soil, (g)	$w_3 = w_1 - w_2$	4,233	4,422	4,625	4,602	4,558
	Wet Density of Soil, (g/Cm^3)	$w_d = w_3/v$	1.99	2.08	2.18	2.17	2.15
Moisture	Container Number		AA	BB	CC	DD	EE
	Wet Soil + Container, (g)	a	413.6	475.1	521.3	437.8	429.5
	Dry Solil + Container, (g)	b	371.2	420.1	449.1	368.4	357.5
	Weight of Container, (g)	c	33.9	36.2	33.4	35.4	34.1
	Weight of Water, (g)	d = a-b	42.4	55.0	72.2	69.4	72.0
	Weight of Dry Soil, (g)	e = b-c	337.3	383.9	415.7	333.0	323.4
	Moisture Content, (%)	**m = (d/e)*100**	12.57	14.33	17.37	20.84	22.26
Dry Density of Soil, (g/Cm3)		**$D_d = W_d/(100+m)*100$**	1.77	1.82	1.86	1.79	1.76
		MDD, g/cm3:	**1.86**				
		OMC, %:	**17.40**				

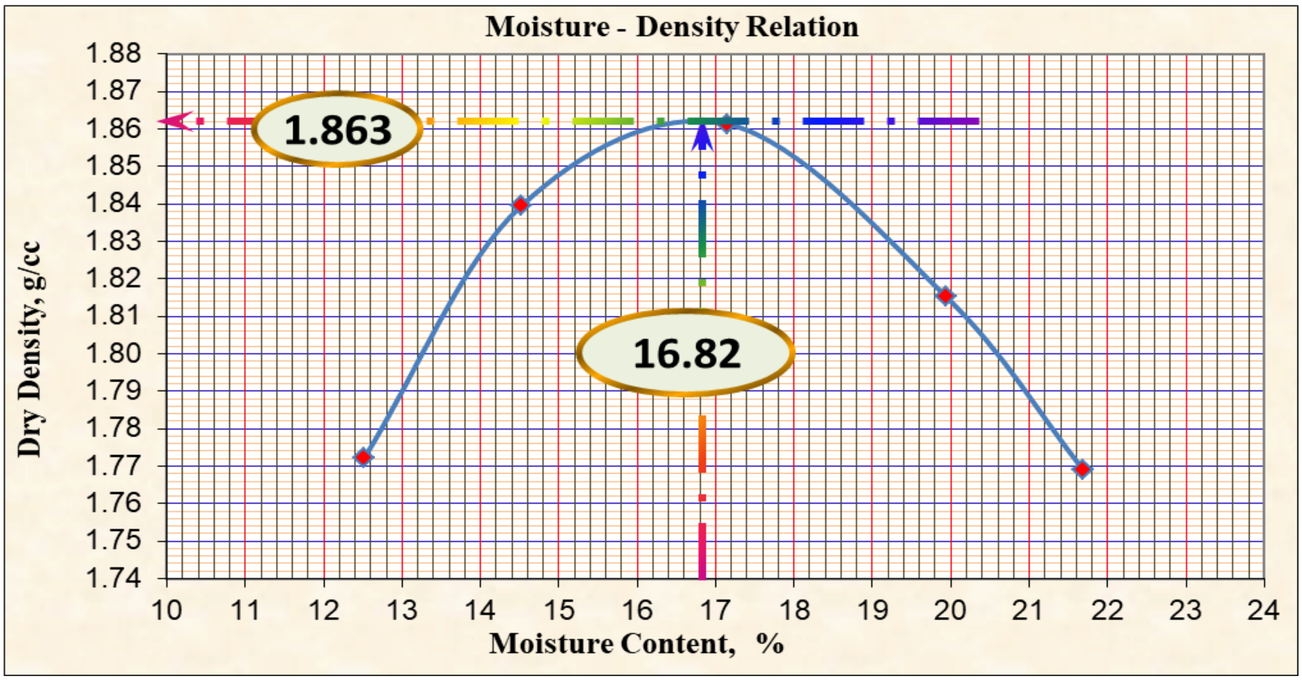


MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade fill/capping**
Sampled at	**62+800**	**Lab #**	**Lab.02**
Source Type	**Approved subgrade borrow area**	**Sampling date**	**30/10/2020**
Visual Description	**Light brown sandy soil with gravel soil**	**Testing Date**	**05/11/20**

			1	2	3	4	5
Density	Trial Number		1	2	3	4	5
	Weight of Soil + Mold, (g)	w_1	8,787	9,026	9,183	9,176	9,124
	Weight of Mold, (g)	w_2	4553.8	4553.8	4553.8	4553.8	4553.8
	Volume of Mold, (Cm^3)	v	2123	2123	2123	2123	2123
	Weight of Wet Soil, (g)	$w_3 = w_1 - w_2$	4,233	4,472	4,629	4,622	4,570
	Wet Density of Soil, (g/Cm^3)	$w_d = w_3/v$	1.99	2.11	2.18	2.18	2.15
Moisture	Container Number		AA	BB	CC	DD	EE
	Wet Soil + Container, (g)	a	421.2	485.2	531.4	442.3	432.4
	Dry Solil + Container, (g)	b	378.2	428.3	458.6	374.3	361.2
	Weight of Container, (g)	c	34.6	36.4	34.1	33.2	32.9
	Weight of Water, (g)	d = a-b	43.0	56.9	72.8	68.0	71.2

	Weight of Dry Soil, (g) e = b-c	343.6	391.9	424.5	341.1	328.3
	Moisture Content, (%) m = (d/e)*100	12.51	14.52	17.15	19.94	21.69
Dry Density of Soil, (g/Cm3) $D_d = W_d/(100+m)*100$		1.77	1.84	1.86	1.82	1.77
MDD, g/cm3:		**1.86**				
OMC, %:		**16.82**				

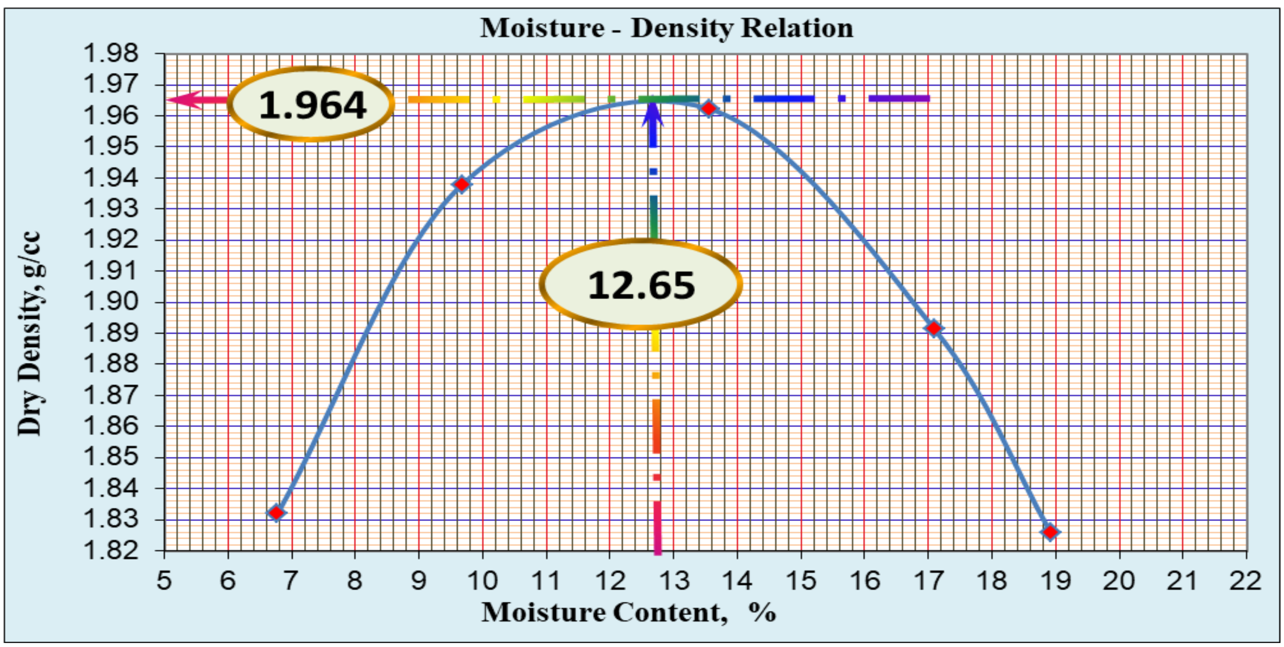


MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base layer**
Sampled at	**63+995**	**Lab #**	**Lab.001**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed rock aggregate with light brown sandy soil**	**Testing Date**	**09/11/20**

Density	Trial Number	1	2	3	4	5
	Weight of Soil + Mold, (g) w_1	8,707	9,066	9,285	9,256	9,164
	Weight of Mold, (g) w_2	4554.2	4554.2	4554.2	4554.2	4554.2
	Volume of Mold, (Cm^3) v	2123	2123	2123	2123	2123

	Weight of Wet Soil, (g)	$w_3 = w_1 - w_2$	4,153	4,512	4,731	4,702	4,610
	Wet Density of Soil, (g/Cm^3)	$w_d = w_3/v$	1.96	2.13	2.23	2.21	2.17
Moisture	Container Number		1SA	2SB	3SC	4SD	5SE
	Wet Soil + Container, (g)	a	412.2	451.3	453.8	456.7	430.1
	Dry Solil + Container, (g)	b	388.2	414.7	403.6	395.2	367.1
	Weight of Container, (g)	c	33.9	36.2	33.4	35.4	34.1
	Weight of Water, (g)	d = a-b	24.0	36.6	50.2	61.5	63.0
	Weight of Dry Soil, (g)	e = b-c	354.3	378.5	370.2	359.8	333.0
	Moisture Content, (%)	**m = (d/e)*100**	6.77	9.67	13.56	17.09	18.92
Dry Density of Soil, (g/Cm3)		**$D_d = W_d/(100+m)*100$**	1.83	1.94	1.96	1.89	1.83
		MDD, g/cm3:	**1.97**				
		OMC, %:	**12.65**				

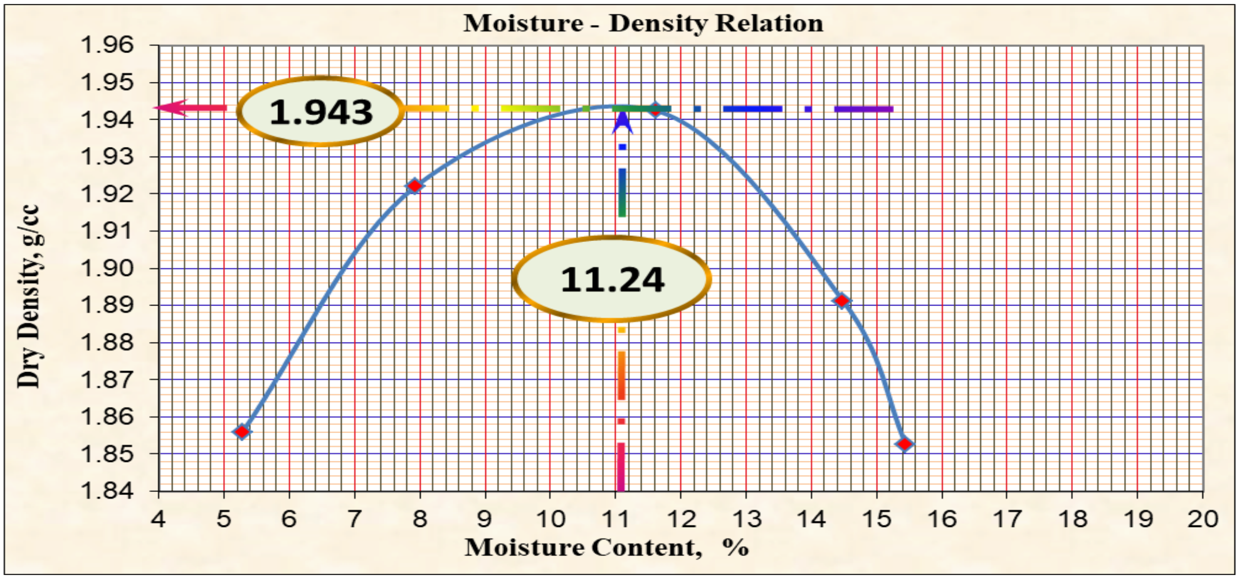


MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base layer**
Sampled at	**62+800 & 75+05**	**Lab #**	**Lab.002**
Source Type	**Approved sub-base borrow area and crushed agg. stock (70:30)**	**Sampling date**	**31/10/2020**

Visual Description	**Crushed rock aggregate with light brown sandy soil**	**Testing Date**	**11/11/20**

		1	2	3	4	5
Density	Trial Number	1	2	3	4	5
	Weight of Soil + Mold, (g) w_1	8,702	8,958	9,157	9,151	9,095
	Weight of Mold, (g) w_2	4554.3	4554.3	4554.3	4554.3	4554.3
	Volume of Mold, (Cm^3) v	2123	2123	2123	2123	2123
	Weight of Wet Soil, (g) $w_3 = w_1-w_2$	4,148	4,404	4,603	4,597	4,541
	Wet Density of Soil, (g/Cm^3) $w_d = w_3/v$	1.95	2.07	2.17	2.17	2.14
Moisture	Container Number	1SAA	2SBB	3SCC	4SDD	5SEE
	Wet Soil + Container, (g) a	414.5	454.1	426.5	468.8	441.2
	Dry Solil + Container, (g) b	395.4	423.3	385.7	413.7	386.8
	Weight of Container, (g) c	33.2	34.7	34.4	33.3	34.7
	Weight of Water, (g) d = a-b	19.1	30.8	40.8	55.1	54.4
	Weight of Dry Soil, (g) e = b-c	362.2	388.6	351.3	380.4	352.1
	Moisture Content, (%) m = (d/e)*100	5.27	7.93	11.61	14.48	15.45
Dry Density of Soil, (g/Cm3) $D_d = W_d/(100+m)*100$		1.86	1.92	1.94	1.89	1.85
MDD, g/cm3:		**1.94**				
OMC, %:		**11.24**				

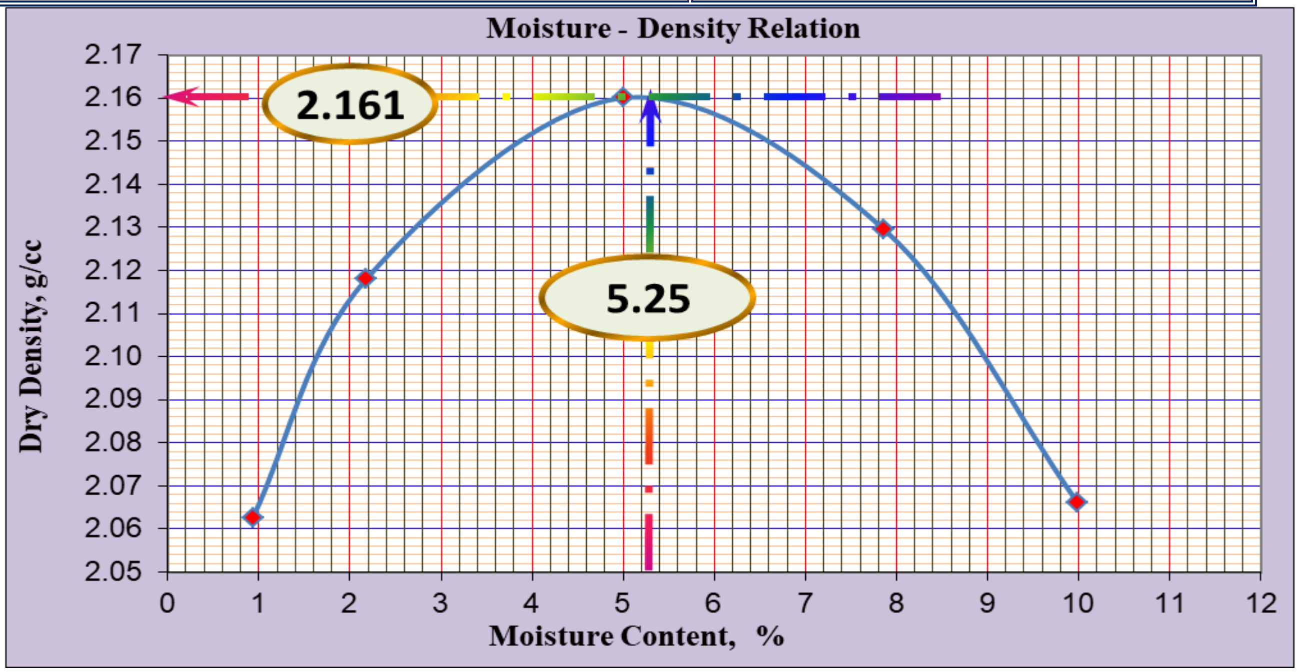


MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: ASTM D 1557)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**63+995**	**Lab #**	**Lab.0001**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**11/11/20**

			1	2	3	4	5
Density	Trial Number		1	2	3	4	5
	Weight of Soil + Mold, (g)	w_1	8,976	9,151	9,372	9,433	9,381
	Weight of Mold, (g)	w_2	4554.2	4554.2	4554.2	4554.2	4554.2
	Volume of Mold, (Cm^3)	v	2124	2124	2124	2124	2124
	Weight of Wet Soil, (g)	$w_3 = w_1 - w_2$	4,422	4,597	4,818	4,879	4,827
	Wet Density of Soil, (g/Cm^3)	$w_d = w_3/v$	2.08	2.16	2.27	2.30	2.27
Moisture	Container Number		1BA	2BB	3BC	4BD	5BE
	Wet Soil + Container, (g)	a	413.2	461.9	528.1	446.1	431.1
	Dry Solil + Container, (g)	b	409.7	452.8	504.5	416.2	395.1
	Weight of Container, (g)	c	34.2	35.2	33.2	35.6	34.5
	Weight of Water, (g)	d = a-b	3.5	9.1	23.6	29.9	36.0
	Weight of Dry Soil, (g)	e = b-c	375.5	417.6	471.3	380.6	360.6
	Moisture Content, (%)	**m = (d/e)*100**	0.93	2.18	5.01	7.86	9.98

Dry Density of Soil, (g/Cm3) $D_d = W_d/(100+m)*100$	2.06	2.12	2.16	2.13	2.07
MDD, g/cm3:	2.16				
OMC, %:	5.25				

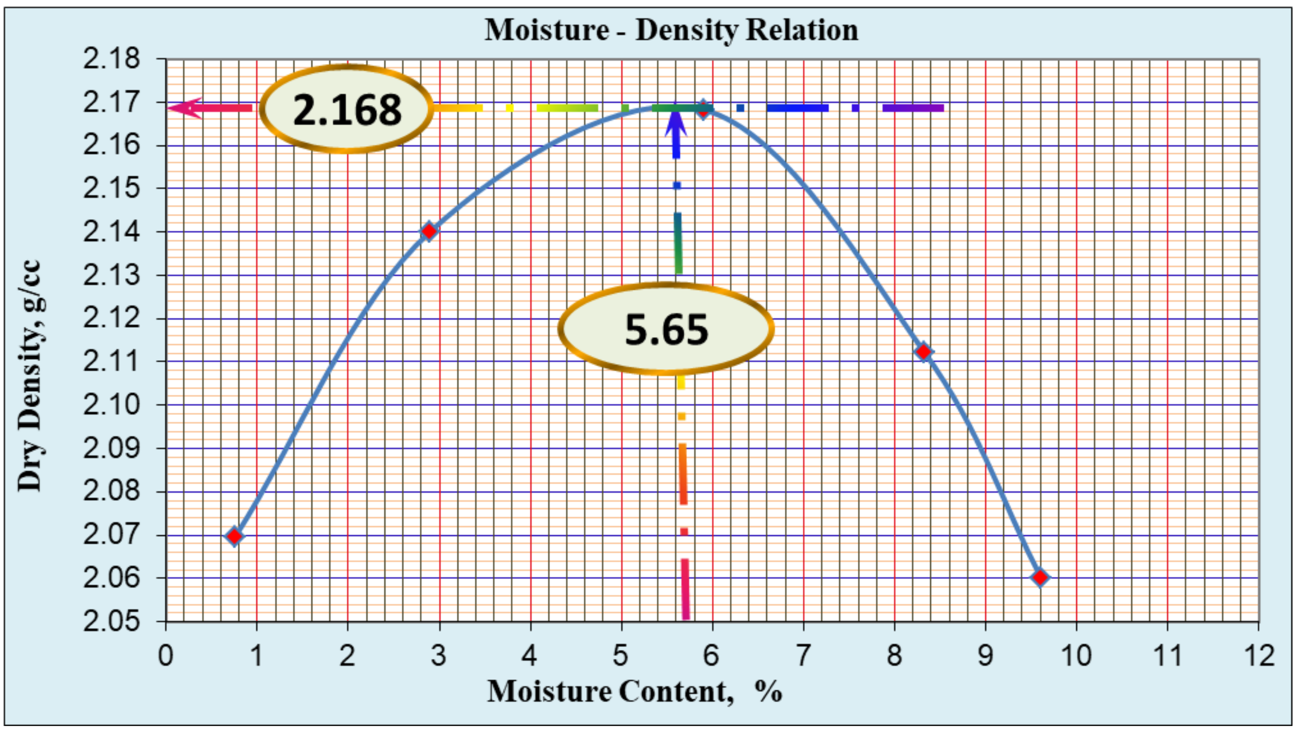


MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: ASTM D 1557)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**75+050**	**Lab #**	**Lab.0002**
Source Type	**Approved stone quarry/crushed agg. stock**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**14/11/20**

		1	2	3	4	5
Density	Trial Number	1	2	3	4	5
	Weight of Soil + Mold, (g) w_1	8,983	9,231	9,431	9,414	9,350
	Weight of Mold, (g) w_2	4554	4554	4554	4554	4554
	Volume of Mold, (Cm^3) v	2124	2124	2124	2124	2124
	Weight of Wet Soil, (g) $w_3 = w_1 - w_2$	4,429	4,677	4,877	4,860	4,796
	Wet Density of Soil, (g/Cm^3) $w_d = w_3/v$	2.09	2.20	2.30	2.29	2.26
Moisture	Container Number	1BA	2BBB	3BCC	4BD	5BE

			A			D	E
	Wet Soil + Container, (g)	a	421.7	454.7	538.3	441.6	421.6
	Dry Solil + Container, (g)	b	418.8	442.9	510.2	410.4	387.7
	Weight of Container, (g)	c	34.7	35.1	33.8	35.5	34.8
	Weight of Water, (g)	d = a-b	2.9	11.8	28.1	31.2	33.9
	Weight of Dry Soil, (g)	e = b-c	384.1	407.8	476.4	374.9	352.9
	Moisture Content, (%)	**m = (d/e)*100**	0.76	2.89	5.90	8.32	9.61
Dry Density of Soil, (g/Cm3) D_d = W_d/(100+m)*100			2.07	2.14	2.17	2.11	2.06
		MDD, g/cm3:	**2.17**				
		OMC, %:	**5.65**				



Appendix G: Laboratory CBR analysis data for sub-grade, sub-base and base-course sample

CALIFORNIA BEARING RATIO TEST (TEST METHOD: AASHTO T-193)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade fill/capping**
Sampled at	**63+995**	**Lab #**	**Lab.01**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Light brown sandy soil with gravel soil**	**Testing Date**	**04/11/2020 - 08/11/2020**

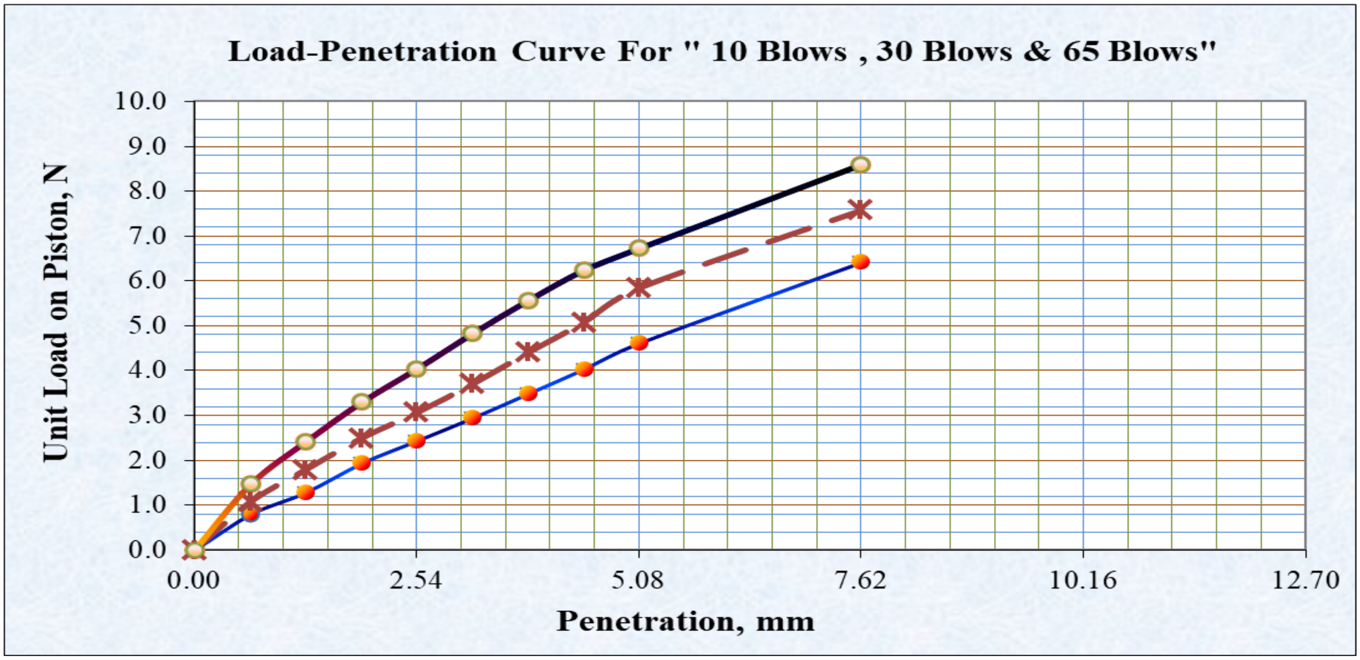
Density Determination							
Soaking Condition		**10 Blows**		**30 Blows**		**65 Blows**	
		Before	After	Before	After	Before	After
Mold Number		AAA		BBB		CCC	
Weight of Soil + Mold (g)	**w_1**	10394	10874	10732	11072	10826	11013
Weight of Mold (g)	**w_2**	6328.3	6328.3	6304	6304	6201.8	6201.8
Volume of Mold (Cm^3)	**v**	2123	2123	2123	2123	2123	2123
Weight of Wet Soil (g)	**$w_3 = w_1 - w_2$**	4066	4546	4428	4768	4624	4811
Wet Density of Soil (g/cm3)	**$w_d = (w_3/v)$**	1.92	2.14	2.09	2.25	2.18	2.27
Dry Density of Soil (g/cm3)	**$D_d = W_d/(100+m)*100$**	1.58	1.65	1.78	1.85	1.91	1.94

Moisture Determination									
Soaking Condition	**10 Blows**			**30 Blows**			**65 Blows**		
	Before	After		Before	After		Before	After	
		Top 1 in.	Avg.		Top 1 in.	Avg.		Top 1 in.	Avg.
Container Number	A1	A2		B1	B2		C1	C2	
Wet Soil + Container (g) a	447.4	504.6		456.3	497.4		433.1	458.6	
Dry Soil + Container (g) b	375.1	398.3		394.1	416.8		384.1	397.4	
Weight of Container (g) c	36.6	37.4		34.4	35.5		32.8	35.2	
Weight of Water (g) d = a - b	72.3	106.3		62.2	80.6		49.0	61.2	

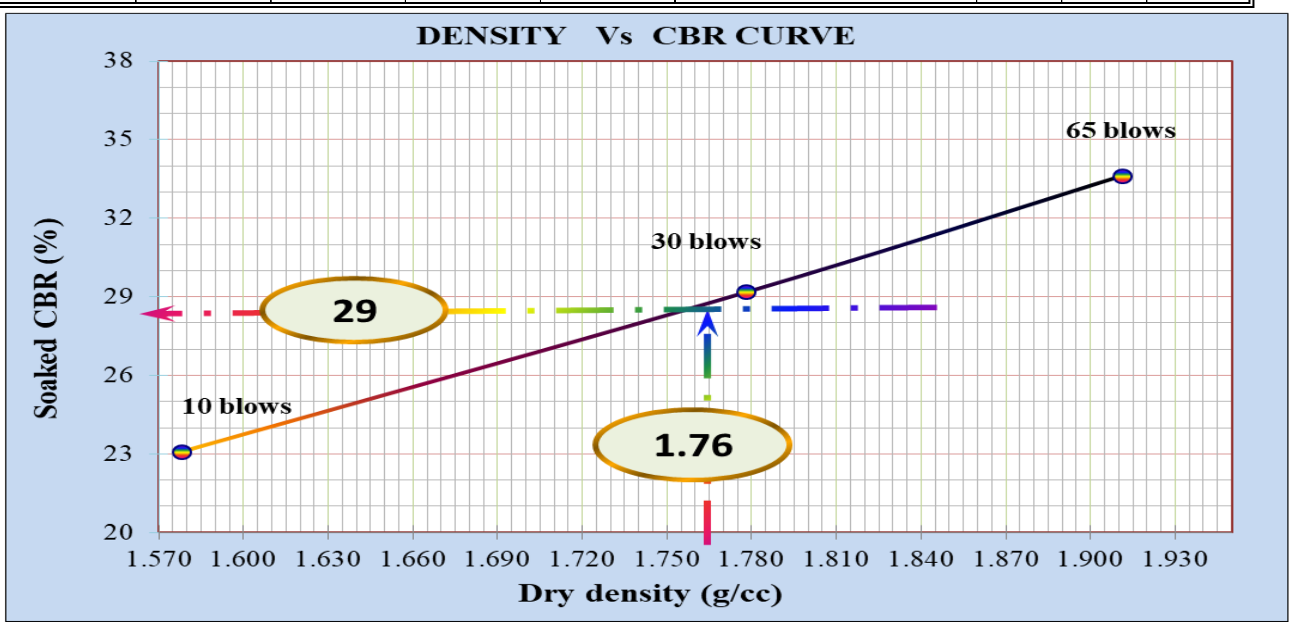
Weight of Dry Soil	(g) e = b - c	338.5	360.9		359.7	381.3		351.3	362.2	
Moisture Content	(%) m =(d/e)*100	21.36	29.45		17.29	21.14		13.95	16.90	
Avg. Moisture Content (%)										

Penetration Test Data, after 96 hrs Soaking Period					**Surcharge Weight = 4.55 KG**				**Plunger cross-section area, mm^2 = 1935.5**			
Standard Load, N/mm^2			**at 2.54mm = 6.89**					**at 5.08mm = 10.34**				
Penet.	**10 Blows**				**30 Blows**				**65 Blows**			
(mm)	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	DIAL RDG	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**
0.00	0.00	0.00	0.00		0.00	0.000	0.00		0.00	0.000	0.00	
0.64	63.0	0.81	0.42		84.0	1.074	0.56		115.0	1.471	0.76	
1.27	101.0	1.29	0.67		140.0	1.791	0.93		189.0	2.417	1.25	
1.91	152.0	1.94	1.00		195.0	2.494	1.29		258.0	3.300	1.70	
2.54	191.0	2.44	1.26	18.32	239.5	3.063	1.58	22.97	316.0	4.042	2.09	30.31
3.18	231.0	2.95	1.53		289.5	3.703	1.91		378.0	4.835	2.50	
3.81	273.0	3.49	1.80		344.0	4.400	2.27		435.0	5.564	2.87	
4.45	316.0	4.04	2.09		397.0	5.078	2.62		488.0	6.242	3.22	
5.08	361.0	4.62	2.39	23.07	456.5	5.839	3.02	29.17	526.0	6.728	3.48	33.62
7.62	502.0	6.42	3.32		592.0	7.572	3.91		672.0	8.595	4.44	
10.16												
12.70												

Swell				**Ring Factor**			
No. of Blows	**10**	**30**	**65**			MDD (gm/cc)	1.86
RDG (Before Soaking)	4.430	3.410	5.320			95 % of MDD	1.76
RDG (After Soaking)	6.540	4.730	6.410	0.01279	N/Divis..		
Percent Swell	1.81	1.13	0.94			**C.B.R.at 95% of MDD**	**29.00**
Average Percent Swell	1.29						



BLOWS	Load (KN)		CBR (%)		Dry Density Vs Socked C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	1.26	2.39	18.3	23.1	**No # of Blows**	**10**	**30**	**65**
30	1.58	3.02	23.0	29.2	**Dry Density**	1.58	1.78	1.91
65	2.09	3.48	30.3	33.6	**soaked C.B.R.**	23.1	29.2	33.6



MDD (g/cc) :	**1.86**	**95% of MDD (g/cc)**	**1.76**	**CBR at 95% of MDD**	**29**

CALIFORNIA BEARING RATIO TEST (TEST METHOD: AASHTO T-193)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-grade fill/capping**
Sampled at	**62+800**	**Lab #**	**Lab.02**
Source Type	**Approved subgrade borrow area**	**Sampling date**	**30/10/2020**
Visual Description	**Light brown sandy soil with gravel soil**	**Testing Date**	**06/11/2020 - 10/11/2020**

Density Determination

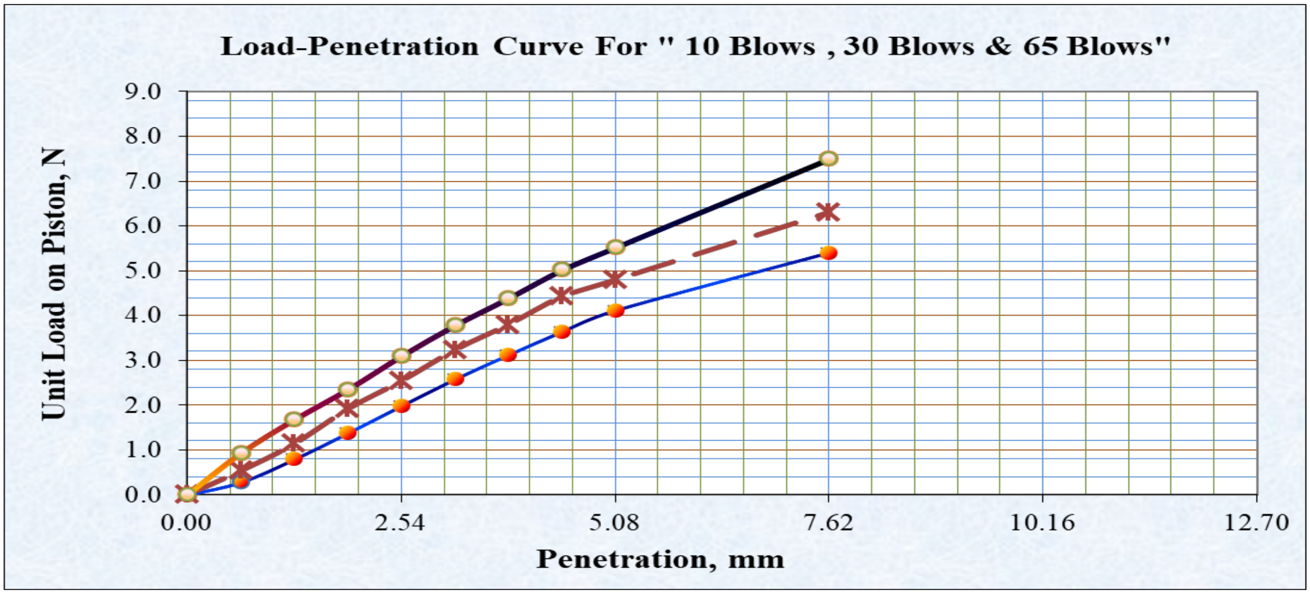
Soaking Condition		**10 Blows**		**30 Blows**		**65 Blows**	
		Before	After	Before	After	Before	After
Mold Number		AA1		BB2		CC3	
Weight of Soil + Mold (g)	w_1	10685	11533	10542	11069	11224	11742
Weight of Mold (g)	w_2	6570.3	6570.3	6201.8	6201.8	6570.3	6570.3
Volume of Mold (Cm^3)	v	2123	2123	2123	2123	2123	2123
Weight of Wet Soil (g)	$w_3 = w_1 - w_2$	4115	4963	4340	4867	4654	5172
Wet Density of Soil (g/cm3)	$w_d = (w_3/v)$	1.94	2.34	2.04	2.29	2.19	2.44
Dry Density of Soil (g/cm3)	$D_d = W_d/(100+m)*100$	1.60	1.76	1.74	1.81	1.91	1.99

Moisture Determination

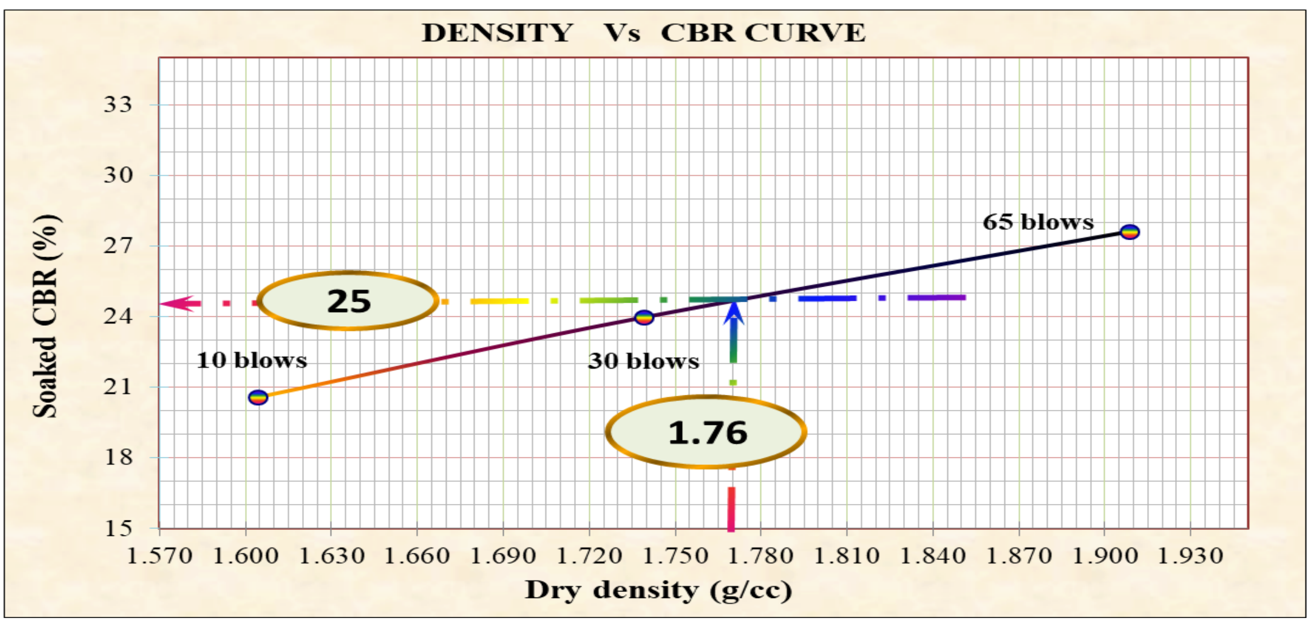
Soaking Condition		**10 Blows**			**30 Blows**			**65 Blows**		
		Before	After		Before	After		Before	After	
			Top 1 in.	Avg.		Top 1 in.	Avg.		Top 1 in.	Avg.
Container Number		A11	A22		B11	B22		C11	C22	
Wet Soil + Container (g)	a	466.3	526.2		477.2	518.4		438.2	467.4	
Dry Soil + Container (g)	b	392.3	405.9		411.1	416.8		385.9	387.7	
Weight of Container (g)	c	36.4	37.9		34.7	35.1		33.8	34.1	
Weight of Water (g) d =	a - b	74.0	120.3		66.1	101.6		52.3	79.7	
Weight of Dry Soil (g) e =	b - c	355.9	368		376.4	381.7		352.1	353.6	
Moisture Content (%) m=(d/e*)100		20.79	32.69		17.56	26.62		14.85	22.54	
Avg. Moisture Content (%)										

Penetration Test Data, after 96 hrs Soaking Period					Surcharge Weight = 4.55 KG				Plunger cross-section area, mm^2 = 1935.5			
Standard Load, N/mm^2			at 2.54mm = 6.89						at 5.08mm = 10.34			
Penet.	**10 Blows**				**30 Blows**				**65 Blows**			
(mm)	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	DIAL RDG	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**
0.00	0.00	0.00	0.00		0.00	0.000	0.00		0.00	0.000	0.00	
0.64	22.0	0.28	0.15		42.0	0.537	0.28		73.0	0.934	0.48	
1.27	62.0	0.79	0.41		89.0	1.138	0.59		131.0	1.675	0.87	
1.91	108.0	1.38	0.71		150.0	1.919	0.99		184.0	2.353	1.22	
2.54	155.0	1.98	1.02	14.87	198.5	2.539	1.31	19.04	242.0	3.095	1.60	23.21
3.18	202.0	2.58	1.33		253.0	3.236	1.67		296.0	3.786	1.96	
3.81	244.0	3.12	1.61		297.0	3.799	1.96		343.0	4.387	2.27	
4.45	285.0	3.65	1.88		346.0	4.425	2.29		393.0	5.026	2.60	
5.08	322.0	4.12	2.13	20.58	375.0	4.796	2.48	23.97	432.0	5.525	2.85	27.61
7.62	423.0	5.41	2.80		493.0	6.305	3.26		587.0	7.508	3.88	
10.16												
12.70												

Swell				**Ring Factor**		MDD (gm/cc)	1.86
No. of Blows	**10**	**30**	**65**	0.01279	N/Divis.	95 % of MDD	1.77
RDG (Before Soaking)	4.010	3.480	2.340				
RDG (After Soaking)	5.890	4.760	3.120				
Percent Swell	1.61	1.10	0.67			**C.B.R.at 95% of MDD**	**25.00**
Average Percent Swell	1.13						



BLOWS	Load (KN)		CBR (%)		Dry Density Vs Socked C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	1.02	2.13	14.9	20.6	**No # of Blows**	**10**	**30**	**65**
30	1.31	2.48	19.0	24.0	**Dry Density**	1.60	1.74	1.91
65	1.60	2.85	23.2	27.6	**soaked C.B.R.**	20.6	24.0	27.6



MDD (g/cc) :	**1.86**	**95% of MDD (g/cc)**	**1.77**	**CBR at 95% of MDD**	**25**

CALIFORNIA BEARING RATIO TEST (TEST METHOD: AASHTO T-193)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base layer**
Sampled at	**63+995**	**Lab #**	**Lab.001**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed rock aggregate with light brown sandy soil**	**Testing Date**	**10/11/2020 - 14/11/2020**

Density Determination

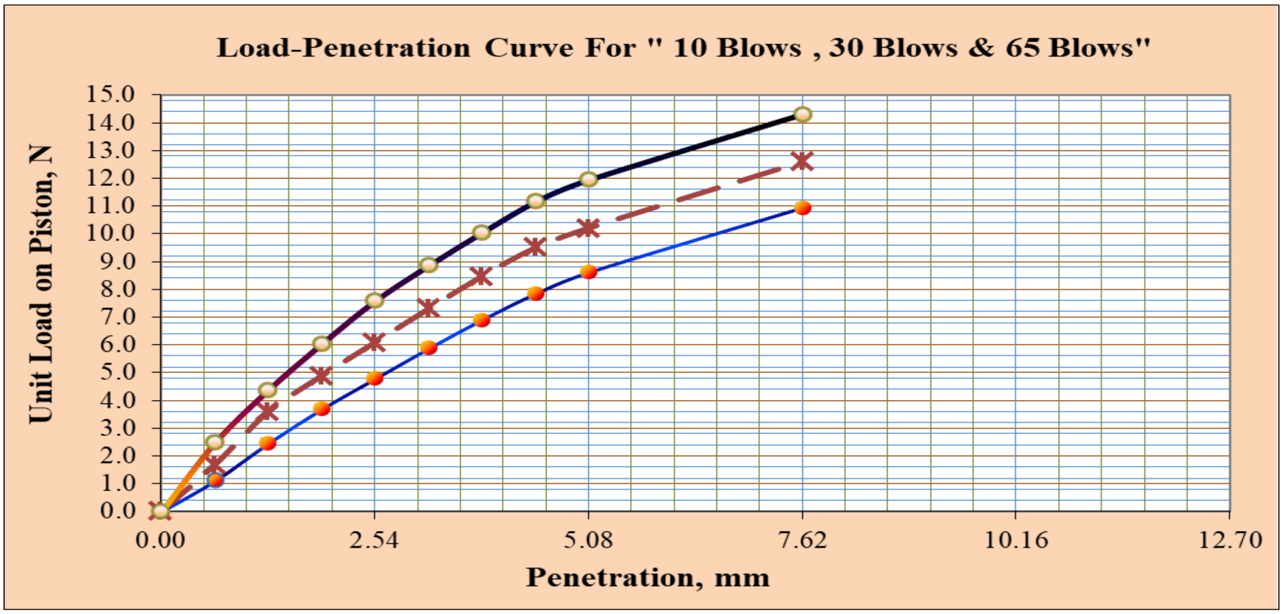
Soaking Condition		**10 Blows**		**30 Blows**		**65 Blows**	
		Before	After	Before	After	Before	After
Mold Number		A1A		B1B		C1C	
Weight of Soil + Mold (g)	w_1	10785	11507	10827	11394	10576	11143
Weight of Mold (g)	w_2	6201.8	6201.8	6328.3	6328.3	6012.5	6012.5
Volume of Mold (Cm^3)	v	2123	2123	2123	2123	2123	2123
Weight of Wet Soil (g)	$w_3 = w_1 - w_2$	4583	5305	4499	5066	4564	5131
Wet Density of Soil (g/cm3)	$w_d = (w_3/v)$	2.16	2.50	2.12	2.39	2.15	2.42
Dry Density of Soil (g/cm3)	$D_d = W_d/(100+m)*100$	1.84	1.98	1.90	2.00	1.99	2.13

Moisture Determination

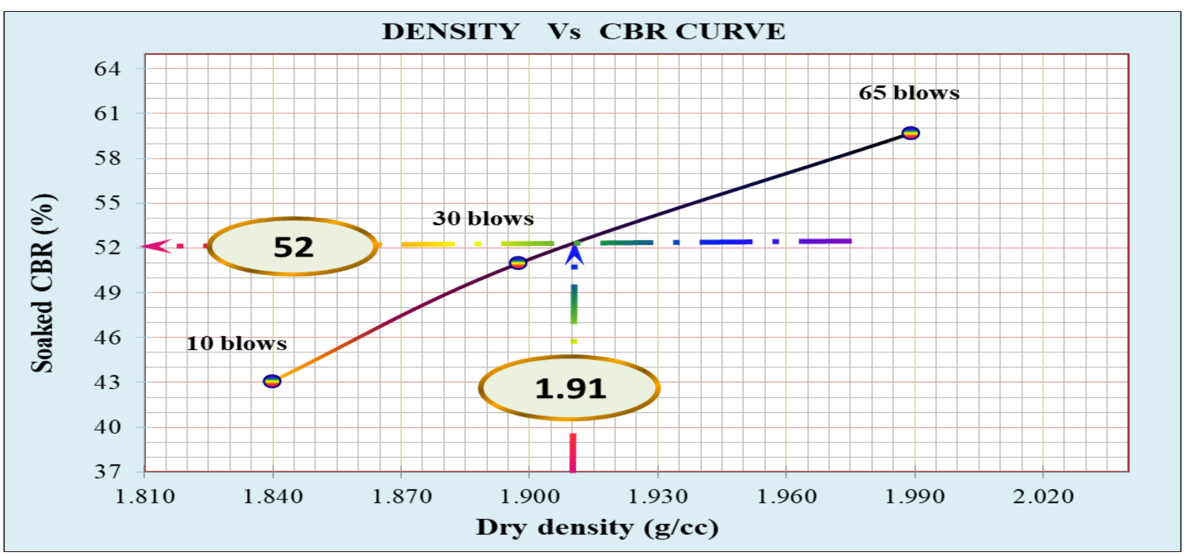
Soaking Condition		**10 Blows**			**30 Blows**			**65 Blows**		
		Before	After		Before	After		Before	After	
			Top 1 in.	Avg.		Top 1 in.	Avg.		Top 1 in.	Avg.
Container Number		A12	A21		B12	B21		C12	C21	
Wet Soil + Container (g)	A	436.2	501.4		477.4	538.1		431.3	479.1	
Dry Soil + Container (g)	b	377.1	405.4		431.1	457.2		401.6	427.2	
Weight of Container (g)	c	36.4	37.9		34.7	35.1		33.8	34.1	
Weight of Water (g)	d = a - b	59.1	96.0		46.3	80.9		29.7	51.9	
Weight of Dry Soil (g)	e = b - c	340.7	367.5		396.4	422.1		367.8	393.1	
Moisture Content (%) m=(d/e*)100		17.35	26.12		11.68	19.17		8.08	13.20	
Avg. Moisture Content (%)										

Penetration Test Data, after 96 hrs Soaking Period					Surcharge Weight = 4.55 KG				Plunger cross-section area, mm^2 = 1935.5			
Standard Load, N/mm^2			at 2.54mm = 6.89				at 5.08mm = 10.34					
Penet.	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	CBR %	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	CBR %	DIAL RDG	Load (N)	Resistance to Penetration (N/mm^2)	CBR %
0.00	0.00	0.00	0.00		0.00	0.000	0.00		0.00	0.000	0.00	
0.64	87.0	1.11	0.57		132.0	1.688	0.87		195.0	2.494	1.29	
1.27	192.0	2.46	1.27		280.0	3.581	1.85		342.0	4.374	2.26	
1.91	289.0	3.70	1.91		382.0	4.886	2.52		473.0	6.050	3.13	
2.54	374.0	4.78	2.47	35.87	476.0	6.088	3.15	45.65	593.0	7.584	3.92	56.87
3.18	460.0	5.88	3.04		571.0	7.303	3.77		693.0	8.863	4.58	
3.81	540.0	6.91	3.57		662.0	8.467	4.37		785.0	10.040	5.19	
4.45	614.0	7.85	4.06		743.0	9.503	4.91		873.0	11.166	5.77	
5.08	674.0	8.62	4.45	43.07	798.0	10.206	5.27	51.00	934.0	11.946	6.17	59.69
7.62	856.0	10.95	5.66		985.0	12.598	6.51		1119.0	14.312	7.39	
10.16												
12.70												

Swell				Ring Factor			
No. of Blows	10	30	65			MDD (gm/cc)	1.97
RDG (Before Soaking)	2.100	2.170	2.120	0.01279	N/Divis.	97 % of MDD	1.91
RDG (After Soaking)	3.070	3.120	3.240				
Percent Swell	0.83	0.82	0.96			**C.B.R.at 97% of MDD**	**52.00**
Average Percent Swell	0.87						



BLOWS	Load (KN)		CBR (%)		Dry Density Vs Socked C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	2.47	4.45	35.9	43.1	**No # of Blows**	**10**	**30**	**65**
30	3.15	5.27	45.7	51.0	**Dry Density**	1.84	1.90	1.99
65	3.92	6.17	56.9	59.7	**soaked C.B.R.**	43.1	51.0	59.7



MDD (g/cc) :	**1.97**	**97% of MDD (g/cc)**	**1.91**	**CBR at 97% of MDD**	**52**

CALIFORNIA BEARING RATIO TEST (TEST METHOD: AASHTO T-193)

Represented Section	**61+000 - 111+659**	**Material For**	**Sub-base layer**
Sampled at	**62+800 & 75+05**	**Lab #**	**Lab.002**
Source Type	**Approved sub-base borrow area and crushed agg. stock (70:30)**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed rock aggregate with light brown sandy soil**	**Testing Date**	**12/11/2020 - 16/11/2020**

Density Determination

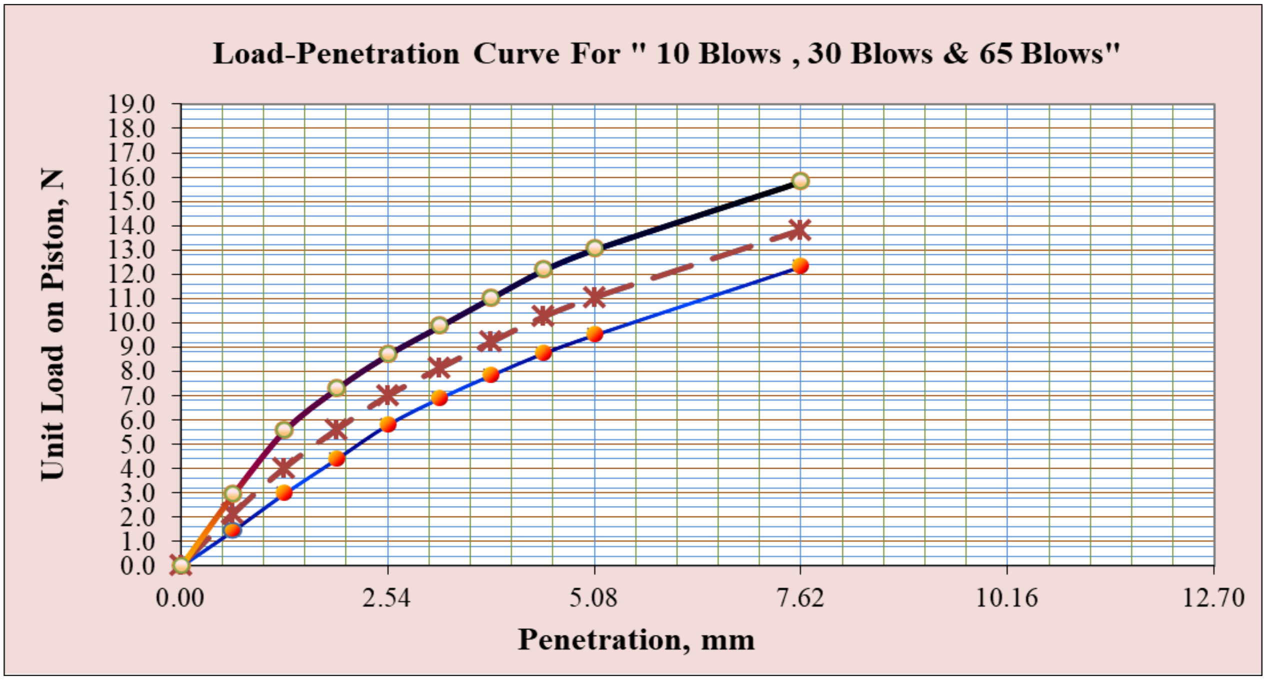
Soaking Condition		**10 Blows**		**30 Blows**		**65 Blows**	
		Before	After	Before	After	Before	After
Mold Number		A2A		B2B		C2C	
Weight of Soil + Mold (g)	**w_1**	10742	11512	10613	11156	10512	10732
Weight of Mold (g)	**w_2**	6328.3	6328.3	6201.8	6201.8	6012.4	6012.4
Volume of Mold (Cm^3)	**v**	2123	2123	2123	2123	2123	2123
Weight of Wet Soil (g)	**$w_3 = w_1 - w_2$**	4414	5184	4411	4954	4500	4720
Wet Density of Soil (g/cm3)	**$w_d = (w_3/v)$**	2.08	2.44	2.08	2.33	2.12	2.22
Dry Density of Soil (g/cm3)	**$D_d = W_d/(100+m)*100$**	1.81	1.96	1.89	1.99	1.98	1.98

Moisture Determination

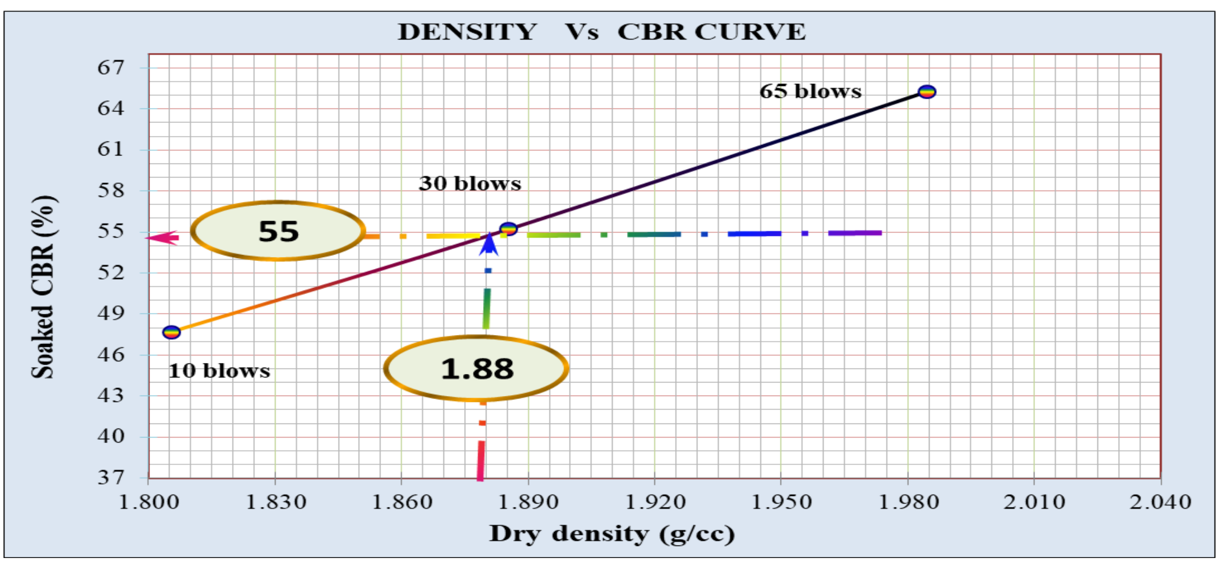
Soaking Condition	**10 Blows**			**30 Blows**			**65 Blows**		
	Before	After		Before	After		Befor e	After	
		Top 1 in.	Av g.		Top 1 in.	Avg.		Top 1 in.	Avg.
Container Number	A122	A211		B122	B211		C122	C211	
Wet Soil + Container (g) a	428.7	487.1		439.2	518.2		421.1	503.2	
Dry Soil + Container (g) b	377.1	397.4		401.8	447.4		396.5	452.2	
Weight of Container (g) c	36.7	36.7		35.4	34.2		34.7	33.4	
Weight of Water (g) d = a - b	51.6	89.7		37.4	70.8		24.6	51.0	
Weight of Dry Soil (g) e = b - c	340.4	360.7		366.4	413.2		361.8	418.8	
Moisture Content (%) m =(d/e)*100	15.16	24.87		10.21	17.13		6.80	12.18	
Avg. Moisture Content (%)									

Penetration Test Data, after 96 hrs Soaking Period					Surcharge Weight = 4.55 KG				Plunger cross-section area, mm^2 = 1935.5			
Standard Load, N/mm^2		at 2.54mm = 6.89					at 5.08mm = 10.34					
Penet.	10 Blows				30 Blows				65 Blows			
(mm)	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	CBR %	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	CBR %	DIAL RDG	Load (N)	Resistance to Penetration (N/mm^2)	CBR %
0.00	0.00	0.00	0.00		0.00	0.000	0.00		0.00	0.000	0.00	
0.64	114.0	1.46	0.75		167.0	2.136	1.10		231.0	2.954	1.53	
1.27	234.0	2.99	1.55		315.0	4.029	2.08		436.0	5.576	2.88	
1.91	345.0	4.41	2.28		438.0	5.602	2.89		571.0	7.303	3.77	
2.54	456.0	5.83	3.01	43.73	547.0	6.996	3.61	52.46	681.0	8.710	4.50	65.31
3.18	542.0	6.93	3.58		636.0	8.134	4.20		773.0	9.887	5.11	
3.81	616.0	7.88	4.07		720.0	9.209	4.76		864.0	11.051	5.71	
4.45	687.0	8.79	4.54		801.0	10.245	5.29		954.0	12.202	6.30	
5.08	746.0	9.54	4.93	47.68	864.0	11.051	5.71	55.22	1021.0	13.059	6.75	65.25
7.62	967.0	12.37	6.39		1081.0	13.826	7.14		1240.0	15.860	8.19	
10.16												
12.70												

Swell				Ring Factor			
No. of Blows	10	30	65	0.01279	N/Divis.	MDD (gm/cc)	1.94
RDG (Before Soaking)	2.020	2.120	2.010			97 % of MDD	1.88
RDG (After Soaking)	2.920	3.080	3.220				
Percent Swell	0.77	0.82	1.04			**C.B.R.at 97% of MDD**	**55.00**
Average Percent Swell	0.88						



BLOWS	Load (KN)		CBR (%)		Dry Density Vs Socked C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	3.01	4.93	43.7	47.7	**No # of Blows**	**10**	**30**	**65**
30	3.61	5.71	52.5	55.2	**Dry Density**	1.81	1.89	1.98
65	4.50	6.75	65.3	65.3	**Soacked C.B.R.**	47.7	55.2	65.3



MDD (g/cc) :	**1.94**	**97% of MDD (g/cc)**	**1.88**	**CBR at 97% of MDD**	**55**

CALIFORNIA BEARING RATIO TEST (TEST METHOD: AASHTO T-193)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**63+995**	**Lab #**	**Lab.0001**
Source Type	**Test Pit #T01**	**Sampling date**	**30/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**12/11/2020 - 16/11/2020**

Density Determination

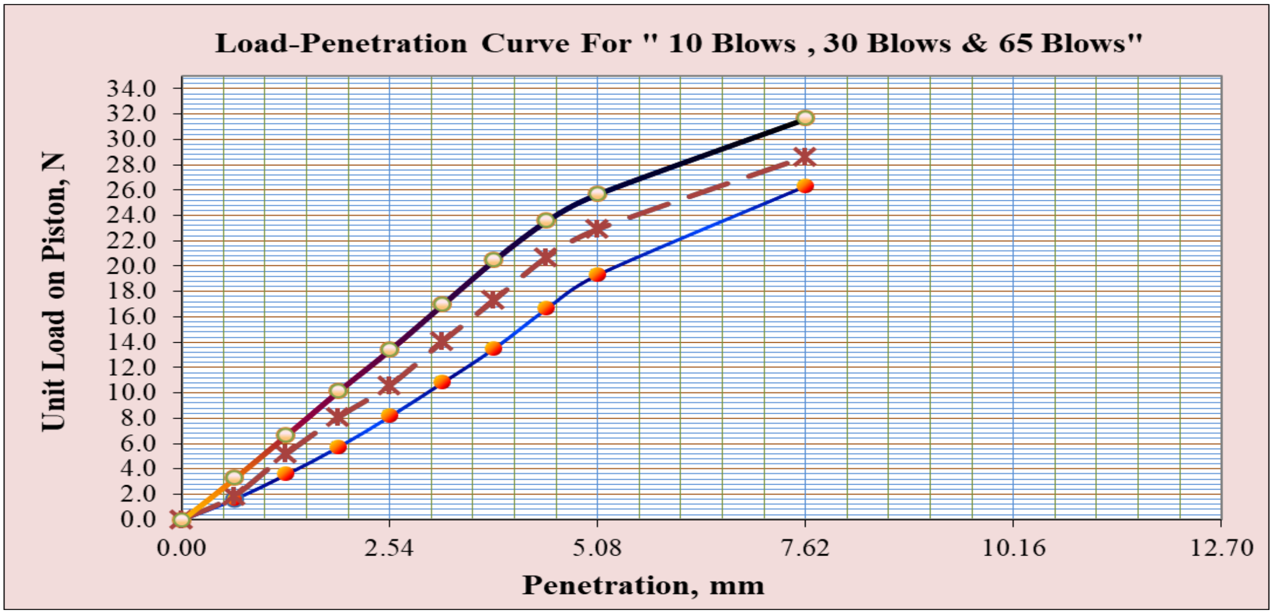
Soaking Condition		**10 Blows**		**30 Blows**		**65 Blows**	
		Befor e	After	Before	After	Before	After
Mold Number		A11A		B11B		C11C	
Weight of Soil + Mold (g)	**w_1**	11091	12023	11229	11828	10931	11317
Weight of Mold (g)	**w_2**	6201. 2	6201.2	6328.4	6328.4	6012.5	6012. 5
Volume of Mold (Cm^3)	**v**	2123	2123	2123	2123	2123	2123
Weight of Wet Soil (g)	**$w_3 = w_1 - w_2$**	4890	5822	4901	5500	4919	5305
Wet Density of Soil (g/cm3)	**$w_d = (w_3/v)$**	2.30	2.74	2.31	2.59	2.32	2.50
Dry Density of Soil (g/cm3)	**$D_d = W_d/(100+m)*100$**	2.10	2.34	2.19	2.32	2.28	2.34

Moisture Determination

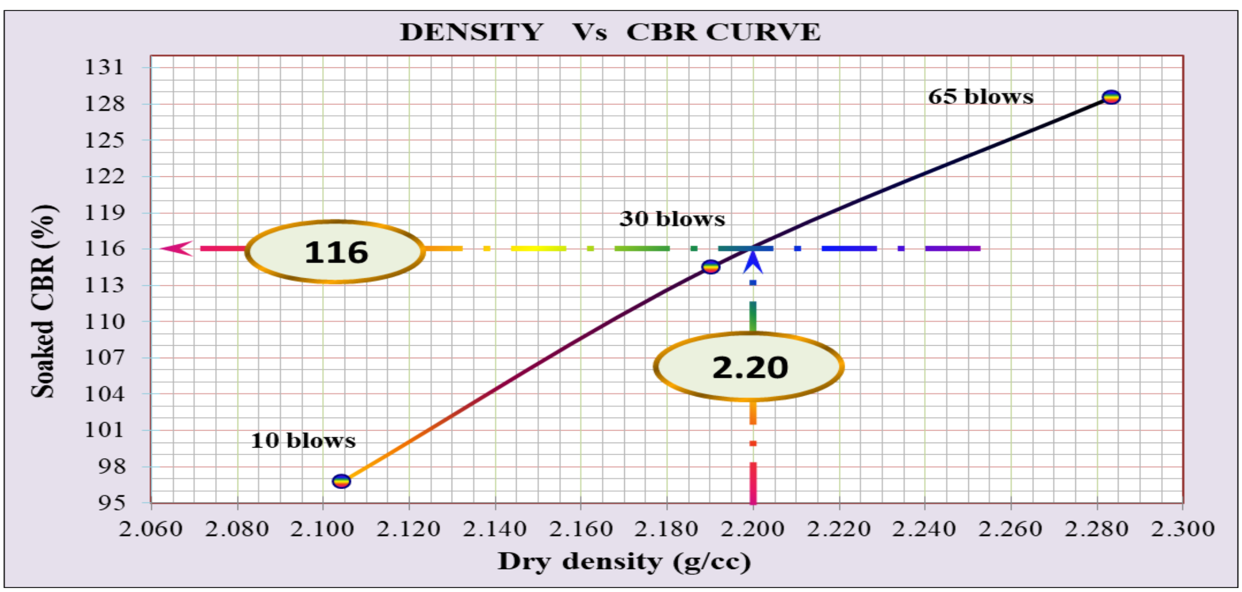
Soaking Condition	**10 Blows**			**30 Blows**			**65 Blows**		
	Before	After		Befor e	After		Befor e	After	
		Top 1 in.	Avg.		Top 1 in.	Avg.		Top 1 in.	Av g.
Container Number	A1C	A2C		B1A	B2A		C1B	C2B	
Wet Soil + Container (g) a	415.1	476.3		446.3	494. 2		421.2	453.2	
Dry Soil + Container (g) b	382.3	412.6		425.2	445. 4		415.6	427.3	
Weight of Container (g) c	35.4	36.9		34.2	34.1		34.4	34.2	
Weight of Water (g) d = a - b	32.8	63.7		21.1	48.8		5.6	25.9	
Weight of Dry Soil (g) e = b - c	346.9	375.7		391	411. 3		381.2	393.1	
Moisture Content (%) m =(d/e)*100	9.46	16.96		5.40	11.8 6		1.47	6.59	
Avg. Moisture Content (%)									

Penetration Test Data, after 96 hrs Soaking Period					Surcharge Weight = 4.55 KG				Plunger cross-section area, mm^2 = 1935.5			
Standard Load, N/mm^2		at 2.54mm = 6.89					at 5.08mm = 10.34					
Penet.	**10 Blows**				**30 Blows**				**65 Blows**			
(mm)	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	DIAL RDG	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**
0.00	0.00	0.00	0.00		0.00	0.000	0.00		0.00	0.000	0.00	
0.64	128.0	1.64	0.85		147.0	1.880	0.97		258.0	3.300	1.70	
1.27	281.0	3.59	1.86		404.0	5.167	2.67		523.0	6.689	3.46	
1.91	451.0	5.77	2.98		631.0	8.070	4.17		796.0	10.181	5.26	
2.54	641.0	8.20	4.24	61.48	828.0	10.590	5.47	79.41	1052.0	13.455	6.95	100.90
3.18	848.0	10.85	5.60		1097.0	14.031	7.25		1330.0	17.011	8.79	
3.81	1059.0	13.54	7.00		1352.0	17.292	8.93		1603.0	20.502	10.59	
4.45	1304.0	16.68	8.62		1616.0	20.669	10.68		1845.0	23.598	12.19	
5.08	1514.0	19.36	10.00	96.76	1792.0	22.920	11.84	114.52	2012.0	25.733	13.30	128.58
7.62	2061.0	26.36	13.62		2238.0	28.624	14.79		2476.0	31.668	16.36	
10.16												
12.70												

Swell				**Ring Factor**		MDD (gm/cc)	2.16
No. of Blows	**10**	**30**	**65**	0.01279	N/Divis.	102 % of MDD	2.20
RDG (Before Soaking)	1.500	2.040	2.420				
RDG (After Soaking)	1.760	2.430	2.860				
Percent Swell	0.22	0.33	0.38			**C.B.R.at 102% of MDD**	**116.00**
Average Percent Swell	0.31						



BLOWS	Load (KN)		CBR (%)		Dry Density Vs Socked C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	4.24	10.00	61.5	96.8	**No # of Blows**	**10**	**30**	**65**
30	5.47	11.84	79.4	114.5	**Dry Density**	2.10	2.19	2.28
65	6.95	13.30	100.9	128.6	**Soacked C.B.R.**	96.8	114.5	128.6



MDD (g/cc) :	**2.16**	**102% of MDD (g/cc)**	**2.20**	**CBR at 102% of MDD**	**116**

CALIFORNIA BEARING RATIO TEST (TEST METHOD: AASHTO T-193)

Represented Section	**61+000 - 111+659**	**Material For**	**Base-course layer**
Sampled at	**75+050**	**Lab #**	**Lab.0002**
Source Type	**Approved stone quarry/crushed agg. Stock**	**Sampling date**	**31/10/2020**
Visual Description	**Crushed basaltic rock agg.**	**Testing Date**	**17/11/2020 - 21/11/2020**

Density Determination

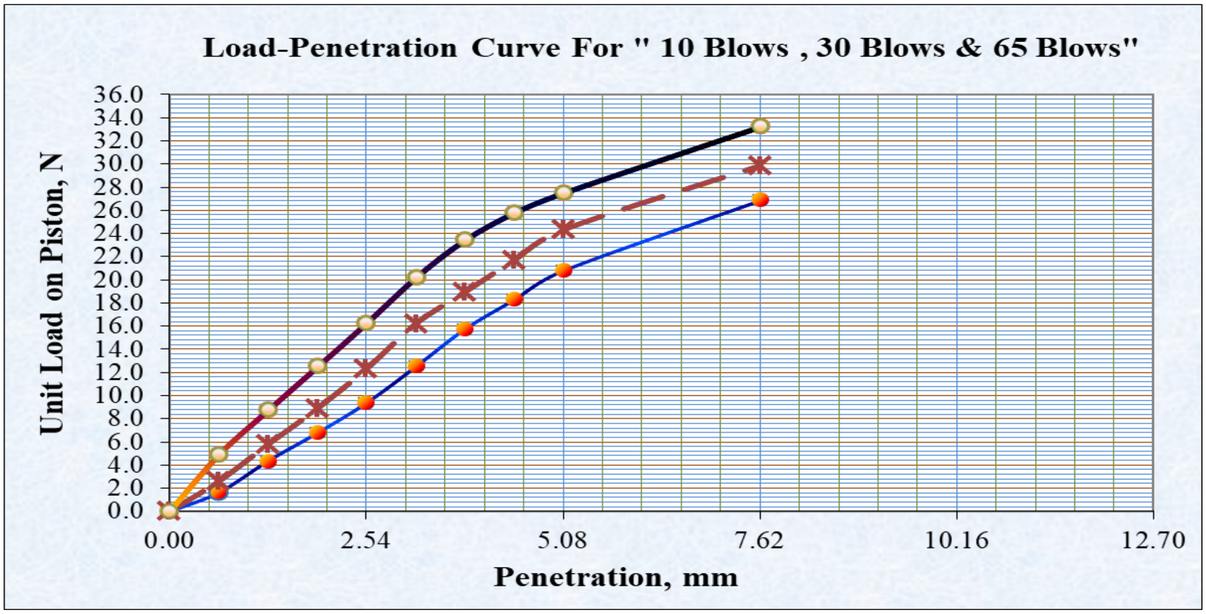
Soaking Condition		**10 Blows**		**30 Blows**		**65 Blows**	
		Before	After	Before	After	Before	After
Mold Number		A1A1		B2B2		C3C3	
Weight of Soil + Mold (g)	w_1	11265	11967	11343	11742	10984	11422
Weight of Mold (g)	w_2	6201.1	6201.1	6328.2	6328.2	6012.6	6012.6
Volume of Mold (Cm^3)	v	2123	2123	2123	2123	2123	2123
Weight of Wet Soil (g)	$w_3 = w_1 - w_2$	5064	5766	5015	5414	4971	5409
Wet Density of Soil (g/cm3)	$w_d = (w_3/v)$	2.39	2.72	2.36	2.55	2.34	2.55
Dry Density of Soil (g/cm3)	$D_d = W_d/(100+m)*100$	2.16	2.34	2.22	2.27	2.32	2.40

Moisture Determination

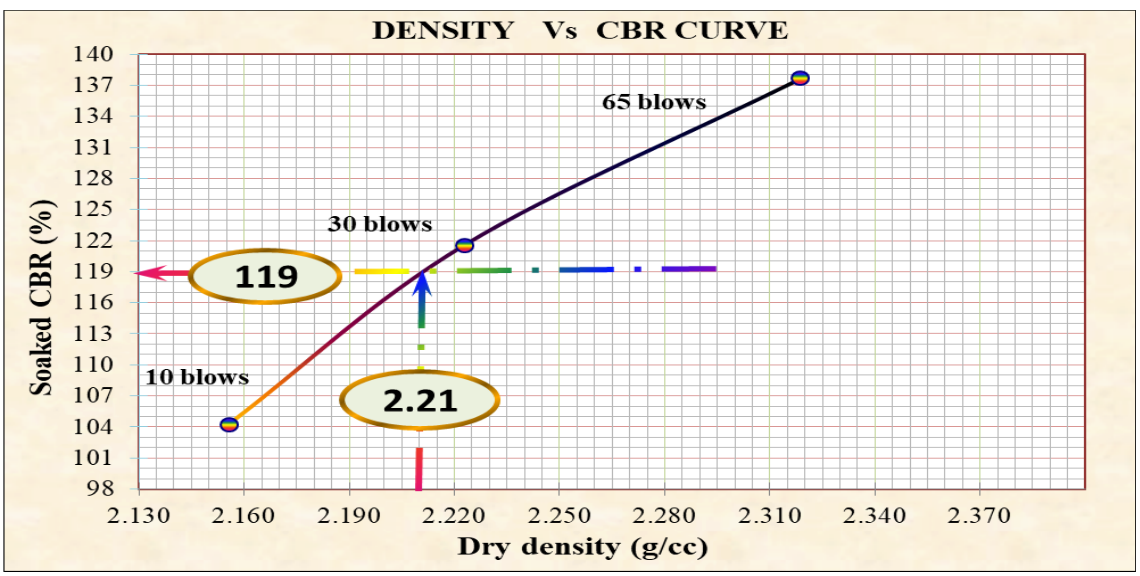
Soaking Condition		**10 Blows**			**30 Blows**			**65 Blows**		
		Before	After		Before	After		Before	After	
			Top 1 in.	Avg.		Top 1 in.	Avg.		Top 1 in.	Avg.
Container Number		A23	A24		B32	B34		C42	C43	
Wet Soil + Container (g)	a	421.5	484.6		456.7	507.1		432.4	443.6	
Dry Soil + Container (g)	b	384.3	422.1		431.8	455.4		428.5	419.1	
Weight of Container (g)	c	34.8	36.4		34.6	34.5		34.2	33.9	
Weight of Water (g)	d = a - b	37.2	62.5		24.9	51.7		3.9	24.5	
Weight of Dry Soil (g)	e = b - c	349.5	385.7		397.2	420.9		394.3	385.2	
Moisture Content (%)	m =(d/e)*100	10.64	16.20		6.27	12.28		0.99	6.36	
Avg. Moisture Content (%)										

Penetration Test Data, after 96 hrs Soaking Period					Surcharge Weight = 4.55 KG			Plunger cross-section area, mm^2 = 1935.5				
Standard Load, N/mm^2				at 2.54mm = 6.89				at 5.08mm = 10.34				
Penet.	**10 Blows**				**30 Blows**				**65 Blows**			
(mm)	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	Dial Rdg	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**	DIAL RDG	Load (N)	Resistance to Penetration (N/mm^2)	**CBR %**
0.00	0.00	0.00	0.00		0.00	0.000	0.00		0.00	0.000	0.00	
0.64	128.0	1.64	0.85		205.0	2.622	1.35		387.0	4.950	2.56	
1.27	341.0	4.36	2.25		453.0	5.794	2.99		685.0	8.761	4.53	
1.91	532.0	6.80	3.52		696.0	8.902	4.60		980.0	12.534	6.48	
2.54	734.0	9.39	4.85	70.40	963.0	12.317	6.36	92.36	1273.0	16.282	8.41	122.09
3.18	982.0	12.56	6.49		1268.0	16.218	8.38		1583.0	20.247	10.46	
3.81	1235.0	15.80	8.16		1481.0	18.942	9.79		1836.0	23.482	12.13	
4.45	1435.0	18.35	9.48		1698.0	21.717	11.22		2021.0	25.849	13.35	
5.08	1631.0	20.86	10.78	104.23	1902.0	24.327	12.57	121.55	2154.0	27.550	14.23	137.66
7.62	2106.0	26.94	13.92		2334.0	29.852	15.42		2602.0	33.280	17.19	
10.16												
12.70												

Swell				**Ring Factor**		MDD (gm/cc)	2.17
No. of Blows	**10**	**30**	**65**	0.01279	N/Divis.	102 % of MDD	2.21
RDG (Before Soaking)	2.300	2.120	1.870				
RDG (After Soaking)	2.870	2.870	2.310				
Percent Swell	0.49	0.64	0.38			**C.B.R.at 102% of MDD**	**119.00**
Average Percent Swell	0.50						



BLOWS	Load (KN)		CBR (%)		Dry Density Vs Socked C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	4.85	10.78	70.4	104.2	**No # of Blows**	**10**	**30**	**65**
30	6.36	12.57	92.4	121.6	**Dry Density**	2.16	2.22	2.32
65	8.41	14.23	122.1	137.7	**Soaked C.B.R.**	104.2	121.6	137.7



MDD (g/Cm^3) :	**2.17**	**102% of MDD (g/Cm^3)**	**2.21**	**CBR at 102% of MDD**	**119**

Appendix H: Letters from the concerned body

የኢትዮጵያ መንገዶች ባለሥልጣን

ETHIOPIAN ROADS AUTHORITY

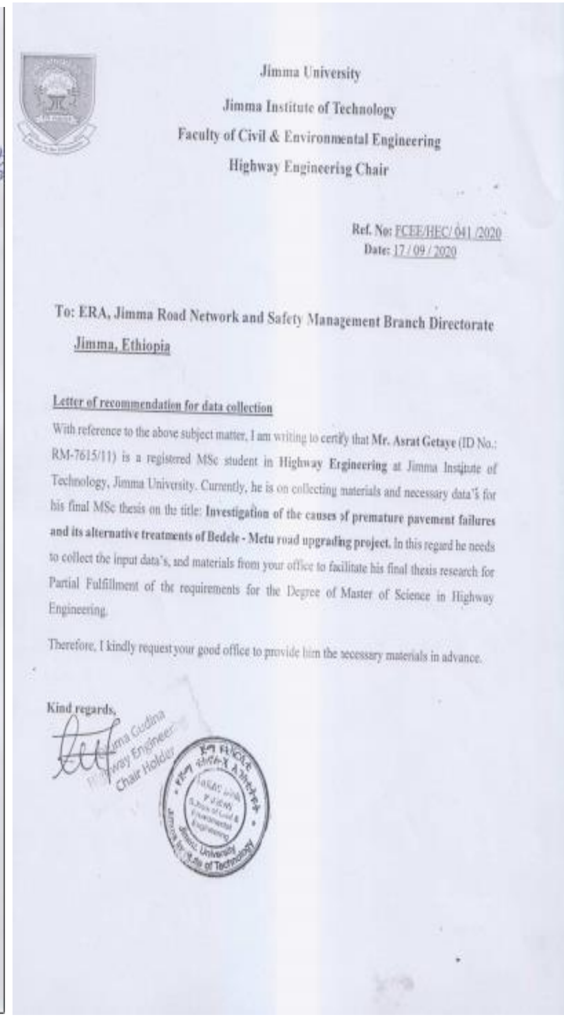
ቁጥር /Ref.No. [illegible]

ቀን /Date 20/02/2013

ጉዳዩ፡- ለሚመለከተው ሁሉ

የኢትዮጵያ መንገዶች ባለስልጣን ሰራተኞች የሆኑት አቶ አስራት ጌታዬ፣አቶ ታምራት መሉቀን እና የተላኩትን የቀን ሰራተኞች ጨምሮ በተሽከርካሪ ሰሌዳ ቁጥር 98882 እና ሾፌር አቶ ፋሚ ዘይት አማካኝነት ደምቢ - በደሌ እና በደሌ - መቱ መንገዶች ላይ ጥናት/ምርመር ለማድረግ የማቴሪያል ናሙና ስለሚወስዱ ተገቢውን ትብብር እንዲደረግላቸው ስንል በትህትና እንጠይቃለን፡፡

ከሠላምታ ጋር



Jimma University

Jimma Institute of Technology

Faculty of Civil & Environmental Engineering

Highway Engineering Chair

Ref. No: FCEE/HEC/ 041 /2020

Date: 17 / 09 / 2020

To: ERA, Jimma Road Network and Safety Management Branch Directorate

Jimma, Ethiopia

Letter of recommendation for data collection

With reference to the above subject matter, I am writing to certify that **Mr. Asrat Getaye** (ID No.: RM-7615/11) is a registered MSc student in Highway **Engineering** at Jimma Institute of Technology, Jimma University. Currently, he is on collecting materials and necessary data's for his final MSc thesis on the title: **Investigation of the causes of premature pavement failures and its alternative treatments of Bedele - Metu road upgrading project.** In this regard he needs to collect the input data's, and materials from your office to facilitate his final thesis research for Partial Fulfillment of the requirements for the Degree of Master of Science in Highway Engineering.

Therefore, I kindly request your good office to provide him the necessary materials in advance.

Kind regards,

Jimma University

Jimma Institute of Technology

Faculty of Civil & Environmental Engineering

Highway Engineering Chair

Ref. No: FCEE/HEC/ 107 /2020
Date: 10 / 09 / 2020

To: ERA, Own Force Road Maintenance

Jimma District Jimma, Ethiopia

Subject: Letter of conducting Laboratory Activities

With reference to the above matter, I am writing to certify that **Mr. Asrat Getaye** with **ID No.RM7615/11** is a registered student of Master of Science in **Highway Engineering** at Jimma institute of technology, Jimma University. He is collecting laboratory activities for the Final MSc. thesis on the title: **Investigation of The Causes of Premature Pavement Failures and Its Alternative Treatments of Bedele - Metu Road Upgrading Project.** In this regard he needs to conduct laboratory activities in your laboratory.

Therefore, this is to kindly request your good office to provide him the necessary support in advance.

Kind regards,

Ref. No ISCEE/HEC /47/2020

Date I sep. 7/ 2020

To: Highway Laboratory Test

Jimma University

From Highway Engineering Chair

JIT

Subject:- Requesting help for JIT Msc student

This collaboration latter is written up on the request of **stadents listed below** those were the students in our University Kito Furdissa Campus Faculty of civil and environmental engineering Highway engineering 6th batch and those wants to use your laboratory. So we are requesting you your collaboration to permit them to use your laboratory service in our campus.

S.N	Name of Students	I.D
1	Bilisumma Lami	RM7618/11
2	Tiruwork Mulatu	RM7642/11
3	Yisak Kibru	RM7645/11
4	Tokkumma Jabessa	RM7643/11
5	Asebe Alemu	RM7614/11
6	Muluken Geremew	RM7638/11
7	Dawit Sekata	RM7622/11
8	Desta Moshe	RM7625/11
9	Asrat Getaye	RM7615/11
10	Ayalew Adello	RM7616/11
11	Kadir Mohammed	RM7615/11
12	Yan Asegic	RM7644/11
13	Kinfe g/georges	Rm7634/11
14	Abuye Boja	RM7611/11
15	Bulcha Assefa	RM7619/11

With Regards

CC:

Faculty of Civil and Environmental Engineering

Appendix I: Summary of traffic analysis data

Average Equivalency Factors For Major Class of Vehicles		
S/No.	Vehicle Category	Vehicle Equivalence Factor
1	Small Bus	0.228
2	Large Bus	1.230
3	Small Truck	0.089
4	Medium Track	1.275
5	Heavy Truck	1.960
6	Truck and Trailer	6.300

Traffic Growth Rates (Med. Growth Scenario)				
S/No.	Vehicle Category	Traffic Growth in %		
		2009 - 2013	2014 - 2023	2024 - 2036
	Car	7	8	7
	4WD	7	8	7
1	Small Bus	7	8	7
2	Large Bus	7	8	7
3	Small Truck	8	9	8
4	Medium Track	8	9	8
5	Heavy Truck	8	9	8
6	Truck and Trailer	8	9	8

Design Lane MSA Calculations with Consultant Data with recommended weighted Average Truck Factor								
Vehicle Type	S/ Bus	L/ Bus	S/ Truck	M/ Truck	H/ Truck	T & T	Directional Distribution	0.50
Truck Factor	0.23	1.23	0.09	1.28	1.96	6.30	Lane Distribution Factor	0.60

Year	Total AADT with Count Location at Yayoo, Km 78						Total MSA	Loading in MSA On Proposed C/W		REMARKS
	S/ Bus	L/ Bus	S/ Truck	M/ Truck	H/ Truck	T & T		Design Lane Yearly MSA	Design lane Cumulative MSA	
2015	76	23	77	74	140	167	0.54	0.16	0.16	The upgraded road will open to traffic at the start of Year 2015
2016	82	25	84	81	152	182	0.59	0.18	0.34	
2017	89	27	92	88	166	198	0.64	0.19	0.53	
2018	96	29	100	96	181	216	0.69	0.21	0.74	
2019	103	32	109	105	197	235	0.76	0.23	0.96	
2020	112	34	119	114	215	256	0.82	0.25	1.21	
2021	121	37	130	124	234	279	0.90	0.27	1.48	
2022	130	40	141	136	255	304	0.98	0.29	1.77	
2023	140	43	153	147	278	331	1.06	0.32	2.09	
2024	150	46	166	159	300	357	1.15	0.34	2.44	
2025	161	49	179	172	324	386	1.24	0.37	2.81	
2026	172	53	193	186	350	417	1.34	0.40	3.21	
2027	184	56	209	200	378	450	1.45	0.43	3.65	
2028	197	60	225	216	408	486	1.56	0.47	4.11	
2029	211	65	243	234	441	525	1.69	0.51	4.62	
2030	225	69	263	253	476	567	1.82	0.55	5.17	
2031	241	74	284	273	514	613	1.97	0.59	5.76	
2032	258	79	307	295	555	662	2.12	0.64	6.39	
2033	201	70	247	223	485	582	1.85	0.55	6.95	
2034	285	97	338	308	652	786	2.50	0.75	7.70	

Appendix J: List of Recorded AC Layer Thickness

List of AC Layer Thickness					
Station	**Layer Type**	**Location Detail**		**Measured Layer Thickness, mm**	**Project Material Description**
		Lane Side	**Position**		
63+400	AC/Surfacing	RHS	Verge Side	47.85	AC
			Average	**47.87**	
			Wheel path	47.89	
63+995		LHS	Verge Side	40.7	AC
			Average	**40.57**	
			Wheel path	40.44	
64+015		Center	Verge Side	40.24	AC
			Average	**40.25**	
			Wheel path	40.26	
78+900		RHS	Verge Side	38.60	AC
			Average	**38.66**	
			Wheel path	38.72	
85+490		RHS	Verge Side	39.85	AC
			Average	**39.88**	
			Wheel path	39.91	

Appendix K: Summary of DCP Collected Data

Dynamic Cone Penetrometer (DCP) Test Field Sheet			
Site/Road	Bedelle - Metu Lot - II (61+000 - 111+659)		
Test No.	DCP02		
Section No./Chainage	64+015	**Date**	30/10/2020
Direction	Bedelle - Metu	**Ave. Zero Reading of DCP, mm**	45.25
Wheel Path	CL	**Test Started**	11:30 AM

No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm	No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm	No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm
0	0		45.25	1	29	2.50	95.75	1	55	2.00	156.25
1	1	1.00	46.25	1	30	1.50	97.25	1	56	2.00	158.25
1	2	1.50	47.75	1	31	3.00	100.25	1	57	1.00	159.25
2	4	2.00	49.75	1	32	3.50	103.75	1	58	0.50	159.75
1	5	2.00	51.75	2	34	2.50	106.25	1	59	2.00	161.75
1	6	2.00	53.75	1	35	2.00	108.25	1	60	2.00	163.75
1	7	2.50	56.25	1	36	2.00	110.25	1	61	1.50	165.25
1	8	1.00	57.25	1	37	2.00	112.25	1	62	1.50	166.75
1	9	2.00	59.25	1	38	3.00	115.25	1	63	2.00	168.75
2	11	2.00	61.25	1	39	3.00	118.25	1	64	2.50	171.25
1	12	1.50	62.75	1	40	2.50	120.75	1	65	2.00	173.25
1	13	2.50	65.25	1	41	3.00	123.75	1	66	2.00	175.25
1	14	2.00	67.25	1	42	3.00	126.75	1	67	3.00	178.25
1	15	2.00	69.25	1	43	3.00	129.75	1	68	2.00	180.25
1	16	2.00	71.25	1	44	2.00	131.75	1	69	2.00	182.25
1	17	1.50	72.75	1	45	2.00	133.75	1	70	3.50	185.75
2	19	2.00	74.75	1	46	2.00	135.75	1	71	3.00	188.75

1	20	2.00	76.75	1	47	1.00	136.75	1	72	3.00	191.75
1	21	2.00	78.75	1	48	3.00	139.75	1	73	2.50	194.25
1	22	1.50	80.25	1	49	3.00	142.75	1	74	2.00	196.25
1	23	3.00	83.25	1	50	2.00	144.75	1	75	3.00	199.25
1	24	3.00	86.25	1	51	3.00	147.75	1	76	3.00	202.25
2	26	3.00	89.25	1	52	2.00	149.75	1	77	3.50	205.75
1	27	2.00	91.25	1	53	2.50	152.25	1	78	3.00	208.75
1	28	2.00	93.25	1	54	2.00	154.25	1	79	3.00	211.75
1	80	3.00	214.75	1	105	3.00	302.25	1	131	7.00	419.75
1	81	3.00	217.75	1	106	4.00	306.25	1	132	6.00	425.75
1	82	3.00	220.75	1	107	4.50	310.75	1	133	6.00	431.75
1	83	2.00	222.75	1	108	5.50	316.25	1	134	7.00	438.75
1	84	3.00	225.75	1	109	5.00	321.25	1	135	7.00	445.75
1	85	2.00	227.75	1	110	5.00	326.25	1	136	6.00	451.75
1	86	2.00	229.75	1	111	6.00	332.25	1	137	6.00	457.75
1	87	2.00	231.75	1	112	6.00	338.25	1	138	5.00	462.75
1	88	3.00	234.75	1	113	4.50	342.75	1	139	5.00	467.75
1	89	3.00	237.75	1	114	4.00	346.75	1	140	5.00	472.75
1	90	3.00	240.75	1	115	4.50	351.25	1	141	4.00	476.75
1	91	2.00	242.75	1	116	4.50	355.75	1	142	5.00	481.75
1	92	2.00	244.75	1	117	5.00	360.75	1	143	4.00	485.75
1	93	4.00	248.75	1	118	6.00	366.75	1	144	5.00	490.75
1	94	3.00	251.75	1	119	5.00	371.75	1	145	4.00	494.75
1	95	4.00	255.75	1	120	4.00	375.75	1	146	4.00	498.75
1	96	3.50	259.25	1	121	4.00	379.75	1	147	4.75	503.50
1	97	4.50	263.75	2	123	4.00	383.75	1	148	6.00	509.50
1	98	5.00	268.75	1	124	2.00	385.75	1	149	6.00	515.50
1	99	4.50	273.25	1	125	3.00	388.75	1	150	6.50	522.00
1	100	5.00	278.25	1	126	4.00	392.75	1	151	5.00	527.00

1	101	5.00	283.25	1	127	4.00	396.75	1	152	5.00	532.00
1	102	6.00	289.25	1	128	5.00	401.75	1	153	7.00	539.00
1	103	5.00	294.25	1	129	5.00	406.75	1	154	6.00	545.00
1	104	5.00	299.25	1	130	6.00	412.75	1	155	6.00	551.00
1	156	6.50	557.50								
1	157	6.00	563.50								
1	158	7.00	570.50								
1	159	6.50	577.00								
1	160	5.00	582.00								
1	161	6.00	588.00								
1	162	6.50	594.50								
1	163	7.00	601.50								
1	164	7.50	609.00								
1	165	6.00	615.00								
1	166	8.00	623.00								
1	167	11.00	634.00								
1	168	10.00	644.00								
1	169	12.00	656.00								
1	170	13.00	669.00								
1	171	12.00	681.00								
1	172	14.00	695.00								
1	173	9.00	704.00								
1	174	9.00	713.00								
1	175	8.00	721.00								
1	176	9.50	730.50								
1	177	11.00	741.50								
1	178	10.00	751.50								
1	179	12.00	763.50								

Dynamic Cone Penetrometer (DCP) Test Field Sheet			
Site/Road	Bedelle - Metu Lot - II (61+000 - 111+659)		
Test No.	DCP03		
Section No./Chainage	78+900	**Date**	31/10/2020
Direction	Bedelle - Metu	**Ave. Zero Reading of DCP, mm**	38.66
Wheel Path	RHS	**Test Started**	9:30 AM

No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm	No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm	No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm
0	0		43.66	1	26	2.00	108.16	1	51	2.00	164.66
2	2	2.00	45.66	1	27	2.00	110.16	1	52	1.50	166.16
1	3	2.00	47.66	1	28	2.50	112.66	1	53	2.00	168.16
1	4	1.50	49.16	1	29	4.00	116.66	1	54	3.00	171.16
1	5	1.50	50.66	1	30	3.00	119.66	1	55	3.00	174.16
1	6	2.00	52.66	1	31	2.00	121.66	1	56	3.00	177.16
1	7	2.00	54.66	1	32	2.00	123.66	1	57	3.00	180.16
1	8	2.50	57.16	1	33	2.00	125.66	1	58	2.00	182.16
1	9	3.00	60.16	1	34	3.00	128.66	1	59	3.00	185.16
1	10	3.00	63.16	1	35	2.00	130.66	1	60	3.50	188.66
1	11	3.50	66.66	1	36	2.00	132.66	1	61	2.00	190.66
1	12	3.00	69.66	1	37	2.00	134.66	1	62	1.50	192.16
1	13	3.00	72.66	1	38	3.00	137.66	1	63	2.00	194.16
1	14	5.00	77.66	1	39	2.00	139.66	1	64	2.00	196.16
1	15	2.50	80.16	1	40	2.00	141.66	1	65	2.50	198.66
1	16	3.00	83.16	1	41	2.00	143.66	1	66	3.00	201.66
1	17	3.00	86.16	1	42	2.50	146.16	1	67	3.00	204.66
1	18	3.00	89.16	1	43	2.00	148.16	1	68	3.00	207.66

1	19	2.50	91.66	1	44	2.00	150.16	1	69	3.00	210.66
1	20	2.50	94.16	1	45	2.50	152.66	1	70	2.50	213.16
1	21	3.00	97.16	1	46	2.00	154.66	1	71	3.00	216.16
1	22	3.00	100.16	1	47	2.00	156.66	1	72	3.00	219.16
1	23	2.00	102.16	1	48	2.00	158.66	1	73	2.50	221.66
1	24	2.00	104.16	1	49	2.00	160.66	1	74	3.00	224.66
1	25	2.00	106.16	1	50	2.00	162.66	1	75	3.00	227.66

1	76	3.00	230.66	1	101	4.00	333.16	1	127	6.00	457.16
1	77	3.00	233.66	1	102	4.00	337.16	1	128	4.00	461.16
1	78	3.00	236.66	1	103	4.50	341.66	1	129	4.00	465.16
1	79	2.50	239.16	1	104	4.00	345.66	1	130	4.00	469.16
1	80	3.00	242.16	1	105	4.00	349.66	1	131	5.00	474.16
1	81	3.50	245.66	1	106	5.00	354.66	1	132	4.00	478.16
1	82	4.00	249.66	1	107	4.00	358.66	1	133	5.00	483.16
1	83	4.00	253.66	1	108	3.00	361.66	1	134	5.00	488.16
1	84	5.00	258.66	1	109	4.50	366.16	1	135	4.00	492.16
1	85	5.00	263.66	1	110	4.00	370.16	1	136	5.00	497.16
1	86	5.00	268.66	1	111	5.00	375.16	1	137	6.00	503.16
1	87	4.00	272.66	2	113	2.50	377.66	1	138	6.00	509.16
1	88	4.00	276.66	1	114	3.00	380.66	1	139	4.00	513.16
1	89	3.50	280.16	1	115	3.50	384.16	1	140	4.00	517.16
1	90	3.50	283.66	1	116	4.00	388.16	1	141	3.00	520.16
1	91	4.00	287.66	1	117	4.00	392.16	1	142	4.00	524.16
1	92	3.50	291.16	1	118	6.00	398.16	1	143	5.00	529.16
1	93	4.00	295.16	1	119	6.00	404.16	1	144	5.00	534.16
1	94	4.00	299.16	1	120	6.00	410.16	1	145	5.50	539.66
1	95	3.50	302.66	1	121	7.00	417.16	1	146	5.00	544.66
1	96	3.50	306.16	1	122	7.00	424.16	1	147	4.00	548.66
1	97	6.00	312.16	1	123	8.00	432.16	1	148	4.50	553.16

1	98	5.00	317.16	1	124	7.00	439.16	1	149	4.00	557.16
1	99	6.00	323.16	1	125	6.00	445.16	1	150	2.00	559.16
1	100	6.00	329.16	1	126	6.00	451.16	1	151	3.00	562.16
1	152	3.00	565.16								
1	153	3.00	568.16								
1	154	4.00	572.16								
1	155	6.00	578.16								
1	156	6.00	584.16								
1	157	7.00	591.16								
1	158	8.00	599.16								
1	159	9.00	608.16								
1	160	12.00	620.16								
1	161	10.00	630.16								
1	162	11.00	641.16								
1	163	8.00	649.16								
1	164	7.00	656.16								
1	165	6.50	662.66								
1	166	5.50	668.16								
1	167	7.00	675.16								
1	168	7.00	682.16								
1	169	9.00	691.16								
1	170	9.00	700.16								
1	171	13.00	713.16								
1	172	10.00	723.16								
1	173	9.00	732.16								
1	174	11.00	743.16								
1	175	7.00	750.16								
1	176	10.00	760.16								

Dynamic Cone Penetrometer (DCP) Test Field Sheet			
Site/Road	Bedelle - Metu Lot - II (61+000 - 111+659)		
Test No.	DCP04		
Section No./Chainage	85+490	**Date**	31/10/2020
Direction	Bedelle - Metu	**Ave. Zero Reading of DCP, mm**	39.88
Wheel Path	RHS	**Test Started**	11:30 AM

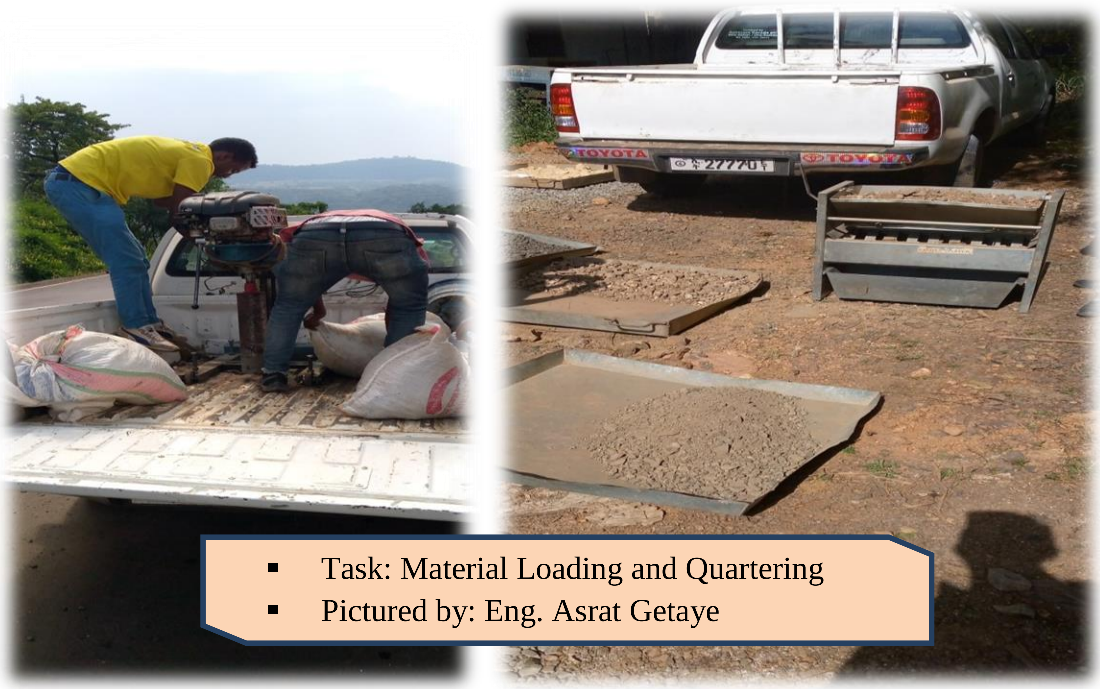
No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm	No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm	No. of Blows	Sum of Blows	Penetr. Depth, mm	Cum. Penetr., mm
0	0		46.58	1	30	3.50	101.08	1	55	1.00	161.58
1	1	1.00	47.58	1	31	2.00	103.08	1	56	1.00	162.58
1	2	2.00	49.58	1	32	3.50	106.58	1	57	1.00	163.58
1	3	1.00	50.58	1	33	3.00	109.58	1	58	0.50	164.08
1	4	2.50	53.08	1	34	3.00	112.58	1	59	2.00	166.08
2	6	2.00	55.08	1	35	3.00	115.58	1	60	2.00	168.08
1	7	2.00	57.08	1	36	2.00	117.58	1	61	1.50	169.58
1	8	2.00	59.08	1	37	3.00	120.58	1	62	1.50	171.08
1	9	2.50	61.58	1	38	3.00	123.58	1	63	2.00	173.08
1	10	2.00	63.58	1	39	3.00	126.58	1	64	2.50	175.58
1	11	2.00	65.58	1	40	2.00	128.58	1	65	2.00	177.58
1	12	2.00	67.58	1	41	3.50	132.08	1	66	2.00	179.58
1	13	2.00	69.58	1	42	3.00	135.08	1	67	3.00	182.58
1	14	2.00	71.58	1	43	1.00	136.08	1	68	2.50	185.08
2	16	2.00	73.58	1	44	2.00	138.08	1	69	3.00	188.08
2	18	2.00	75.58	1	45	2.00	140.08	1	70	2.00	190.08
2	20	2.00	77.58	1	46	2.00	142.08	1	71	2.00	192.08
2	22	1.50	79.08	1	47	1.00	143.08	1	72	2.00	194.08

1	23	3.00	82.08	1	48	3.00	146.08	1	73	1.00	195.08
1	24	1.50	83.58	1	49	3.00	149.08	1	74	2.00	197.08
1	25	2.00	85.58	1	50	2.00	151.08	1	75	2.00	199.08
1	26	3.00	88.58	1	51	3.00	154.08	1	76	2.00	201.08
1	27	3.00	91.58	1	52	2.00	156.08	1	77	2.50	203.58
1	28	4.00	95.58	1	53	2.50	158.58	1	78	2.00	205.58
1	29	2.00	97.58	1	54	2.00	160.58	1	79	3.00	208.58
1	80	3.00	211.58	1	105	5.00	280.58	1	130	4.00	412.08
1	81	1.50	213.08	1	106	5.00	285.58	1	131	5.00	417.08
1	82	1.00	214.08	1	107	6.00	291.58	1	132	5.00	422.08
1	83	2.00	216.08	1	108	6.00	297.58	1	133	5.00	427.08
1	84	2.00	218.08	1	109	7.00	304.58	1	134	4.50	431.58
1	85	1.50	219.58	1	110	7.00	311.58	1	135	5.00	436.58
1	86	3.00	222.58	1	111	5.00	316.58	1	136	4.50	441.08
1	87	2.00	224.58	1	112	8.00	324.58	1	137	5.00	446.08
1	88	3.00	227.58	1	113	8.00	332.58	1	138	7.00	453.08
1	89	3.00	230.58	1	114	8.50	341.08	1	139	7.00	460.08
1	90	1.50	232.08	1	115	7.00	348.08	1	140	6.00	466.08
1	91	2.00	234.08	1	116	6.00	354.08	1	141	6.00	472.08
1	92	2.00	236.08	1	117	6.00	360.08	1	142	6.00	478.08
1	93	2.00	238.08	1	118	3.00	363.08	1	143	5.00	483.08
1	94	2.50	240.58	1	119	3.50	366.58	1	144	7.00	490.08
1	95	2.00	242.58	1	120	4.00	370.58	1	145	5.50	495.58
1	96	2.00	244.58	1	121	4.00	374.58	1	146	6.00	501.58
1	97	1.50	246.08	1	122	5.50	380.08	1	147	5.50	507.08
1	98	4.00	250.08	1	123	4.00	384.08	1	148	5.00	512.08
1	99	3.00	253.08	1	124	4.00	388.08	1	149	6.00	518.08
1	100	4.00	257.08	1	125	3.00	391.08	1	150	6.00	524.08
1	101	3.50	260.58	1	126	4.00	395.08	1	151	4.00	528.08

1	102	3.00	263.58	1	127	5.00	400.08	1	152	4.50	532.58
1	103	6.00	269.58	1	128	5.00	405.08	1	153	6.00	538.58
1	104	6.00	275.58	1	129	3.00	408.08	1	154	6.00	544.58
1	155	7.00	551.58								
1	156	7.00	558.58								
1	157	6.00	564.58								
1	158	6.50	571.08								
1	159	7.00	578.08								
1	160	6.50	584.58								
1	161	6.00	590.58								
1	162	6.00	596.58								
1	163	7.00	603.58								
1	164	7.00	610.58								
1	165	7.00	617.58								
1	166	8.00	625.58								
1	167	8.00	633.58								
1	168	10.00	643.58								
1	169	11.00	654.58								
1	170	12.00	666.58								
1	171	14.00	680.58								
1	172	13.00	693.58								
1	173	12.00	705.58								
1	174	11.00	716.58								
1	175	10.00	726.58								
1	176	9.00	735.58								
1	177	10.00	745.58								
1	178	9.00	754.58								
1	179	8.50	763.08								

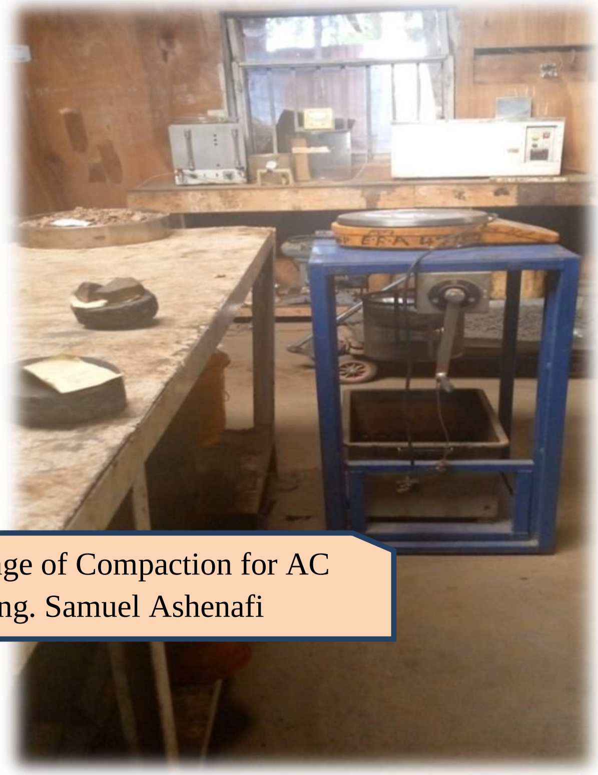
Appendix L: Summary of Pictures showing Laboratory Tests

- Task: Asphalt Cutting
- Pictured by: Eng. Asrat Getaye



- Task: Material Loading and Quartering
- Pictured by: Eng. Asrat Getaye

- Task: Material on Direct Sun-light
- Pictured by: Eng. Asrat Getaye



- Task: Percentage of Compaction for AC
- Pictured by: Eng. Samuel Ashenafi

- Task: Atterberg Limit Test
- Pictured by: Eng. Asrat Getaye

- Task: Moisture Density Relationship of Soil
- Pictured by: Eng. Asrat Getaye

- Task: CBR Test
- Pictured by: Eng. Samuel Ashenafi

- Task: CBR Test
- Pictured by: Eng. Samuel Ashenafi