



JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
GEOTECHNICAL ENGINEERING STREAM

**INVESTIGATION ON THE CAUSES OF FAILURE IN UNPAVED ROADS AND
RECOMMENDED REMEDIAL MEASURES (THE CASE OF JIMMA –METESO
ROAD SECTION)**

A FINAL THESIS SUBMITTED TO JIMMA UNIVERSITY, SCHOOL OF GRADUATE
STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF
MASTERS OF SCIENCE IN CIVIL ENGINEERING (GEOTECHNICAL ENGINEERING)

BY: RUHAMA BEYENE

DECEMBER, 2019
JIMMA, ETHIOPIA

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DECEMBER, 2019

JIMMA, ETHIOPIA

DECLARATION

I, the undersigned, declare that this thesis entitled: **“Investigation on the Causes of Failure in Unpaved Roads and Its Remedies: A Case Study of Jimma – Meteso Road Section”** is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

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Signature_____
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As Master’s Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by Ruhama Beyene entitled: **“Investigation on the Causes of Failure in Unpaved Roads and Its Remedies: A Case Study of Jimma – Meteso Road Section.”**



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ABSTRACT

The pavement is the uppermost layer of the road that carries the vehicle load. A road pavement can be flexible pavement, rigid pavement, or unpaved road materials such as gravel wearing course, stabilized gravel, or earth road. Gravel roads are composed of the gravel wearing course, a subgrade layer, and an optional sub-base layer. The most common failures on gravel roads are raveling, rutting, potholes, erosion, and gravel loss, and these failures are associated with a number of factors. This research tried to identify the causes of failures on unpaved gravel roads by considering the Jimma Meteso road project as a case study. From the road, sections that are severely damaged were identified the most common types of failures observed are potholes, rutting, raveling, corrugation and gravel loss and erosion. Based on a visual inspection, to determine the field density of the subgrade sand replacement method was used and soil samples were collected and tested in the laboratory. The tests included sieve analysis, Atterberg's limit, gradation, Californian Bearing Ratio (CBR), and compaction was conducted on the wearing course material as well as the subgrade. The traffic loading on the site has also been analyzed from the traffic count data. From the comparison of the laboratory test results with the Ethiopian Roads Authority (ERA) gravel and low volume road manual, indicated that there is a variation for most of the tests. The gravel wearing course has more amounts of fines than required and has higher plasticity index. Whereas, the subgrade has a high plasticity index and is not strong enough to sustain the axle loads. From secondary data obtained from ERA traffic analysis, it has been observed the actual traffic on the road is greater than the design traffic AADT; thus, the failure of the road has been attributed to poor construction material and heavy traffic. Finally, for each type of failure observed, remedial actions such as spot regravelling, installing proper drainage, blading the gravel and blending with better material were recommended.

Keywords: *unpaved roads, causes of failure, remedial measures*

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ACRONYMS

AASHTO - American Association of State Highway and Transportation Officials

AADT- Average Annual Daily Traffic

ASTM -American Society of Testing and Materials

BS- British Standard

CBR-Californian Bearing Ratio

Cc- Coefficient of Curvature

Cu- Coefficient of Uniformity

ERA- Ethiopian roads authority

KM- kilometer

LI - Liquidity Index

LL-Liquid Limit

LVR-Low Volume Roads

MDD-Maximum Dry Density

MM- Millimeter

NMC- Natural Moisture Content

OMC- Optimum Moisture Content

PI- Plasticity Index

PL- Plasticity Limit

URRAP- Universal Rural Roads Access Program

USCS- Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Road network play a vital role in the development of one nation because it is the connection between two places. Especially for developing countries like our country Ethiopia in which most of the population lives in the rural areas and the economy is highly dependent on agriculture the need for safe transport sector is undeniable. Ethiopian unpaved road comprises a significance amount of the road network, and it likely increases in the future due to the URRAP gravel road projects. [1] But most of the roads are largely deteriorated and in poor condition.

All roads have some form of surfacing whether it is a concrete, asphalt, crushed aggregate, stabilized aggregate or just earth. Depending on the surface types, roads can be classified as paved roads or unpaved roads. For the case of unpaved roads, the wearing course is the base layer of the road which is most of the time constructed from gravel materials. Gravel roads are the major component of the road networks in developing countries. And in many localities they far outnumber their paved counter parts. Gravel roads are highly affected by their environment these includes both natural and manmade environments including topography, drainage, and climatic environment such as precipitation, temperature and wind, geology of the area such as surfacing materials and subgrade, and traffic. [2]

In Ethiopia road transport is the dominant mode of transportation and accounts for 90 to 95 percent of motorized inter-urban freight and passenger movements. The road network of the country coverages is 110441 km in 2015 of which only 14% of it is paved. Road density per 1000 sq.km increased from 44km in 1997 to 100.4km. In addition, areas further than 5km from an all-weather road decreased from 64% in 1997 to 37% in 2015. Also, average distance to the nearest all-weather road decreased from 21km in 1997 to 5 km in 2015. The road condition also shows a considerable improvement the percentage of roads in good condition is 70% in 2015[2] and the road network coverage of the country is expected to increase in the coming years.

The Ethiopian road authority is the agency that regulates the road sectors in Ethiopia since its commencement in 1957 in collaboration with public and private construction and consulting companies. Regional road authorities and donor partners like African development fund, European Union and World Bank.

Jimma is one of the areas in Ethiopia that is known for its extensive cultivation of the cash crop coffee which is exported and known as the green gold and many more natural resources that contribute to the national economy. It is also a link for areas of the south western regions of the country with the central part of the nation. The road network that this study focuses on as a case study is one of the networks that connect Jimma to Chida, site known for being the location of gibe IV hydroelectric project currently under construction. The road segment Jimma –Meteso covers a total of 42 km and was constructed in 1973 EC under ERA by the contractor BERTA construction and the consultant DIWI consulting company. The road is classified under link road and it is DS 5 based on ERA standards. The wearing course material is selected gravel so it will be classified under high volume unpaved gravel road.

1.2 Statement of the Problem

Gravel roads are used as rural roads in most countries and over time there are a lot of issues due to movement of traffic and climatic conditions. The issues include dust generation, gravel loss, safety hazards, health hazards and discomfort and leads to increased cost of maintenance and regravelling [3]. The main defects associated with unpaved roads are potholes, ruts, cracks, erosion and cracking and this are attributed to three reasons [4]

In Ethiopia lots of unpaved road networks are under construction and pavement failure is becoming a common problem and great challenge. In some cases failure is observed even before the completion of the project [5]. And the lower quality of service on gravel roads is being the main source of complaint the main defects observed includes slope rate, road gradient, ruts, potholes and drainage conditions [6]. Even though lots of the countries networks are unpaved roads and there is a considerable amount budget issued each year to the maintenance, there is a little emphasis given to this sector with regards to studying their failures.

As being one of the zones in Oromia region Jimma has also a considerable coverage of gravel roads; Most of the road networks have significant defects. This study tried to identify the

causes of failures of unpaved roads constructed by gravel wearing course taking the Jimma – Meteso road project as a case study.

1.3 Objectives of the Study

1.3.1. General Objective

The general objective of this research is to investigate the major causes of failure of the unpaved road networks in Jimma zone along Jimma- Meteso road section

1.3.2 Specific Objective

- To identify the causes, level of severity of failures of the unpaved road.
- To determine the geotechnical properties of the pavement layers and to compare the test results with the ERA Standard Specifications.
- To suggest appropriate remedial measures according to the type of each failure.

1.4 Research Questions

1. What are the causes and level of severity of failures of the unpaved road?
2. What are the existing geotechnical properties of the pavement layers and how much deviation of its value from the ERA Standard Specifications?
3. Which appropriate remedial measures that can be recommended according to each type of failure?

1.5 Scope of the study

The study has evaluated the failures of gravel roads in Jimma area by taking the Jimma-Meteso link road as a case study. For the intended purpose, soil samples were collected from the worst road failures and laboratory tests were conducted. The relevant laboratory tests are particle size distribution (gradation), Atterberg limit tests, compaction tests, CBR test. Then the results of the tests are compared to the specifications secondary data on the traffic count (AADT) obtained from ERA was also checked and a conclusion is reached on what is the cause of the road failure. And possible recommendations are established on what shall be the best suitable remedial measures.

1.6 Significance of the Study

This study mentions the main causes of failure in unpaved roads and the relation it has with the geotechnical properties of the soil used as a construction material. It also investigates the impact of unsuitable subgrade on the performance of a pavement/wearing course. It will be used by governmental agencies like road authorities and consultants for new roads design.

These study will also enable to solve issues with failed roads as it will recommend a proper remedial measures used on unpaved gravel roads. The research will also be used by researchers; the findings will be used in literature review of future researches.

1.7 Organization of the Thesis

- Chapter one deals with the Introduction; Road Network and condition in Ethiopia; Statement of the Problem; Objectives of the research; Research questions; Scope; and Organization of the thesis work.
- Chapter Two deals with discussions of pavement functions; pavement types of unpaved roads materials of the different layer types and factors that are influencing the performance of gravel wearing course, gravel road deterioration causes and its types, and finally road maintenance and rehabilitation alternatives are discussed here
- Chapter Three deals with discussions regarding research methodologies such as; study area, study population, dependent and independent variables, study design, sampling methods and their procedures, data collection process, data analysis and ethical considerations.
- Chapter Four deals with assessments of test results which were gathered from laboratory tests, whether it complies with the requirements set in the design specification. In addition, comparison was made between the quality requirements set for, wearing course materials and subgrade in the specification of the project to that of the requirements set for the same in the ERA's specifications.
- Chapter Five finally deals with the development of the conclusions and with devising and forwarding recommendations of the study for possible considerations by pertinent policy makers.

CHAPTER 2

LITERATURE REVIEW

2.1 Unpaved Roads

The functional classifications of road in Ethiopia fall under 5 classes and low volume roads can fall into one of them [7]

- Trunk roads: roads linking Addis Ababa to centers of international importance and international boundaries
- Link roads: connecting centers of national and international importance such as principal towns and urban centers;
- Main access: connecting centers of provincial importance
- Collectors: connecting locally important centers to each other or to a more important center or to a higher class road; and
- Feeder roads: connecting minor centers such as a market to other parts of the network.

Roads in Ethiopia can be divided into three classes based on their regulating bodies of government [8]

- Federal roads:- under the responsibility of ERA
- Regional roads:- under the responsibility of regional or rural roads authority
- Other rural roads: under the responsibility of local administration like woreda

A pavement is the part of the roadway which is above the formation level and consists of wearing course, subbase course and base course [9]. Pavement is also defined as the uppermost layer of the road which carries the wheel load and transfers it to the wider area or the subgrade [10]. Depending on the type of pavements roads can be classified as paved or unpaved. Paved roads are defined as a road with bituminous bound wearing course as a wearing course [11] with sufficient depth to support the load from high traffic volume, speed or load that they are designed to carry [9]. Paved roads are also characterized by higher construction costs and lower maintenance and user costs. Unpaved roads are roads built without an asphalt or concrete wearing course. Unpaved roads are also a more comprehensive category because it includes a lot of types of roads that are not paved. In comparison to that of paved road unpaved roads are designed and constructed to accommodate lighter traffic

that's why it is also called low volume roads (LVR). Based on the ERA LVR design standards LVR are defined as roads of having a daily traffic of up to 300 vehicles [6]. Three of the most common types of unpaved roads are gravel roads, earth roads and earth track roads [11]. Parallel ruts crossed by vegetation that are not passible during the wet weather are classified as earth track roads where as roads that are lightly compacted without imparted gravel but cleared of vegetation are called earth road. Roads that are constructed by specifications of required material and road width with designed layer of imported material are classified under gravel roads. Earth roads and gravel roads are widely constructed in Ethiopia and they are characterized by lower construction cost and higher maintenance cost [12].

Gravel roads are roads that are regulated under the Ethiopian Road Authority, a federal structure. These are a type of unpaved roads with materials brought to the site from the quarry. Gravel roads are easy to construct and cheap but if constructed well it can serve both the dry and rainy seasons. The horizontal and vertical alignment of the road is also upgraded than that of earth roads [6]. The gravel used for the construction of gravel roads includes a wide variety of crushed stones, sands and fine sands. Gravel roads are maintained on a regular basis and higher level of surface is obtained [13] in addition to being rather safe than sealed roads by generating slow traffic unpaved gravel roads contribute to a less global warming in being easier to maintain, requiring less equipment and laboring experience [14]. The climates of sub-Sahara Africa are less "prone" to the performance of gravel roads than in those regions of the world where damp, cold and frosty condition prevails. In most of sub Saharan African countries there is an abundance in many areas of good unsealed road surfacing materials, derived from the weathering of surface rocks [13].

Earth roads are roads constructed and regulated by local administrative such as regional and woreda level road authorities. In earth roads, there is no additional gravel transported to the site but the in-situ materials are lightly compacted [13]. This roads are often shaped but with materials removed from the side of the roads to form side drains [6], and unlike the gravel roads these roads require periodic maintenance

2.2 Materials

The pavement type that is predominant in low volume roads is untreated gravel on a granular subbase layer with a subgrade of various soils [15]. As derived from British and American standards the main criteria for the selection of the naturally occurring gravel are common

tests such as particle size distribution and fines plasticity. The central use of the LVR design according to ERA design manual is the maximization of the use of naturally occurring materials. Surface materials, where these are present, need to resist wear and abrasion in dry weather and promote surface drainage and run-off in wet weather [16]. The most essential consideration in the design of gravel roads is providing all weather access. Under traffic the materials need to resist whip off, dust generation and be stable enough when compacted to resist deformation. The compacted material needs to resist erosion and scour. The nature of the underlying layer is also very critical in determining the performance of low volume roads. The performance of the gravel surface mainly depends on material quality, the location of the road, and the volume of traffic using the road. Gravel roads passing through populated areas in particular require materials that do not generate excessive dust in dry weather. Steep gradients place particular demands on gravel wearing course materials, which must not become slippery in wet weather or erode easily so consideration should be given to type of gravel wearing course [11]

A gravel road is mostly constructed of three layers the subgrade, the subbase placed on top of the sub grade and the surface (wearing course) [10] but in practice many gravel roads have only a subgrade and surface layer.

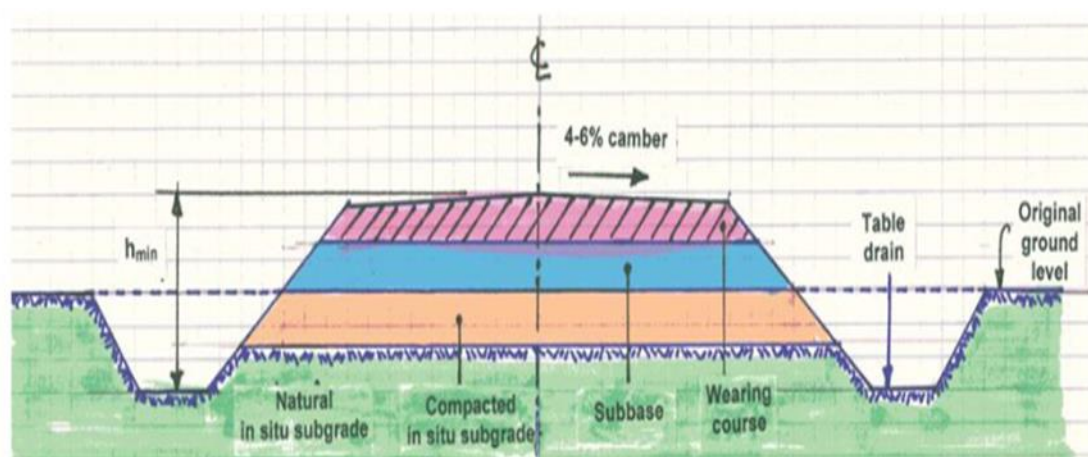


Figure 2-1 typical section of gravel roads

2.2.1 Subgrade

Subgrade is the upper layer of the natural or imported soil. It is also referred to as the foundation of the pavement which supports the pavement. Thus it must be able to support the load coming from the pavement without an excessive settlement. Subgrade type critically affects unsealed roads' performance. Although it would be helpful to have detailed laboratory

tests on every subgrade, a simple rating on a scale from very good to very poor or soil classification systems might provide useful information. When one road is performing better or worse than another, the subgrade type may be causing the discrepancy. It would be helpful to recognize that by having an evaluation of the subgrade [13] [12]. The performance of the subgrade depends on its load-bearing capacity, moisture and volume changes and subgrade is classified based on the Californian soaked bearing ratio(CBR) the minimum CBR value to be used for subgrade material is 3% based on the ERA low volume roads design manual and based on their CBR values there are six road classes. If the CBR of the subgrade is greater than 30% no subbase is required. Adequate subgrade compaction reduces the possibility of subgrade deformation and reduces the permeability and strengthens the subgrade. Also subgrade must be slightly plastic to provide stable platform for construction of the wearing course [10] suggests a minimum PI of about 4. The subgrade class based on the CBR value is given in table 2.1 below.

Table 2-1 Subgrade class (source [6])

Class	Range (CBR %)
S1	2
S2	3-4
S3	5-7
S4	8-14
S5	15-29
S6	30+

2.2.2 Sub Base

Sub base is a strong and stable [11] pavement layer placed on top of the subgrade that reduces the stress to an acceptable limit in the subgrade. The requirements of sub base for gravel roads shall be that it satisfies both the bearing capacity and moisture retention so the materials must be of minimum fines to retain water and in turn increase the strength of the layer. The minimum requirements for sub-base strength are 30% based on the ERA LVR design manual. Under good drainage conditions, the field moisture content under a sealed pavement will be equal to or less than the optimum moisture content in the AASHTO T180 compaction test. In such conditions the soil must be tested in the laboratory in the unsaturated

condition [10]. To achieve the required bearing capacity and to provide support for the upmost layer limits on the soils plasticity and particle size distribution may be required.

Table 2-2 typical particle size distribution of sub base [6]

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

The plasticity characteristics of granular sub-base material for low volume roads is shown in Table 2.3 below

Table 2-3 Plasticity characteristics of sub-base soil [6]

Climate	Liquid limit	Plasticity index	Linear shrinkage
Moist tropical and wet tropical	<35	<6	<3
Seasonally wet tropical	<45	<12	<6
Arid and semi-arid	<55	<20	<10

2.2.3 Gravel Wearing Course

The wearing course is the upper layer of the road pavement on which the traffic runs and is expected to wear under the action of traffic. The materials used for the wearing course of unpaved roads includes fine-grained materials such as well graded silty and clayey sands (sand-clay), coarse and medium grained materials such as natural gravels and materials produced by ripping and rolling rock [17]. The material used for wearing course needs to fulfill a number of functions and need to comply with a number of engineering properties. The most important property is it must have sufficient cohesion, have a particle size distribution that facilitates interlocking of particles and must have enough strength to support the applied traffic loads [18]. Shrinkage product and grading coefficient which are determined from the particle size distribution curve and linear shrinkage or alternatively the plasticity index are two of the most important parameter to determine the most suitable material for wearing course. Dr Paige green [19] also stated that the performance of gravel road is highly affected by the performance of the gravel wearing course which is affected by the plasticity and gradation of the gravel. [13] States that the wearing course material should satisfy full bearing capacity when saturated and the particle size distribution should provide the greatest possible cohesion.

According to literature the wearing course for unpaved roads should have the following attributes [20]

- Ability to provide a smooth and safe ride without excessive maintenance
 - Stability under wet and dry season
 - Ability to shed water without erosion
 - Freedom from excessive dust during the dry season and slipperiness during the wet season
 - Low cost of maintenance

The typical defects which may affect unpaved roads, such as dustiness, potholes, stoniness, corrugations, ruts, cracks, raveling, erosion, slipperiness, impassability and loss of surfacing or wearing course. The soil properties that require alteration to prevent the effects mentioned above include [19]:

- Strength to increase stability and bearing capacity
- Volume stability to control swelling shrinkage caused by changes in moisture content

- Durability to increase resistance to erosion either from weather or traffic
- Reduction in permeability, that is, reduce the ability of water to enter and pass through the soil

Of these soil properties the most important wearing course material parameter is strength (bearing capacity). This leads to four aspects that must be satisfied with regard to the selection of materials – and potential improvement by adding a soil stabilizer – for low-volume roads they are [21]

- Adequate bearing capacity under any individual applied load
- Adequate bearing capacity to resist progressive failure under repeated individual loads
- The ability to retain that bearing capacity with time (durability)
- The ability to retain bearing capacity under various environmental influences (which relates to material moisture content and in turn to climate, drainage and moisture regime)(performance of unpaved road materials using soil stabilizers

2.3 Properties Which Affect Gravel Performance

The ideal gravel should consist largely of pebbles which are hard and tough and will offer great resistance to abrasion. They should be well graded from the coarse to fine particles. There should be intermingled with the particles some material which will bond them into a compact mass. A careful examination of the gravel, with regard to these characteristics, will give this information. The following properties of the gravel affect its performance

1. Plasticity: - developed by the Swedish scientist Atterberg. The Atterberg limits are a set of water contents that show the consistency of a soil. Soil is classified under four states based on its water content and the limits show in which state the soil is. The LL is the water content at which the soil transfers to no strength to small strength. And the PL is the liquid limit at which the soil transfers from the plastic state to the semi-solid state at these state the soil starts to crumble when rolled into the thread. The PI is the difference between the LL and PL it also indicates the amount of clay minerals in the soil. Specification limits on liquid limit (LL), plasticity index (PI) and linear shrinkage (LS) follow conventional practice, except that they can generally be relaxed in well drained arid areas where loss of strength due to moisture is less likely. Base course gravels with PI of 12-16, and in extreme cases 18, have been used with success in semi-arid and arid regions [18].

2. Bearing capacity: - the bearing capacity of subgrades, sub-bases and bases is determined by the Californian bearing ration test (CBR). Developed by the California

division of highways the laboratory CBR test is generally carried out on a remolded samples that must be compacted to the expected field dry density at appropriate moisture content. The strength requirements may vary based on climate and traffic but the soaked CBR tests is used to specify the minimum strength of the material [6].

3. Compaction: -compaction is a critical component in construction activities and also in the construction of roads. And the durability of road depends on the achievement of proper compaction.

4. Gradation: - the grading analysis is performed by mechanical sieving to determine the percentage of particles finer than a certain sieve. The results are presented in curves called particle size distribution curve. Then depending on the percentage of fines the soil can be classified based on AASHTO or USCS schemes. Gravel is a mixture of three types of materials stone, sand and fines and the proper blending of these three will make the gravel perform well [22]. Good surface material for a gravel road would need more material passing a #200 sieve than a good base material. There is also a difference in the need. The compositions of the gravel wearing course must satisfy the following criteria based on [13] the maximum size of an aggregate in a wearing course must not exceed 20 mm the particle size distribution must be so that it has the minimum amount of voids. A maximum size of 40mm to 45mm is adequate to provide all weather pass ability. [16] Based on researches conducted in South Africa and adopted for international use the particle size distribution of the gravel wearing course can be used to understand how the material will behave the type of distress to be observed on the road and the type of road maintenance.

5. Los Angeles abrasion value: -Abrasion value is the percentage of aggregate weights that passing sieve (No. 12 = 1.7mm) after application of standard abrasion by mechanical rotation parallel with standard iron balls for a dry aggregate. It is used to calculate the hardness of aggregates and to choose the best type of aggregate due to abrasion value.

2.4 Defects in Gravel Roads

There are numerous causes of pavement failures some of which are inadequate design, excessive loading, weathering and climatic conditions and poor quality construction materials and supervision [14] . The design of gravel roads is with very low design input, and these can be one of the main reasons for the deterioration of the roads. The causes of failure can be grouped into three aspects due to the design, the construction material used and the way that the roads have been maintained. Although the performance of wearing course is the

important parameter in road the failure of the road is highly dependent on the underlying subgrade material on which the pavement is built [21]. The following are some of the problems that are common to the subgrade [5].

1. Excessive volume changes as a result of moisture changes in the case of expansive and collapsible soils
2. The non -uniform support resulting from wide variations in soil types over the road length
3. The migrations of soluble salts will in turn result to cracking

The gravel wearing course must have the following desirable characteristics like good skid resistance, smooth riding characteristics, resistance to raveling and scour and to meet this requirement the gravel wearing course must be durable and of consistent quality. However, the most common defects observed in the gravel wearing course are the loss of gravel. The main causes of road deteriorations are classified under the following categories

1. Traffic: - confirmed to be “the greatest cause of wear of road” [13] Hossein Alzubaid also states that the wearing course is continuously broken down by the vehicle wheels crushing the larger particle. The result is the shortage of aggregate and an excess of sand. Dust is the fine material released from the road surface under the wheels of moving vehicles and the turbulence caused by vehicles. Silt-sized particles are the predominant elements in dust and the quantity of dust generated by a vehicle is a function of its aerodynamic shape, speed of travel and the surfacing material properties [19]

The carriage way deflects to some extent under the wheel load when the particles of the aggregate are subjected to considerable forces when the wheels of the vehicle roll along the road. The particles grind to one another and are abraded making larger particles smaller and when the vehicles rush along the road some particles are thrown to the side and vanish. [23]

2. Precipitation/climate: - the conditions of gravel roads greatly vary with climate from season to season. A gravel road is susceptible to variations in climatic condition of the area to which the road is located. In rainy season, the moisture content in the road become higher and due to this bearing capacity of the gravel road in general reduces and this leads the roads to rutting. In dry season the moisture content of the gravel

roads reduces and this leads the roads to be corrugated and dusty. Never underestimate the force of a drop of rainwater. It is that water drop exploding when it impacts bare soil that starts the erosion process. If water passes through a road and fills the native soil, the road, whatever may be its thickness, loses its support and goes to pieces [24]

The matter of drainage is more important to the roadway having a gravel surface than to those of the more permanent type (paved roads). Water is more damaging to the gravel surface than traffic. During wet seasons the power of the binding material is weakened and the road is rutted. There is no reason to believe that the soil under the surface of the roadway contains less moisture than that of the adjacent fields. [21]

3. Surfacing materials: - Low-volume road surfaces and structural sections are typically built from native materials that must support light vehicles and may have to support heavy commercial truck traffic. In addition, low-volume roads should have a surface that, when wet, will not rut and will provide adequate traction for vehicles. Roadway materials, and particularly roadway surfacing materials, such as aggregate or paving, can be half the cost of a road. Selection of materials directly affects the function, structural support, rider comfort, environmental impact and safety of the road user. [24]
4. Geometric design of gravel roads: - to meet the needs of all the road users. It covers road width, cross-fall, horizontal and vertical alignments, sight distance and transverse profile or cross-section. The geometric features influencing gravel loss [25] are horizontal and vertical curvature, the cross section elements and longitudinal grades. Geometric cross-sectional characteristics particularly crown, camber, side drain and run-off points have pronounced effects on drainage and gravel road deterioration during high rainfall

2.4.1. Rutting

Longitudinal depressions parallel to the road track which are caused by permanent deformation of the subgrade or road surface are called rutting. [23]. Ruts are caused by the compaction of the subgrade, compaction and loss of gravel from the wearing course. Ruts are classified as slight or severe ruts based on the rut depth. If the rut depth is less than 25mm the ruts are slight ruts [2]

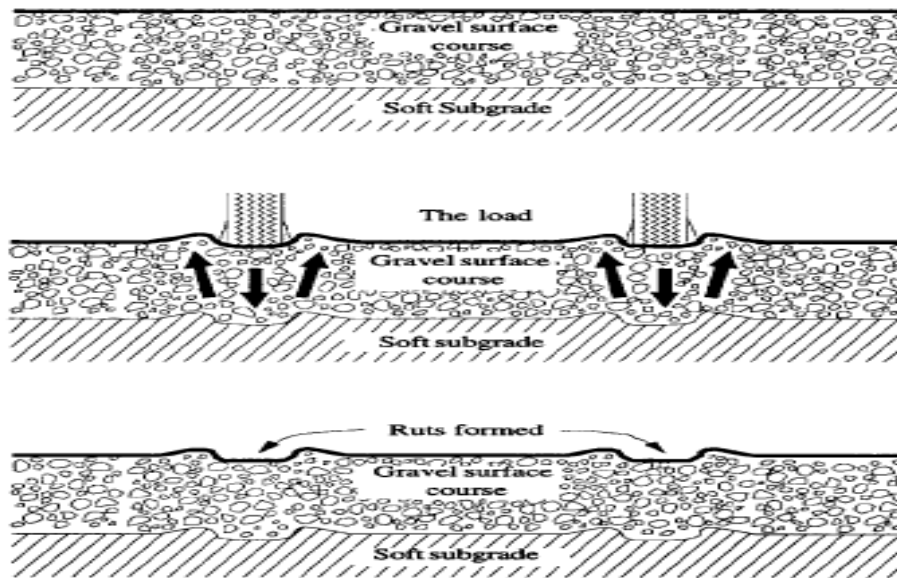


Figure 2-2 development of ruts (source [13])

According to the unsealed road manual [26] the causes of deformation are as follows

- In appropriate aggregate composition
- Wearing course of insufficient thickness
- in adequate compaction
- in sufficient drainage
- high fines content

Ruts can be corrected by taking the following measures [20] [18]

- improving the drainage
- adding gravel to the wearing course
- stabilizing the gravel

2.4.2 Potholes

Potholes are bowl-shaped, round or elongated depressions in gravel road surface. Potholes predominantly form in areas where the *subgrade* is wet, and the action of passing vehicles causes a failure in the *subgrade* producing a series of deformations in the road surface [11]. Jones and Paige green [27] [18] states the main causes of potholes as



Figure 2-3 regular potholes on gravel roads (source [23])

Potholes on the roads can be caused by due to:

- poor road shape and drainage
- poor grader operation practice (e.g. plucking of oversize material and destruction of the crown)
- compaction of material behind oversize stones under wheel loads
- poor compaction
- material and moisture variability
- enlargement of corrugation troughs
- deformation of weak subgrade and wearing courses
- subsidence or excavation of animal and insect burrows
- disintegration of highly cracked roads (i.e. excessive plasticity)
- disintegration of soft oversize materials
- dispersive soils

2.4.3 Corrugation

Gravel roads consist of coarse and fine aggregates. The coarse aggregate is gradually broken down by wear and sand is formed. When the road contains a lot of sand it is susceptible to Corrugation [13]. Vehicle acceleration, deceleration and turning, increases the abrasive effects of tires and their tendency to corrugate the road surface. Accelerating quickly from a

dead stop, decelerating suddenly to zero, or turning sharply at high speed, all heightens the effects even more. The parts of the road to which the road surface mostly corrugated are intersections, drive ways, curves grade of the roads [11].corrugation is caused by lack of fines in the aggregate and air suspensions it can be caused due to dusted and washed away or lack of fines initially during construction [2]can be corrected by increasing the content of fines up to 10-15% and adding more plastic fines in the aggregate. [27] Corrugation can be corrected by taking the following measures

- constructing the gravel roads on firm subgrades that are stable materials and drain well
- the road must be constructed of well graded aggregate that has sufficient amount of fines

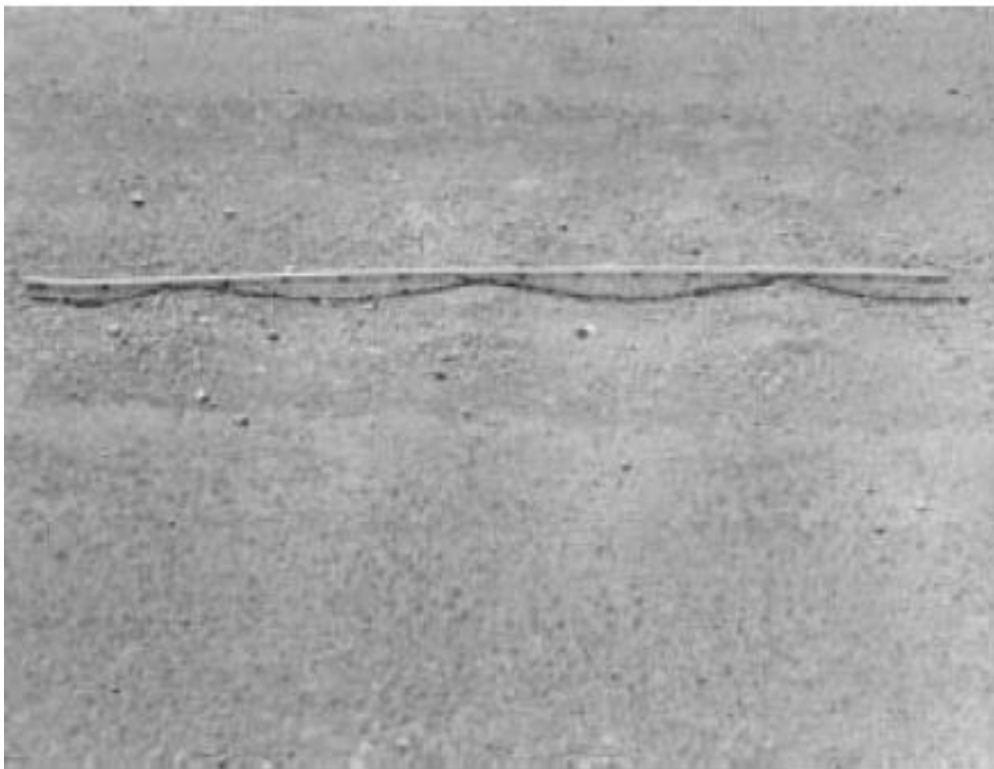


Figure 2-4 corrugation on gravel roads (source [19])

2.4.4 Erosion

Erosion is defined as the natural process by which wind, moving water, ice, and gravitational Forces displace the solid and particulate materials of the land .and in gravel roads, erosion of surfacing material is caused by the flow of water over the road and by the action of traffic and

wind. The ability of a material to resist erosion depends on the shear strength (equal to the cohesion, as the normal stress is zero) under the conditions at which the water flow occurs. Erosion will occur if the shear strength of the material is less than the tractive forces induced by the water flowing over the materials, grains will become detached [19]. materials that are prone to erosion are typically fine grained and have some plasticity. But these materials generally perform well when used in roads on flat terrain or in areas of very low rainfall. In other areas they will quickly erode during rainfall, leaving channels in the road that are dangerous and unpleasant to drive over and expensive to maintain [18]



Figure 2-5 transverse erosion on gravel roads (Source [28])

The characteristics of the surfacing material are crucial in reducing erosion. Some of the behaviors of the material that are related to erosion are:-

- soil texture (particle size and gradation)
- percentage of organic content
- soil structure
- soil permeability [28]

2.4.5 Cracks

Cracking is not a usual deterioration type on gravel roads but in some circumstances it is observed on the surface of the roads. These defects are due to highly plastic surface material and the percentage of fines material become higher than the allowable range. Cracks can be the cause of pothole formation in dry season.



Figure 2-6 cracks on unpaved roads (source [23])

2.4.6. Raveling

The generation of loose gravel under traffic is termed raveling and is mainly caused by a deficiency of fine material (and hence cohesion), a poor particle size distribution (e.g. skip grading) in the wearing course gravel and inadequate compaction [19]. Raveling is generally worse in the dry season than in the wet season when capillary suction results in some “cohesion”. Although Materials that ravel have some plasticity, but are gap-graded the presence of clay does not prevent raveling. [18] Fine material can often be blended with the gravel to increase cohesion. A good degree of moist compaction can also be used to cut down raveling



Figure 2-7 raveling on unpaved roads (source: [18])

2.4.7 Slipperiness

Slipperiness is the loss of traction caused by an accumulation of excessively fine or plastic material on the surface of the wearing course in wet conditions. Slipperiness can often be evaluated by observing wheel tracks formed during wet weather that are retained in the road after drying and other indicators [20]. Slipperiness is rated as either acceptable or unacceptable

In dry weather, unpaved roads may become slippery if an excess of loose, fine gravel (between 2 and 7 mm in diameter) accumulates on the road surface through raveling under traffic or poor blading practices. This layer behaves like a layer of ball bearings and the skid resistance is reduced practically to zero. In wet weather, slipperiness is caused by excessively fine or plastic material in the wearing course. Even materials with adequate coarse aggregate may become slippery if the fine silt and clay fraction becomes concentrated near the surface [19]

Materials that are slippery when wet and very dusty when dry typically have high fines and clay contents. Increasing clay content also results in decreasing CBR, leading to poor passability in addition to the slipperiness [16].



Figure 2-8 slippery gravel road (source [19])

2.4.8 Gravel Loss

The loss of gravel from the wearing course will eventually lead to permanent damage of the road structure unless remedial treatment is carried out in time [29]. Although the loss of the wearing course material from the road surface under traffic and climatic conditions (rain and wind) is inevitable, the replacement of this lost material is the most costly maintenance operation. Material which ravels is most likely to result in a high gravel loss. Although the major contributor to the gravel loss is the traffic, significant reductions in gravel loss can be obtained by selecting material with a suitably high plastic factor (PF greater than 500) and percentages passing the 26.5 mm sieve. Well-graded and well-compacted gravels resist gravel loss better than materials deficient in either fine or coarse fractions. Erosion should be reduced as far as possible to avoid excessive gravel loss on longitudinal grades.

2.5 Maintenance and Rehabilitation Alternatives

Unlike Paved roads that are usually designed and then constructed with careful consideration given to the correct shape of the cross-section, for paved roads, once paving is finished, the roadway keeps its shape for an indefinite period of time; Gravel roads are not constructed well initially. In addition, gravel roads tend to rut more easily in wet weather. Traffic also tends to displace gravel from the surface to the shoulder area and even to the ditch during dry weather [26].

Good gravel road maintenance or rehabilitation depends on two basic principles: these principles are proper use of a motor grader or other grading device and use of good surface gravel [30]. While there is understanding on use of the grader to properly shape the road, the

quality, volume, and size distribution of gravel needed is not as well understood. It seems that most gravel maintenance or rehabilitation problems are blamed on the grader operator when the actual problem is often material related. The gravel road construction and maintenance guide gives the example [31] this is particularly true when dealing with the problem of corrugation as it is often called in the field. This problem is often perceived as being caused by the grader, but it is primarily caused by the material itself.

According to Dr. Paige green [19]the major categories of maintenance are

1. road side maintenance
2. surface maintenance
3. drainage maintenance

For local conditions it is considered prudent to define the roadside as the full road reserve the roadside is defined [32] as the first 3 m (10 feet) adjacent to the edge of the shoulder or pavement. Bush clearing and grass cutting are the main maintenance activity affecting the roadside. This procedure is carried out mainly for safety reasons but also to avoid damage to vehicles from vegetation overhanging the pavement edge and to reduce the fire hazard in some areas. Another roadside maintenance activity which should not be neglected is the repair and prevention of erosion affecting cut and fill slopes and ditches.

Drainage maintenance is done to overcome the drainage problems affecting unpaved roads the first problem is the erosion of the gravel wearing course from the surface by rain water to maintain this the road should have good shape and adequate cross falls. Other drainage maintenance is the maintenance of side drains, miter drains and culverts which should be done more regularly on unpaved roads

The maintenance of the surface of unpaved roads is the major cost factor in the maintenance program. Improved surfacing may be provided for the entire length of a road, or only on the most vulnerable sections. The approach may include dealing only with individual critical sections (weak or vulnerable sections; roads through villages or settlements) on a road link (spot improvements), or providing a total whole rural link design, which could comprise different design options along its length. [6]

Surface maintenance activities include:

- grader blading which is a grader is run across the surface of the road with the blade set to smooth and shape the surface and done in the case of potholes, corrugations, excessive loose material, large boulders, ruts or erosion;

- regravelling which is the single most expensive maintenance and carried out when the exiting gravel on the road is totally loss by erosion, wind, traffic and inappropriate material
- Spot regravelling Spot regravelling is carried out to replace the gravel over areas where it has become excessively thin or worn through and for filling potholes, ruts, erosion channels and even corrugations.

The quality of most unpaved road materials can be improved with traditional chemical additives, such as cement and lime, to improve strength and durability properties, but stabilization with electrochemical-based non-traditional soil stabilization additives chemical additives), such as enzyme and sulphonated oil (also referred to as ionic additive) may offer a more cost-effective and practical solution to address these ongoing problems. Chemical additives used for strength improvement are referred to as stabilizers or additives, and for dust suppression are referred to as dust palliatives [33]

CHAPTER 3

MATERIALS AND RESEARCH METHODOLOGY

3.1 Study Area

The research was conducted on the Jimma –Meteso road segment 42 km road located in Oromia region Jimma Zone. The road segment is part of a link road which runs from Jimma to Chida. The study area starts at Jimma town which is located at latitude and longitude of 7°40'N 36°50'E respectively with an elevation of 1780m A.S.L and the elevation on the road rises to a maximum 2620m around km30. The topography of the terrain can be classified as flat, rolling and mountainous. The woredda crossed by these road are seka chekorsa and Deddo of the Jimma zone of Oromia regional state. The number of population that lives in these areas is estimated at 311485.

The geology of the project area according to the geological map of Ethiopia is From Jimma Km 0+000 to about Km 20+000 is Nazret Series: Ignimbrites, un-welded Tuffs, rhyolitic flows, domes and trachyte. From about Km 20+000 to about Km 40 is Jimma Volcanic rhyolite & trachyte flows and tuffs with minor basalt.

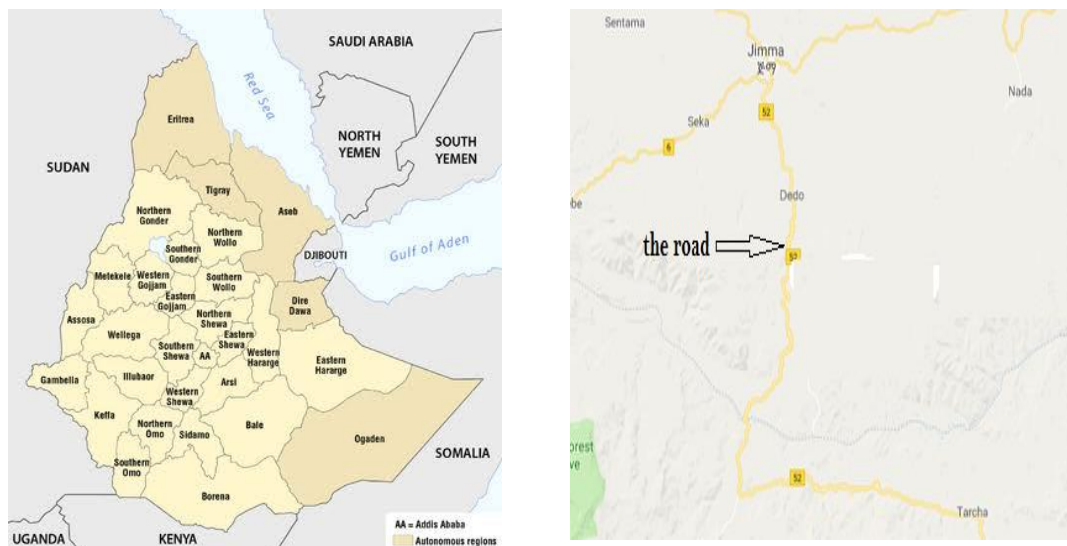


Figure 3-1 Location of the *study area* (Source: Google 2019)

The Project Climate has a rainy season from April to October and Dry Season until into February continuing into March. The duration of the rainy season is longer in the vicinity of the project of a road project and the mean annual rainfall is in the order of 2000mm. The mean maximum temperature ranges 20°C - 25°C and the mean minimum temperature is 10°C

-15^o C. The climatic data that we get from the national meteorological agency is that of Jimma town the climatic data for rainfall and temperature of Jimma town is given in the Figure 3.2 and Figure 3.3 below.

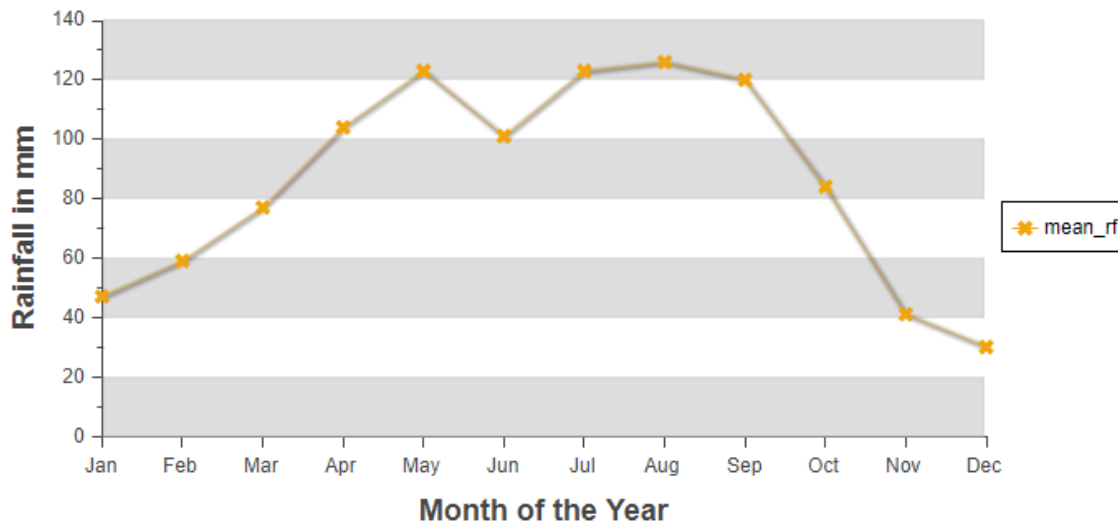


Figure 3-2 Average monthly rainfall data of Jimma area

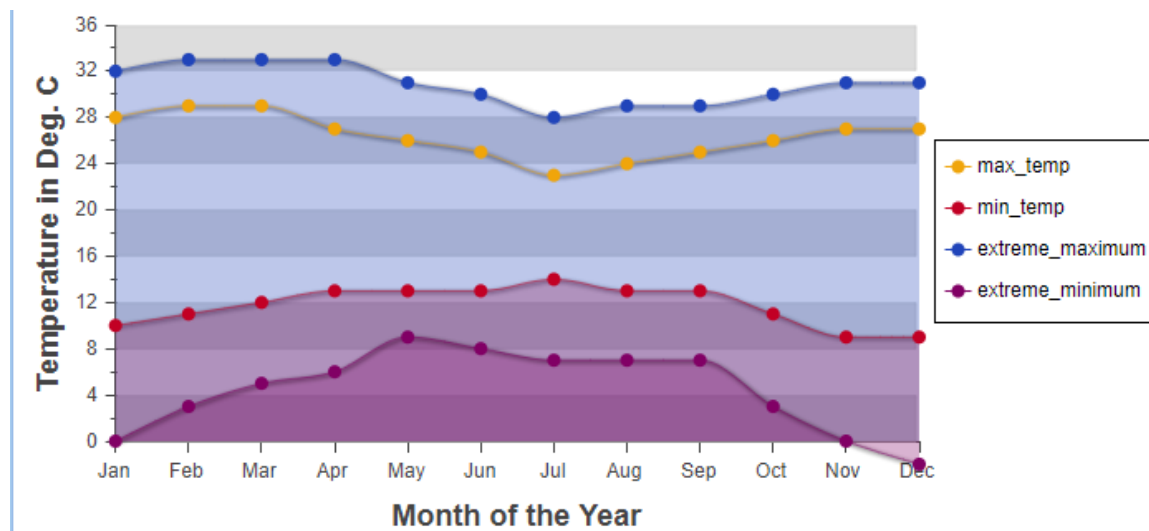


Figure 3-3 Average monthly temperature data of Jimma area

3.2 Research Design

To achieve the desired objectives of the research the first task was analyzing, reviewing and organizing literature review of previous works on related fields and geographical, geological and topographical maps. In experimental study design, it consists of two tasks; field work and laboratory tests. The field work extends from detail observation of

the road environment, taking sample from different places within the study area to investigate the possible causes which lead pavement distresses and also to investigate the engineering properties of sub grade soil, gravel wearing course and the surface condition and conducting field density test. In laboratory tests, the samples, taken from the study area, were tested to measure the physical properties of the soil, the materials strength and pavement moisture content and to identify possible remedies after conducting laboratory tests and observing the results in order to reduce the problems the distresses.

In this study design, laboratory tests such as checking moisture content, grain size distribution, CBR test, standard sieve analysis, Atterberg limits test, were conducted. The laboratory results were needed for interpretation and to come up with accurate remedies. There was field surveys and visual identification of the roads. This was incorporated with conducting field density test on the subgrade, sampling of soil from the site and laboratory testing of the soil samples were carried out. Secondary data were obtained from the Ethiopian roads authority on the traffic data of the road the traffic count (AADT) from 2002-2016 was obtained and compared with the design AADT. Finally, the results were analyzed using specifications and conclusion and recommendation were given. And the final draft of the thesis was prepared.

3.3 Study Variables

There are two variables that will be taken into consideration; dependent variables and independent variables

Dependent variable: - Causes of failures of the gravel roads

Independent variables: -

- Extent of defects,
- Type and strength of the subgrade and the gravel,
- Particle size distribution of the soil,
- Index properties of the soil, Compaction

3.4 Population

In this study, failures on Jimma –Meteso road segment were considered as the population of the study.

3.5 Sampling Methods

To achieve the objectives of the research the sampling technique that was used is the nonprobability purposive sampling method. The idea is to collect soil samples at different locations of the road with the worst failure rates.

The disturbed soil was collected from their respective sites and placed in a tight plastic bag with a reference tag to describe the location of the sample and the depth taken. This was done in order to avoid the possibility of contaminating the sample being collected and to know which sample is from where.

3.6 Data Collection Processing

In order to achieve the objectives of the research, data were required. The methodologies applied to collect the data are discussed below. The first stage in data collection was to be obtaining consent letter from ERA and local governments. Field visits in the study area were undertaken and samples were collected from the prevalent distressed gravel road. Wearing course and sub-grade materials were collected at each failed section based on colour and texture change. Representative samples at each test pits and photographs at representative location were taken. The road was categorized into different road failures based on condition survey. In addition, adequate numbers of representative samples were carefully selected based on visual inspection. Finally, the collected representative samples were tested in laboratory.

Preliminary visual survey was undertaken along the Jimma –Meteso road segment. During field observation, it was necessary to begin by conducting visual inspection and site inventory of the whole stretch of the road segment. The initial site visit was undertaken on the whole portion of the road. After finishing the initial visual inspection, the conditions of the road failures along the road section were categorized. Next, the representative locations for sampling based on their failure conditions/types were selected. Accordingly, nine sample locations/stations of test pits that represent the type of failures observed along the road section were selected. The locations of the sampling sites were recorded by using google earth software and GPS on smart phone. The coordinates and stations of the sampling sites are given in table 3.1.

Table 3-1 location of sampling stations

Station	Location(latitude, longitude , elevation ASL)
4+800	7°36'24"N ,36°50'21"E ,1735m
11+000	7°33'38"N ,36°51'44"E ,1872m
17+400	7°30'00"N ,36°52'30"E ,2108m
22+000	7°29'03"N ,36°52'46"E ,2088m
33+300	7°25'50"N ,36°52'29"E ,2376m
38+800	7°23'41"N ,36°52'19"E ,2270m
26+600	7°27'13"N ,36°52'21"E ,2555m
30+400	7°24'11"N ,36°52'24"E ,2661m
41+000	7°21'34"N ,36°52'13"E ,2114m

3.7. Data Quality Assurance

During the sampling and laboratory testing, proper precautions were taken and the laboratory tests will be conducted according to the standards of laboratory testing. Training will be given for lab assistants on how to conduct the tests, if necessary. The reliability and accuracy of data will be checked. In order to avoid erroneous results, repeated laboratory tests will be done, and the results will be recorded in an appropriate manner

3.8 Data Processing and Analysis

The selection of the sampling stations was dependent on the severity of the failure observed. And the sampling of the soil was accompanied with field density tests for the subgrade .The samples that are collected from the site and it will be processed through laboratory tests using the ASTM and AASHTO principles. And the results will be analyzed by comparing using the standard specifications

To determine the causes of failures the following laboratory Tests will be performed

- ✚ Grading analysis
- ✚ Atterberg limits tests
- ✚ Soil compactions
- ✚ CBR tests
- ✚ Moisture content determination

1. Grading analysis / sieve analysis

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

2. Atterberg limits tests(LL and PL)

This test determines the clay content in terms of liquid limit, plastic limit and plasticity index in order to estimate plasticity, strength and settlement characteristics of the soil sample. For the determination of liquid limit, the soil sample passing through 425 μm sieve, weighing 200 g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casagrande apparatus cup with a groove created and the number of blows to close it was recorded. The moisture content vs number of blows is plotted on a graph and the water content corresponding to 25 blows is taken as liquid limit. Similarly, for plastic limit determination, the soil sample weighing 200 g was taken from the material passing the 425 μm test sieve and then mixed with water till; it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit

3. Compaction test

Compaction tests were performed for sub-base, selected fill and natural subgrade soil materials based on AASHTO T-180 test procedure for compaction. The densification of soil with mechanical equipment thereby rearranging the soil particles which makes them more

closely packed resulting in an increase of the ratio at horizontal effective size to the vertical effective stress. The degree of compaction is measured in terms of its dry weight increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and curbs undesirable settlement of structures. The mold was filled and compacted with soil in five layers of a 4.5 kg rammer. And the water content and density of the soil was measured and dry density is calculated from the moisture density relationship. Then the graph of dry density vs moisture content is plotted and the peak points on the graph are taken as optimum moisture content (OMC) and maximum dry density (MDD)

4. CBR/ Californian Bearing Ratio

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

After the data were processed using the above explained laboratory methods the results were analyzed by comparing with ERA standards. The standard used for this case was the Gravel and Low volume roads design manual and the requirements set for both subgrade and gravel wearing course materials are presented.

The wearing course material shall be compacted to a minimum in-situ density of 95% of the maximum dry density determined in accordance with the requirements of AASHTO T 180. The plasticity index should be not greater than 15 and not less than 8 for wet climatic zones and should be not greater than 20 and not less than 10 for dry climatic zones. The CBR value of the gravel wearing course compacted at 95% and four days soaking should be 20% minimum. The gradation requirements of the gravel wearing course material is given in Table 3.2 below

Table 3-2 gravel wearing course requirement (source ERA [34])

Test sieve size (mm)	Percentage (%) by mass of total aggregate passing test sieve					
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
6	-	-	-	100	-	-
37.5	100	-	100	80-100	-	-
28	-	100	95-100	-	-	-
19.5	80-100	95-100	85-100	60-80	100	-
14	-	80-100	65-100	-	-	-
9.5	55-100	65-100	55-100	45-65	80-100	100
4.75	40-60	45-85	35-90	30-50	60-85	80-100
2.36	30-50	-	-	20-40	45-70	50-80
2	-	30-65	22-75	-	-	-
1	-	25-55	18-60	-	-	-
0.425	15-30	18-45	15-50	10-25	25-45	25-45
0.075	5-15	12-32	10-40	5-15	10-25	10-25

All subgrade materials shall be brought to strength of at least a minimum CBR of 7% for minor gravel roads and at least a minimum CBR 25 % for major gravel roads. Soils used for improved subgrade layers shall be non-expansive, non-dispersive and free from any deleterious matter. The material requirements for subgrade given on ERA design manual are given in the Table 3.3 below

Table 3-3 requirements for subgrade of gravel roads (source ERA [34])

Material properties	G20 upper limit	G7 lower limit
CBR dry climatic zones	Minimum 25 after 4 days soaked	Minimum 7 after 4 days soaking
CBR wet climatic zones	Minimum 20 at OMC Minimum 7 after 4 days soaking	Minimum 7 at OMC Minimum 3 after 4 days soaking
PI[%]	Maximum 25	Maximum 30
Compacted density	95% of AASHTO T 180	95% of AASHTO T 180
Maximum particle size	2/3 of layer thickness	2/3 of layer thickness
Compacted layer thickness	Maximum 200 mm	Maximum 250 mm

To check if the road failure was associated with traffic or not the traffic count (AADT) from 2002-2016 G.C was obtained and compared with the design AADT for the road which is DS5. The traffic count data was obtained from ERA south west branch and is presented in the table 3.4 below.

Table 3-4 Traffic Count AADT

Year	Car	L/rover	s/bus	l/bus	s/truck	m/truck	h/truck	Truck and trailer	total
2002	0	17	4	5	22	34	50	2	122
2003	0	20	7	8	24	50	37	1	149
2004	0	11	7	11	17	7	30	5	151
2005	1	14	10	15	16	54	25	14	149
2006	0	38	50	15	44	75	27	1	250
2007	0	16	37	6	17	62	6	3	147
2008	0	4	27	16	13	31	25	1	117
2009	0	36	47	9	33	54	40	2	221
2010	0	17	43	22	15	42	29	2	170
2011	0	17	17	36	11	52	34	2	169
2012	0	15	41	26	17	59	39	8	205
2013	0	32	36	34	11	82	49	3	247
2014	0	18	10	57	26	50	37	10	207
2015	0	22	37	43	28	63	22	4	219
2016	0	24	54	36	31	61	25	11	242

3.9 Ethical Consideration

A copy of the research proposal will be submitted to the JU, JIT research coordinating office. Ethical clearance from Jimma University, JIT and permission from respective authorities was granted. The purpose of the study will be clearly described to the concerned governmental and non-governmental authorities.

3.10 Plan for Dissemination of Findings

This research is conducted for academic purposes and the findings will be presented to Jimma Institute of Technology, Civil Engineering Department, and Geotechnical Engineering Stream. And the document disseminated to Jimma University Technology library. In addition to this, the findings of this research will be given to concerned governmental and nongovernmental office.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Visual Condition Survey

The visual survey of the road is used to collect important data on the conditions of the road and is an important input for the maintenance management. The condition evaluation on the road has been carried out from May to June of 2018. The assessment of condition of unpaved roads differs from that of paved roads because the nature of unpaved road surface is highly dynamic and the appearance is changing almost day to day. The distresses on unpaved roads are described by using the following characteristics: type, degree and extent.

The degree of a particular type of distress is a measure of its severity. Since the degree of distress can vary over the pavement section, the degree to be recorded should be in connection with the extent of occurrence to get the predominant severity of a particular type of distress. The degree is described by a number where:

- Degree 1 indicates the first evidence of a particular type of distress (“slight”).
- Degree 3 indicates a warning condition. This would normally indicate that intervention might be required in order to avoid the distress deteriorating to a severe condition.
- Degree 5 indicates the worst degree (“severe”). Urgent attention is required.

The extent of distress is a measure of how widespread the distress is over the length of the road segment. The extent is also indicated on a five-point scale in which the length of road affected by the distress is estimated as a percentage. The rating scale for extent is given in Appendix A.

In the rating of the Jimma-Meteso gravel road network the combination of degree and extent is used by using the South African assessment manual for unsealed road as a guideline. The road stretch is classified into three sections based on the parameters. The station 0+000 is taken at the start of the road sections located at the Deddo junction in Jimma town.

The entire road was visually surveyed the type of failure, extent and degree were recorded and the road was classified into uniform sections based on the degree of the failures. The most commonly observed type of distress were potholes, ruts, corrugation (wash boarding), impassibility, raveling were noted and recorded

The uniform sections in the road are presented in table 4.1 below

Table 4-1 Uniform Sections on the Road

Road section	Chainage		Remark
	From	To	
Uniform section 1	2+400	4+000	Degree 1
	23+000	25+000	
	40+000	42+000	
Uniform section 2	0+000	2+400	Degree 3
	12+000	16+000	
	34+000	38+000	
Uniform section 3	4+000	12+000	Degree 5
	17+000	23+000	
	26+000	34+000	
	38+000	40+000	

The condition survey was conducted at every 1km interval for failure types of rutting, potholes, corrugation, impassibility and, raveling. The extent and severity of failure were summarized and analyzed based on each type of failure.

The degree of potholes are calculated based on the information given on table 4.2

Table 4-2 Description And Rating Of Degree Of Potholes On Gravel Road

Degree	Description
1	Depressions just visible. Cannot be felt in the vehicle
2	<20 mm deep
3	Larger potholes affecting safety – 20- 50 mm deep
4	50-75 mm deep
5	Large, dangerous potholes requiring evasive action - >75 mm deep

The extent of potholes was sever (5) on the stations located between 8 -13km and 22-29 km the rest of the stations are intermediate and slight failures observed. The rating of the severity was also in accordance with the degree. Extent of potholes on the road varies on the road as given on figure 4.1

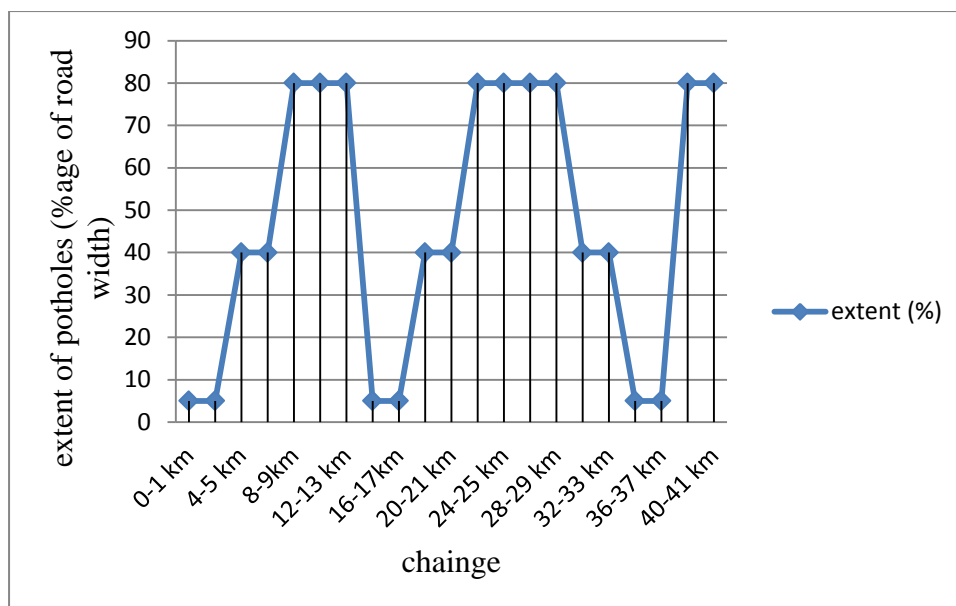


Figure 4-1 Extent of Potholes

Rutting, which is the parallel depression in the road was also one of the predominantly observed and recorded type of distress on the road ruts are assessed visually by considering their capacity to retain water and estimating their average depth the degree of rutting is expressed by using the data given on the following table 4.3

Table 4-3 Description of the Degree of Rutting

Degree	Description
1	Rutting is just visible
2	<20 mm deep
3	Rutting between 20 -40 mm deep
4	40- 60 mm deep
5	Rutting >60 mm deep affecting directional stability of a vehicle

The extent of rutting on the road was done on accordance with estimation of the depth of the rutting to determine the severity. Over the width of the road rutting was dominantly observed between stations 2-5 km, 22-25 km and 30-33 km on the rest it was only slight and intermediate. The extent of rutting on the road is given in figure 4.2 below

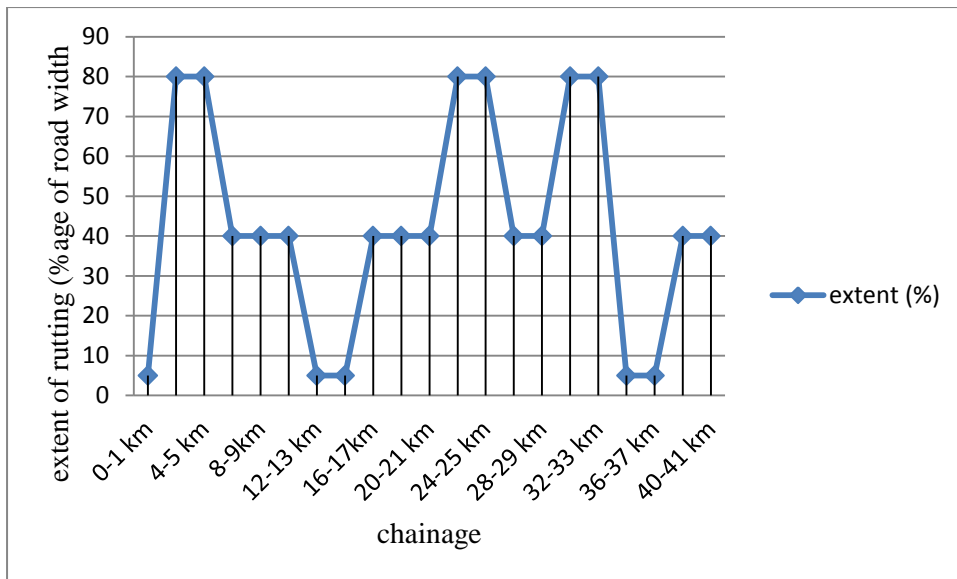


Figure 4-2 Extent of Rutting

Corrugation can be assessed visually by using rating mechanisms the degree of corrugation varies from not heard or felt in light vehicles (degree 1) to degree 3 which is heard and felt and requires speed reduction and degree 5 where drivers have to select a different path and derive very slowly and is a safety is affected. In the Jimma Meteso road section the corrugation observed are in these ranges. And the extent with respect to the coverage of the width of the road is presented in the figure 3.3 below

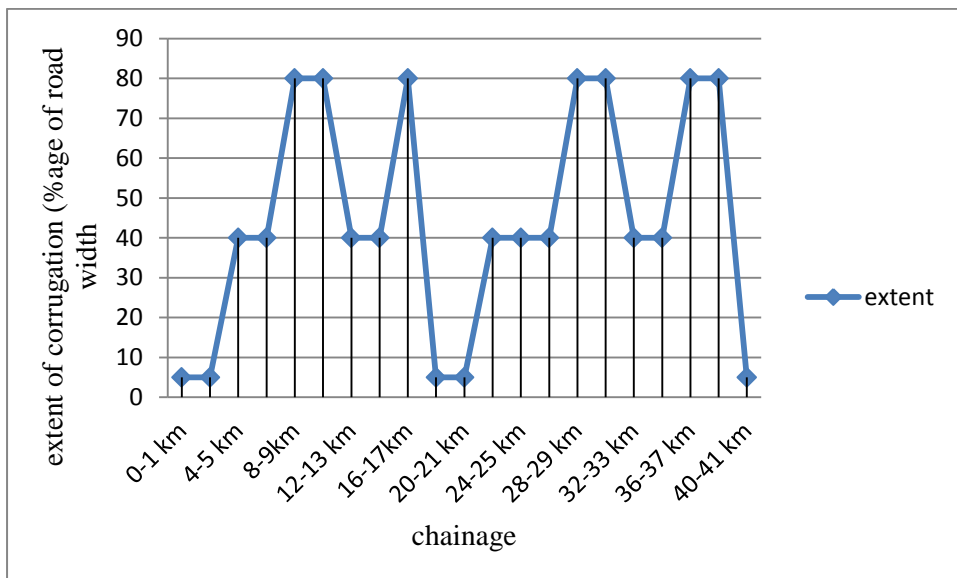


Figure 4-3 Extent of Corrugation

Raveling was observed in the road it could be associated with the generation of loose aggregate or stoniness. The extent of raveling in most of the road section was extent 3

between 20-60% but in station from station 37 to 40 km the extent was 5 between 80-100 percent the variation of the extent of raveling over the road section is given in figure 4.4 below

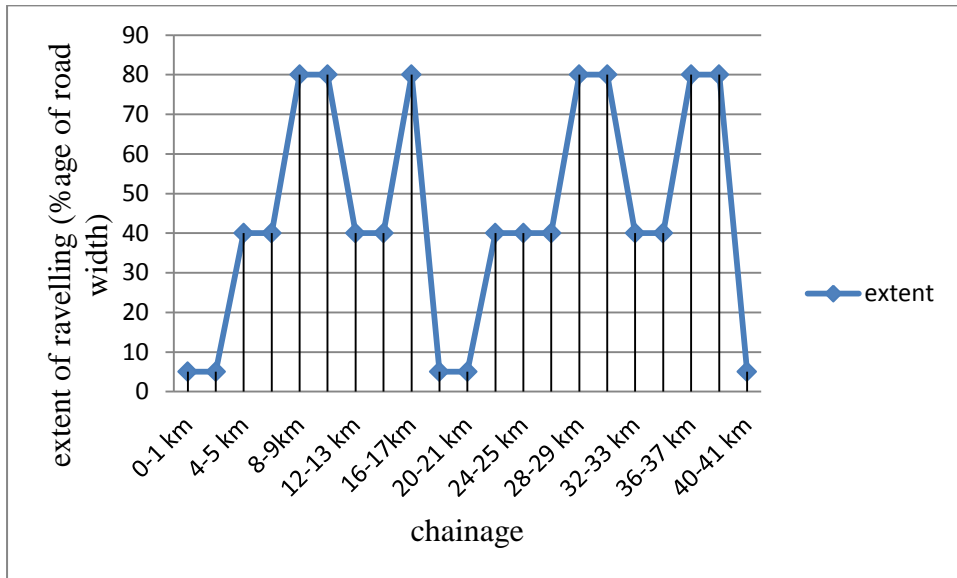


Figure 4-4 Extent of Raveling

Impassibility on the road section is observed in extent 5 from 0-1 km, 10-13km and 36-39 km on the rest of the stations the extent is slight and intermediate. The extent of impassibility on the road

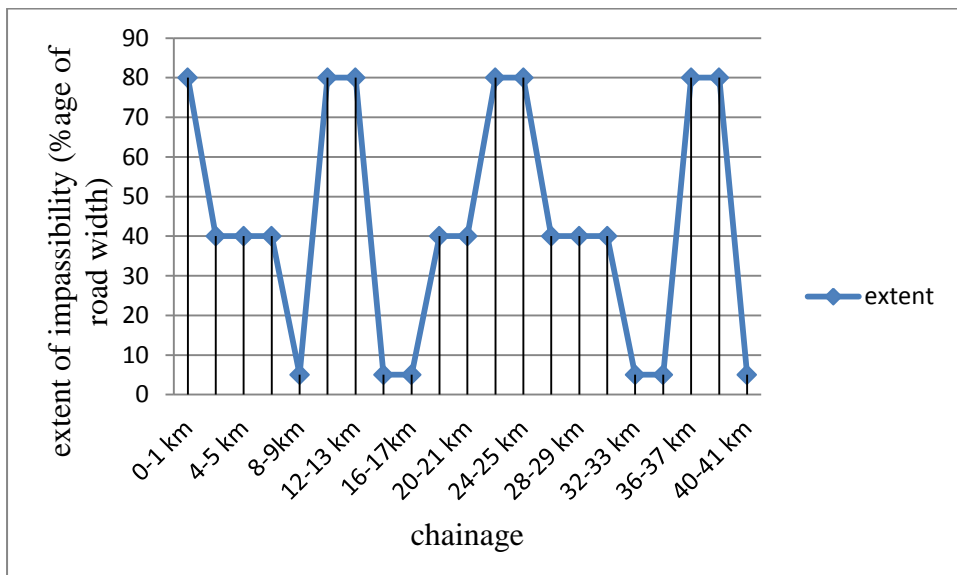


Figure 4-5 Extent of Impassibility

The different types of distresses on the road are presented in the following figures

Some of the representative photographs taken on the site are presented below



Figure 4-6 Failures observed on the road: pothole



Figure 4-7 Failure observed on the road: rut.



Figure 4-8 Failure observed on road corrugation



Figure 4-9 Failure observed on road raveling



Figure 4-10 Failure observed on the road: slipperiness and impassibility

4.2 Field Density Test Results

From the selected sites from visual inspection the density tests were conducted. A hole was excavated through the guide of the base plate. The material from the hole to a depth of 52cm – 90cm was carefully collected in a polyethylene bag, and then weighed tightly sealed, and labeled for subsequent natural moisture content determination. Dry free – flowing sand of known density was then poured into the hole from the sanded sand cone. From the weight of sand required to fill the excavated space the volume of hole was determined. The bulk density was computed upon completion of each test. The field dry densities were later computed based on the results of natural moisture content determined in the laboratory. And the samples only on the subgrade because of the thickness if the gravel wearing course material which was less than 200mm in most of the failed sections. The results of these tests can be used to determine the degree of compaction of the layer and the drainage issues in the layer. The results are given in the Table 4.4 below.

Table 4-4 Field Density Test Results

station	pavement layer	Moisture content (%)	wet density(g/cc3)	dry density (g/cc3)
4+800	gravel w.course	20	-	-
	subgrade	35.95	1.4837	1.0914
11+000	gravel w.course	21.2	-	-
	subgrade	33.37	1.358	1.0185
17+400	gravel w.course	14.6	-	-
	subgrade	20.8	1.632	1.3515
22+000	gravel w.course	14.8	-	-
	subgrade	32.4	1.657	1.2516
26+600	gravel w.course	20.43	-	-
	subgrade	31.4	1.62	1.26
30+400	gravel w.course	23.3	-	-
	subgrade	28.6	1.6195	1.2593
33+300	gravel w.course	19.62	-	-
	subgrade	30.02	1.5936	1.224
38+800	gravel w.course	21.3	-	-
	subgrade	29.8	1.6391	1.2627
41+000	gravel w.course	18.4	-	-
	subgrade	32.1	1.733	1.312

The water content in the layer is also an indication of the degree of compaction. The determination of the NMC is also important to check if the level of water in the layer is safe or unsafe because there is a recommended range of variation between NMC and OMC which is 2%.

4.3 Laboratory Test Results

For the selected soil samples from visual inspections undisturbed soil samples were taken for the laboratory tests. Representative samples were collected from each test pit Samples were collected, labeled and transported to the laboratory for tests and each layer of Pavement. The laboratory analysis was performed according AASHTO standard method, ASTM standard

test methods and the British standard. The laboratory test was carried out to determine the suitability of the soils for use as gravel wearing course and sub-grade using the AASHTO standard method in relation to the generation specification for roads. The following tests are performed according to AASHTO specifications on the subgrade and wearing course layer.

- Gradation test
- Atterburg's tests
- Compaction test
- CBR test

These tests are useful for identification and classification purposes and to establish the quality of materials according to the specifications and design procedures

4.3.1 Gradation Test Results

This test was performed to determine the percentage of different grain sizes contained within the subject soil. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger-sized particles; and, its classification is a laboratory based process of grouping soils and rocks with similar engineering characteristics based on the measured properties. Table 4.5 below shows the sieve analysis result for the subgrade soil

Table 4-5 Gradation results of the subgrade

sieve size	Percentage passing (%)								
	station 4+800	station 11+000	station 17+400	station 22+000	station 26+600	station 30+400	station 33+300	station 38+800	station 41+000
4.75	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2	79.44	93.79	92.41	85.85	94.80	90.19	93.53	96.50	95.64
0.85	65.84	74.02	68.22	73.02	73.22	70.83	72.90	82.52	81.92
0.425	58.57	63.45	55.29	61.96	56.65	60.48	61.87	69.35	70.64
0.3	49.27	49.93	44.49	52.38	46.44	52.27	53.14	59.73	60.56
0.25	44.12	42.44	35.32	52.03	32.37	44.51	40.67	46.40	42.09
0.15	35.74	30.25	27.00	43.73	23.51	32.74	33.33	29.00	27.48
0.075	16.76	19.45	19.69	15.85	14.85	20.07	21.58	15.63	17.56

Based on USCS soil classification scheme the soils are classified under coarse grained sand soils specifically the soils are classified under clayey and silty sands. The symbol used is SM and SC. The Table 4.4 below shows the sieve analysis results of the gravel wearing course material

Table 4-6 Gradation Test Results of the Gravel Wearing Course

sieve no.	Percentage passing (%)										
	station 1	station 2	station 3	station 4	station 5	station 6	station 7	station 8	station 9	upper limit	lower limit
63.0	100.0	100.0	100.00	100.0	100.0	100	100	100.0	100.0	100.0	100.0
37.50	100.0	100.0	100.00	100.0	100.0	100	100	100.0	100.0	100.0	100.0
19.50	81.10	72.57	81.75	75.90	75.09	72.32	74.69	71.37	76.33	100.0	80.0
9.500	56.69	54.20	55.79	59.77	56.83	56.52	59.7	55.64	52.37	100.0	55.0
4.750	40.84	42.72	32.10	49.69	45.41	46.85	49.28	45.36	44.37	60.0	40.0
2.360	30.69	32.00	24.06	42.95	37.78	39.08	43.1	40.12	30.27	50.0	30.0
0.425	19.64	20.32	13.46	30.05	23.17	24.18	29.77	25.46	26.36	30.0	15.0
0.075	11.82	12.07	8.82	26.59	19.26	21.59	26.43	17.33	9.56	15.0	5.00

The USCS is provided here for information but in most cases of site investigation in Ethiopia, the AASHTO classification system is recommended. The USCS is based on identifying soils according to their textural and plastic characteristic, and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component. They are usually found as mixtures with varying proportions of particle sizes. Each component part contributes its characteristics to the soil mixture.

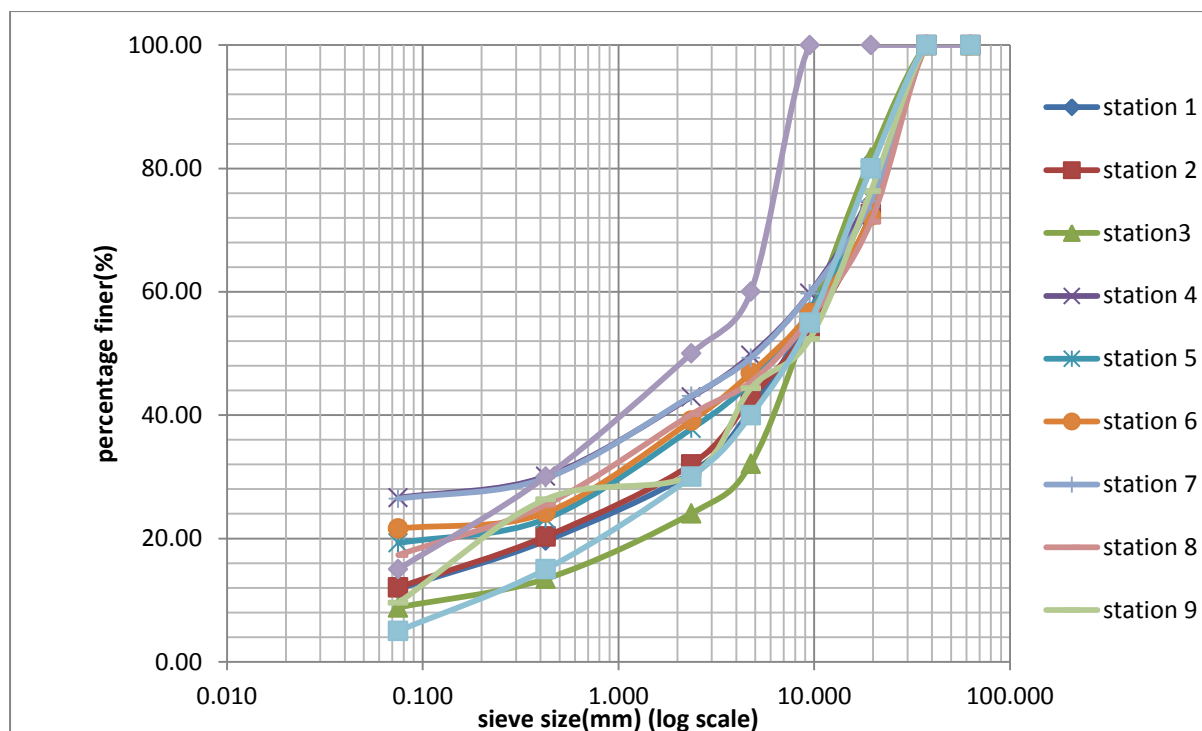


Figure 4-6 Particle Size Distribution Curves of the Gravel Wearing Course

Based on ERA gravel road design manual gravel roads are categorized under two categories, major and minor gravel roads. Since the AADT of the road is greater than 200 it falls under major gravel roads. The grading envelop used for major gravel roads is grading envelop 1 given in Table 3.3. When considering the gradation test results for the wearing course material the percentage passing for most sieve sizes is within specifications based on ERA grading requirement envelop 1. But for some sieve sizes, sieve size 0.425mm and 0.075mm we can see that the soil is finer than requirement this indicates more amount of fine materials than required in the specification. The amount of fine grained soils (silt and clay) passing sieve number 200 is in the range of 8.86-26.59%, but the specification is set to be between 5-15 percent. This value does not satisfy the specifications set and the gravel wearing course has more amount of fine materials have been used on the site.

4.3.2 Atterburg's Test Results

The LL and PL tests were conducted on the soil sample to determine the consistency characteristics of the soil. The plasticity index is obtained by subtracting the liquid limit from the plastic limit. Atterberg limit tests are important classification criteria for soils' engineering properties. The Atterberg Limits and Plasticity Index values of the representative soil samples of Jimma-Meteso road sub grade are tabulated in Table 4.7 below.

Table 4-7 Atterburg's Limit Tests of the Subgrade

Station	Liquid limit(LL)	plastic limit(LL)	Plasticity index(PI)
17+400	41.9	21.8	20.1
11+000	53	34.39	18.62
17+400	43	21.83	21.3
22+800	48.7	20.56	28.16
26+600	49	26.44	22.6
30+400	54	26.47	27.6
33+300	51.8	31.61	20.2
38+800	49.5	31.52	18
41+000	52.5	26.2	26.3

Atterburg's limits have also close relationships with the soils compressibility, permeability and strength. From the results of the subgrade tests it is observed that the soil has medium to high plasticity. Plasticity index is also used to identify between fine grained soils (silts and clays) if the soil has low plasticity the fine grained soils are dominantly silts and if the plasticity is high the soils are clays. Although detailed investigation on the type of the fine grained soils remains it can be concluded that there is high amount of plastic clays in the subgrade soil. The plasticity index of the subgrade is required to be a maximum of 25% this is satisfied in almost all samples except in three samples with PI 26.3, 27.6 and 28.16%

Plastic limit and liquid limit tests were done of the wearing course material and the results were given by the Table 4.8 below

Table 4-8 Atterburg's Test Results for Wearing Course

Station	Liquid limit(LL)	plastic limit(LL)	Plasticity index (PI)
17+400	24	18.27	5.79
11+000	40	27.64	12.36
17+400	42.5	25	17.62
22+000	39	23.25	16.62
26+600	37.5	24.15	13.4
30+400	38.5	20.02	18.42
33+300	36	29.5	6.42
38+800	40	24.76	15.6
41+000	38.5	23.69	14.87

From the plasticity index of the gravel wearing course materials the soil is slight to medium plasticity. The ERA gravel and low manual road design manual suggests that the PI for the gravel wearing course must be in the range between 8-15 percent this condition is satisfied for some samples but few of the PI values are not with on this range.

4.3.3 Compaction test results / proctor test

The compaction tests are conducted on a soil to determine the grading characteristics and the degree of compaction of the layer by taking the ratio between the field and laboratory density results. It is also conducted to determine the amount of compaction energy and water needed during compaction Proctor test were performed based on AASHTO T-180 the optimum moisture content (OMC) and the maximum dry density (MDD) results for the soil samples for the subgrade is given in the Table 4.9 below

Table 4-9 Proctor Test Results

Station	MDD	OMC
17+400	1.39	29.5
11+000	1.38	29.01
17+400	1.618	18
22+000	1.418	27.5
26+600	1.58	21
30+400	1.365	32.5
33+300	1.38	30.5
38+800	1.62	17.6
41+000	1.44	28

When compared to the field test results that are presented in table 4.9 above the comparison between the NMC for the entire test stations the value of OMC is below that of the NMC. This variation is not within the acceptable limit of 2% variation. The difference between the NMC and OMC for the subgrade ranges between 7.45 and 2.8 percent. When considering the relationship between the field and laboratory value of dry density for the subgrade soil the degree of compaction is obtained and for the soil samples taken the degree of compaction of the subgrade ranges from 70 to 84 percent.

The natural moisture content of the subgrade is in the range of The NMC on the failed sections of the road is ranging between 10.31%-35.96% when comparing this with the OMC which is between 18% and 30.5% we see that the NMC is increased.

The averages MDD for the subgrade material are 1.5275 gm/cc and the range for the field densities is between 1.0185g/cc-1.3515 g/cc the percentage of compaction range is between 70%-84.95% which is lower than what is required by the specification (95%).

The compaction curves for the subgrade are given in the Figure 4.11 below

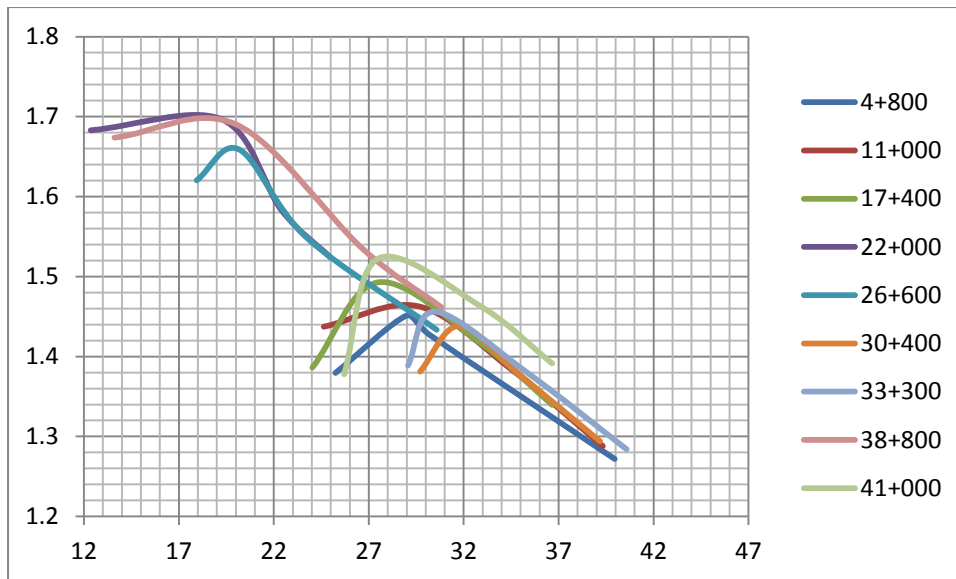


Figure 4-11 Compaction Curves for The Subgrade

Proctor test was performed on the samples taken from the gravel wearing course and the range of values for MDD and OMC is Tabulated 4.10 below

Table 4-10 Proctor Test Results for Wearing Course

Station	OMC (%)	MDD(g/cc ³)
17+400	13.8	1.67
11+000	12.9	1.735
17+400	13.2	1.78
22+000	13.6	1.68
26+600	13.8	1.705
30+400	12.8	1.85
33+300	14	1.79
38+800	13.8	1.83
41+000	13	1.79

The comparison between the NMC for the gravel wearing course given in table 4.2 and the OMC obtained in the above table shows that for all of the test stations the value of NMC is greater than that of the OMC the variation ranges between 8.7 and 0.8 percent.

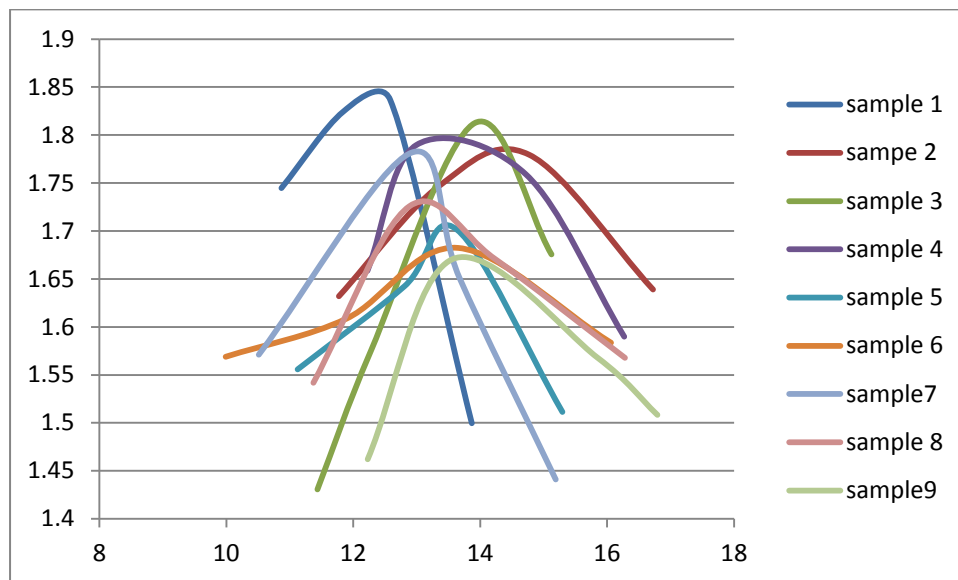


Figure 4-12 Compaction Curves of the Gravel Wearing Course

The wearing course used for the extremely damaged road section has the average OMC value of 14.5 % and MDD of 1.705 gm/cc and on the other hand the field test results for moisture content are ranging from 14.6%-21.3% when compared with the OMC obtained from the laboratory test result there is an increase in the value of NMC. The increase in the value of NMC could be associated with infiltration of water and poor drainage conditions on the road.

4.3.4 CBR

Soaked CBR tests for the subgrade soils were performed to observe the effects of soaking on their strength characteristics and to identify the soils strength parameters at its weakest state. The range of CBR test results for the nine soil samples are presented in table 4.11 below

Table 4-11 Range of CBR values for the subgrade

Station	CBR (%)	CBR Swell (%)
17+400	8.1	0.52
11+000	7.7	1.83
17+400	7.6	1.1
22+000	7	0.79
26+600	4.8	1.64
30+400	6.5	1.14
33+300	6.51	1.02
38+800	8.5	0.55
41+000	6.7	1.25

From the results of the CBR test value the subgrade is classified under subgrade class S3 and S4 based on ERA manual. The subgrade falls under poor to fair condition as a subgrade. The subgrade can be used as a construction material since the CBR > 3.5% and swell is less than 2% [34]. Based on the CBR swell results the subgrade has low expansion characteristics. The subgrade soil used in the construction of the road segment has low to medium load bearing capacity based on scholars' relationship between CBR and strength. The subgrade is categorized under subgrade class S4 based on the CBR value and for this subgrade class can be used as a general construction material. The ERA specifications requirements set that for major gravel roads the sub grade should be to a CBR of minimum of 25%, but the test on the subgrade shows that the value of the CBR is ranging between 4.8 %-8.5 %. The value of the subgrade CBR is much less than the required value

A result of CBR test result for the gravel wearing course material is given in the Table 4.12 below.

Table 4-12 Range of CBR value for wearing course

Station	CBR (%)	CBR Swell (%)
17+400	30	1.06
11+000	38.5	0.51
17+400	32.4	0.84
22+000	39.2	0.55
26+600	40.6	0.44
30+400	42	0.32
33+300	31.2	0.99
38+800	38	0.55
41+000	40.4	0.97

Based on ERA gravel roads and low volume roads manual (2002) the minimum requirement for the CBR of all major gravel roads is 20% this value is satisfied in all of the soil samples

4.4 Proposed remedial measures

The proposed remedial measures to the failures on the gravel road of Jimma –Meteso road section are given below

- To propose a remedial measure for each type of failure observed it is necessary to identify the causes and also to identify the option which is suitable for gravel roads. Before paving gravel roads with asphalt or concrete we have to use different methods to optimize the use of unpaved roads because the cost of construction of paved road is higher than unpaved roads.
- From the failures observed on the road section potholes were one of the most significant and observed more frequently. Potholes are depressions on the road and most of the time water is collected on this depression and if not properly treated other failures like corrugation may rise. The proper remedial action suggested will be avoiding materials of large stone and pebbles from the wearing course, spot regravelling the area with good quality gravel that have adequate soaked strength.
- Ruts are also extensively observed on the road section. Ruts can be caused due to the poor compaction of the sub grade or wearing course and in gravel roads they can rise from in-appropriate aggregate composition. The wearing course has more or less satisfied the requirement for the aggregate composition of the wearing course but the degree of compaction both in the subgrade and wearing course is less than the requirement so the cause is relative to weak compaction. To repair the rutted area proper drainage structures should be constructed. The side drains in the site are filled with silt and have vegetation so periodic maintenance works should be carried out to correct these drainage issues and the wearing course must be compacted to the required degree.
- Corrugation that covered noticeably large areas was observed on the road. Corrugation is caused by the lack of fine aggregate in the subgrade soil. the corrective measure that is suggested to be used are properly blading the area with grader not just making the surface layer smooth but also homogeneous and avoiding porous material on the subgrade soil

- For soils that are eroded the actions that are best appropriate are reducing the grade and cross fall of the road making sure that the length of cross-path is minimized.
- Raveling of gravel roads is also observed on the road sections. To correct this, materials that are used for gravel wearing course must have good grading and should not be gap graded. But the materials that are used on the road are poorly graded sandy soils could be the cause of raveling this should be corrected by blending the material with material of good quality.
- The failures that are observed on the road section can be caused due to weak material but also it is observed that the actual traffic given on Table 3.4 on the road is higher than the traffic (AADT) the road is designed for DS5 roads have design AADT of 100-200. In such cases paving of gravel road or increasing the standard of the road could also be suggested.

CHAPTER 5

CONCLUSION AND RECCOMENDATION

5.1 conclusion

Based on the laboratory tests on the soil the following conclusions are drawn

- This thesis aimed at investigation of the cause of failure on Jimma- Meteso unpaved road segment. The overall analysis in the study is based on the road condition at the time of testing Detail Investigation was carried out on the road section of Jimma- Meteso and more attention given to more damaged section of the road. In this study, a sampling of pavement materials (the gravel wearing course and the sub -grade) from the road was collected for laboratory tests. To find out the real cause of pavement damaged related to gravel wearing course and subgrade soil, the pavement layers property was conduct different laboratory tests. Such as; sieve analysis (Wet method) to check the soil layer grain size distribution, Atterberg limit (LL and PL test), to find out the plasticity index of their soil, Compaction test (Modified) to get MDD and OMC of the soil and finally California Bearing Ratio test to check the soil strength and stability From the test result, It was confirm that the sub-grade is so weak based on strength parameter
- Based on the visual inspection of the road different types of distresses were observed. The most dominant types of distresses observed were potholes, rutting, corrugation and impassibility as a result of gravel loss from the surface and erosion. The distresses from the road were categorized based on the extent and degree based on measurements and coverage of the overall road section and the sites that have high severity were selected for laboratory testing. b
- From the subgrade strength tests along the study area revealed that the subgrade has a weak material based on ERA design manual. The rest of the test results on subgrade have got a CBR of less than the one given on the standards and the subgrade strength has unsatisfactory, for the design class which classified under DS5. Therefore, it has a high problem with the pavement structural thickness to accommodate the current traffic.
- The comparison between the NMC on the subgrade and the OMC obtained from laboratory show that there is a variation or increase in the moisture content of the road

and it could be attributed to the poor drainage on the road or that there is an infiltration in the subgrade. The compaction required by the specification used ERA gravel road design manual is not met for the soil samples from the road this could be the result of poor compaction effort during the construction of the road

- The laboratory tests on the subgrade for the atterburg's limit show that the plasticity index of the subgrade is more than that is given by the specifications this could be related to the fewer amounts of fine materials in the subgrade. And some of the failures observed in the road are caused due to the loss of plasticity or binding in the soil. The tests conducted on the subgrade indicate that the subgrade is poor quality and not suitable for construction as it doesn't meet the minimum standards
- From the tests done on the gravel wearing course the grading requirement based on ERA manual is not met and there is variation on some sieves on the sieve no. 0.075 the wearing course material has more fines than required. The wearing course is also lightly compacted as it doesn't meet the compaction requirement and the moisture condition in the wearing course indicated that there is an infiltration in the road. This indicates that one of the findings of this research is the problem of drainage
- From the particle size distribution (gradation tests) on the gravel wearing course the material satisfies the grading requirement based on the ERA specification and the material is classified under poor graded to well grade sandy soil.
- Traffic data given showed that the design traffic AADT is less than the actual traffic for this traffic load section; hence, the road has been carrying traffic much more than design. The under loading of the road blow the design loading had not caused structural failure which can be easily maintained.

5.2 Recommendation

- To increase the performance of the gravel road the road layers must be compacted to the specified degree. Proper and adequate drainage systems must be provided this drainage systems could be side drains and cleaning of vegetation. In addition to this carefully managed maintenance programs with well executed maintenance operations result in far more satisfactory roads.
- Proper attention should be given the material used for construction although the core value of design for low volume road is using materials in the locality if the materials do not satisfy the strength requirements the use of stabilizers and blending of materials must be encouraged
- Proper attention should be given to the study on unpaved roads maintenance and optimization there are only few studies conducted in our country on unpaved roads and the focus is only on paving the roads but if properly constructed to the standards it should be known that unpaved roads are the best option for our country since we are rich in construction materials

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APENDICES

Appendix A: pavement condition assessment

Pavement failure quantification (source standard visual assessment manual for unpaved Roads)

Degree	Severity	Description
0	None	No distress visible
1	Slight	Distress difficult to discern. Only the first signs of distress are visible.
2	Between slight and warning	
3	Warning	Distress is distinct. Start of secondary defects. (Distress notable with respect to possible consequences. Maintenance might be required in near future e.g. potholes can be removed by blading)
4	Between warning and severe	
5	Severe	Distress is extreme. Secondary defects are well-developed (high degree of secondary defects) and/or extreme severity of primary defect. (Urgent attention required e.g. potholes require manual repair).

Extent	Description	Estimate (%)
1	Isolated occurrence, not representative of the segment length being evaluated. They are usually associated with localised changes in the material, subgrade or drainage conditions. Intersections, steep grades or sharp curves may also result in isolated occurrences.	< 5
2		5 – 20
3	Intermittent occurrence, over most of the segment length, or extensive occurrence over a limited portion of the segment length. When occurring over most of the segment length, problems are usually associated with the material quality or maintenance procedures. When occurring over limited portions, the problem is usually a result of local material variations or drainage problems.	20 – 60
4		60 – 80
5	Extensive occurrence. This is usually a result of poor quality or insufficient wearing course material, or inadequate maintenance.	80 - 100

Appendix B: Atterburg's test results

Liquid limit determination

station	trial	can name	n.blow	mc	mc+ms	mc+mds	mw	mds	w
17+400	1	F	35	36.35	54.51	50.33	4.18	13.98	29.9
	2	A2	27	36.96	56.73	49.99	6.74	13.03	51.73
	3	c-11	22	18.07	30.86	26.99	3.87	8.92	43.39
4+800	1	p1	35	32.03	44.68	41.22	3.46	9.19	37.65
	2	h2	20	17.71	38.74	30.74	8	13.03	61.4
	3	m	27	40.11	59.6	53.49	6.11	13.38	45.67
22+300	1	A-13	36	18.13	38.83	32.25	6.58	14.12	46.6
	2	P-65	24	37.75	57.83	50.95	6.88	13.2	52.12
	3	G-53	17	17.7	30.55	26.38	4.17	8.68	48.04
11+000	1	201	16	18.8	34.12	28.28	5.84	9.48	61.6
	2	p-1	26	18.03	35.12	29.05	6.07	11.02	55.08
	3	21-11	33	26	48.63	41.65	6.98	15.65	44.6
38+800	1	302	16	17.4	33.36	27.38	5.98	9.98	59.92
	2	p-12	20	14.6	36.32	29.15	7.17	14.55	49.28
	3	11	34	13.5	45.8	35.85	9.95	22.35	44.52
33+300	1	D7	18	19.2	32.3	27.28	5.02	8.08	62.13
	2	4	28	20.04	29.95	26.55	3.4	6.51	52.23
	3	BD51	32	24.4	36.56	32.65	3.91	8.25	47.39
26+600	1	9	31	20.34	32.4	27.48	4.92	7.14	68.91
	2	KL9	24	19.03	29.85	26.05	3.8	7.02	54.13
	3	H7	17	17.7	32.12	27.81	4.31	10.11	42.63
30+400	1	F4	18	19.56	26.4	24.28	2.12	4.72	44.92
	2	F5	25	22.36	32.6	29.15	3.45	6.79	50.81
	3	E3	31	25.5	42.6	35.65	6.95	10.15	68.47
41+000	1	25	15	22.4	41.8	34.28	7.52	11.88	63.3
	2	p-33	22	15.5	39.6	30.85	8.75	15.35	57
	3	G5	30	16.8	42.6	34.95	7.65	18.15	42.15

PLASTIC LIMIT DETERMINATION

station	trial	can name	mc	mc+ms	mc+m _{ds}	mw	m _{ds}	w	PL
17+400	1	G3	8.23	15.19	14	1.19	5.77	20.624	21.80
	2	ATR	6.48	17.56	15.49	2.07	9.01	22.974	
11+000	1	2	4.69	16.18	13.09	3.09	8.4	36.786	34.39
	2	7	4.78	12.95	10.97	1.98	6.19	31.987	
4+800	1	27	5.85	15.07	12.26	2.81	6.41	43.838	31.61
	2	R	3.42	15.8	13.79	2.01	10.37	19.383	
22+000	1	20	5.48	12.78	11.84	0.94	6.36	14.78	21.83
	2	30	7.87	13.373	12.14	1.233	4.27	28.876	
33+300	1	11	5.76	16.74	13.57	3.17	7.81	40.589	31.52
	2	9	4.02	15.8	13.64	2.16	9.62	22.453	
38+800	1	22	6.02	14.32	13.462	0.858	7.442	11.529	20.56
	2	PK4	8.54	15.487	13.901	1.586	5.361	29.584	
30+400	1	K9	8.765	16.46	14.87	1.59	6.105	26.043	26.44
	2	13	9.02	14.36	13.23	1.13	4.21	26.841	
26+600	1	PG	6.42	16.62	14.7	1.92	8.28	23.188	26.47
	2	16	10.02	14.84	13.735	1.105	3.715	29.744	
41+000	1	5	7.42	15.98	14.868	1.112	7.448	14.93	26.20
	2	ST1	8.88	16.84	14.67	2.17	5.79	37.478	

Liquid limit of the wearing course

Station	trial	can name	n.blow	mc	mc+ms	mc+m _{ds}	mw	m _{ds}	w
22+000	1.0	p	31.00	20.60	54.51	49.33	5.18	28.73	18.03
	2.0	km	24.00	22.60	56.73	50.99	5.74	28.39	20.22
	3.0	B6	18.00	18.07	30.86	26.99	3.87	8.92	43.39
38+800	1.0	V	35.00	19.60	44.68	39.22	5.46	19.62	27.83
	2.0	B23	20.00	15.30	38.74	30.74	8.00	15.44	51.81
	3.0	N1	27.00	20.90	45.30	39.40	5.90	18.50	31.89
11+000	1.0	A-13	36.00	16.40	35.37	31.05	4.32	14.65	29.50
	2.0	P-65	24.00	16.30	65.09	49.95	15.14	33.65	45.00
	3.0	G-53	17.00	17.60	29.14	25.18	3.96	7.58	52.30
4+800	1.0	GB	33.00	14.00	36.68	31.05	5.63	17.05	33.04
	2.0	O	22.00	19.50	64.11	49.95	14.16	30.45	46.50
	3.0	D2	15.00	16.80	29.39	25.18	4.21	8.38	50.20
17+400	1.0	RR	38.00	15.30	36.39	32.05	4.34	16.75	25.91
	2.0	B2	26.00	20.40	59.52	49.95	9.57	29.55	32.40
	3.0	13.00	19.00	14.80	28.88	24.28	4.60	9.48	48.47
26+600	1.0	LM1	30.00	13.50	58.62	47.62	11.00	34.12	32.24
	2.0	S23	35.00	19.50	42.36	37.86	4.50	18.36	24.51
	3.0	14.00	20.00	16.80	32.34	26.84	5.50	10.04	54.78

33+300	1.0	I	18.00	20.20	44.34	37.05	7.29	16.85	43.26
	2.0	LM	40.00	14.60	34.26	30.24	4.02	15.64	25.70
	3.0	S1	32.00	13.64	28.84	25.18	3.66	11.54	31.72
41+000	1.0	G-54	16.00	11.90	41.36	31.35	10.01	19.45	51.47
	2.0	13.00	35.00	10.32	60.65	50.23	10.42	39.91	26.10
	3.0	PL1	23.00	20.80	63.62	49.96	13.66	29.16	46.84
30+300	1.0	LL	37.00	10.92	36.68	30.85	5.83	19.93	29.27
	2.0	PM2	25.00	15.80	64.11	50.23	13.88	34.43	40.31
	3.0	BN	15.00	22.40	49.39	40.18	9.21	17.78	51.78

Plastic limit of the wearing course

STATION	TRIAL	can name	mc	mc+ms	mc+mds	mw	mds	w	PL
4+800	1	J3	11	16.5	15.39	1.11	4.39	25.285	25
	2	8	10.8	16.4	15.29	1.11	4.49	24.722	
11+000	1	MV	9.3	17	15.392	1.608	6.092	26.395	27.65
	2	32	11.6	17.8	16.41	1.39	4.81	28.898	
41+000	1	KL	8.3	15.6	14.31	1.29	6.01	21.464	23.7
	2	4	12.4	19.2	17.8	1.4	5.4	25.926	
38+800	1	N3	8.4	17.92	16.19	1.73	7.79	22.208	24.16
	2	BK	10.2	15.32	14.26	1.06	4.06	26.108	
33+300	1	C3	12.1	16.8	15.76	1.04	3.66	28.415	29.58
	2	15	10.6	16.68	15.25	1.43	4.65	30.753	
17+400	1	TR-4	10.2	18.6	17.8	0.8	7.6	10.526	18.27
	2	TT	8.04	14.82	13.42	1.4	5.38	26.022	
30+400	1	5	13.4	19.96	18.54	1.42	5.14	27.626	20.03
	2	BR-3	12.6	16.4	15.98	0.42	3.38	12.426	
22+000	1	40	14.2	20.64	19.27	1.37	5.07	27.022	23.25
	2	H2	7.9	12.44	11.7	0.74	3.8	19.474	
26+600	1	G4	9.88	17.36	15.9	1.46	6.02	24.252	24.76
	2	GG	13	16.5	15.8	0.7	2.77	25.271	

Appendix C: Proctor test results

Station 4+800

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w	wav	mass of sample	volume	gwet	gdry
1	4058	5689	A2	36.8	151.4	128.4	23	91.6	25.109	25.2	1631	994	1.6408	1.3101
			B	31.2	80.1	70.2	9.9	39	25.385		1631	994	1.6408	
2	4058	5825.8	P15	33.3	176	143.4	32.6	110.1	29.609	29	1767.8	994	1.7785	1.3785
			P4	24.4	126.5	103.9	22.6	79.5	28.428		1767.8	994	1.7785	
3	4058	5812	E	37.8	149.7	123.9	25.8	86.1	29.965	30.2	1754	994	1.7646	1.3551
			P8	19.1	115	92.6	22.4	73.5	30.476		1754	994	1.7646	
4	4058	5738.3	HC11	17.7	153.3	114.7	38.6	97	39.794	40	1680.3	994	1.6904	1.2079
			4-	17.6	118.2	89.4	28.8	71.8	40.111		1680.3	994	1.6904	

Station 11+000

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w	wav	mass of sample	volume	gwet	gdry
1	4058	5749	II	17.4	140.7	116.3	24.4	98.9	24.671	24.6	1691	994	1.7012	1.365
			SM	17	93.5	78.4	15.1	61.4	24.593		1691	994	1.7012	
2	4058	5848	A	17.4	105.1	85.2	19.9	67.8	29.351	29.6	1790	994	1.8008	1.3891
			T2C2	17.1	112.2	90.3	21.9	73.2	29.918		1790	994	1.8008	
3	4058	5815	T-11	17.3	88.7	70.5	18.2	53.2	34.211	34.5	1757	994	1.7676	1.3138
			P5	37.6	110.7	91.8	18.9	54.2	34.871		1757	994	1.7676	
4	4058	5752	3	17.1	90.3	69.8	20.5	52.7	38.899	39.3	1694	994	1.7042	1.2232

			D	17.4	86.3	66.7	19.6	49.3	39.757		1694	994	1.7042	
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Station 17+400

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4075	5698	11	17.3	99.1	83.3	15.8	66	23.939	24	1623	994	1.6328	1.3164
			P5	17.8	95.5	80.4	15.1	62.6	24.121		1623	994	1.6328	
2	4075	5872	10G	17.6	83	68.9	14.1	51.3	27.485	27.5	1797	994	1.8078	1.4178
			101	17.9	95.7	78.9	16.8	61	27.541		1797	994	1.8078	
3	4075	5852	P4	18.6	91.4	73.4	18	54.8	32.847	32.9	1777	994	1.7877	1.345
			4	17.3	83	66.7	16.3	49.4	32.996		1777	994	1.7877	
4	4075	5803	P15	25.3	139.7	109.1	30.6	83.8	36.516	36.7	1728	994	1.7384	1.2721
			C7	25.2	110.7	87.7	23	62.5	36.8		1728	994	1.7384	

Station 22+000

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4075	5860	F	36.3	220	199.8	20.2	163.5	12.355	12.4	1785	994	1.7958	1.5983
			WX	17.8	136.9	123.8	13.1	106	12.358		1785	994	1.7958	
2	4075	5985	C11	18	117.2	101.4	15.8	83.4	18.945	19.3	1910	994	1.9215	1.6113
			P6	17	116	99.8	16.2	82.8	19.565		1910	994	1.9215	
3	4075	5904	J41	32.6	145.9	125.5	20.4	92.9	21.959	22.4	1829	994	1.84	1.5032
			G	17.8	118.3	99.6	18.7	81.8	22.861		1829	994	1.84	
4	4075	5873	C1	18.7	101	84.6	16.4	65.9	24.886	25	1798	994	1.8089	1.4472
			P2	17.4	84.2	70.8	13.4	53.4	25.094		1798	994	1.8089	

Station 30+400

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4075	5879.00	MC1	35.80	224.00	180.60	43.4	144.8	29.972	17.9	1804	994	1.8149	1.5389
			C12	16.80	129.90	123.60	6.3	106.8	5.8989		1804	994	1.8149	
2	4075	5957.00	P7	16.80	116.20	96.20	20	79.4	25.189	20.2	1882	994	1.8934	1.5753
			J21	16.40	114.20	101.30	12.9	84.9	15.194		1882	994	1.8934	
3	4075	5884.00	G3	31.60	148.30	123.80	24.5	92.2	26.573	23.7	1809	994	1.8199	1.471
			C12	15.80	121.80	103.50	18.3	87.7	20.867		1809	994	1.8199	
4	4075	5842.00	P3	19.60	109.60	88.30	21.3	68.7	31.004	30.6	1767	994	1.7777	1.3614
			12	17.40	86.90	70.80	16.1	53.4	30.15		1767	994	1.7777	

Station 33+300

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4058	5749	G4	18.4	143.7	116.3	27.4	97.9	27.988	29.7	1691	994	1.7012	1.3116
			KL7	17.6	97.5	78.4	19.1	60.8	31.414		1691	994	1.7012	
2	4058	5847	24	18.4	107.1	85.2	21.9	66.8	32.784	31.8	1789	994	1.7998	1.3658
			B4	19.1	112.2	90.3	21.9	71.2	30.758		1790	994	1.8008	
3	4058	5813	C2	18.3	89.7	70.5	19.2	52.2	36.782	34.9	1755	994	1.7656	1.3087
			PL1	34.6	110.7	91.8	18.9	57.2	33.042		1757	994	1.7676	
4	4058	5758	B7	15.1	93.3	69.8	23.5	54.7	42.962	39.2	1700	994	1.7103	1.2288

			A4	17	84.3	66.7	17.6	49.7	35.412		1694	994	1.7042	
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Station 26+600

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4058	5750	L2	16.5	142.7	116.3	26.4	99.8	26.453	29.1	1692	994	1.7022	1.3189
			V14	15.9	98.2	78.4	19.8	62.5	31.68		1691	994	1.7012	
2	4058	5852	KK	17.6	106.8	85.2	21.6	67.6	31.953	30.5	1794	994	1.8048	1.3829
			BB	16.7	111.7	90.3	21.4	73.6	29.076		1790	994	1.8008	
3	4058	5820	DD	18.9	90.1	70.5	19.6	51.6	37.984	35.4	1762	994	1.7726	1.3088
			21	37.4	109.7	91.8	17.9	54.4	32.904		1757	994	1.7676	
4	4058	5762	W6	14.9	94	69.8	24.2	54.9	44.08	40.6	1704	994	1.7143	1.2195
			10	16.8	85.2	66.7	18.5	49.9	37.074		1694	994	1.7042	

Station 38+800

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4075	5870	MB	34.6	218.8	200	18.8	165.4	11.366	13.6	1795	994	1.8058	1.5896
			SA	18.8	140.9	124.2	16.7	105.4	15.844		1795	994	1.8058	
2	4075	5990	AN	19.8	119.2	100.6	18.6	80.8	23.02	20	1915	994	1.9266	1.6052
			MB1	19.7	114.6	100.8	13.8	81.1	17.016		1915	994	1.9266	
3	4075	5910	NN	30.6	150	123.5	26.5	92.9	28.525	26.7	1835	994	1.8461	1.457
			MK	14.8	119.2	98.4	20.8	83.6	24.88		1835	994	1.8461	

4	4075	5880	RB2	17.7	110.3	88.6	21.7	70.9	30.606	30.8	1805	994	1.8159	1.3879
			MA	16.8	90.2	72.8	17.4	56	31.071		1805	994	1.8159	

Station 41+000

trial	m/mold(g)	m mold+sample	can code	can mass	mc+wt	mc+dr	mass of water	mass of dry	w		mass of sample	volume	gwet	gdry
1	4075	5710	7	25.4	99.1	83.3	15.8	57.9	27.288	25.7	1635	994	1.6449	1.3085
			33	17.8	95.5	80.4	15.1	62.6	24.121		1635	994	1.6449	
2	4075	5908	J7	17.6	83	68.9	14.1	51.3	27.485	27.5	1833	994	1.8441	1.4462
			B6	17.9	95.7	78.9	16.8	61	27.541		1833	994	1.8441	
3	4075	5910	D3	18.6	91.4	73.4	18	54.8	32.847	32.9	1835	994	1.8461	1.3888
			H6	17.3	83	66.7	16.3	49.4	32.996		1835	994	1.8461	
4	4075	5870	T4F5	25.3	139.7	109.1	30.6	83.8	36.516	36.7	1795	994	1.8058	1.3214
			CC	25.2	110.7	87.7	23	62.5	36.8		1795	994	1.8058	

Appendix D: CBR test results

Compaction Determination @ 22+300										
COMPACTION DATA	65 Blows			30 Blows			10 Blows			
	Before soak		After soak	Before soak		After soak	Before soak		After soak	
Mould No.	F1		F1	F2		F2	F3		F3	
Mass of soil + Mould	g	8338.2	8410.7	8090.7	8143.5	10257.9	10359			
Mass Mould	g	4201.8	4201.8	4156.1	4156.1	6566.5	6566.5			
Mass of Soil	g	4136.4	4208.9	3934.6	3987.4	3691.4	3792.5			
Volume of Mould	g	2124	2124	2124	2124	2124	2124			
Wet density of soil	g/cc	1.947	1.982	1.852	1.877	1.738	1.786			
Dry density of soil	g/cc	1.494	1.424	1.399	1.385	1.315	1.289			
Moisture Determination										
MOISTURE CONTENT DATA	65 Blows			30 Blows			10 Blows			
	Before soak		After soak	Before soak		After soak	Before soak		After soak	
Container no.	22	T	43	N	19	38	S1	21	34	
Mass of wet soil + Container	g	182.4	152.8	177.7	120.7	177.5	146.9	163.7	154.0	194.1
Mass of dry soil + Container	g	149.0	124.1	138.0	95.0	143.7	118.0	130.5	122.9	150.6
Mass of container	g	40.4	28.5	36.5	17.7	36.6	36.6	28.8	25.3	37.7
Mass of water	g	33.4	28.7	39.7	25.7	33.8	28.9	33.2	31.1	43.5
Mass of drysoil	g	108.6	95.6	101.5	77.3	107.1	81.4	101.7	97.6	112.9
Moisture content	%	30.8	30.0	39.1	33.2	31.6	35.5	32.6	31.8	38.6
Average moisture content										
*/	%	30.4	39.1	32.4	35.5	32.2	38.6			

CBR Penetration Determination

65 Blows				30 Blows				10 Blows			
Pen.mm	Load, KN	Stress, Mpa	CBR %	Pen.mm	Load, KN	Stress, Mpa	CBR %	Pen.mm	Load, KN	Stress, Mpa	CBR %
0.00	0.001	0.001		0.00	0.000	0.000		0.00	0	0.000	
0.63	0.372	0.192		0.63	0.277	0.143		0.63	0.204	0.105	
1.27	0.744	0.384		1.27	0.561	0.290		1.25	0.512	0.265	
1.91	1.209	0.625		1.91	0.797	0.412		1.88	0.612	0.316	
2.54	1.433	0.741	10.73	2.54	0.948	0.490	7.10	2.54	0.882	0.456	6.61
3.81	1.929	0.997		3.81	1.120	0.579		3.75	1.051	0.543	
5.08	2.195	1.134	11.01	5.08	1.249	0.645	6.27	5.08	1.175	0.607	5.88
7.62	2.618	1.353		7.62	1.469	0.759		7.50	1.364	0.705	
10.00	2.963	1.531		10.00	1.679	0.868		10.00	1.519	0.785	
12.50	3.282	1.696		12.50	1.896	0.980		12.50	1.665	0.860	
Modified Max.Dry Density g/cc			1.418	OMC %			27.5				
Swell Determination											
Date		65 Blows		30 Blows		10 Blows					
		Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %	Gauge rdg mm	Swell in %				
#REF!	Initial	20.11	1.21	25.92	0.79	18.58	0.57				
#REF!	Final	21.52		26.84		19.24					

for Contractor

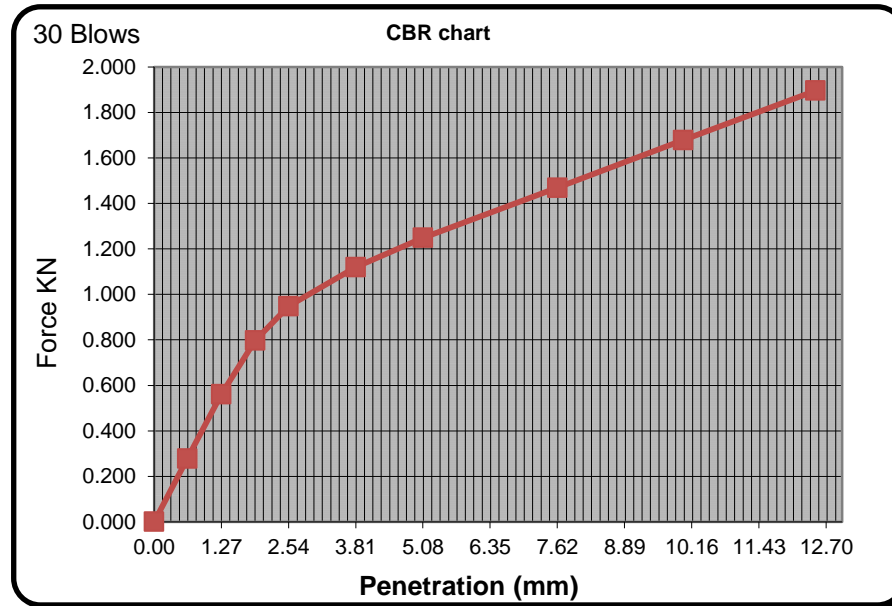
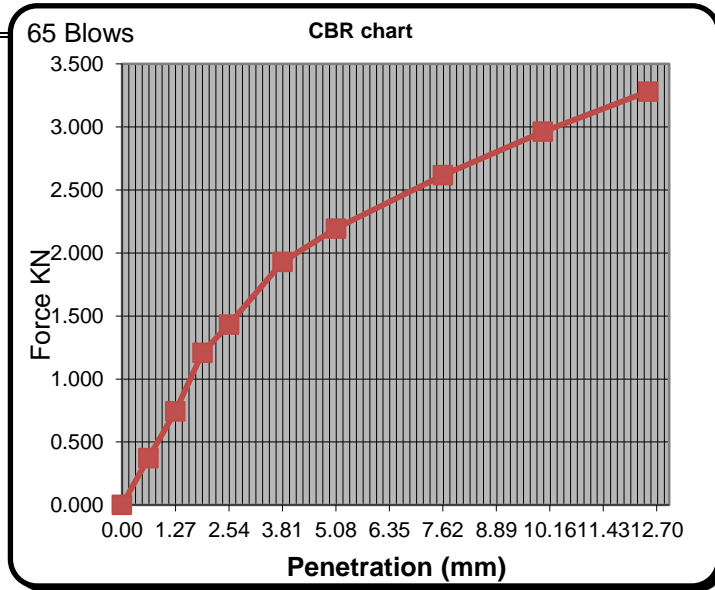
For Consultant

Lab. Tech.

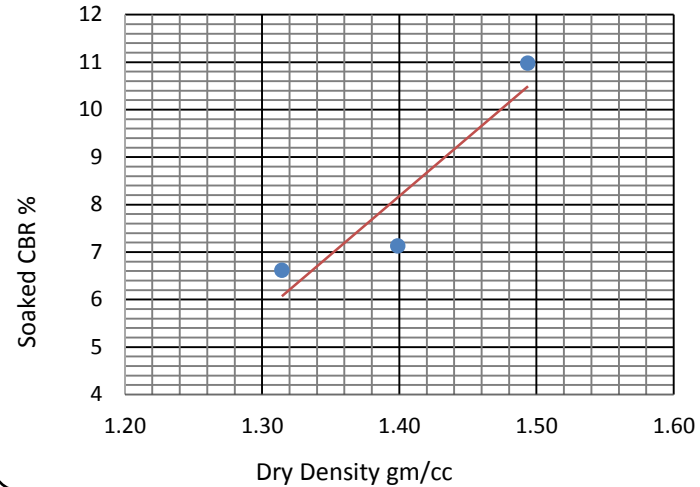
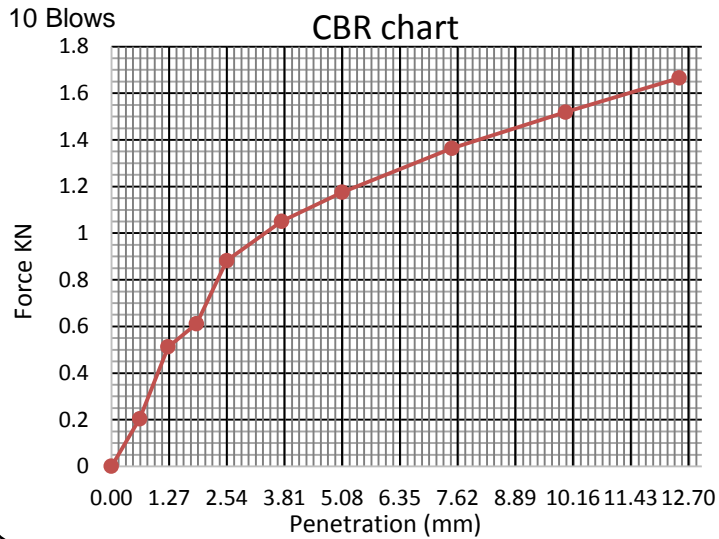
Material Engineer

Lab. Tech.

P/Material Engineer



Penetration (mm)	Load KN		Corr. CBR %	Swell %	Penetration (mm)	Load KN		Corr. CBR %	Swell %
	Top	Bottom				Top	Bottom		
2.54mm		1.4	10.8	1.21	2.54mm		0.9	7.1	0.79
5.08mm		2.2	11.0		5.08mm		1.2	6.2	



Dry Density at 95% of MDD:

1.35

Penetration (mm)	Load KN		Corr. CBR %	Swell %	No.of blows	MCBS %	DDBS g/cm ³	Correect CBR %	% OF Compaction
	Top	Bottom							
2.54mm		0.9	6.6	0.57	10	32.2	1.31	6.6	93
					30	32.4	1.40	7.1	99
5.08mm		1.2	5.9		65	30.4	1.49	11.0	105

CBR % at 95 % MDD	7.0	Swell %	0.79
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