JIMMA UNIVERSITY

SCHOOL OF GRADGUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

DEPARTMNT OF CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING CHAIR

Investigation of the Effects of Geogrid Reinforcement in Flexible Asphalt Pavement Layers using Numerical analysis method: The case of Jimma to Sekoru road Corridor, South Western Ethiopia

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY, DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN GEOTECHNICALENGINEERING.

BY

TIGIST MEZMUR

JANUARY, 2020

JIMMA ETHIOPIA

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BY

TIGIST MEZMUR

MAIN ADVISOR: EMER T. QUEZON, P.ENG (Professor)

CO ADVISOR: DAMTEW TSIGE (PhD)

JANUARY, 2020

JIMMA ETHIOPIA

DECLARTION

I, the undersigned, declare that this thesis entitled "**Investigation of the Effects of Geogrid Reinforcement in Flexible Asphalt Pavement Layers using numerical analysis method: The case of Jimma to Sekoru road section, South Western Ethiopia**" 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 theses have been duly acknowledged.

Candidate:

TIGIST MEZMUR

Signature___________________________Date___________________

As Master research Advisors, we hereby certify that we have read and evaluated this MSc. research prepared under our guidance, by TIGIST MEZMUR entitled "**Investigation of the Effects of Geogrid Reinforcement in Flexible Asphalt Pavement Layers using numerical analysis method: The case of Jimma to Sekoru road section, South Western Ethiopia**" We recommend that it can be submitted as fulfilling the MSc

Thesis requirements.

Main adviser: Prof. Emer T. Quezon, P.Eng

Signature___________________________Date_15/1/2020

Co- Adviser. Damtew Tsige (PhD)

Signature___________________________Date___________

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ABSTRACT

A flexible pavement is a load bearing structure, consisting of layers of different granular materials above the earth. There are factors that affect this structure, such as, increasing traffic intensity; high tire pressure, increasing axle loads, weak subgrade material, are causing early signs of distress on bituminous pavements throughout the world. The road segment of the study area is affected due to the presence of week subgrade material (existence of expansive soil) as well as the presence of shallow groundwater. Therefore, the study aims to conduct the effect of geogrid in flexible asphalt pavement using numerical analysis method. To achieve the objective of the study the following activities were conducted (i) survey of the pavement surface condition, (II) assessment of engineering properties of pavement layers, (iii) conducting pavement analysis by incorporating the effect of geogrid reinforcement on pavement layers by taking into consideration the influence of geogrid location and groundwater fluctuations.

From site investigation, rutting and longitudinal crack was recorded as high sever condition on the section. From PLAXIS 2D analysis, significant improvement in pavement stabilization was observed using geogrid. The effectiveness of geogrid were obtained at the interface between sub-base and base course, sub-base and sub-grade of pavement. As a result 10.29% reduction in total deformation was observed for road section having block cotton soil as subgrade when geogrid was reinforced between sub base and sub grade. But for road having red clay as subgrade soil, 9.13% total deformation reduction was observed with the same geogrid reinforcement. Comparatively a high deformation was observed when the ground water level was reached at subgrade surface and 33.33% increment was shown for road with block cotton soil at subgrade and 35.71% increment was also shown for road with red clay as subgrade. Therefore the geogrid material was effectively stabilize the pavement layers.

Key Words: Distress, Expansive soil, Flexible Pavement, Geogrid, Plaxis 2D, Reinforcement,

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

ACRONYMS

ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
ERCC	Ethiopian Road Construction Corporation
ERA	Ethiopia road authority
ESAL	Equivalent standard axle load
FEA	Finite Element Analysis
FEM	Finite Element Method
GW	Ground Water
MC	Mohr-Coulombs
PCS	Pavement Conditions Survey
USCS	Unified Soil Classification System
2D	Two Dimensional

CHAPER ONE

INTRODUCTION

1.1. BACKGROUND

Road is the most important infrastructure, that provides access to rural and urban areas and it plays crucial role to reduce transportation costs and support economic growth through enhancement of passenger and freight movements.

Ethiopia's road network has increased from 26,550 km in 1997 to 113,066 km in 2016 (an increase of 326 percent). As a result, the road density per 1,000 sq. km has increased from 24.1 km in 1997 to 102.8 km in 2016 [1].

Nowadays, most of the road type that constructed in Ethiopia is flexible pavement. Flexible pavements are most commonly used for low to medium volume roads with significant usage also found in high volume interstate highways and airfield runways, taxiways and aprons subjected to heavy aircraft gear/wheel loads. Flexible pavements transfer wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure. The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth [2].

There are different factors that affect the performance of flexible pavement, such as under the Traffic case, the loading magnitude, configuration and the number of load repetitions by heavy vehicles, infiltration of moisture (water) can significantly weaken the support strength of natural gravel materials [3]. The presence of those factor had a great effect on the reduction of the pavement life (reduce durability) of the pavement.

Jimma to Sekoru road is one of the section of Addis Ababa to Jimma road, is one of investigated road section under this main trunk road. Which is the main trunk road and it is flexible pavement type that connect Oromia region with Southern Nation and Nationality. And it was initially constructed by Italians, in 1930 G.C. Since 1998G.C the road is under rehabilitation.

The sub grade condition of this section shows that it is covered with expansive soil and red clay soil. So this is the fact that many road failure, such as, cracks, deformation and potholes are may be caused by presence of such types of soil in large amount. Because, the properties of the expansive soils vary from place to place due to topography, climate, geological history and formation [4].

Several researchers have done studies the effect of geogrid-reinforced pavement over the structural performance of roads through laboratory, field, and finite element methods and the result shows that when the pavement layer reinforced with the geogrid having high axial stiffness the vertical deformation (rutting) is decreased and the pavement layer improve the bearing capacity(increase the bearing capacity) [5].

1.2. Problem Statement

Distribution of expansive soil is generally a result of geological history, sedimentation and local climatic conditions. In Ethiopia, covering nearly 40% surface area of the country , expansive soils are observed in area such as central Ethiopia, following the major trunk road like Addis Ababa - Ambo, Addis Ababa - Weliso, and the most Southern, Addis Ababa – Jimma and south-east part of the capital Addis Ababa area in which the most major recent construction are being carried out [6].

The fact that expansive soils are a major engineering problem. It made this study an important research aspect due to the accruing cost involved in terms of economic loss when construction is undertaken without due consideration to the probability of their presence. The biggest problem is the presence of differential water content due to seasonal variations within the locality. Expansive soil had changed their behavior when it contacts with water, so such variation of behavior affect the performance of the pavement [6,4]. Due to expansiveness of the soil under the Pavement layers, it decreases the serviceability caused by the development of surface distresses such as cracks, potholes and ruts [7].

Different scholars are trying to stabilize (reinforced) such type of weak soil with geosynthetics material, especially with geogrid. Because when such soil reinforced with geogrid, the water will be drained easily and the bearing capacity of the soil is improved. In addition, a geogrid material had the ability to increase fatigue resistance, reduce rutting and limit reflective cracking when properly used [8].

Hence, this research focused on the different factors causing deformation of pavement layers by using finite element method, including the selection of the best geogrid location for the selected pavement layers.

1.3. Research Questions

The research questions that this study sought to answer are as follows.

1. What are the factors responsible for pavement distress/failure?
2. Can geogrid reinforcement enhances the stability of pavement?
3. What factors influences the effectiveness of geogrid reinforcement?
4. Can geogrid reinforcement makes sustainable within the pavement design life?

1.4. Objectives

1.4.1 General Objective

The general objective of the study is to evaluate the effects of Geogrid in flexible asphalt pavement using numerical method/PLAXIS 2D analysis. .

1.4.1 Specific Objectives

- To identify the different types of distresses and evaluate its severity level
- To assess the engineering properties of the different pavement layers
- To conduct sensitivity analysis considering geogrid location, number of geogrid layers and ground water condition.
- To validate the effect of geogrid reinforcement in stabilization of pavement failure

1.5. Significance of the study

Effectiveness of geogrid materials in flexible pavement reinforcement was investigated throughout finite-element analysis (FEA). The analysis was carried based on the current pavement layers engineering properties and evaluate the effectiveness and location of geogrid on the sections.

Addis Ababa to Jimma road section is one of the major road section that need a grate maintenance and reconstruction. Still now some section from this major road has been under maintenance and Jimma to Sekoru road section is one of the section that ERA put it to be reconstructed. Therefor the stakeholders such as ERA (Ethiopian Road Authority) and ERCC (Ethiopian Road Construction Corporation) use the result of the finding to go for their aim of maintenance and reconstruction.

In addition to this research would be plat form for the research institutions, because such type of research wasn't done before.

1.6. Scopes of the Studies

This research was focused particular on investigation of effectiveness of geogrid by evaluating the vertical deformation only. But there are some base points before evaluation, such as:

- Exploring some of pavement surface condition and rating the severity level. This is important only to know how much damaged and used to identify types of distress.
- Determining engineering properties of each pavement layers. This is not conducted in field or laboratory, hence the values were taken from ERA and USCS.
- Properties of geogrid materials also taken from journals based on ERA manual and subgrade soil properties.
- Based on the plaxis 2D software output values compare and evaluate the vertical deformation of geogrid reinforced and un-reinforced section on both dry and wet season. But rainfall data's were not considered in this research
- Lastly at which layer does geogrid decrease the vertical deformation on both section?

Finally conclusions and recommendation were listed based on the results as per the specific objectives.

CHAPTER TWO

LITRATURE REVIEW

2.1 Introduction

A flexible pavement is a load bearing structure, consisting of layers of different granular materials above the earth. According to Ethiopian road authority (ERA 2013) manual flexible pavement is defined that ,it is simply a pavement that does not include a layer of high strength concrete, it include pavements with unbound granular aggregate layers and pavements with aggregate layers that are bound together with bitumen. Making a safe riding base without any discomfort for the passenger and vehicles due to excessive deformation of pavement structures, that is the primary function of flexible pavement. The objective of flexible pavement design is, to avoid the excessive flexing of any layer, failure to achieve this will result in the over stressing of a layer, which ultimately will cause the pavement to fail. In flexible pavements, the load distribution pattern changes from one layer to another, because the strength of each layer is different. The strongest material (least flexible) is in the top layer and the weakest material (most flexible) is in the lowest layer. The reason for this is that at the surface the wheel load is applied to a small area, the result is high stress levels, deeper down in the pavement, the wheel load is applied to larger area, and the result is lower stress levels thus enabling the use of weaker materials. Some pavement parameters such as pavement layers thickness, quality of pavement materials and environment conditions affect the pavement durability [3, 5, 9,].

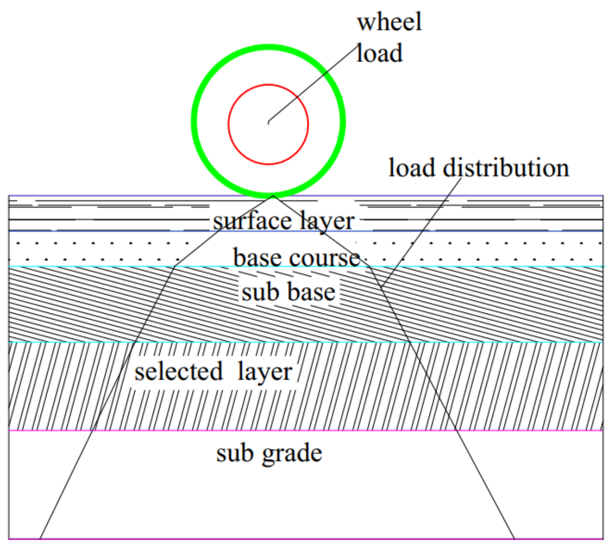

Figure 2.1: Load distribution of flexible pavement (11)

2.2 Factors That Affect Flexible Pavement

There are different factors that affect flexible pavement, among this, increasing traffic intensity, high tire pressure, increasing axle loads etc. are causing early signs of distress to bituminous pavements throughout the world. Permanent deformation cause rutting that affect vehicle steering and the deep rutting also causes longitudinal cracks where they drain free water into the underlying pavement layer, which means indirectly it increase deterioration rate. The deterioration of the paved roads in tropical and subtropical countries differs from those in the more temperate regions of the world. This can be due to the harsh climatic conditions and sometimes due to the lack of good pavement materials and construction practices. (10, 11)

The deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. It is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles. Moisture (water) may enter through the cracks and holes that arise on the pavement surfaces, this may cause weakening of the support strength of natural gravel, especially the subgrade and also from the underlying water table through capillary action.

If the subgrade is too weak to support the wheel loads, the pavement will flex excessively which ultimately causes the pavement to fail. If natural variations in the composition of the subgrade are not adequately addressed by the pavement design, significant differences in pavement performance will be experienced. Failure to obtain proper compaction, improper moisture conditions during construction, quality of materials, and accurate layer thickness (after compaction) all directly affect the performance of a pavement. (3, 9)

2.3. Common Flexible Pavement Distresses

One of the most common problems afflicting flexible pavements is cracking of the asphalt surface. The rapid reappearance of these cracks through an asphalt surface that is laid directly over them is a well-known phenomenon that must be solved [9].

According to [12] the defects on pavements, usually quantified through pavement condition survey, can be classified into three major modes of distress, cracking (fracture), disintegration and Permanent deformation.

Table 2.1 shows types of distress, its cause with brief description and figure 2.2 also show some of flexible pavement distress types that frequently seen.

Table 2.1 Types of distress and its cause [12].

Mode	Type	Brief Description	Primary cause
Cracking	Alligator	Interconnected polygon of less than 300mm diameter	traffic
	Longitudinal	Line crack longitudinal along pavement	Material/climate
	Transversal	Line crack transverse along pavement	Material/climate
	Block	Intersecting line crack in rectangular pattern	Material/climate
Disintegration	Raveling	Loss of stone particles from surface	Material/climate
	Rutting	Open cavity in surface >150mm diameter and >50mm depth	traffic
	Edge break	Loss of surface at the edge	traffic
Deformation	Rut	Longitudinal depression in wheel path	Traffic
	Depression	Bowl shape depression	Material/climate
	Mound	Localized rise of surface	Material/climate
	Corrugation	Transverse depression at close spacing	Material/climate
	Undulation	Transverse depression at lunge spacing>5m	Material/climate
	roughness	Irregularity of pavement surface in wheel path	Traffic/ Material/clim

Most of the time such types of distress was seen after construction of pavements. This means when the pavement is opened for traffic. Thus, distress is the combined factor of traffic load (wheel load) and environmental condition of the given area.

Figure 2.2 Flexible pavement distress [14]

2.4. Geosynthetics

Geosynthetics are a class of geo-materials that are used to improve soil conditions for a number of applications. They consist of polymeric materials manufactured in different forms The most common applications to roads are for reinforcing embankments and foundation soils, creating barriers to water flow in liners and cut-offs, and improving drainage. [13].

The geosynthetics products most commonly used in roadway systems include geotextiles (woven and non-woven) and geogrids (biaxial and multi-axial), although erosion-control products, geo-cells, geo-nets (or geo-composite drainage products) and geo-membranes have also been incorporated in a number of applications These various types of geosynthetics can be used to fulfill one or more specific functions in a variety of roadway applications. For example, geosynthetics have been in use since the 1970s to improve the performance of unpaved roads on soft subgrade soils [14, 15].

2.5. General Function of Geosynthetics

The three primary uses of a geosynthetics in a pavement system are to serve as a construction aid over soft subgrades, improve or extend the estimated service life of the pavement, and reduce the thickness of the structural cross section for a given design period.[13]. Some or all of these objectives are normally achieved through at least one of the four functions and figure 2.3 clearly demonstrate the function of geosynthetics.

- **Separation**: it placed between two dissimilar materials to maintain the integrity and functionality of the two materials. It may also involve providing long-term stress relief
- **Filtration**: it use to allow liquid flow across its plane, while retaining fine particles on its upstream side.
- **Reinforcement**: The geosynthetics develops tensile forces intended to maintain or improve the stability of the soil geosynthetics composite and the geosynthetics tensile strength property must be properly determined before use.
- **Stiffening**: The geosynthetics develops tensile forces intended to control the deformations in the soil-geosynthetics composite [15].

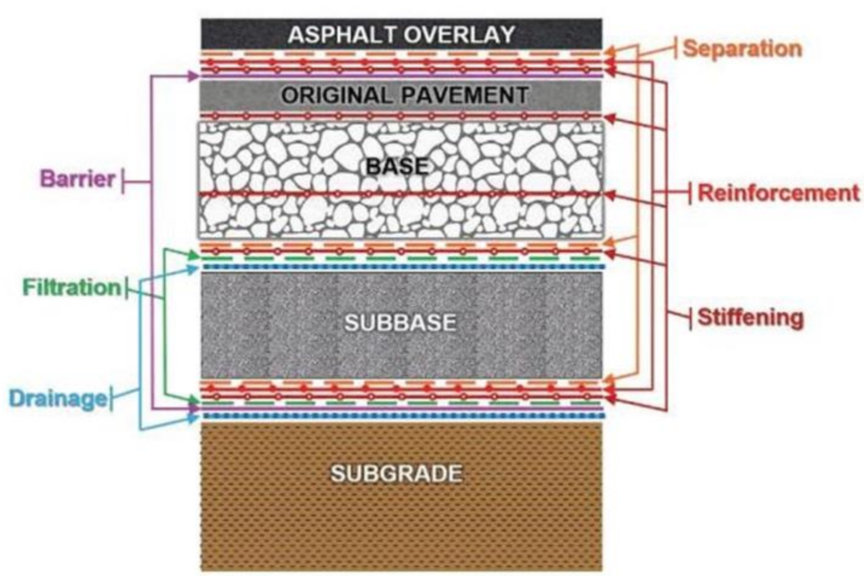

Figure 2.3 Function of geosynthetics on asphalt pavement [15]

2.6. Types of Geosynthetics

There are different types of geosynthetics with their different function. The following table 2.2 gives more information about them, for instance geotextile, geogrids and geonets has used as a separators, this shows that such types of geosynthetics have the same function even if they made from different material and figure 2.4 shows types of geosynthetics diagrammatically.

Table 2.2 Types of geosynthetics and their function [5, 15]

Type of geosynthetics	Description	function
Geotextile	Woven and non-woven type	separators, filters drainage layers
Geogrids	There are different types of geogrid are used in worldwide such as plastic, triaxial, Biaxial, uniaxial	Separation ,reinforcement and filtration
Geonets	Made from polymers, plastic type of geonets were largely used	Separation ,filtration
Geosynthetic clay liners (GCLs):	Made of clay bonded to a single geosynthetics layer or to multiple geosynthetic layers.	hydraulic barriers
Geomembranes	polymeric material	separation
Erosion control materials	degradable and non-degradable products	work with accompanying vegetation to form a bio-composite solution to erosion

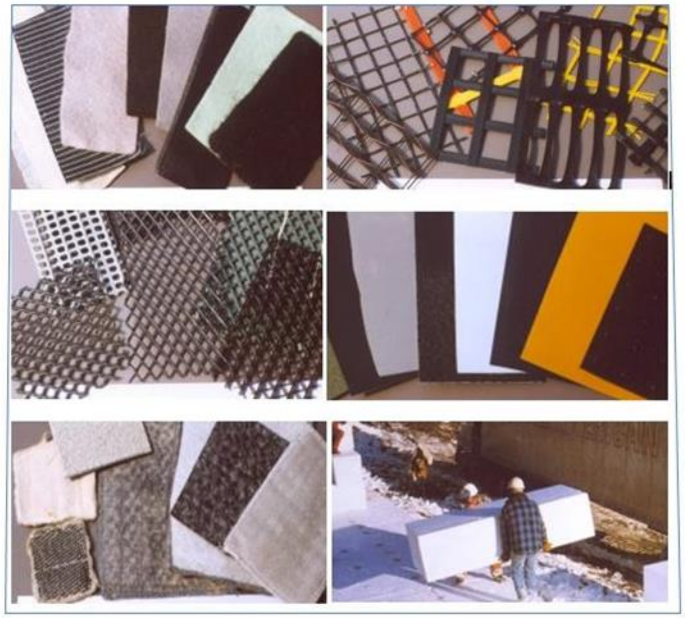

Figure 2.4 Types of geosynthetics [15].

2.7. Use of Geosynthetics for Road Construction

In many ground-engineering problems, geosynthetics are mainly required to perform its function in full capacity, only for a limited duration: for example, within temporary haul roads, basal reinforcements for new embankments, vertical drainage to increase shear strength, etc. Among different geosynthetics a geotextile is one of it and it can perform one or several functions to improve the mechanical and or hydraulic behavior of the structure in which it is incorporated, for instance using the coir-geotextile reinforcement is a superior solution for the construction of roads on weak subgrade soils. [16]

Geosynthetics clay liners (GCLs) are also used as environmental protection barriers in transportation facilities (roads and railways) and geotechnical applications such as minimizing pollution of subsurface strata from accidental spills and seepage of chemicals from road accidents. [17]

According to [18] the geo-cell- reinforcement reduced the vertical stresses transferred to the subgrade by distributing the load over a wider area and base sections and the base sections over moderate subgrade showed a stable response whereas the unreinforced base over weak subgrade showed unstable response.

Expanded Polystyrene (EPS) Geo-foam has a remarkably high strength-to density ratio and the standard material types available worldwide are capable of supporting long-term compressive stresses up to approximately 100 KPa (2000 lb/ft2). Because of its uniquely low density, the use of EPS as lightweight fill generally does not require using additional ground improvement techniques such as preloading or soil mixing when soft ground conditions exist at a project sire. [19]

In addition to this now a days different countries are use geogrid as a reinforcement material for road construction and it is used to increase stability and improve performance of soft and weak subgrade in roadways. If it is placed between pavement layers, it provides subgrade restraint, stabilizes aggregate particles, and increases the bearing capacity of a pavement structure. Due to the wide application of this technique, many experimental and analytical studies have been conducted to assess and potentially quantify the improvements associated with geogrid base reinforcement of roadways [20].

2.8. The importance of Geogrid reinforcement on Flexible Asphalt Pavement

The quality of materials for subgrade, sub-base and base has a great effect on the life of pavement. The nature of subgrade soil has the most important effect among other materials. There is a real concern in construction flexible pavements over a weak subgrade and the California bearing ratio (CBR) is critical parameter and very low for such soils. Therefore, pavement constructed on such problematic soil needs improvement [21]. Now a days many scholars are use geogrid as reinforcement for flexible asphalt pavement because, geogrids are very good in improving shear strength properties when used as a reinforcement with construction and demolition materials. In addition, when geogrid is used as reinforcement on pavement layer it make the pavement layer stiffer and reduces the deformation due to repeated wheel loads and it provides lateral confinement to resist the lateral movement of aggregates by the interlocking effect that happens between geogrid openings and surrounding aggregates. The presence of geogrid affects the resilient behavior of stabilized bases and benefits the stabilized bases by reducing permanent deformations (i.e. rutting) [22, 23, and 24].

Prof Vikram, J.P and et.al conduct their studies on one of Indian place called Shirpur city which is highly affect by the heavy ground water and high pavement failures was also happened due to the presence of ground water on this area. To reduce such problem on the pavement they use geogrid as reinforcement to stabilize the soil and to decrepit water from the road. In the previous history of the area there was traditional practices to undercut and stabilization soils but this solution is often costly and always time-consuming.

Geogrids are often used as a replacement for these traditional solutions and it helps to increase the bearing capacity of the subgrade soil while greatly reducing the loss of the aggregate cover material into weak, wet, or saturated subgrade soils. The use of geogrid also provides, extensive cost savings and decreased life cycle costs when compared to other structural solutions [25].

2.9. Numerical Modeling

The finite element method (FEM), sometimes referred to as finite element analysis (FEA), is a computational technique used to enhance and insures the safe design solutions for problems in engineering. The effectiveness of finite element method is based on the type of problem, on several mathematic/physical principles [26].

2.9.1. Type of Modeling

There are different ways of material modeling, in most geotechnical engineers the phase 'strength of soil' raises up image of Mohr –Coulomb failure criteria. Mohr –Coulomb failure criteria is concerned with stress conditions on potential rupture plane within the soil and it says that failure of soil mass will occur if the resolved shear stress on any plane in that soil mass reaches a critical value [27]. During finite element analysis was done for granular materials at low stress level Mohr-Coulomb material model was used [22].

The linear elastic model is extensively used in pavement analysis, mainly due to its simplicity. However, it cannot adequately model the behavior of unbound pavement layers composed by soils and other granular materials [28].

2.9.2. Loading Condition

To carry finite element method and to simulate the materials, it must to identify types of loading condition. In general there are two types of loading conditions, static and dynamic loading? Some scholar are used both type of loading at different time for the same pavement layers [20] use both type of loading but the effect of dynamic loading frequency on pavement behavior was significant only for high stress amplitude. It is possible also to model flexible pavement as a multilayer structure subjected to static loading. To model the vehicle load axisymmetric modeling was used, because the load is act as circular [29].

2.9.3. Numerical Modeling of Pavement Layers and Geogrid Material

Faheem. H et al. [20] ware used axisymmetric pavement response model developed through the FE program PLAXIS and Bituminous concrete layer and geogrid were modeled as a linear elastic isotropic material. While the Mohr- Coulomb material model was adapted to represented granular base material. An axisymmetric model was utilized in the analysis using 15-noded structural solid element with medium refinement. Axisymmetric modeling was chosen in this study because it could simulate circular loading and did not require excessive computational time under dynamic loading. As per there analysis, the pavement performance was evaluated by changing the axial stiffness of geogrid material and also vary the location of geogrid on the same pavement. Then the result shows that, when the axial stiffness of geogrid increases the pavement increase its strength and no significant in vertical displacement is gained by placing two geogrid on two places (reinforce geogrid between, asphalt and base as well as base and sub base) and figure 2.5 indicates such condition clearly

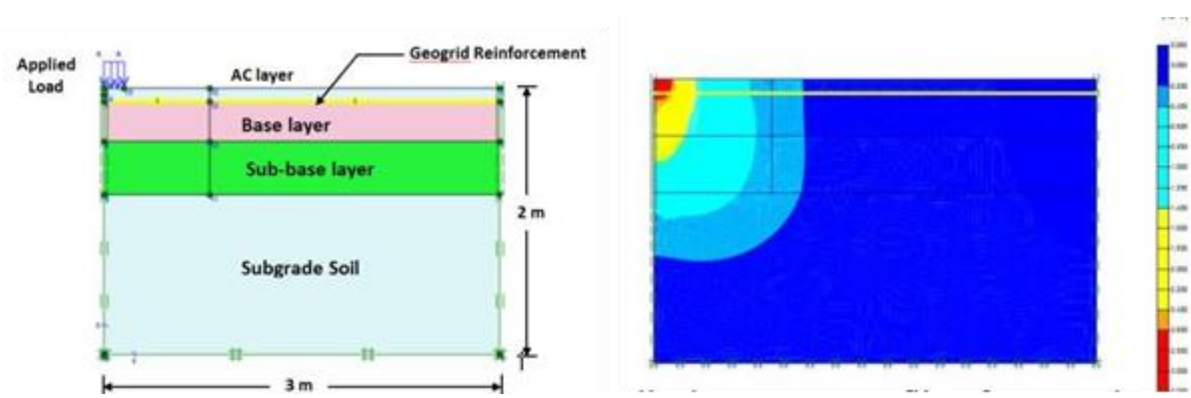

Figure 2.5 Geogrid Reinforced Pavement [20].

As a result of the research that they conducted and plaxis 2D software they are clearly illustrate the effect of geogrid reinforced and unreinforced section on the figure 2.6 below. As the applied stress increase the vertical deformation of the pavement reduces when geogrid was reinforced than the unreinforced one.

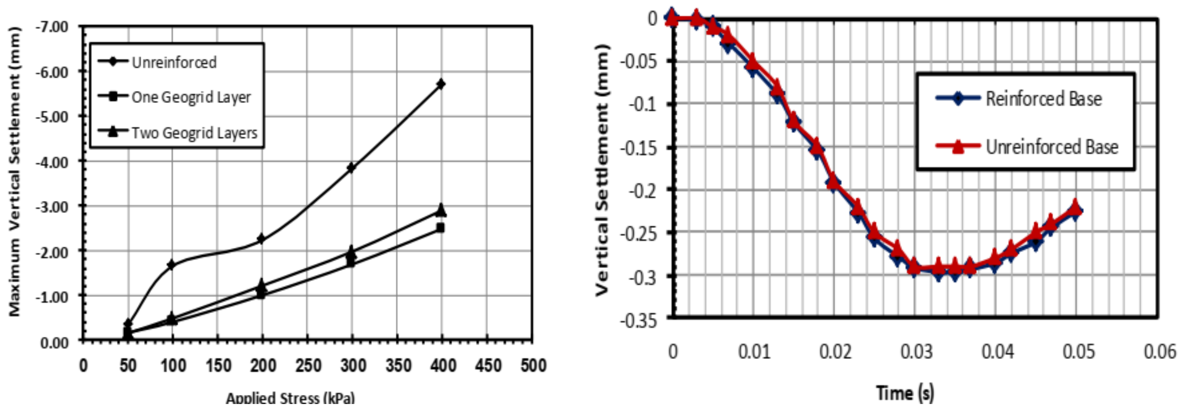

Figure 2.6: Vertical Settlement and Stress Effect [20]

Moayedi,H et.al [30] also want to show the effect of geogrid location on paved road, from their analysis, when the load is applied to the surface of the pavement, a zone of tension is developed at the lower section of the asphalt concrete layer as depicted from Figure 2.6. To improve the rigidity of the asphalt concrete layer, which may be considered as a beam, the geogrid is included as tensile reinforcement.

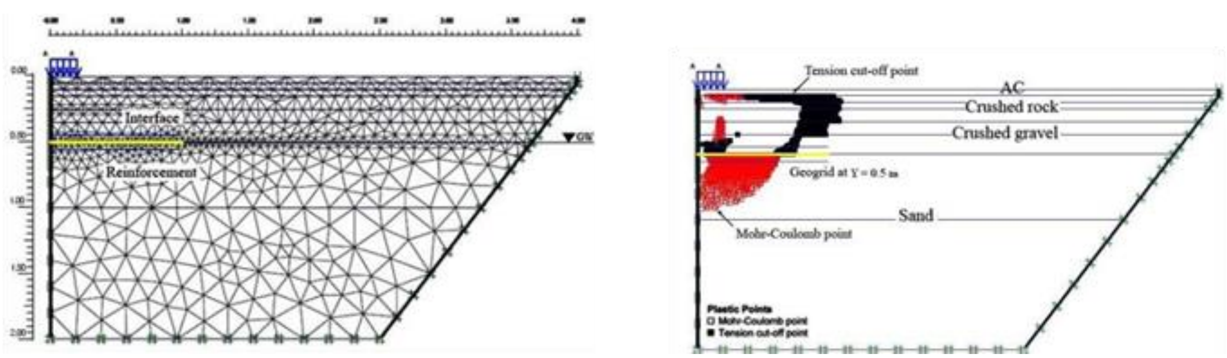

Figure 2.7: Effect of geogrid [29].

2.9.4. Meshing

The composition of finite element is called “Mesh”. So when the mesh is generated, finite element analysis was carried. In particular for stability and bearing capacity problems, the accuracy of the solution depends on the type and size of the elements. Upon global or local mesh refinement, the accuracy of results tends to improve. In addition to the refinement of the mesh the quality of the mesh has to be considered [31]. The research called Adel also use typical finite element mesh consisted of 15473 nodes and 5006 eight-node axisymmetric quadrilateral elements (PLANE82 elements) and Geogrid has been modeled using 360 three- node axisymmetric shell element (SHELL 209 elements). He use the ANSYS software for the simulation of pavement with the selected mesh element [29].

CHAPTER THREE

MATERIALS AND METHOD

This chapter focuses on the methodologies and materials that was used during the execution of the research and also showed the different variability, what the study design (steps of the research) was clearly defined, sampling process, data collection process and data analysis were discussed.

Starting from general over view of study area, Investigation of the existing pavement with identification of the distress type and severity level, selection of critical section of the pavement based on the sub-grade soil properties and selection of material modeling was clearly defined.

3.1. Study Area

Jimma to Sekoru road section is one of the road section which is found on the way Jimma to Addis Ababa national road, and the total distance is 99 km as shown from Figure 3.1 A. The study area is located It has a latitude and longitude of 7°40′N 36°50′E. Sekoru is one of the woredas in the Oromia Region of Ethiopia and it is also administered under Jimma zone. The altitude of this woreda ranges from 1160 to 2940 meters above sea level. The Gilgel Gibe 1 reservoir is also located behind to this road section around Deneba as it is shown on the figure 3.1 B below.

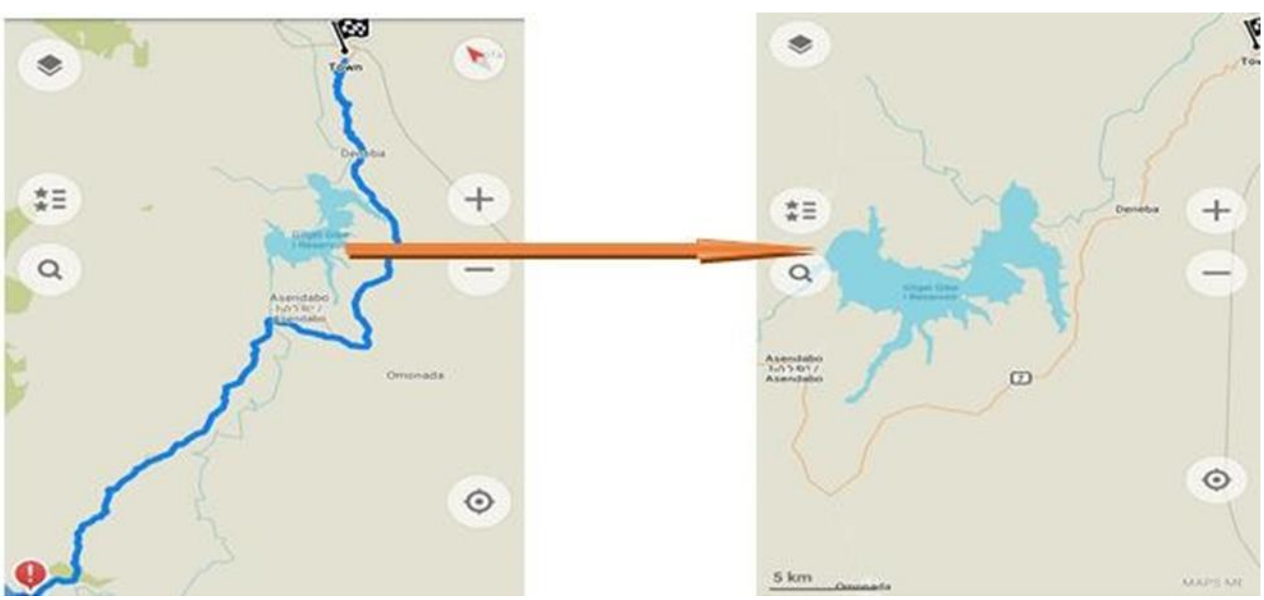

Figure 3. 1 A. Jimma –Sekoru road cross section B. Gilgel Gibe 1 Reservoir [Google Map]

3.2. Study Design

The overall flow of the study design of this research was started from the site selection of study area as it is shown on figure 3.2 and it is used to identify the more affected section. Direct field survey and literature was the second most important task. It also incorporate identification of distress types with their extent as a primary data that was registered from the site as well as assessing the engineering properties of the selected pavement layers as secondary data. The secondary data's were taken from Ethiopian Road Construction Corporation (ERCC) Jimma district and it use as an input parameter for the analysis. The analysis of this research was conducted by using the finite element method (PLAXIS 2D) software.

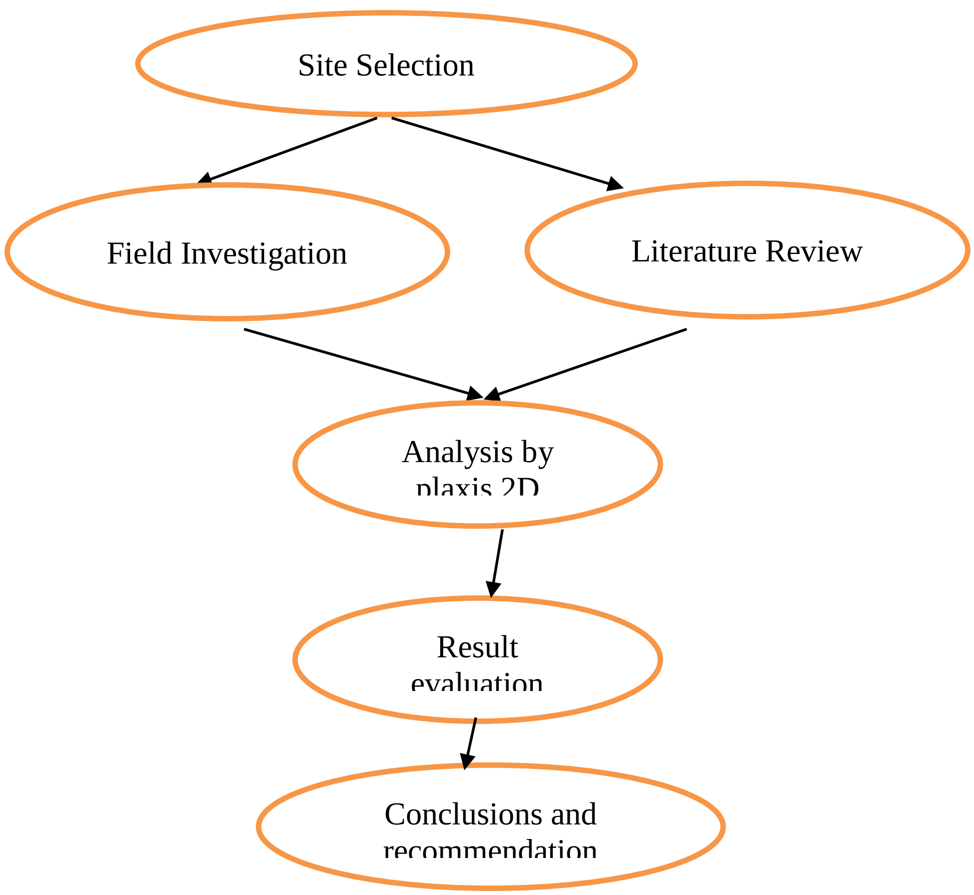

Figure 3.2: Study Design

The study design of this research is generally had a collaboration of distress identification, assessing the engineering properties of the pavement layer and also software simulation are some of them. So the next statements were clearly shows what the design looked like

3.2.1. Some Pavement surface distress on Jimma to Sekoru road section

The researcher was conducted pavement condition survey (PCS) of the study area by measuring the damaged pavement surface. .The relevance of this task was, to evaluate the existing condition of pavement surface and to identify types of distress. Execution of such survey was important to go to the next work, without knowing the existing condition of the pavement, it is meaningful to talk about effects of geogrid. But the field measurement result is not the same with the software result, because the existing pavement surface deformation was occurred due to the repetitive effect of axle load within a long period of time and the software result was simulated without bearing in mind the time impact.

This task was done directly on the field and the following points show clear steps on this stage:

- Measuring the length and width of cracks as well as the direction of crack along the wheel path or parallel to center of pavement. This is important to identify types of distress and to know the severity level based on the measurement, for instance to say this is alligator crack or longitudinal crack see the extent of severity

Figure 3.3: Longitudinal and Alligator Crack

- ★ Depth of pavement distress, this is important to clearly identify how much pavement surface is deformed. For example figure 3.4 shows that there is rutting after the road depth was measured.

Figure 3.4: Rutting

- ★ By observing distress and defect to the pavement surface, predict the possible cause of failure. Every distress cannot have the same cause to be happened, therefore is vital to identify the cause of the distress.

Therefor the above points were taken as primary data to this research and all information also recorded and evaluated as per [33].

3.2.2. Severity level of damaged pavement surface

It is must to know how much the pavement surface is damage, after measuring and identifying distress types. Table 3.1 clearly describe types of distress with their severity level. For instance if the crack width of longitudinal crack is less than 6mm, it shows that it is low damaged pavement and the same is true for pavement having crack depth greater than 50mm in depth, it indicates that the pothole on that section is high. In addition to this knowing the extent of pavement damage is used to identify that the pavement needs reconstruction or maintenance. Based on the damaging scale and degree of the pavement, the travelling public are affected their riding comfortability, as well as their safety.

Table 3.1: Distress type and Severity level [33]

Distress type	Severity level	Description
Longitudinal cracking	Low	crack with a mean width ≤ 6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined
	Moderate	Any crack with a mean width > 6 mm and ≤ 19 mm; or any crack with a mean width ≤ 19 mm and adjacent low severity random cracking.
	High	Any crack with a mean width > 19 mm; or any crack with a mean width ≤ 19 mm and adjacent moderate to high severity random cracking
Edge cracking	Low	Cracks with no breakup or loss of material.
	Moderate	Cracks with some breakup and loss of material for up to 10 percent of the length of the affected portion of the pavement
	High	Cracks with considerable breakup and loss of material for more than 10 percent of the length of the affected portion of the pavement.
Alligator crack	Low	An area of cracks with no or only a few connecting cracks; cracks are not spelled or sealed; pumping is not evident.
	Moderate	An area of interconnected cracks forming a complete pattern; cracks may be slightly spelled; cracks may be sealed; pumping is not evident.
	High	An area of moderately or severely spelled interconnected

		cracks forming a complete pattern; pieces may move when subjected to traffic; cracks may be sealed; pumping may be evident.
Potholes	Low	< 25 mm deep.
	Moderate	25 mm to 50 mm deep
	High	> 50 mm deep.
Rutting	Not applicable. Severity levels could be defined by categorizing the measurements taken. A record of the measurements taken is much more desirable, because it is more accurate and repeatable than are severity levels.	

In general knowing the severity level of pavement distress is important to predict what types of maintenance that the road is needed.

3.2.3. Pavement Layer Thickness and Properties

On the selected road section there was two type of expansive soil exist as subgrade soil and the sub base layer thickness is also vary. The CBR value of subgrade soils are ranged 5%-7%. This is important to know their strength and as per ERA manuals such types of soil is classified under the weak soil type.

Therefore two pavement sections were selected based on subgrade soil and thickness variation, those sub grade soil properties are not the same so it was better to see them separately. The need to select two type of pavement section was to evaluate the performance of the pavement and it use to know effects of geogrid on such subgrade soil type.

Both road section had four layers such as

- Asphalt layer
- Base course layer
- Sub base course layer
- Sub grade layer

But they have different sub grade soil type and all others layer are the same, like sub base and base course had crushed aggregate material and their CBR value are greater than 80%. This indicates that the materials are so strong to bear incoming load.

The first pavement section had Black Cotton soil as sub grade and the second one had Red Clay

soil as sub grade material. This classification was based on their CBR values, because the current practices of ERA for the design of highway is depend on the CBR values of soils.
Those soils have different engineering properties in all season, or their properties were changed when the environmental condition had also changed.

Therefore the pavements layer thickness and properties were taken from ERA AutoCAD design reports and appendix 6 and 7 shows the two pavement section. Each layer had their own CBR values and based on their CBR values modules of elasticity and Poisons Ratio were define from ERA manual and those values were written on table 3.2. The CBR value for base and sub base was grater that 80, this means the materials are strong. But all the sub grade CBR value is less than 15, therefore the subgrade material strength is weak.

Table 3.2 Material Properties [9]

Material	Elastic modulus (MPa)	Poisson's ratio
Asphalt surface	3000	0.35
Base course layer	300	0.30
Sub-base layer	175	0.30
Subgrade layer	53	0.35

The CBR value could change by using different institution of laboratory test equations. The most popular equations throughout the world is equation 3.1 and For Poisson's ratio, the common practice is to use typical value based on the type of material as required in equation 3.2

$E=250CBR^{1.2}$ (1500CBR) Psi ………………………………………………………...3.1[9]

$V=\Sigma D/\Sigma L$ ……………………………………………………………….…..3.2

Where

$\Sigma D=\Delta D/D$=is strain along diametrical (horizontal) axis.

$\Sigma L=\Delta L/L$=is strain along longitudinal (vertical) axis.

3.2.4. Numerical analysis (Finite Element Method Analysis) Plaxis 2D

The major thing that the researcher performed in this stage was first specifying proper dimension and select axisymmetric modeling(assuming the load as circular) with 15-noded element of the pavement , because the 15-node triangle is a very accurate element that has produced high quality result and one 15 –node element can be thought of a composition of four 6-node element , since the figure below shows that the total number of nodes and stress points is equal, so that one 15-node element is more powerful that 6-node element.[31]

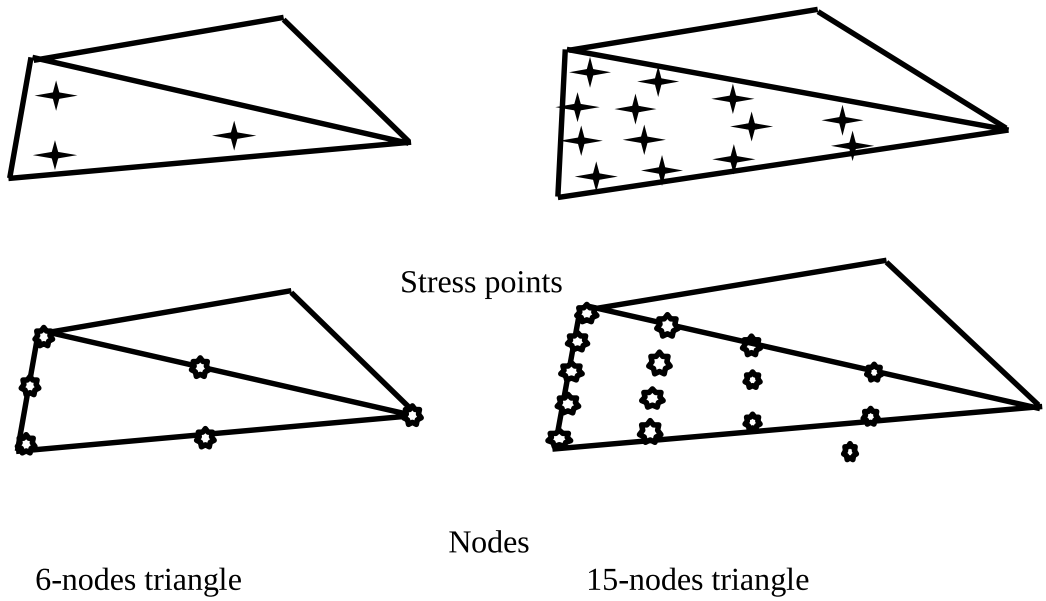

Figure 3.5: Position of Nodes and Stress in a Soil Elements [31]

3.2.5. Loading

For the design and analysis case the load was considered as either static loading or dynamic loading, but for this research, it was considered only the static load than dynamic loading, because static load is best to see the vertical deflection of the section and the CBR value is a static property that can't account for the actual response of the pavement under the dynamic loads of moving vehicles. In addition to this, when the dynamic loading is assign no significant geogrid reinforced pavement behavior is observed [19, 13].

Load configuration has an effect on the stress distribution and deflection within a pavement. Many trucks have dual wheels which guarantee that the contact pressure is within the limits. In this study for simplification of the analysis, the dual wheels are converted into an equivalent 80 KN single axle load (ESAL).

To determine the axle load, it was important to know the contact area of wheel. The load distribution assumed to be uniformly distributed load. In this study, only wheels on one side (the outer wheel path) need to be considered. Each tire is assumed to have circular contact area. The tire spacing assumed with a typical distance between dual tires of 35 cm and tire radius of the contact area for commercial vehicles is 10.75cm [35]. Since the load is analyzed using 80 KN single axle load (ESAL), the tire pressure is calculated using Equation

$P=F/A =F/\pi r^2 =80/2* \pi*0.10752 =550$ MPa…………………….. 3.3

In this research both pavement layer analysis with and without geogrid and by generate ground water up to top sub-grade surface. The relevance of such analysis is:

- ✓ First to see and compare the maximum pavement layer deflection when the pavement is at dry condition (dry season).
- ✓ Second to evaluate pavement layer deformation reduction with in this dry season if the pavement ware reinforced with geogrid
- ✓ The other one to evaluate the pavement layer deformation at rain season, by assuming that if the worst condition is happened and the ground water will rise until the surface of the sub grade layer of the pavement and evaluate deformation reduction after geogrid reinforcement.

3.2.6. Direct Shear Test

To determine the shear strength properties of the subgrade soil material of the study area it is important to conduct direct shear test by following the procedure on ASTM D 3080.

Direct shear test used to determine the consolidated drained shear strength of a soil material.

This test can be used for all soil materials and undisturbed, remolded or compacted materials. There is however, there is a limitation on maximum particle size. The minimum specimen diameter for circular specimens, or width for square specimens, shall be 2.0 in. (50 mm), or not less than 10 times the maximum particle size diameter [39].

The researcher was conduct the direct shear test for the sub grade soils. The need to conduct this test is only to see the current shear strength parameters of those soils, however the test was not recommended for expansive type of soils. But with the absence of triaxial test it is possible to use it. Figure 3.6 below shows that the clear procedure of the test, that the researcher was following during the laboratory testing and also preparing the samples, operating the machine and taking the reading from the machine.

Figure 3.6: Direct Shear Testing

3.2.7. Input Parameters

The input parameter that the researcher was used for the plaxis 2D software with their measurements are:

- Material types,
- Material modeling
- Pavement Thickness
- Young's modulus(KPa)
- Poisson's ratio
- Dry density (KN/m3)
- Wet density(KN/m3)
- Cohesion(KN/m3)
- Friction angle(degree)

3.2.8. Models

There are two most important types of modeling was selected as per the material type and their properties, those are linear elastic model and Mohr coulomb model.

Linear Elastic Model

Linear elasticity is a mathematical **model** of how solid objects deform and become internally stressed due to prescribed loading conditions. It is a simplification of the more general nonlinear theory of **elasticity** and a branch of continuum mechanics. If the constitutive stress-strain low is restricted to be linear also we call it linear elastic solid [37].

It is insufficient to capture the essential feature of soil, this is due to soil behavior is highly non- linear and irreversible, therefore linear elastic model is used to model massive structures, so during analysis of this research linear elastic model was used for the asphalt and geogrid material.

Mohr – Coulomb Model (MC) is linear- elastic -perfectly -plastic model that involve the five input parameters ,i.e E and V for soil elasticity ;ψ as an angle of dilatancy, Φ and c for soil plasticity [31].

The most popular formula of this model and that is incorporated in plaxis 2D software is

$$\zeta = c + \sigma \tan\Phi \qquad 3.4$$

Where ζ= shear strength

Φ=angle of internal friction c=cohesion

σ=normal stress

3.2.9. Geogrid

The geogrid type that the researcher used in this research is based on ERA manual and those condition that was listed in the manual was satisfied. Therefore Jimma to Sekoru road section fulfilled the condition and the researcher decided to use Bi –axial geogrid, because it exhibit significant stiffness and strength in two orthogonal directions. In these materials, the ribs and junctions provide geometrical stability during transport and installation and may provide the possibility of interlock with the soil in which they are placed. The average axial stiffness of geogrid was used in this research which means 600 KN/m.

Table 3.3 Material Properties of Reinforcement (Geogrid) [5].

Type of Material	Material Model	Axial Stiffness
Geogrid	Linear Elastic	200-1000KN/m

Anisotropic biaxial geogrids exhibit dissimilar stiffness's in the two principal directions. They are used in anisotropic loading conditions, i.e. where there is a primary and a secondary degree of loading/strain. Isotropic biaxial geogrids exhibit very similar stiffness's and strengths in the two orthogonal directions. They are used in isotropic loading conditions, i.e. where there is almost an equal degree of loading/strain in two orthogonal directions [32].

Therefor based on the loading condition of this research, the researcher select isotropic biaxial geogrid with its axial stiffness.

Figure 3.7: Biaxial Geogrid [32]

3.2.9. Evaluation of the Result

Finally the total deformation of the pavements was computed based on the plaxis 2D output result value and figure 3.5 shows how the computation was carried, as per the figure the first thing was total deformation was simulated the pavement only, which means without geogrid reinforcement and ground water generation. All other analysis was computed in reference with this pavement.

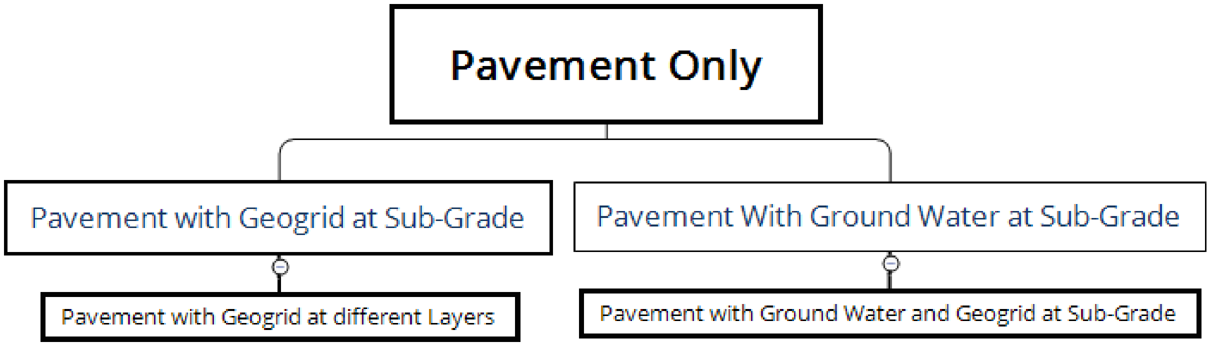

Figure 3.8: Analysis chart

Finally based on the results from the analysis, each conclusion and recommendation was drawn.

3.2.10 Tools

There was tools also that used in this research during field survey and for the analysis. Such as:

- Meters to measure crack length, width and depth,
- Excel sheet format that used to write crack and deformation history,
- Microsoft words that used to writ the overall progress report of the research and
- Plaxis 2D software that used to carry analysis.
- XMIND software

3.3 Study Variables

Dependent Variables: Performance of flexible pavement

Independent Variables: Surface conditions of the

: Engineering properties of pavement layers

: Geogrid Type

: Geogrid Location

3.3 Sampling Procedure and Data collection

The sampling technics is non-probabilistic, purposive which means pick out the sample in relation to some criterion from the pavement layer. Both qualitative and quantitative data's were used. The qualitative data's the data was expressed in word based on the research objectives and the quantitative data's are data's that was expressed numerically, which means the numerical data from the site and software. To collect the samples that used for the research the major criterion that the researcher was used:

- ❖ Select the most affected section of the road, for example looking and measuring the crack width, length and depth.
- ❖ Based on the above information, identify what types of distress is that and predicting the possible cause.
- ❖ Then put the severity level, that is important to identity the most damaged part of the pavement

The data collection process were conducted as per the research objective and research questions. Both primary and secondary data's were collected.

Primary data's were data's that was taken directly from the field. Secondary data's were data's that was taken from ERA Jimma office AUTOCAD file, laboratory result, ERA manual and (Unified Soil Classification System)USCS and those materials are attached at the end of this research page Those manuals and standards were used to know each pavement layers properties in detail. Because those parameters was the input for the software.

3.4. Data analysis

The data analysis was conducted by using plaxis 2D software and the analysis expressions as follows

- ✧ First all the proper dimension of pavement layer was drawn and choose units of measurement
- ✧ Selection of element and modeling type
- ✧ All pavement material was alleged on each pavement layer
- ✧ Load was assigned
- ✧ No horizontal movement is allowed ,only vertical movement was assumed
- ✧ Finite element analysis were executed before calculation by generate mesh
- ✧ Then assign the ground water if there is
- ✧ Initial pore pressure was conducted

- Finally under calculation stage by selecting plastic analysis to see deformation in pavement layer and from the output take total deformation for all pavement with and without geogrid.

Lastly comparatively evaluate total deformation from all calculation and select the best geogrid location for both selected pavements.

CHAPTR FOUR

RESULT AND DISCUSSION

This chapter in general shows that the result of the study as per the specific objectives and their clear discussion of them. The first part of this chapter presents the existing pavement surface condition of the road section as per the field investigation, the second part cover identification of some of engineering properties of each pavement layer. It was done based on ERA manual, laboratory report and USCS. Third one, a comparative study of vertical deformation between the sub grade geogrid reinforced and unreinforced road section, then the other one is the comparative total deformation study of the pavement when the ground water level reaches at the sub grade level. Finally, the reinforced pavement layers by geogrid and show the best location of the geogrid based on the vertical deformation value of plaxis 2D output.

4.1. Surface Condition of the Road result

As per the field observation and investigation of the existing road section of Jimma to Sekoru, the existing surface condition of the road had different types of distress on both sections. Almost half of the distress among the sample was observed on the right side of the pavement direction towards Addis Ababa to Jimma. Table 4.1 also shows that rutting, edge and longitudinal cracks were observed on the right side of the pavement.

Table 4.1: Surface Condition of Jimma to Sekoru Road Section

SAMPLE NUMBER	SIDE	Offset from CL (m)	WIDTH (mm)	DEPTH (mm)	LENGTH (m)	EMBANKMENT	SHOULDER	CARRIAGEWAY	CONDITION OF CRACK
1	RS	1.9	8		5.0	•			Edge and Longitudinal crack
2	RS	1.0	12		4.4	•			Edge and Longitudinal crack
3	RS	0.5	1600	800	8.6			•	Rutting
4	RS	1.6	25		8.6			•	Longitudinal crack
5	C	-	1300	600	2.1				Rutting
6	LS	2.0	25		7.4		•		Longitudinal crack

7	LS	1.2	600	1000	1		•		Rutting
8	RS	0.5	-	500	10			•	Rutting
9	LS	-	300	700	10			•	Longitudinal crack
10	RS	-	1000	-	1.2		•		shoulder bulging out
11	C	-	1300	50	2.6			•	Longitudinal crack and pothole
12	C		1000	400	1.5			•	Rutting
13	RS		10		2.3			•	alligator crack
14	ALL				70	•	•	•	Total pavement damage and the base course material also observed
15	C				17			•	pavement bulge out
16	RS	2.0	8	-	5		•		alligator crack
17	RS		20		5		•		Edge crack
18	LS		1000	40	3		•		Edge crack and pothole

The main importance of studying of pavement distress was used to reach on the decision whether this road need rehabilitation or reconstruction. Also, it served to validated the existing condition based on ERA manuals that the rapid reappearance (or reflection) of these cracks through on asphalt surface that is laid directly over them, is a well-known phenomenon that must be solved as part of the rehabilitation process [9].

4.1.1 Severity levels

The severity level of both investigated sections of road depends on the above table 4.1 information, because in order to talk about its severity level, it is important to know the depth, width and length of cracks. Edge crack, longitudinal crack and rutting are on high severity level than others table 4.2 also clearly identify this distress.

As a result shows the road is highly damaged even around 17meter length of the section is totally destroyed and it cause disruption on transportation system. Due to such effect of road damage passengers feel discomfort and it may cause traffic accident.

As per the history of Addis Ababa to Jimma road such types of pavement distress with their severity level was recorded and they are trying to maintain some road section but, still now they are working with reconstruction and rehabilitations of some section of this road [unpublished document 36].

Table 4.2 Severity Level

Distress type	Severity level
Edge crack	high
Longitudinal crack	high
Alligator crack	moderate
pothole	moderate
Rutting	high
Total pavement damage	high

In general Jimma to Sekoru road corridor need some improvement to increase the serviceability life and to decrease discomfort to passengers.

4.1.2. Possible Cause of Pavement Surface Failures (Jimma to Sekoru)

Always if there is distress in a pavement there must be a cause to that distress to be happening. Therefore, for those distress listed before there is a possible cause that was observed from the field. Poor drainage, poor construction quality and weak subgrade material are the main cause to this pavement to be failed that clearly illustrated on table 4.3

Table 4.3: Types of Distress and Observed Possible Cause

Types of distress/defect	Description	Observed possible cause
Edge crack	Crescent-shaped cracks or fairly continuous cracks which intersect the pavement edge and are located within 0.6 m of the pavement edge, adjacent to the shoulder	Poor drainage And it may be weak shoulder

Pothole	Bowl-shaped holes of various sizes in the pavement surface.	Poor drainage and weakness of pavement surface
Longitudinal crack	Cracks predominantly parallel to the pavement centerline	Poor construction joints
Alligator crack	Interconnected crack forming a series of small block resembling an alligator skin	When the bearing capacity of the pavement is lower than the incoming load Poor sub grade quality Saturation of the sub grade material
Rutting	A longitudinal surface depression in the wheel path. It may have associated transverse displacement.	Joining of pavement layer under traffic It may be insufficient pavement thickness during construction
Total pavement damage and the base course material also observed	Total destruction of the pavement	Poor construction quality Poor pavement material Poor drainage facility Excessive incoming load from the vehicle's

4.2. Engineering Properties of Pavement Layers

It is important to know the engineering properties of each pavement layer, because finite element analysis of pavement depended on such property. Those pavement layer properties of each investigated section were taken from the ERCC Jimma district laboratory test result Such as dry and wet density of pavement layers were taken and clearly show on Table 4.4 and 4.5 shows engineering properties for road section one and road section two respectively.

For dry and wet density of pavement layers, the laboratory result was reported in kg/m^3 but to use such result as an input for the software, it must be changed to kN/m^3 ,therefor it need conversation factor that convert kilogram in to kilo newton.

1 kN = 102 **kg, which means 1kg =1/102=0.00980392157** so all units much be changed

The value of young's modules and poisons ration are depend on the CBR values of pavement materials, based on CBR values those parameters were extracted from ERA manuals. Like that of CBR value depending on the material type it is possible to take the angle of internal friction and cohesion from standard.so to get more information on the sub grade strength properties look at appendix 1(USCS) and appendix 2(ERA 2013) at the end.

In addition to this, from the direct shear test for the subgrade soils angle of internal friction and cohesion was taken. But those parameters were taken after the shear stress and the normal stress graph was constructed. So figure 4.1 and 4.2 clearly illustrate the graphs for both soil types. For instance figure 4.1 shows that when the soil sample was loaded with the increment of normal stress of 100kpa, 200kpa and 300kpa the corresponding maximum shear stress value was 68.1048218 kpa,104.3982779kpa and 150.9790342 respectively. The same is true for the subgrade soil type (red clay) figure 4.3 was clearly illustrate it. Then by depending on this value the graph was constructed and angle of internal friction and cohesion was computed from the graph.

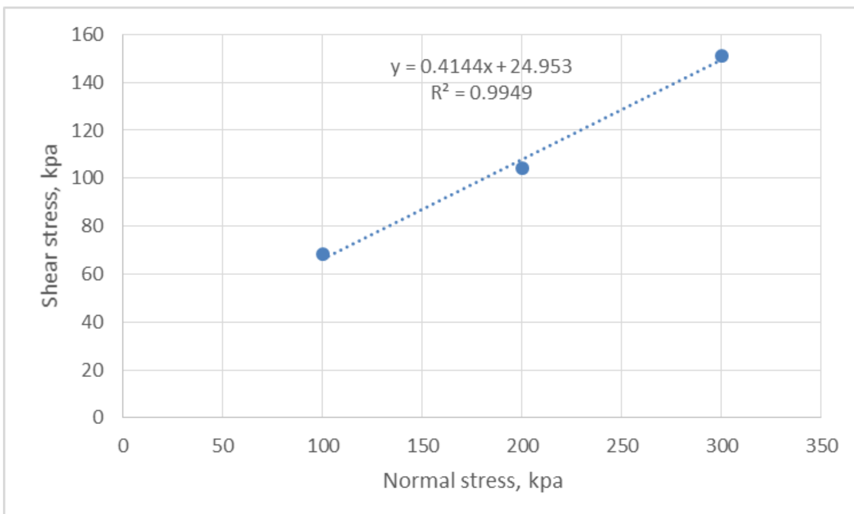

Figure 4.1: Normal Stress vs. Shear Stress for Black Cotton soil

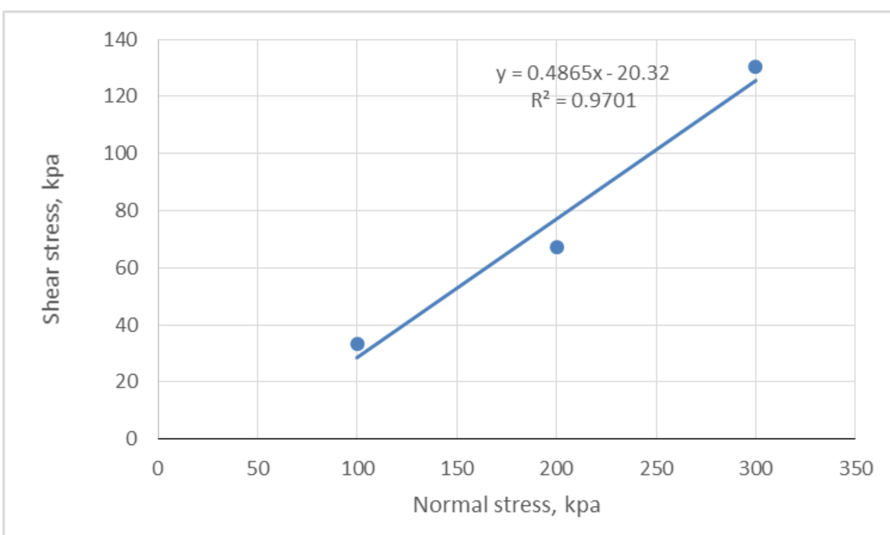

Figure 4.2: Normal Stress vs. Shear Stress for Red clay soil

The laboratory test (direct shear test) result of the subgrade soil samples was attached in appendix 7 for the road section one that have black cotton soil as sub grade and appendix 8 for road section two that has red clay soil as subgrade soil.

As it is shown those asphalt layers, base layer and sub base layers are strong on their properties. The only weak portion is the sub grade layer of pavement on both sections. The estimated total distance of road section one, which is the total asphalt surface destruction was observed, had 17meter in length and all the width of the pavement that it covers. All the pavement layer thickness of this section was clearly shown in appendix 6 first figure.

Table 4.4 Pavement Layer Property of Road Section One

Material	Asphalt wearing Course	Base course (crushed aggregate)	Sub base course (crushed aggregate)	Sub grade (black cotton)
Model	Linear Elastic	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb
Thickness(m)	0.05	0.2	0.2	4.55
Young's modulus(KPa)	$3*10^{+6}$	$3*10^{+5}$	$1.75*10^{+5}$	$5.3*10^{+4}$
Poisson's ratio	0.35	0.3	0.3	0.35
Dry density (KN/m^3)	22.3	22.43	18.60	16.04
Wet density(KN/m^3)	23.3	23.4	20.84	18.69
Cohesion(KN/m^3)	-	1	1	25
Friction angle(degree)	-	40	38	22

The second road section with red clay as sub grade soil had covered around 10meter in length and half part of the pavement is in good condition. All the pavement thickness of this section was clearly shown on appendix 6 second figure.

Table 4.5 Pavement Layer Property of Road Section Two

Material	Asphalt wearing course	Base course (crushed aggregate)	Sub base course (crushed aggregate)	Sub grade (red clay)
Model	Linear Elastic	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb
Thickness(m)	0.05	0.2	0.3	4.45
Young's modulus(KPa)	$3*10^{+6}$	$3*10^{+5}$	$1.75*10^{+5}$	$5*10^{+4}$
Poisson's ratio	0.35	0.3	0.3	0.35
Dry density (KN/m^3)	22.3	22.43	18.60	16.55
Wet density(KN/m^3)	23.3	23.4	20.84	18.89
Cohesion(KN/m^3)	-	1	1	20
Friction angle(degree)	-	40	38	27

4.3. Sub -Grade Reinforcement

The total deformation of the sub grade reinforced and unreinforced pavement was computed. At this stage the ground water condition was not considered, by assuming the depth of ground water table may be deeper than 5 m in depth. The geogrid was reinforced on the top surface of subgrade soil. The geogrid material that was used in both sections are the same. Therefore, the geogrid material have axial stiffness of 600kN/m, with this material both sections was stabilized. That means the total deformation was decreased when geogrid was used as a reinforcement. In this study, analysis was carried and computed with in two types of road section with their sub grade soil types. The road section one refers, road with black cotton soil as subgrade material and road section two means, road with red clay soil as subgrade material. Those sub grade soil shear strength parameters, that was used for the modeling was taken from the direct shear test results.

4.3.1. Geogrid Unreinforced and Reinforced Road, Section One

The total deformation of unreinforced read section one is $2.43*10^{-3}$meter but this value is decreased when it reinforced with the geogrid and it became $2.18*10^{-}3$meter. Therefore, this value indicates that, the total deformation was reduced by 10.29% when the geogrid is reinforced in between sub base and sub grade. The result variation of pavements was clearly illustrated in Figure 4.1 and 4.2 of both sections.

As the total deformation of the pavement layers decreased after the geogrid material was reinforced at the top of the sub grade surface, the more improvement of bearing capacity. This indicates that, the subgrade soil material was stabilized.

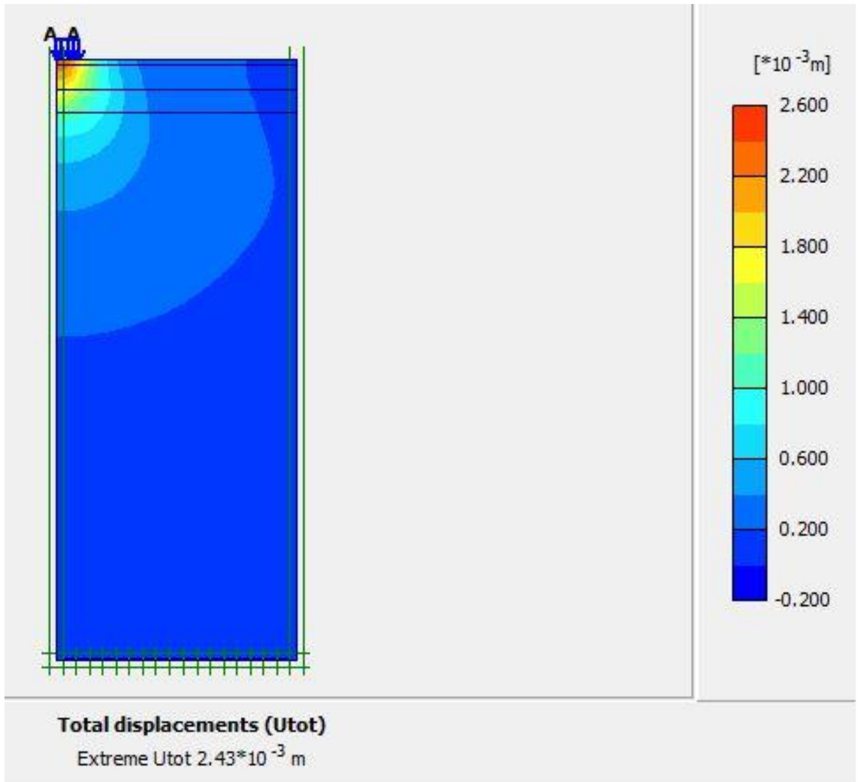

Figure 4.3: Total Deformation of Unreinforced Road Section One

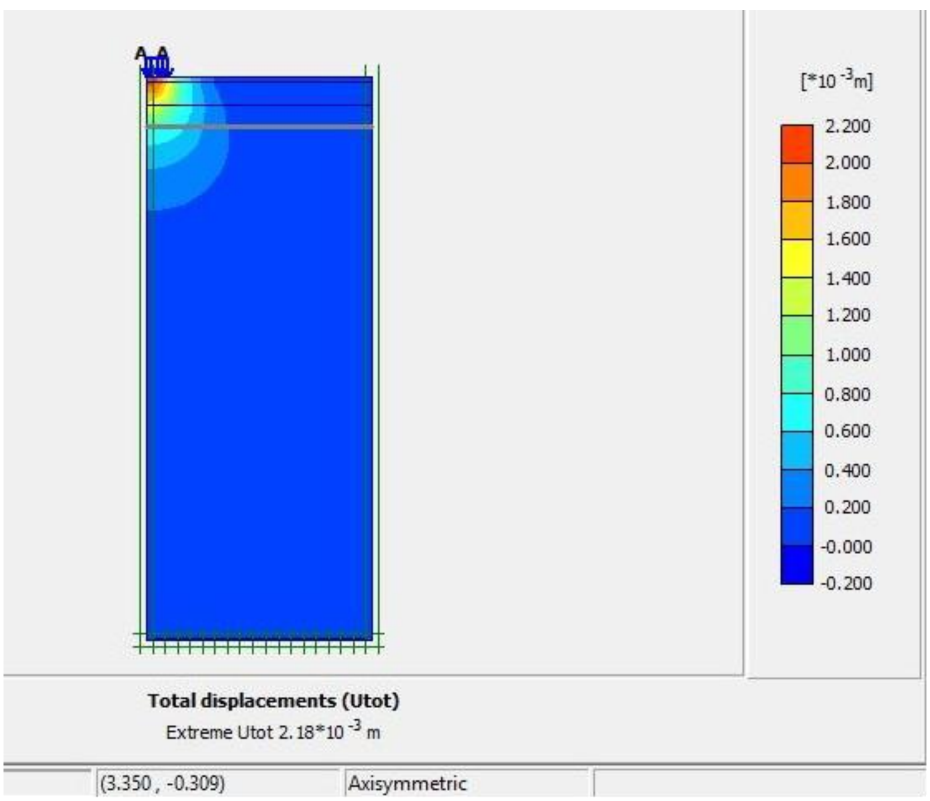

Figure 4.4: Total Deformation of Geogrid Reinforced Road Section One

4.3.2. Geogrid Unreinforced and Reinforced For Road Section Two

The other one was the second pavement (road section two) with the red clay soil as sub grade material. The same is true that, the total deformation of the pavement was computed. As the result shows that, the sub grade soil is stabilized. Figure 4.3 and 4.4.shows the relative decreasing of total deformation of geogrid reinforced pavement by 9.13% than the unreinforced one.

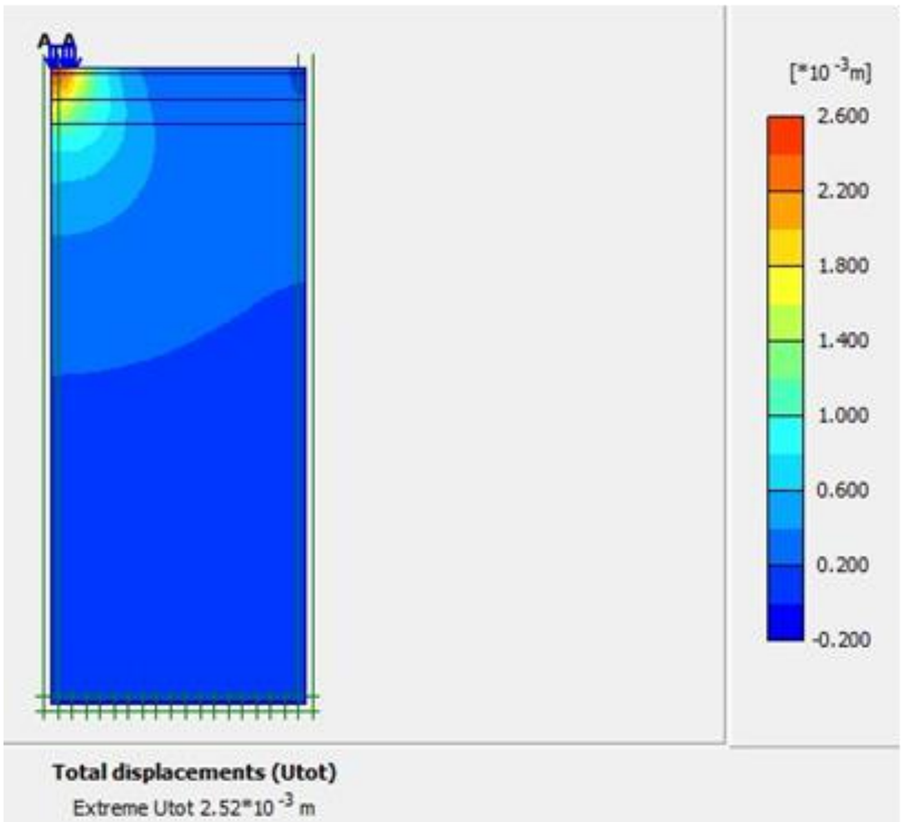

Figure 4.5 Total Deformation of un-Reinforced Road Section Two

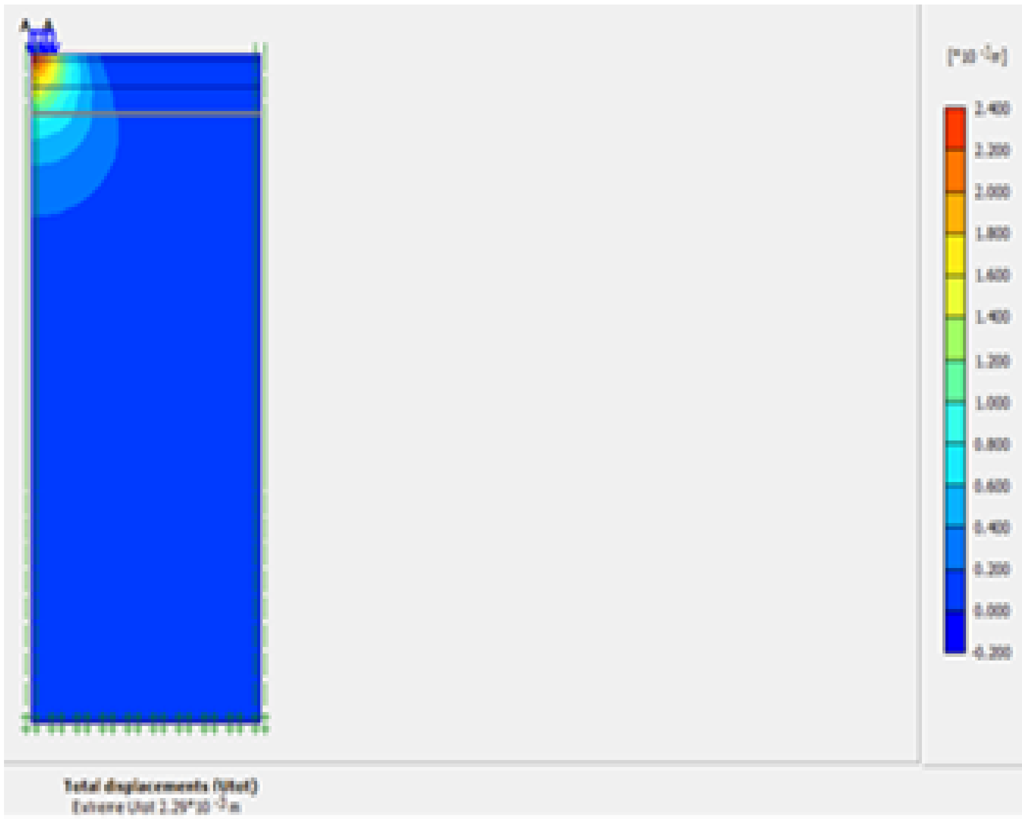

Figure 4.6 Total Deformation of Geogrid Reinforced Road Section Two

In general relatively high total deformation was observed when the pavement had black cotton soil as a sub grade material than red clay soil. There is also the effect of geogrid reinforcement was observed on the road section one and a10.29% of deformation reduction shown, but there is less deformation reduction was shown on road section two, it is about 9.13%.

The bearing capacity of Laterite, Alluvial soil and black cotton soil is increased when geogrid was reinforced on the top of them, but for red clay soil geogrid reinforced in the middle of soil layer [38].Even those soils had different behavior under the geogrid reinforcement.

The mesh deformation of those soils was also different. To see the effects of geogrid on such soils after the mesh generation (finite element analysis) refer appendix 4 and appendix 5. Clearly .put the total vertical deformation for road section one and two respectively.

4.4. Deformation of the Pavements When There is Ground Water at Sub Grade Level

The existence of ground water affects the pavement performance. For the selected road section the analysis was conducted by generating the ground water at the subgrade level and measure the total deformation. As figure 4.5 shows the total deformation of pavement that had ground water at subgrade level increased by 33.33% than the dry one,but when geogrid was reinforced on the top of the sub grade 24.38% reduction was observed and figure 4.6 proves this statement.
This result is shown when there is black cotton soil exist as subgrade material.
There is a great effect, weaken the structural strength of pavement, when the ground water is located at shallow dapth than deep. That is why the researcher takes an assumption of the water table if it is on the surface of sub grade. As it is far from it, the effect with respect to the applied traffic load become less.
The bearing capacity of soil is affected by the ground water table, due to this the pavement failure becomes the major problem.Therfore, geogrid helps to increase the bearing capacity of the subgrade soil,while greatly reducting the loss of the aggregate covering material into weak,wet or saturated subgrade soils [25].

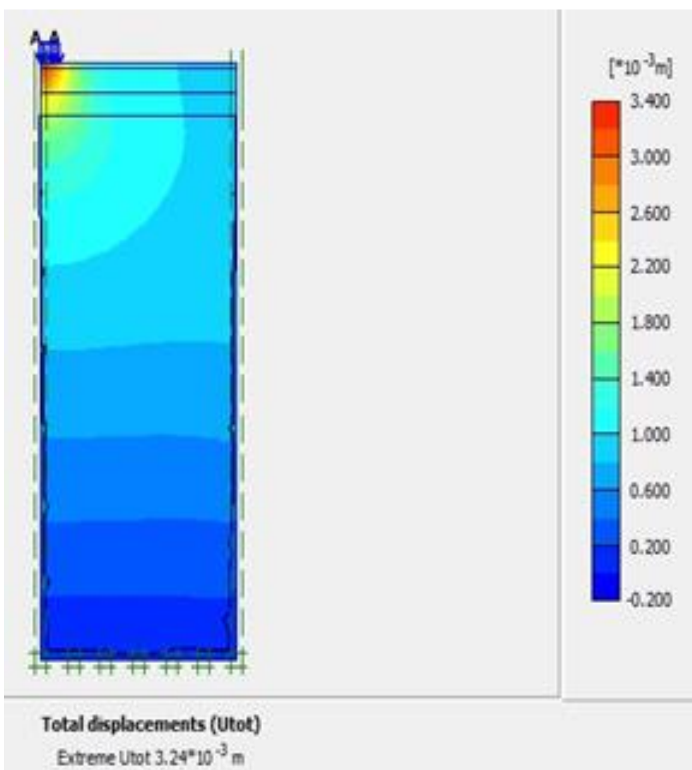

Figure 4.7 Total Deformation of Unreinforced Road Section One with GW at Sub Grade

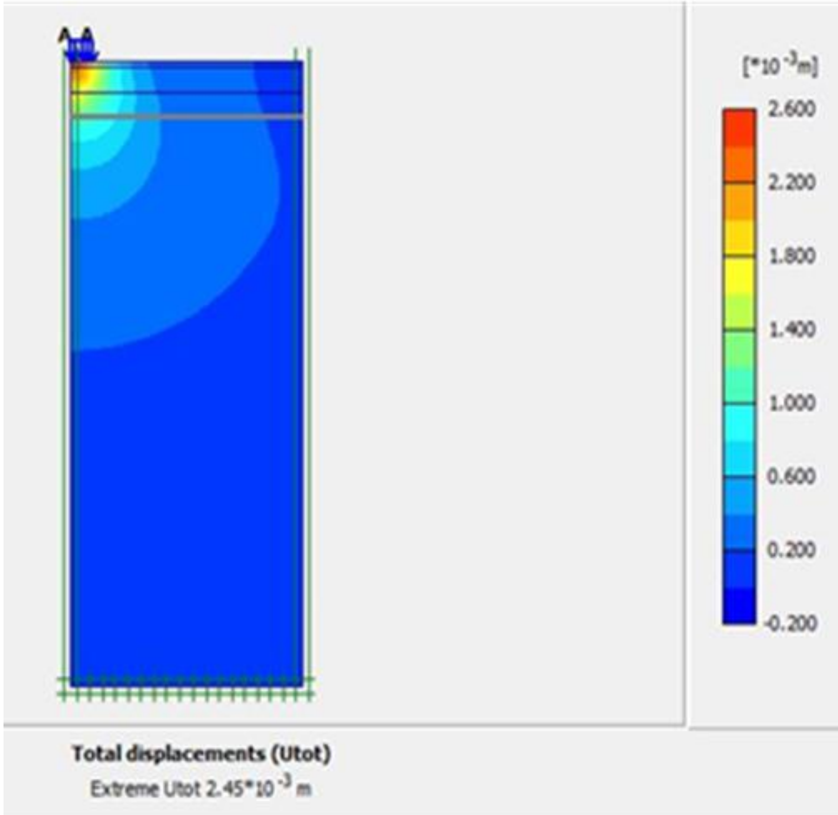

Figure 4.8 Total Deformation of Reinforced Road Section One with GW at Sub Grade

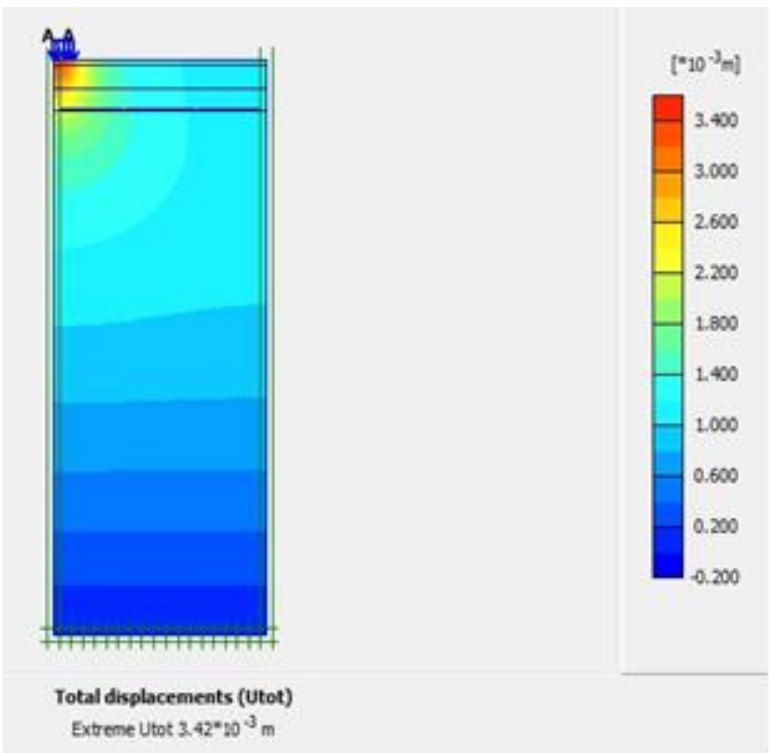

Figure 4.9: Total Deformation of Unreinforced Road Section Two with GW at Sub Grade

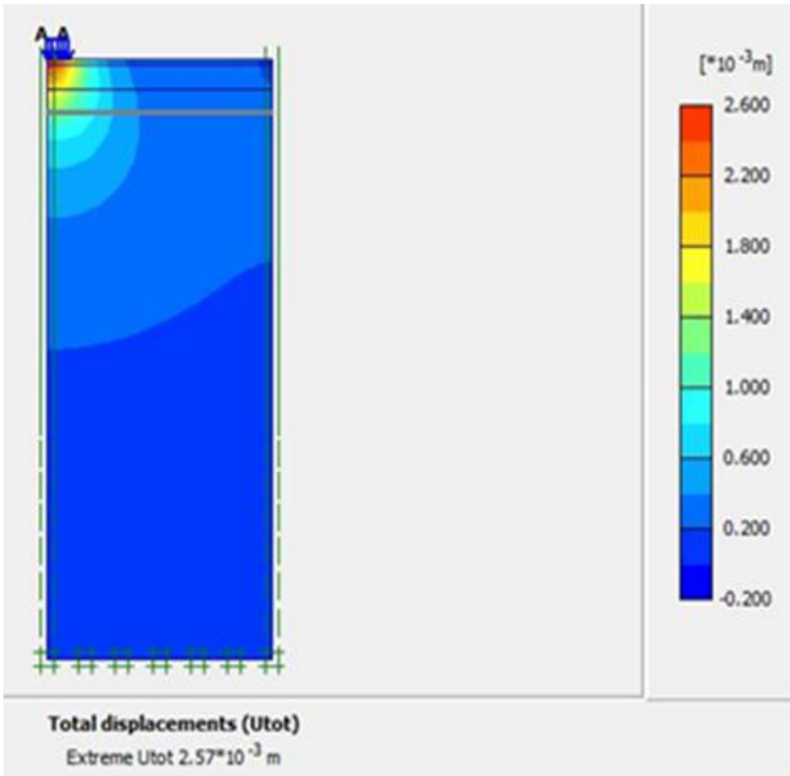

Figure 4.10: Total Deformation of Reinforced Road Section Two with GW at Sub Grade

At figure 4.7 guides, the total deformation of road section two is increased by 35.71%, when the sub grade soil had excess water then dry condition. This deformation value was decreased up to 24.85% after the geogrid reinforcement on the top of subgrade according to figure 4.8 indicates. In general geogrid stabilizs the pavements in both conditions, during the dry and wet condition. This makes my study unique than others. Because, those scholars were done the analysis only when the pavement is dry condition and changing the sub grade thicknes with respect to vartion of axial stiffnes of geogrid [5].

4.5. Geogrid Loction in both Road Section When there is no Ground Water Effect

When the pavement layers are reinforced with geogrid there is an improvement on the pavement performances. But at which layer of the pavement is improved more is the best question. Therefor such question was get an answer in this portion.

4.5.1 Best geogrid location for road section one

Based on the total deformation result the best location of geogrid for this section, is in between base and sub base. Because at this section there is less vertical deformation than others. This result is computed when the road is dry condition only.

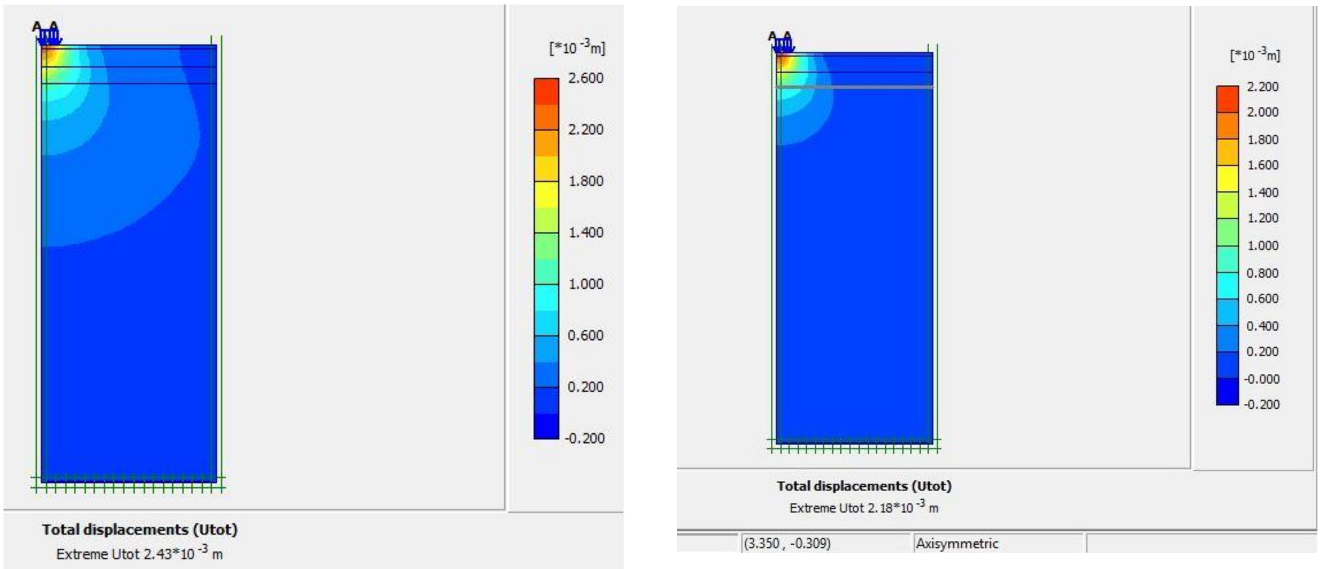

Figure 4.11:A. Unreinforced B. Geogrid location between sub grade and sub base of road section one

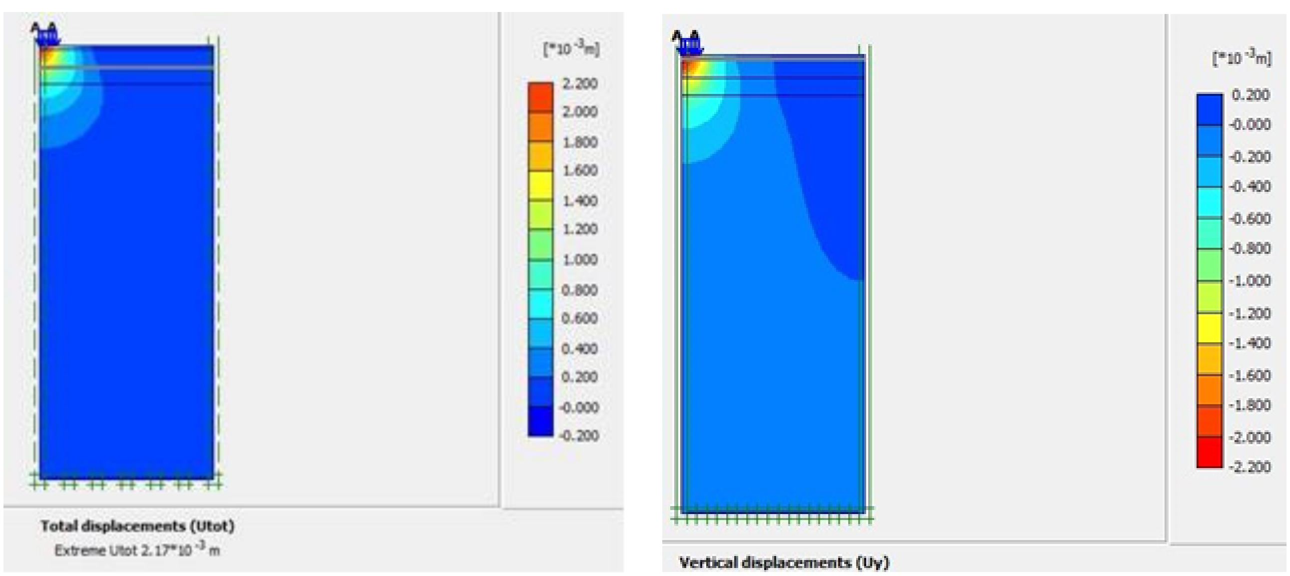

Figure 4.12: A, Geogrid Location between Sub base and Base B, base and Asphalt of Road Section One

4.5.2. Best Geogrid Location for Road Section Two

Based on the vertical deformation result the best location of geogrid for this section, is in between base and sub base. Because at this section there is less vertical deformation than others. This result is computed when the road is dry condition only.

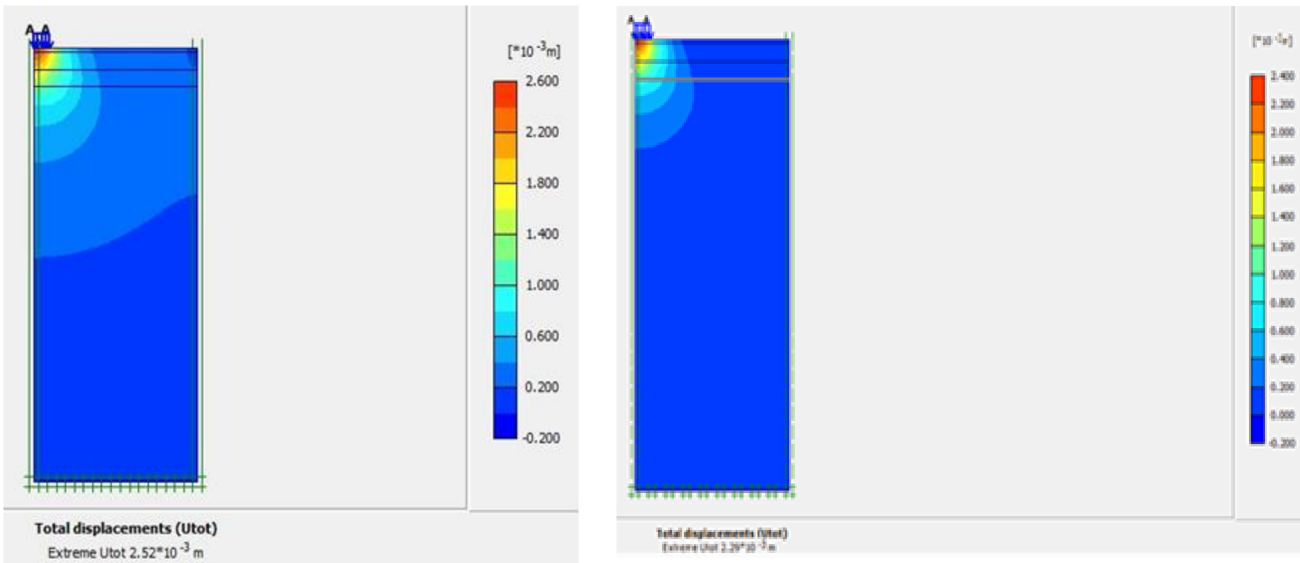

Figure 4.13:A. Unreinforced B. Geogrid location between sub grade and sub base of road section two

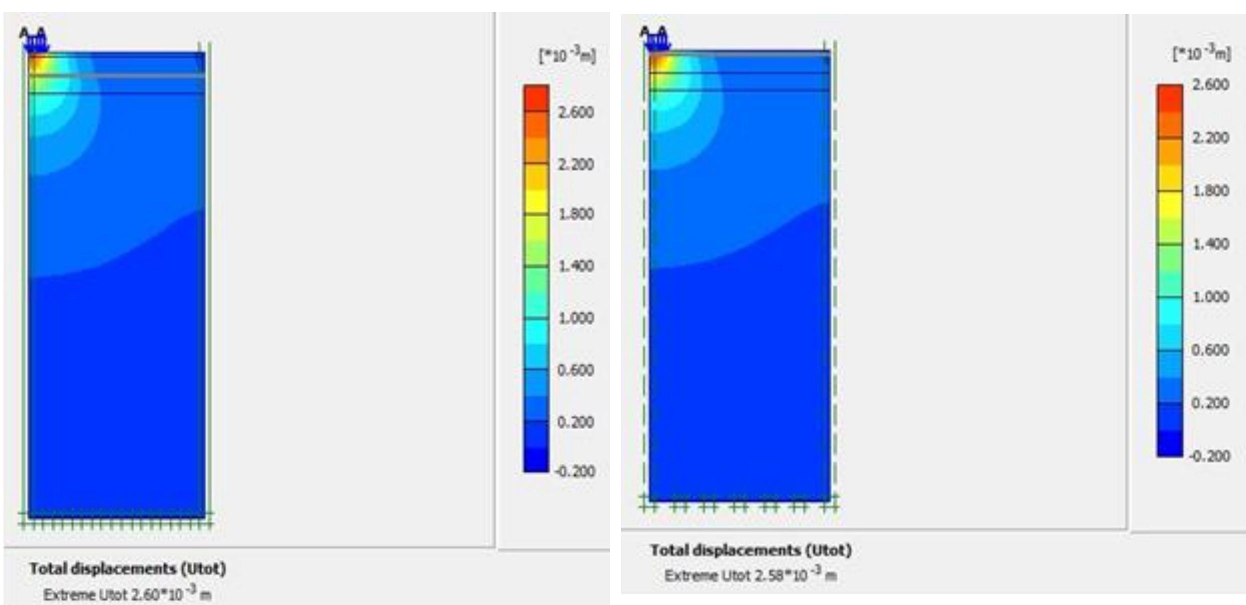

Figure 4.14: A, Geogrid Location between sub base and Base B, Base and Asphalt of Road Section Two

Based on the result shown in the above figures, there is a great improvement of the total deformations shown when geogrid reinforcement location varies from place to place and the total deformation is decreased when geogrid reinforced in between subgrade and sub base than others.

CHAPTER FIVE

CONCLUTION AND RECOMMENDATION

5.1. CONCLUSION

Investigation of effect of geogrid on flexible pavement that have different type of subgrade soil property was conducted by using plaxis 2D software by including distress identification. So the following conclusions was drown as per the result:

- A high deflection is recorded when there is ground water
- Relatively less deflection is observed when the road section analyzed at dry condition(without ground water) than wet condition
- When geogrid is reinforced at sub grade level the total deformation is decreased than unreinforced one
- To decreases the rutting effect of road section one that have black cotton soil as subgrade, it is better to reinforce Bi axial geogrid having 600kN/m in between asphalt and base course.
- To decreases the rutting effect of road section two that have red clay soil as subgrade, it is better to reinforce Bi axial geogrid having 600kN/m in between base course and sub base.
- Use such geogrid as a reinforcement material on different road to improve their performances and decreases a repetitive maintenance and early damage.

5.2. RECOMMENDATION

Based on the result and discussion the following recommendations are draw:

- Stabilize expansive soil using geogrid as a reinforcement
- Improve construction quality
- Construct additional structure on the road along the reservoir that prevent the infiltration of water to the road
- Construct sub surface drainages along the pavements.

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APPENDIX

Appendix –1 Unified Soil Classification System

USCS Soil-class	Description	Cohesion (kPa)	Friction angle (°)
GW	well-graded gravel, fine to coarse gravel	0	40
GP	poorly graded gravel	0	38
GM	silty gravel	0	36
GC	clayey gravel	0	34
GM-GL	silty gravel	0	35
GC-CL	clayey gravel with many fines	3	29
SW	well-graded sand, fine to coarse sand	0	38
SP	poorly graded sand	0	36
SM	silty sand	0	34
SC	clayey sand	0	32
SM-SL	silty sand with many fines	0	34
SC-CL	clayey sand with many fines	5	28
ML	silt	0	33
CL	clay of low plasticity, lean clay	20	27
CH	clay of high plasticity, fat clay	25	22
OL	organic silt, organic clay	10	25
OH	organic clay, organic silt	10	22
MH	silt of high plasticity, elastic silt	5	24

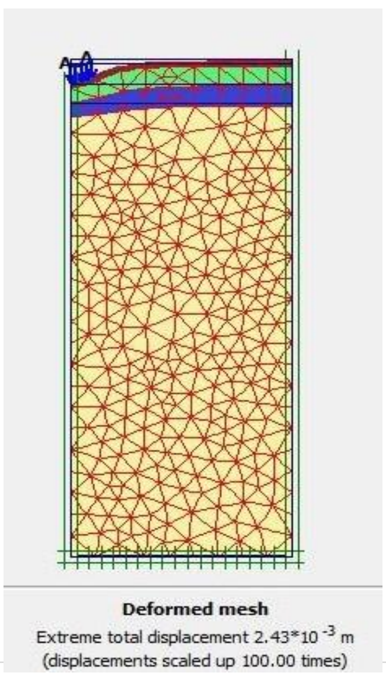
Appendix –2 Material Characteristics (Source ERA)

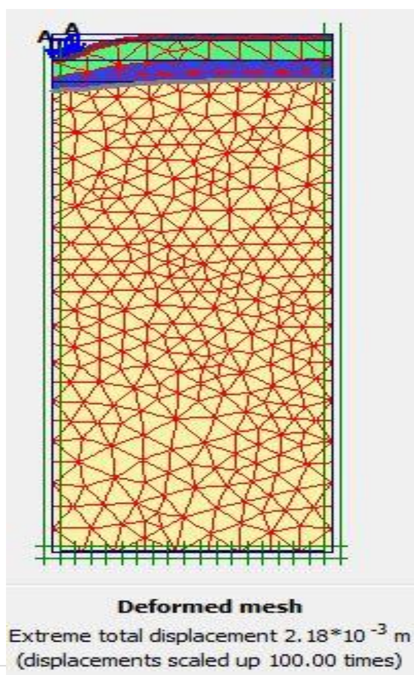
Material	Parameter	Value	Comment
Asphaltic concrete wearing course and binder course	Elastic modulus (MPa)	3000	A balance between a value appropriate for high ambient temperatures and the effect of ageing and embrittlement
	Volume of bitumen	10.5%	
Asphaltic concrete roadbase	Elastic modulus (MPa)	3000	
	Volume of bitumen	9.5%	
Granular roadbase	Elastic modulus (MPa) Poisson's ratio	300 0.30	For all qualities with CBR > 80%
Granular sub-base	Elastic modulus (MPa) Poisson's ratio	175 0.30	For CBR ≥30%
Capping layer	Elastic modulus (MPa) Poisson's ratio	100 0.30	For CBR ≥15%
Subgrades S1 S2 S3 S4 S5 S6	Elastic modulus in MPa	 28 37 53 73 112 175	Poisson's ratio for all subgrades was assumed to be 0.4
Hydraulically stabilised material	Elastic modulus (MPa)	CB1 = 3500 CB2 = 2500 CS =1500	Poissons ratio assumed to be 0.25 The modulus of CS is assumed to decrease with time hence a conservative low value of 1000MPa has been used

Appendix 3 Pavement Distress, Total Wearing Out, Derange Problem, Bulge Out of Material

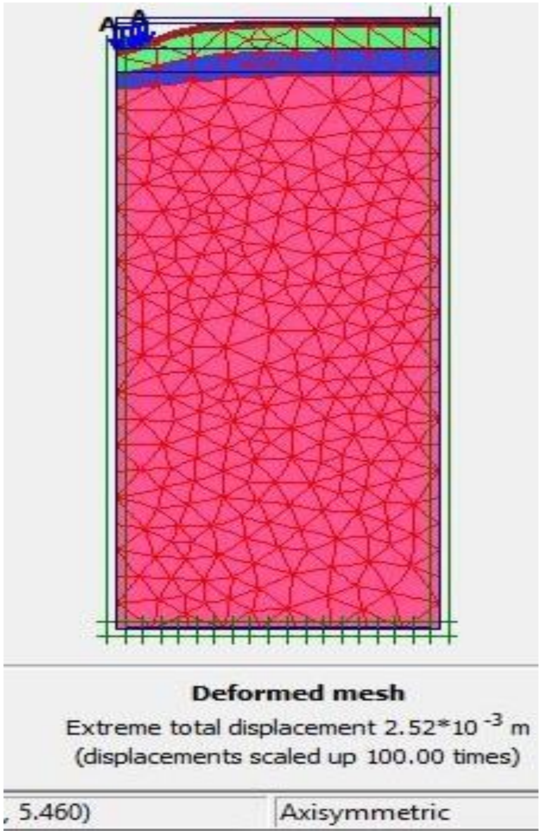


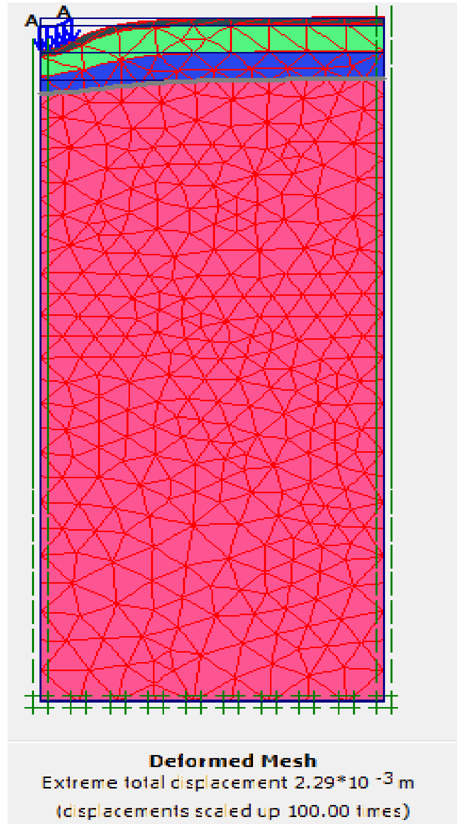

Appendix- 4Ttotal vertical deformation mesh generation of un-reinforced and reinforced road section one



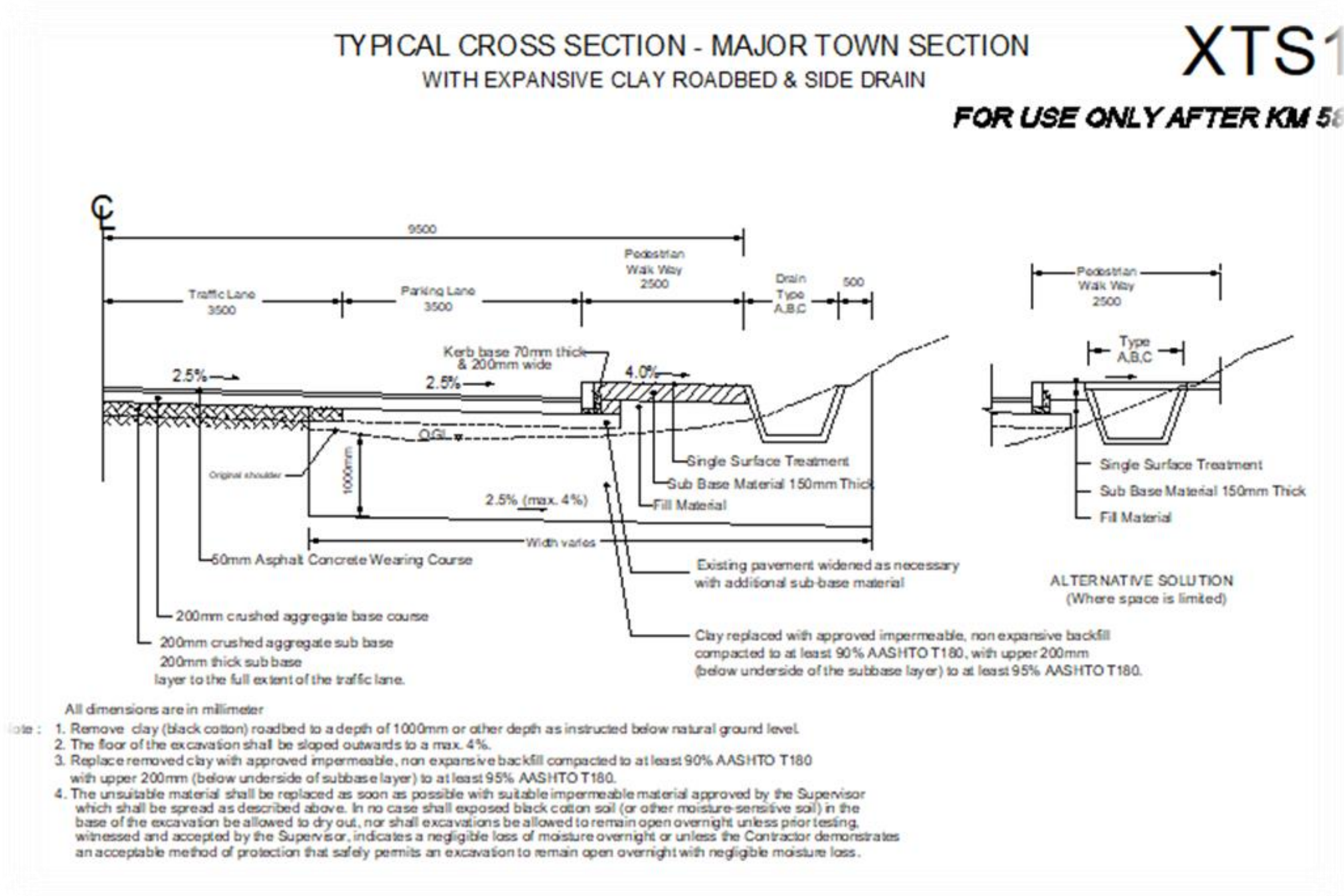


Appendix -5 Total vertical deformation mesh generation of reinforced road section two

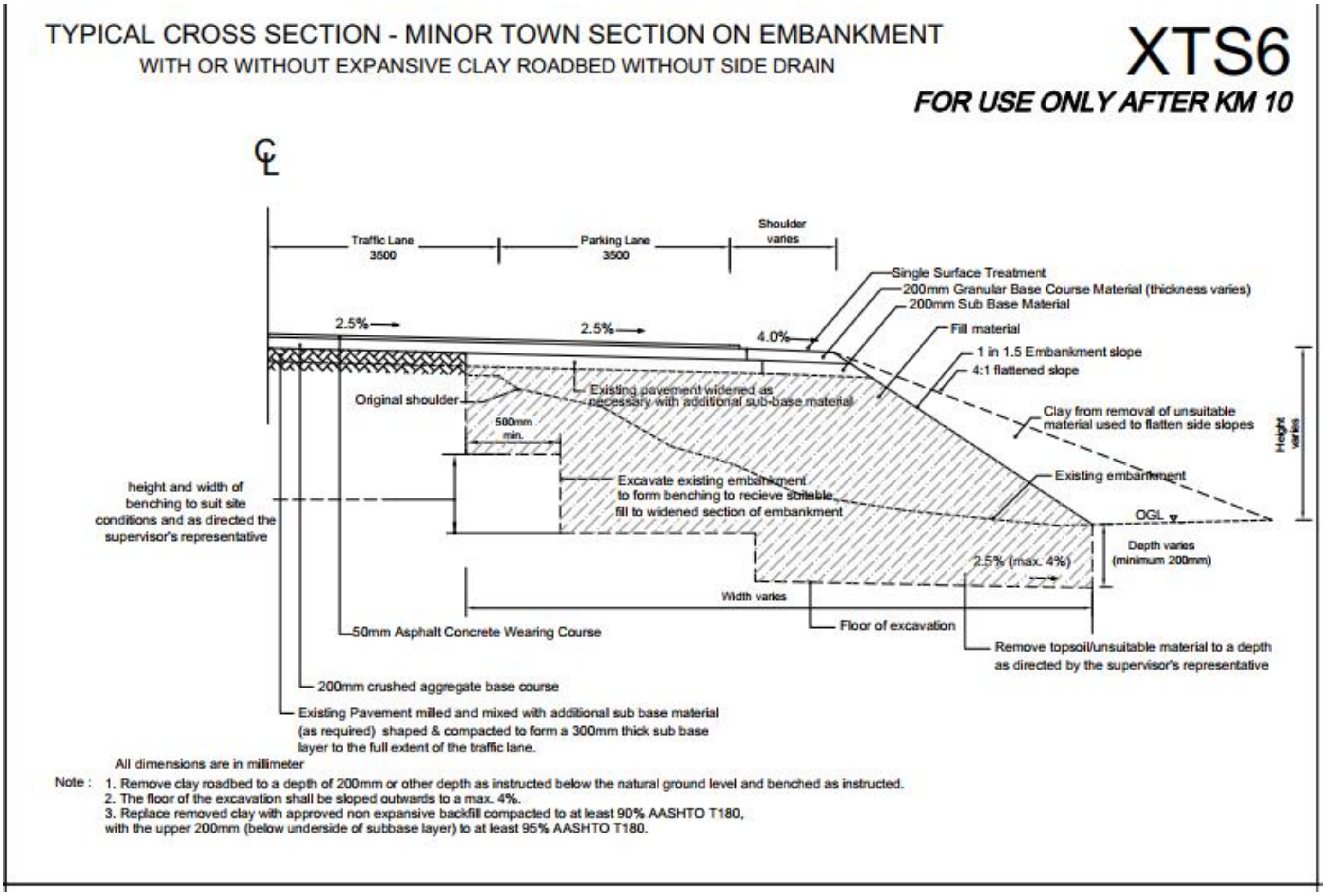




Appendix -6 Typical Road Section (road section 1 and 2)



Road section one



Road section two

Appendix 7: Direct Shear Test Result for Black Cotton Soil, Sample D at 2m depth

Sample No.		P01 A1	Sample Source=		Test Pit		Sample Depth, m:			?
Thickness of sample:		25 mm	Ring Calib. Factor=		0.70 N/div		Wet unit weight, kN/M^3:			18.69
Length of sample :		60 mm	Rate of strain =		1.6 mm/min		Dry Unit Weight, kN/M^3:			16.04
Width of sample:		60 mm	Moisture content, % =		47.33		Sample Condition:			Undisturbed
		Applied Vertical Stress			**Applied Vertical Stress**			**Applied Vertical Stress**		
		100kpa			**200kpa**			**300kpa**		
Horizontal	Corrected	Proving	Shear	Shear	Proving	Shear	Shear	Proving	Shear	Shear
Displace	Area	Ring	Load	Stress	Ring	Load	Stress	Ring	Load	Stress

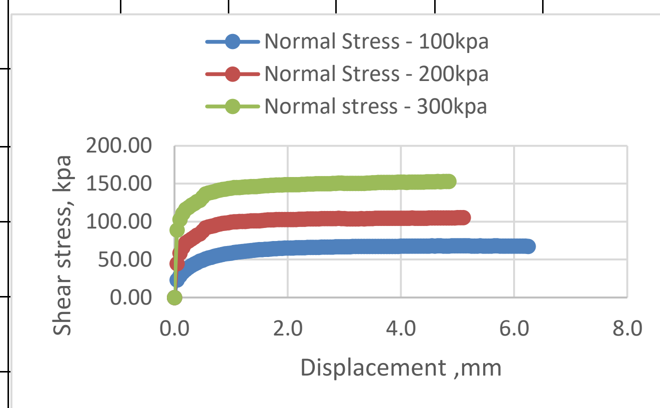
ment										
[mm]	[mm2]	Reading	[N]	[kPa]	Reading	[N]	[kPa]	Reading	[N]	[kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	3597	70.07	83.00	23.08	230.25	161.17	44.81	457.64	320.35	89.06
0.1	3594	90.67	103.60	28.83	301.97	211.38	58.81	529.37	370.56	103.10
0.2	3591	106.27	119.20	33.19	340.78	238.54	66.43	568.18	397.72	110.76
0.2	3588	119.07	132.00	36.79	370.37	259.26	72.26	597.77	418.44	116.62
0.3	3585	129.37	142.30	39.69	382.15	267.51	74.62	609.55	426.69	119.02
0.3	3582	138.17	151.10	42.18	395.59	276.91	77.31	622.99	436.09	121.75
0.4	3579	145.07	158.00	44.15	407.52	285.26	79.70	634.92	444.44	124.18
0.4	3576	152.07	165.00	46.14	419.60	293.72	82.14	647.00	452.90	126.65
0.5	3573	158.57	171.50	48.00	427.45	299.22	83.74	654.85	458.40	128.29
0.5	3570	163.27	176.20	49.36	447.08	312.96	87.66	674.48	472.14	132.25
0.6	3567	168.57	181.50	50.88	468.37	327.86	91.92	695.77	487.04	136.54
0.6	3564	173.27	186.20	52.25	473.81	331.67	93.06	701.21	490.84	137.72
0.7	3561	176.47	189.40	53.19	479.09	335.37	94.18	706.49	494.54	138.88
0.7	3558	180.27	193.20	54.30	482.72	337.90	94.97	710.12	497.08	139.71
0.8	3555	182.97	195.90	55.11	488.15	341.71	96.12	715.55	500.89	140.90
0.8	3552	185.97	198.90	56.00	492.68	344.88	97.09	720.08	504.06	141.91
0.9	3549	188.97	201.90	56.89	495.55	346.89	97.74	722.95	506.07	142.59
0.9	3546	191.37	204.30	57.61	497.82	348.47	98.27	725.22	507.65	143.16
1.0	3543	193.17	206.10	58.17	500.39	350.27	98.86	727.78	509.45	143.79
1.0	3540	195.17	208.10	58.79	502.95	352.07	99.45	730.35	511.25	144.42
1.1	3537	196.87	209.80	59.32	505.07	353.55	99.96	732.46	512.72	144.96

1.1	3534	198.47	211.40	59.82	505.07	353.55	100.04	732.46	512.72	145.08
1.2	3531	199.77	212.70	60.24	505.52	353.86	100.22	732.92	513.04	145.30
1.2	3528	201.47	214.40	60.77	505.67	353.97	100.33	733.07	513.15	145.45
1.3	3525	203.17	216.10	61.31	506.58	354.60	100.60	733.97	513.78	145.75
1.3	3522	204.57	217.50	61.76	507.48	355.24	100.86	734.88	514.42	146.06
1.4	3519	205.87	218.80	62.18	508.09	355.66	101.07	735.48	514.84	146.30
1.4	3516	207.07	220.00	62.57	508.54	355.98	101.24	735.94	515.16	146.52
1.5	3513	208.07	221.00	62.91	508.09	355.66	101.24	735.48	514.84	146.55
1.5	3510	208.77	221.70	63.16	508.09	355.66	101.33	735.48	514.84	146.68
1.6	3507	209.47	222.40	63.42	509.60	356.72	101.72	736.99	515.90	147.10
1.6	3504	209.87	222.802	63.58505	510.80	357.5628	102.0442	738.20	516.7414	147.47
1.7	3501	210.47	223.402	63.81091	512.01	358.4084	102.3732	739.41	517.587	147.84
1.7	3498	211.47	224.402	64.15152	512.62	358.8312	102.5818	740.01	518.0098	148.09
1.8	3495	211.97	224.902	64.34964	512.62	358.8312	102.6699	740.01	518.0098	148.21
1.8	3492	212.67	225.602	64.60538	512.62	358.8312	102.7581	740.01	518.0098	148.34
1.9	3489	213.17	226.102	64.80424	512.92	359.0426	102.907	740.32	518.2212	148.53
1.9	3486	213.57	226.502	64.97476	512.47	358.7255	102.9046	739.86	517.9041	148.57
2.0	3483	214.27	227.202	65.2317	512.77	358.9369	103.0539	740.17	518.1155	148.76
2.0	3480	214.47	227.402	65.3454	512.31	358.6198	103.0517	739.71	517.7984	148.79
2.1	3477	214.57	227.502	65.43054	511.86	358.3027	103.0494	739.26	517.4813	148.83
2.1	3474	214.87	227.802	65.5734	511.41	357.9856	103.0471	738.81	517.1642	148.87
2.2	3471	214.77	227.702	65.60127	510.65	357.4571	102.9839	738.05	516.6357	148.84
2.2	3468	215.17	228.102	65.8	511.11	357.7742	103.1644	738.50	516.9528	149.06

2.3	3465	214.97	227.902	65.77258	511.56	358.0913	103.3453	738.96	517.2699	149.28
2.3	3462	215.372	228.302	65.94512	512.012	358.4084	103.5264	739.41	517.587	149.51
2.35	3459	215.572	228.502	66.06013	512.012	358.4084	103.6162	739.41	517.587	149.63
2.4	3456	215.572	228.502	66.11748	512.012	358.4084	103.7061	739.41	517.587	149.76
2.45	3453	215.772	228.702	66.23284	511.861	358.3027	103.7656	739.259	517.4813	149.86
2.5	3450	215.972	228.902	66.34841	512.314	358.6198	103.9478	739.712	517.7984	150.09
2.55	3447	215.972	228.902	66.40615	511.861	358.3027	103.9462	739.259	517.4813	150.13
2.6	3444	216.172	229.102	66.52207	511.861	358.3027	104.0368	739.259	517.4813	150.26
2.65	3441	216.272	229.202	66.60913	511.408	357.9856	104.0353	738.806	517.1642	150.29
2.7	3438	216.272	229.202	66.66725	510.804	357.5628	104.0031	738.202	516.7414	150.30
2.75	3435	216.372	229.302	66.75459	510.351	357.2457	104.0017	737.749	516.4243	150.34
2.8	3432	216.372	229.302	66.81294	509.898	356.9286	104.0002	737.296	516.1072	150.38
2.85	3429	216.672	229.602	66.95888	510.2	357.14	104.1528	737.598	516.3186	150.57
2.9	3426	216.472	229.402	66.95914	510.955	357.6685	104.3983	738.353	516.8471	150.86
2.95	3423	216.872	229.802	67.13468	510.049	357.0343	104.3045	737.447	516.2129	150.81
3	3420	216.672	229.602	67.13509	509.294	356.5058	104.2415	736.692	515.6844	150.78
3.05	3417	216.472	229.402	67.1355	507.482	355.2374	103.9618	734.88	514.416	150.55
3.1	3414	216.672	229.602	67.25308	507.029	354.9203	103.9603	734.427	514.0989	150.59
3.15	3411	216.672	229.602	67.31223	506.576	354.6032	103.9587	733.974	513.7818	150.62
3.2	3408	216.372	229.302	67.28345	505.066	353.5462	103.7401	732.464	512.7248	150.45
3.25	3405	216.272	229.202	67.31336	505.368	353.7576	103.8936	732.766	512.9362	150.64
3.3	3402	216.172	229.102	67.34333	505.368	353.7576	103.9852	732.766	512.9362	150.77
3.35	3399	216.272	229.202	67.43219	504.764	353.3348	103.9526	732.162	512.5134	150.78

3.4	3396	215.972	228.902	67.40342	505.066	353.5462	104.1067	732.464	512.7248	150.98
3.45	3393	216.072	229.002	67.49248	505.217	353.6519	104.2299	732.615	512.8305	151.14
3.5	3390	215.972	228.902	67.52271	505.519	353.8633	104.3845	732.917	513.0419	151.34
3.55	3387	215.872	228.802	67.553	506.123	354.2861	104.6017	733.521	513.4647	151.60
3.6	3384	215.672	228.602	67.55378	506.576	354.6032	104.7882	733.974	513.7818	151.83
3.65	3381	215.472	228.402	67.55457	506.123	354.2861	104.7874	733.521	513.4647	151.87
3.7	3378	215.572	228.502	67.64417	504.915	353.4405	104.6301	732.313	512.6191	151.75
3.75	3375	215.372	228.302	67.64504	504.764	353.3348	104.6918	732.162	512.5134	151.86
3.8	3372	215.072	228.002	67.61625	503.858	352.7006	104.5969	731.256	511.8792	151.80
3.85	3369	214.772	227.702	67.58741	503.858	352.7006	104.69	731.256	511.8792	151.94
3.9	3366	214.772	227.702	67.64765	503.405	352.3835	104.6891	730.803	511.5621	151.98
3.95	3363	214.572	227.502	67.64853	503.405	352.3835	104.7825	730.803	511.5621	152.11
4	3360	214.672	227.602	67.73869	502.801	351.9607	104.7502	730.199	511.1393	152.12
4.05	3357	214.672	227.602	67.79923	502.197	351.5379	104.7179	729.595	510.7165	152.13
4.1	3354	214.372	227.302	67.77042	500.989	350.6923	104.5594	728.387	509.8709	152.02
4.15	3351	214.472	227.402	67.86094	501.14	350.798	104.6846	728.538	509.9766	152.19
4.2	3348	214.372	227.302	67.89188	501.593	351.1151	104.8731	728.991	510.2937	152.42
4.25	3345	214.072	227.002	67.86308	500.385	350.2695	104.7143	727.783	509.4481	152.30
4.3	3342	214.172	227.102	67.95392	499.932	349.9524	104.7135	727.33	509.131	152.34
4.35	3339	214.472	227.402	68.10482	499.177	349.4239	104.6493	726.575	508.6025	152.32
4.4	3336	214.172	227.102	68.07614	498.573	349.0011	104.6166	725.971	508.1797	152.33
4.45	3333	213.872	226.802	68.0474	498.875	349.2125	104.7742	726.273	508.3911	152.53
4.5	3330	213.872	226.802	68.10871	498.875	349.2125	104.8686	726.273	508.3911	152.67

4.55	3327	213.872	226.802	68.17012	498.422	348.8954	104.8679	725.82	508.074	152.71
4.6	3324	213.472	226.402	68.11131	497.818	348.4726	104.8353	725.216	507.6512	152.72
4.65	3321	213.372	226.302	68.14273	498.271	348.7897	105.0255	725.669	507.9683	152.96
4.7	3318	213.272	226.202	68.1742	497.214	348.0498	104.8975	724.612	507.2284	152.87
4.75	3315	212.872	225.802	68.11523	496.761	347.7327	104.8967	724.159	506.9113	152.91
4.8	3312	212.172	225.102	67.96558	496.157	347.3099	104.8641	723.555	506.4885	152.93
4.85	3309	212.272	225.202	68.05742	495.855	347.0985	104.8953	723.253	506.2771	153.00
4.9	3306	212.372	225.302	68.14943	495.553	346.8871	104.9265			
4.95	3303	212.172	225.102	68.15077	496.157	347.3099	105.1498			
5	3300	212.272	225.202	68.24303	496.308	347.4156	105.2775			
5.05	3297	211.772	224.702	68.15347	496.157	347.3099	105.3412			
5.1	3294	211.572	224.502	68.15483	495.402	346.7814	105.2767			
5.15	3291	211.372	224.302	68.15618						
5.2	3288	211.072	224.002	68.12713						
5.25	3285	210.472	223.402	68.0067						
5.3	3282	210.472	223.402	68.06886						
5.35	3279	210.372	223.302	68.10064						
5.4	3276	210.272	223.202	68.13248						
5.45	3273	209.972	222.902	68.10327						
5.5	3270	209.672	222.602	68.07401						
5.55	3267	209.372	222.302	68.04469						
5.6	3264	208.972	221.902	67.98468						
5.65	3261	209.272	222.202	68.13922						



5.7	3258	209.072	222.002	68.14058						
5.75	3255	207.972	220.902	67.86544						
5.8	3252	207.872	220.802	67.89729						
5.85	3249	207.772	220.702	67.92921						
5.9	3246	207.472	220.402	67.89957						
5.95	3243	207.172	220.102	67.86987						
6	3240	207.072	220.002	67.90185						
6.05	3237	206.472	219.402	67.77943						
6.1	3234	206.272	219.202	67.78046						
6.15	3231	205.972	218.902	67.75054						
6.2	3228	205.672	218.602	67.72057						
6.25	3225	205.372	218.302	67.69054						

Appendix 8: Direct Shear Test Result for Red Clay Soil, Sample D at 2m depth

Sample No.		P01 A1	Sample Source=		Test Pit		Sample Depth, m:			?
Thickness of sample:		25 mm	Ring Calib. Factor=		0.70 N/div		Wet unit weight, kN/M^3:			18.89
Length of sample :		60 mm	Rate of strain =		1.6 mm/min		Dry Unit Weight, kN/M^3:			16.55
Width of sample:		60 mm	Moisture content, % =		47.33		Sample Condition:			Undisturbed
		Applied Vertical Stress			**Applied Vertical Stress**			**Applied Vertical Stress**		
		100kpa			**200kpa**			**300kpa**		
Horizontal	Corrected	Proving	Shear	Shear	Proving	Shear	Shear	Proving	Shear	Shear

Displacement	Area	Ring	Load	Stress	Ring	Load	Stress	Ring	Load	Stress
[mm]	[mm2]	Reading	[N]	[kPa]	Reading	[N]	[kPa]	Reading	[N]	[kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	3597	14.24	9.97	2.77	47.77	33.44	9.30	105.88	74.12	20.61
0.1	3594	34.84	24.39	6.79	119.50	83.65	23.27	345.59	241.91	67.31
0.2	3591	50.44	35.31	9.83	158.31	110.81	30.86	461.66	323.16	89.99
0.2	3588	63.24	44.27	12.34	187.90	131.53	36.66	508.37	355.86	99.18
0.3	3585	73.54	51.48	14.36	199.68	139.78	38.99	544.08	380.86	106.24
0.3	3582	82.34	57.64	16.09	213.12	149.18	41.65	574.31	402.01	112.23
0.4	3579	89.24	62.47	17.45	225.05	157.53	44.02	587.01	410.91	114.81
0.4	3576	96.24	67.37	18.84	237.13	165.99	46.42	602.12	421.49	117.87
0.5	3573	102.74	71.92	20.13	244.98	171.49	47.99	613.11	429.18	120.12
0.5	3570	107.44	75.21	21.07	264.61	185.23	51.88	623.76	436.63	122.31
0.6	3567	112.74	78.92	22.12	285.90	200.13	56.11	629.25	440.48	123.49
0.6	3564	117.44	82.21	23.07	291.34	203.94	57.22	634.06	443.84	124.53
0.7	3561	120.64	84.45	23.71	296.62	207.64	58.31	638.18	446.73	125.45
0.7	3558	124.44	87.11	24.48	300.25	210.17	59.07	641.61	449.13	126.23
0.8	3555	127.14	89.00	25.03	305.68	213.98	60.19	640.93	448.65	126.20
0.8	3552	130.14	91.10	25.65	310.21	217.15	61.13	642.65	449.85	126.65
0.9	3549	133.14	93.20	26.26	313.08	219.16	61.75	644.71	451.29	127.16
0.9	3546	135.54	94.88	26.76	315.35	220.74	62.25	645.39	451.77	127.40
1.0	3543	137.34	96.14	27.13	317.91	222.54	62.81	646.42	452.50	127.72
1.0	3540	139.34	97.54	27.55	320.48	224.34	63.37	647.11	452.98	127.96
1.1	3537	141.	98.7	27.91	322.5	225.8	63.84	647.1	452.98	128.0

		04	3		9	2		1		7
1.1	3534	142.64	99.85	28.25	322.59	225.82	63.90	647.80	453.46	128.31
1.2	3531	143.94	100.76	28.54	323.05	226.13	64.04	647.45	453.22	128.35
1.2	3528	145.64	101.95	28.90	323.20	226.24	64.13	647.80	453.46	128.53
1.3	3525	147.34	103.14	29.26	324.10	226.87	64.36	647.80	453.46	128.64
1.3	3522	148.74	104.12	29.56	325.01	227.51	64.60	647.80	453.46	128.75
1.4	3519	150.04	105.03	29.85	325.61	227.93	64.77	647.11	452.98	128.72
1.4	3516	151.24	105.87	30.11	326.07	228.25	64.92	647.11	452.98	128.83
1.5	3513	152.24	106.57	30.34	325.61	227.93	64.88	647.11	452.98	128.94
1.5	3510	152.94	107.06	30.50	325.61	227.93	64.94	646.77	452.74	128.98
1.6	3507	153.64	107.55	30.67	327.12	228.99	65.29	647.11	452.98	129.16
1.6	3504	154.04	107.828	30.77283	328.33	229.8324	65.59144	647.45	453.2171	129.34
1.7	3501	154.64	108.248	30.91917	329.54	230.678	65.88917	647.80	453.4575	129.52
1.7	3498	155.64	108.948	31.1458	330.14	231.1008	66.06655	648.14	453.6979	129.70
1.8	3495	156.14	109.298	31.27268	330.14	231.1008	66.12326	647.11	452.9767	129.61
1.8	3492	156.84	109.788	31.43986	330.14	231.1008	66.18007	646.42	452.496	129.58
1.9	3489	157.34	110.138	31.56721	330.45	231.3122	66.29756	646.42	452.496	129.69
1.9	3486	157.74	110.418	31.6747	329.99	230.9951	66.26365	646.08	452.2556	129.73
2.0	3483	158.44	110.908	31.84266	330.30	231.2065	66.38142	645.05	451.5344	129.64
2.0	3480	158.64	111.048	31.91034	329.84	230.8894	66.34753	644.36	451.0536	129.61
2.1	3477	158.74	111.118	31.95801	329.39	230.5723	66.31357	644.02	450.8132	129.66
2.1	3474	159.04	111.328	32.04606	328.94	230.2552	66.27956	643.68	450.5728	129.70
2.2	3471	158.94	111.258	32.05359	328.18	229.7267	66.18459	643.68	450.5728	129.81
2.2	3468	159.	111.	32.2	328.6	230.0	66.33	642.9	450.09	129.7

		34	538		3	438	328	9	2	8
2.3	3465	159.14	111.398	32.14949	329.09	230.3609	66.48222	642.65	449.8516	129.83
2.3	3462	159.54	111.678	32.25823	329.54	230.678	66.63143	642.3018	449.6112	129.87
2.35	3459	159.74	111.818	32.32668	329.54	230.678	66.68922	641.9584	449.3709	129.91
2.4	3456	159.74	111.818	32.35475	329.54	230.678	66.74711	641.6149	449.1305	129.96
2.45	3453	159.94	111.958	32.4234	329.389	230.5723	66.77449	640.9281	448.6497	129.93
2.5	3450	160.14	112.098	32.49217	329.842	230.8894	66.92446	640.5847	448.4093	129.97
2.55	3447	160.14	112.098	32.52045	329.389	230.5723	66.89072	640.2413	448.1689	130.02
2.6	3444	160.34	112.238	32.58943	329.389	230.5723	66.94898	639.8979	447.9285	130.06
2.65	3441	160.44	112.308	32.63819	328.936	230.2552	66.9152	639.211	447.4477	130.03
2.7	3438	160.44	112.308	32.66667	328.332	229.8324	66.85061	639.211	447.4477	130.15
2.75	3435	160.54	112.378	32.71557	327.879	229.5153	66.81668	638.1808	446.7265	130.05
2.8	3432	160.54	112.378	32.74417	327.426	229.1982	66.78269	638.1808	446.7265	130.17
2.85	3429	160.84	112.588	32.83406	327.728	229.4096	66.90277	637.8373	446.4861	130.21
2.9	3426	160.64	112.448	32.82195	328.483	229.9381	67.11562	637.8373	446.4861	130.32
2.95	3423	161.04	112.728	32.93252	327.577	229.3039	66.98916	636.8071	445.765	130.23
3	3420	160.84	112.588	32.92047	326.822	228.7754	66.89339	636.8071	445.765	130.34
3.05	3417	160.64	112.448	32.9084	325.01	227.507	66.58092	637.1505	446.0054	130.53
3.1	3414	160.84	112.588	32.97832	324.557	227.1899	66.54654	636.8071	445.765	130.57
3.15	3411	160.84	112.588	33.00733	324.104	226.8728	66.51211	635.7768	445.0438	130.47
3.2	3408	160.54	112.378	32.97477	322.594	225.8158	66.2605	635.4334	444.8034	130.52
3.25	3405	160.44	112.308	32.98326	322.896	226.0272	66.38097	634.4032	444.0822	130.42
3.3	3402	160.34	112.238	32.99177	322.896	226.0272	66.43951	633.7163	443.6014	130.39
3.35	3399	160.	112.	33.04	322.2	225.6	66.37	633.3	443.36	130.4

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3.4	3396	160.14	112.098	33.00883	322.594	225.8158	66.49464	633.3729	443.361	130.55
3.45	3393	160.24	112.168	33.05865	322.745	225.9215	66.58459	631.9992	442.3995	130.39
3.5	3390	160.14	112.098	33.06726	323.047	226.1329	66.70587	631.3124	441.9187	130.36
3.55	3387	160.04	112.028	33.07588	323.651	226.5557	66.88978	629.9387	440.9571	130.19
3.6	3384	159.84	111.888	33.06383	324.104	226.8728	67.04279	629.9387	440.9571	130.31
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3.7	3378	159.74	111.818	33.10184	322.443	225.7101	66.81767	627.8782	439.5148	130.11
3.75	3375	159.54	111.678	33.08978	322.292	225.6044	66.84575	626.848	438.7936	130.01
3.8	3372	159.24	111.468	33.05694	321.386	224.9702	66.71714	625.4743	437.832	129.84
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3.9	3366	158.94	111.258	33.05348	320.933	224.6531	66.74186	623.7572	436.63	129.72
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4	3360	158.84	111.188	33.09167	320.329	224.2303	66.73521	622.3835	435.6685	129.66
4.05	3357	158.84	111.188	33.12124	319.725	223.8075	66.6689	621.6967	435.1877	129.64
4.1	3354	158.54	110.978	33.08825	318.517	222.9619	66.47642	621.0099	434.7069	129.61
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4.25	3345	158.24	110.768	33.1145	317.913	222.5391	66.52888	618.2625	432.7838	129.38
4.3	3342	158.34	110.838	33.16517	317.46	222.222	66.49372	616.8889	431.8222	129.21
4.35	3339	158.64	111.048	33.25786	316.705	221.6935	66.39518	615.8586	431.101	129.11
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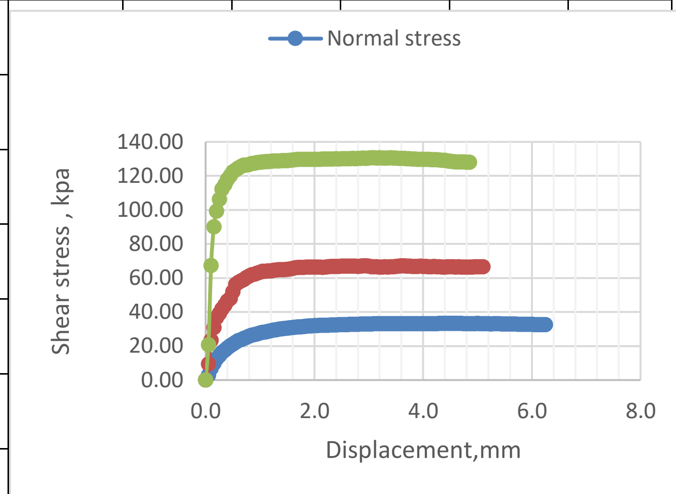
4.5	3330	158.	110.	33.22	316.4	221.4	66.51	611.7	428.21	128.5

		04	628	162	03	821	114	376	63	9
4.55	3327	158. 04	110. 628	33.25 158	315.9 5	221.1 65	66.47 58	610.3 639	427.25 47	128.4 2
4.6	3324	157. 64	110. 348	33.19 735	315.3 46	220.7 422	66.40 86	608.9 902	426.29 32	128.2 5
4.65	3321	157. 54	110. 278	33.20 626	315.7 99	221.0 593	66.56 408	608.3 034	425.81 24	128.2 2
4.7	3318	157. 44	110. 208	33.21 519	314.7 42	220.3 194	66.40 127	607.2 732	425.09 12	128.1 2
4.75	3315	157. 04	109. 928	33.16 078	314.2 89	220.0 023	66.36 57	606.5 863	424.61 04	128.0 9
4.8	3312	156. 34	109. 438	33.04 287	313.6 85	219.5 795	66.29 816	605.2 126	423.64 89	127.9 1
4.85	3309	156. 44	109. 508	33.09 399	313.3 83	219.3 681	66.29 438	604.5 258	423.16 81	127.8 8
4.9	3306	156. 54	109. 578	33.14 519	313.0 81	219.1 567	66.29 059			
4.95	3303	156. 34	109. 438	33.13 291	313.6 85	219.5 795	66.47 881			
5	3300	156. 44	109. 508	33.18 424	313.8 36	219.6 852	66.57 127			
5.05	3297	155. 94	109. 158	33.10 828	313.6 85	219.5 795	66.59 979			
5.1	3294	155. 74	109. 018	33.09 593	312.9 3	219.0 51	66.5			
5.15	3291	155. 54	108. 878	33.08 356						
5.2	3288	155. 24	108. 668	33.04 988						
5.25	3285	154. 64	108. 248	32.95 221						
5.3	3282	154. 64	108. 248	32.98 233						
5.35	3279	154. 54	108. 178	32.99 116						
5.4	3276	154. 44	108. 108	33						
5.45	3273	154. 14	107. 898	32.96 609						
5.5	3270	153. 84	107. 688	32.93 211						
5.55	3267	153. 54	107. 478	32.89 807						
5.6	3264	153. 14	107. 198	32.84 252						
5.65	3261	153.	107.	32.93						

		44	408	714						
5.7	3258	153.24	107.268	32.92449						
5.75	3255	152.14	106.498	32.71828						
5.8	3252	152.04	106.428	32.72694						
5.85	3249	151.94	106.358	32.73561						
5.9	3246	151.64	106.148	32.70117						
5.95	3243	151.34	105.938	32.66667						
6	3240	151.24	105.868	32.67531						
6.05	3237	150.64	105.448	32.57584						
6.1	3234	150.44	105.308	32.56277						
6.15	3231	150.14	105.098	32.52801						
6.2	3228	149.84	104.888	32.49318						
6.25	3225	149.54	104.678	32.45829						



Appendix 9 ERCC Laboratory and Field Test Results of Each Layers

Addis Ababa to Jima Road Rehabilitation Project
Asphalt Wearing Course - Test Results

Station, km	Date Laid	28	20	14	5	2	1	0.6	0.3	0.15	0.075	Bitumen Content, by total weight (5.0 - 5.1)	Bulk Specific Gravity	Max. theoretical density,	Marshall Air voids, % (3 - 5)	VMA (min. 14)	VFA %	Stability (min. 9KN)	Flow (min. 2mm)	Comments
		(100)	(95-100)	(80-90)	(53-63)	(30-40)	(20-30)	(14-22)	(10-16)	(7-11)	(4.3-8.3)									
													2.314					13.22	4.05	
247+700 RHS	25/02/08			85	54	30	18	14	10	8	6.1	5.29	2.304	2.426	4.7			11.12	5.24	
													2.314					12.32	3.88	
													2.304					16.61	4.39	
250+300 LHS	26/02/08			87	53	31	19	14	11	9	6.7	5.21	2.318	2.426	4.7			10.53	7.16	
													2.311					19.76	5.00	
													2.319					12.21	4.53	
250+700 RHS	27/02/08			84	57	34	23	18	13	10	7.9	5.34	2.313	2.438	5.0			10.84	5.15	
													2.309					13.34	5.43	
													2.311					16.91	4.67	
248+900 LHS	29/02/08		99	89	59	33	20	15	11	9	7.0	5.26	2.300	2.429	5.1			15.18	4.18	
													2.303					16.84	5.40	
													2.308					11.93	6.65	
249+600 LHS	29/02/08		99	89	53	32	20	16	11	8	6.3	4.99	2.307	2.428	5.1			11.48	5.78	
													2.300					12.35	4.61	
													2.327					12.27	3.55	
247+200 RHS	01/03/08			91	57	32	19	14	10	8	6.1	5.04	2.303	2.424	4.5			12.69	4.65	
													2.318					11.81	4.62	
													2.305					13.89	3.93	
248+700 LHS	02/03/08			90	59	32	20	15	11	9	7.4	5.24	2.330	2.426	4.5			11.51	4.68	
													2.309					12.45	3.82	
													2.318					11.34	5.31	
248+800 LHS	02/03/08			91	59	33	19	14	10	8	5.7	5.05	2.319	2.426	4.8			16.63	4.11	
													2.297					11.03	5.07	
													2.309					10.63	4.09	
244+000 RHS	03/03/08			93	59	33	18	14	10	8	6.0	5.22	2.308	2.420	4.5			9.58	4.11	
													2.316					11.88	4.50	
													2.302					11.99	4.65	
244+500 RHS	03/03/08			87	55	31	19	15	10	8	5.8	5.19	2.303	2.429	5.1			11.21	5.08	
													2.311					12.31	6.25	
													2.301					9.99	4.33	
245+300 RHS	04/03/08			87	58	33	20	15	10	8	6.3	5.07	2.310	2.430	5.0			9.84	3.14	
													2.314					9.50	3.53	
													2.326					11.77	4.23	
245+450 LHS	05/03/08			90	62	31	19	14	10	9	6.6	5.11	2.336	2.428	4.3			11.91	4.62	
													2.318					11.16	4.22	
													2.311					9.24	3.77	
246+200 RHS	05/03/08			90	61	36	21	16	10	8	6.1	5.09	2.329	2.439	4.7			11.66	4.64	
													2.334					11.29	4.61	

Roads Authority
Road Network & Safety
ment Branch Directorate

Page 1 of 3

AWC Lab

Station, km	Date Laid	28	20	14	5	2	1	0.6	0.3	0.15	0.075	Bitumen Content, by total weight (5.0 - 5.1)	Bulk Specific Gravity	Max. theoretical density,	Marshall Air voids, % (3 - 5)	VMA (min. 14)	VFA %	Stability (min. 9KN)	Flow (min. 2mm)	Comments
		(100)	(95-100)	(80-90)	(53-63)	(30-40)	(20-30)	(14-22)	(10-16)	(7-11)	(4.3-8.3)									
246+500 LHS	06/03/08			89	61	33	18	14	10	8	6.5	5.34	2.318					11.31	4.76	
													2.321	2.431	4.6			11.39	4.06	
													2.317					10.43	4.83	
243+200 LHS	07/03/08			91	59	34	20	15	10	8	5.3	5.12	2.303					13.20	5.76	
													2.315	2.434	5.0			12.85	6.77	
													2.319					10.59	4.48	
243+000 LHS	07/03/08		99	92	60	33	20	15	10	9	6.8	5.21	2.306					12.02	5.16	
													2.324	2.441	5.1			11.10	3.97	
													2.320					12.75	4.90	
250+000 RHS	08/03/08			87	55	32	19	14	10	7	5.5	5.25	2.316					11.10	5.72	
													2.317	2.432	4.9			13.92	6.20	
													2.308					12.58	5.26	
243+902 LHS	09/03/08			90	61	33	20	15	10	8	6.8	5.25	2.312					10.09	4.25	
													2.305	2.434	4.8			12.08	4.77	
													2.334					11.31	4.74	
244+190 LHS	09/03/08			86	62	33	21	16	11	9	7.1	5.09	2.324					13.49	4.70	
													2.323	2.440	5.0			12.68	5.22	
													2.305					11.95	4.29	
245+087 LHS	10/03/08			86	54	31	20	15	11	9	7.4	5.20	2.310					10.34	7.33	
													2.327	2.432	4.8			11.16	6.02	
													2.305					12.72	6.39	
244+758 LHS	10/03/08			90	61	35	20	14	10	8	5.6	5.27	2.310					10.05	5.77	
													2.310	2.434	4.9			10.09	5.92	
													2.322					12.78	7.38	
246+374 RHS	11/03/08			92	55	31	19	15	11	9	7.0	5.05	2.306					11.30	6.24	
													2.321	2.425	4.5			10.23	4.40	
													2.322					10.84	6.89	
242+290 RHS	12/03/08			84	50	32	19	15	10	9	6.7	5.06	2.311					12.08	6.01	
													2.319	2.428	4.6			12.83	6.23	
													2.315					11.20	7.67	
243+126 RHS	13/03/08			85	53	31	20	15	10	8	6.7	5.18	2.316					10.33	4.80	
													2.322	2.437	4.9			10.07	5.83	
													2.314					10.61	6.18	
241+621 LHS	14/03/08			95	60	36	23	18	14	12	10.1	5.07	2.309					12.27	5.60	
													2.322	2.434	4.8			12.15	5.46	
													2.319					13.19	5.39	
241+621 LHS	14/03/08			83	53	31	18	14	10	8	6.6	5.00	2.311					8.11	5.55	
													2.320	2.437	4.9			8.29	4.75	
													2.323					10.29	4.79	
241+096 LHS	15/03/08			89	56	34	22	18	14	10	6.9	5.10	2.313					10.16	5.19	
													2.311	2.440	5.0			10.71	4.39	
													2.327					13.06	6.68	
240+580 LHS	16/03/08			88	62	36	21	16	11	9	7.0	5.02	2.312					10.59	5.51	
													2.308	2.429	4.7			11.39	5.47	
													2.322					12.94	5.93	
240+580													2.319					13.85	5.92	

Roads Authority Network & Safety ... Directorate

Page 2 of 3

AWC Lab

Addis Ababa to Jima Road Rehabilitation Project
Base Course Material - Laboratory Test Results

station	Material source	Date Sampled	Date Tested	Gradation									Modified proctor		LL	PL	PI	CBR	Swell	LA	Remarks
				50	37.5	20	10	5	2	0.6	0.425	0.075	MDD g/cm^3	OMC							
				100	(95-100)	(60-80)	(40-60)	(25-40)	(15-30)	(8-22)	(7-19)	(5-12)					0	>=80	0	<=35	
250+220	R/W	16/02/08	17/02/08												N.P	N.P	N.P				
248+700	R/W	21/02/08	23/02/08										2.24	8.3							
248+000	R/W	26/02/08	01/03/08		99	70	44	27	16	8	7	5	2.20	8.0	N.P	N.P	N.P				
247+000	R/W	26/02/08	01/03/08		99	69	43	26	17	9	8	5			N.P	N.P	N.P				
241+800	R/W	03/03/08	07/03/08		98	72	46	27	17	10	9	6	2.22	7.4							
244+000	R/W	04/03/08	09/03/08		98	83	57	37	22	11	10	6	2.23	7.7							
240+000	R/W	12/03/08	12/03/08										2.24	7.3							
241+600	R/W	12/03/08	12/03/08										2.25	8.3							
240+000	R/W	12/03/08	14/03/08		96	67	46	29	19	10	8	5	2.24	7.2							
241+000	R/W	12/03/08	14/03/08		93	67	47	31	20	11	9	6	2.24	8.0							
239+000	R/W	15/03/08	19/03/08		96	68	46	27	18	9	8	5	2.30	6.7							
237+400	R/W	21/03/08	24/03/08		94	86	43	22	12	8	5	4	2.29	6.1							

Addis Ababa to Jima Road Rehabilitation Project
Subbase Course - Field Density Results

Date Tested	Test-Chainage (km)	MDD (Kg/m³)	OMC (%)	Wet Density (kg/m³)	Dry Density (kg/m³)	% Moisture	% Compaction	Remark
20/02/08	243+720R	2.110	8.7	2288	2114	8.2	100.2	
20/02/08	243+780L	2.110	8.7	2254	2074	8.7	98.3	
20/02/08	243+840L	2.110	8.7	2241	2068	8.4	98.0	
20/02/08	243+900R	2.110	8.7	2261	2093	8.0	99.2	
20/02/08	243+960L	2.110	8.7	2265	2102	7.8	99.6	
20/02/08	244+020L	2.110	8.7	2265	2074	9.2	98.3	
20/02/08	244+080R	2.110	8.7	2255	2083	8.3	98.7	
20/02/08	244+140L	2.110	8.7	2235	2093	6.8	99.2	
20/02/08	244+200L	2.110	8.7	2289	2110	8.5	100.0	
20/02/08	244+260R	2.110	8.7	2360	2183	8.1	98.8	
20/02/08	244+320L	2.110	8.7	2259	2099	7.6	99.5	
20/02/08	244+380L	2.110	8.7	2258	2083	8.4	98.7	
20/02/08	244+440R	2.110	8.7	2290	2097	9.2	99.4	
20/02/08	244+500L	2.110	8.7	2251	2078	8.3	98.5	
25/02/08	242+520L	2.000	11.0	2159	1974	9.4	98.7	
25/02/08	242+580R	2.000	11.0	2169	1988	9.1	99.4	
25/02/08	242+640R	2.000	11.0	2182	1996	9.3	99.8	
25/02/08	242+700L	2.000	11.0	2161	1970	9.7	98.5	
25/02/08	242+760R	2.000	11.0	2244	2072	8.3	98.2	
25/02/08	242+820R	2.000	11.0	2238	2076	7.8	98.4	
25/02/08	242+880L	2.000	11.0	2270	2099	8.1	99.5	
25/02/08	242+940R	2.000	11.0	2262	2083	8.6	98.7	
25/02/08	243+000R	2.000	11.0	2246	2076	8.2	98.4	
25/02/08	243+020L	2.110	9.7	2260	2087	8.3	98.9	
25/02/08	243+080R	2.110	9.7	2276	2097	8.5	99.4	
25/02/08	243+140R	2.110	9.7	2268	2080	9.0	98.6	
25/02/08	243+200L	2.110	9.7	2259	2074	8.9	98.3	
25/02/08	243+260R	2.110	9.7	2269	2089	8.6	99.0	
27/02/08	241+020R	2.100	10.8	2281	2106	8.3	100.3	
27/02/08	241+080L	2.100	10.8	2269	2071	9.6	98.6	
27/02/08	241+140L	2.100	10.8	2252	2066	9.0	98.4	
27/02/08	241+200R	2.100	10.8	2281	2100	8.6	100.0	
27/02/08	241+260L	2.000	11.0	2264	2004	8.0	100.2	
27/02/08	241+320L	2.000	11.0	2195	2010	9.2	100.5	
27/02/08	241+380R	2.000	11.0	2170	1996	8.7	99.8	
27/02/08	241+440L	2.000	11.0	2180	2000	9.0	100.0	
27/02/08	241+500L	2.000	11.0	2205	2008	9.8	100.4	
27/02/08	242+000L	2.100	10.8	2268	2100	8.0	100.0	
27/02/08	242+080R	2.100	10.8	2265	2073	9.3	98.7	
27/02/08	242+140R	2.100	10.8	2265	2087	8.5	99.4	
27/02/08	242+200L	2.100	10.8	2305	2012	10.2	99.6	
27/02/08	242+260R	2.100	10.8	2185	2006	8.9	100.3	

Ethiopian Roads Authority — Road Network & Safety

Date Tested	Test-Chainage (km)	MDD (Kg/m^3)	OMC (%)	Wet Density (kg/m^3)	Dry Density (kg/m^3)	% Moisture	% Compaction	Remark
20/03/08	233+200R	1.97	12.8	2214	1968	12.5	99.9	
20/03/08	233+320R	1.97	12.8	2204	1970	11.9	100.0	
20/03/08	233+520	1.99	12.3	2229	1990	12.0	100.0	
20/03/08	233+580	1.99	12.3	2225	1988	11.9	99.9	
20/03/08	233+640	1.99	12.3	2205	1992	10.7	100.1	
20/03/08	233+700	1.99	12.3	2212	1968	12.4	98.9	
20/03/08	233+760	1.99	12.3	2153	1926	11.8	96.8	
20/03/08	233+820	1.99	12.3	2214	1968	12.5	98.9	
20/03/08	233+880	1.99	12.3	2205	1988	10.9	99.9	
20/03/08	233+940	1.99	12.3	2237	1990	12.4	100.0	
20/03/08	233+980	1.99	12.3	2196	1964	11.8	98.7	
20/03/08	233+760	1.99	12.3	2227	1988	12.0	99.9	
20/03/08	234+020	2.06	9.6	2249	2056	9.4	99.8	
20/03/08	234+080	2.06	9.6	2264	2058	10.0	99.9	
20/03/08	234+140	2.06	9.6	2230	2033	9.7	98.7	
20/03/08	234+200	2.06	9.6	2186	1994	9.6	96.8	
20/03/08	234+260	2.06	9.6	2243	2037	10.1	98.9	
20/03/08	234+320	2.06	9.6	2262	2060	9.8	100.0	
20/03/08	234+380	2.06	9.6	2247	2054	9.4	99.7	
20/03/08	234+420	2.06	9.6	2210	2017	9.6	97.9	
20/03/08	234+480	2.06	9.6	2241	2037	10.0	98.9	
20/03/08	234+200	2.06	9.6	2264	2056	10.1	99.8	
20/03/08	234+420	2.06	9.6	2262	2060	9.8	100.0	
20/03/08	234+520	1.98	10.5	2160	1958	10.3	98.9	
20/03/08	234+580	1.98	10.5	2118	1936	9.4	97.8	
20/03/08	234+640	1.98	10.5	2169	1972	10.0	99.6	
20/03/08	234+700	1.98	10.5	2146	1954	9.8	98.7	
20/03/08	234+760	1.98	10.5	2111	1911	10.5	96.5	
20/03/08	234+820	1.98	10.5	2166	1958	10.6	98.9	
20/03/08	234+880	1.98	10.5	2120	1932	9.7	97.6	
20/03/08	234+940	1.98	10.5	2180	1978	10.2	99.9	
20/03/08	234+980	1.98	10.5	2158	1954	10.4	98.7	
20/03/08	234+580	1.98	10.5	2180	1976	10.3	99.8	Re Test
20/03/08	234+760	1.98	10.5	2166	1958	10.6	98.9	Re Test
20/03/08	234+880	1.98	10.5	2172	1978	9.8	99.9	Re Test
21/03/08	232+520L	1.89	11.4	2115	1894	11.7	100.2	
21/03/08	232+580R	1.89	11.4	2116	1918	10.3	101.5	
21/03/08	232+640R	1.89	11.4	2075	1890	9.8	100	
21/03/08	232+700L	1.89	11.4	2082	1886	10.4	99.8	
21/03/08	232+760R	1.89	11.4	2056	1844	11.5	97.6	
21/03/08	232+820R	1.89	11.4	2104	1899	10.8	100.5	
21/03/08	232+880L	1.89	11.4	2142	1894	13.1	100.2	
21/03/08	232+940R	1.89	11.4	2086	1886	10.6	99.3	
21/03/08	233+000	1.89	11.4	2141	1903	12.5	100.7	

Subbase

Addis Ababa to Jima Road Rehabilitation Project
Subgrade - Field Density Results

Date Tested	Test Chainage (km)	MDD (Kg/m^3)	OMC (%)	Wet Density (kg/m^3)	Dry Density (kg/m^3)	% Moisture	% Compaction	Remark
24/02/08	229+820R	1.85	13.0	1990	1804	10.3	97.5	
24/02/08	230+020R	1.85	13.0	2073	1859	11.5	100.5	
24/02/08	229+720R	1.85	13.0	2039	1852	10.1	100.1	
24/02/08	229+020R	1.85	13.0	2053	1855	10.7	100.2	
24/02/08	229+920R	1.85	13.0	2019	1822	10.8	98.5	
24/02/08	229+820L	1.85	13.0	1972	1795	9.9	97.0	
24/02/08	229+620L	1.85	13.0	2044	1832	11.6	99.0	
24/02/08	229+120R	1.85	13.0	1994	1797	11.0	98.1	
24/02/08	229+220R	1.85	13.0	2001	1788	12.1	96.4	
24/02/08	229+220L	1.85	13.0	2002	1794	12.5	97.0	
24/02/08	229+620R	1.85	13.0	2014	1815	11.0	98.1	
24/02/08	229+520R	1.85	13.0	2039	1819	12.1	98.3	
24/02/08	229+420L	1.85	13.0	1965	1793	9.6	96.9	
24/02/08	229+420R	1.85	13.0	2012	1815	10.8	98.1	
24/02/08	229+120L	1.85	13.0	1995	1889	11.5	96.7	
24/02/08	229+020L	1.85	13.0	1996	1787	11.7	96.6	
24/02/08	229+320L	1.85	13.0	2001	1785	12.1	96.4	
24/02/08	229+320R	1.85	13.0	1996	1808	10.4	97.7	
24/02/08	230+020L	1.85	13.0	1943	1763	10.2	95.3	
24/02/08	229+920L	1.85	13.0	2070	1848	12	99.9	
24/02/08	229+520L	1.85	13.0	2061	1835	12.3	99.2	
24/02/08	229+720L	1.85	13.0	2042	1843	10.8	99.6	
25/02/08	230+940L	1.85	13.0	2072	1852	11.9	100.1	
25/02/08	230+540R	1.85	13.0	2020	1795	12.0	97.0	
25/02/08	230+340R	1.85	13.0	2048	1835	11.6	99.2	
25/02/08	230+340L	1.85	13.0	2047	1857	10.2	100.4	
25/02/08	231+000R	1.85	13.0	2029	1841	10.2	99.5	
25/02/08	230+440R	1.85	13.0	2029	1813	11.9	98.0	
25/02/08	230+840R	1.85	13.0	2038	1828	11.5	98.8	
25/02/08	230+640R	1.85	13.0	1975	1787	10.5	96.6	
25/02/08	230+740L	1.85	13.0	1986	1804	10.1	97.5	
25/02/08	230+740R	1.85	13.0	1979	1769	11.9	95.6	
25/02/08	230+940R	1.85	13.0	1965	1767	11.2	95.5	
25/02/08	230+540L	1.85	13.0	2026	1804	12.3	97.5	
25/02/08	230+040L	1.85	13.0	2000	1793	11.6	96.9	
25/02/08	227+620R	1.85	13.0	1995	1804	10.6	97.5	
25/02/08	227+920L	1.85	13.0	2008	1793	12.0	96.9	
25/02/08	227+120R	1.85	13.0	2067	1841	12.3	99.5	
25/02/08	228+000L	1.85	13.0	2067	1854	11.3	100.4	
25/02/08	227+420L	1.85	13.0	1898	1758	8.0	95.0	
25/02/08	230+140L	1.85	13.0	1972	1768	11.6	95.5	
25/02/08	227+720L	1.85	13.0	1986	1804	10.1	97.5	
25/02/08	227+820L	1.85	13.0	2070	1832	13.0	99.0	
25/02/08	227+720R	1.85	13.0	1977	1767	11.9	95.5	
25/02/08	227+920R	1.85	13.0	2041	1822	12.8	98.5	
25/02/08	227+120L	1.85	13.0	2076	1856	11.9	100.3	
25/02/08	222+220R	1.85	13.0	1963	1782	10.2	96.3	
25/02/08	227+220L	1.85	13.0	1944	1758	10.6	95.0	
25/02/08	227+520L	1.85	13.0	2031	1846	10.0	99.8	
25/02/08	227+020R	1.85	13.0	1986	1776	11.8	96.0	
25/02/08	227+020L	1.85	13.0	1977	1804	9.6	97.5	
25/02/08	227+620L	1.85	13.0	1981	1793	10.5	96.9	

Date Tested	Test Chainage (km)	MDD (Kg/m^3)	OMC (%)	Wet Density (kg/m^3)	Dry Density (kg/m^3)	% Moisture	% Compaction	Remark
02/03/08	225+320L	1.85	13.0	2013	1764	14.1	95.3	
02/03/08	225+420L	1.85	13.0	2021	1783	13.4	96.3	
02/03/08	226+320R	1.85	13.0	1971	1777	11.0	96.0	
02/03/08	225+220L	1.85	13.0	1929	1770	9.0	95.6	
02/03/08	225+320R	1.85	13.0	2010	1761	14.1	95.1	
02/03/08	225+020L	1.85	13.0	1999	1779	12.3	96.1	
02/03/08	226+020R	1.85	13.0	2001	1809	10.6	97.8	
02/03/08	225+220R	1.85	13.0	1942	1789	8.5	96.7	
02/03/08	225+920L	1.85	13.0	1983	1809	9.6	97.8	
02/03/08	226+820L	1.85	13.0	2035	1807	12.6	97.6	
02/03/08	225+020R	1.85	13.0	1978	1762	12.2	95.2	
02/03/08	225+820L	1.85	13.0	2074	1854	11.9	100.2	
16/03/08	197+700R	1.75	17.0	1871	1682	11.3	96.1	
16/03/08	197+900R	1.75	17.0	1907	1691	12.8	96.8	Black
16/03/08	197+800R	1.75	17.0	1905	1666	14.4	95.1	
16/03/08	196+000R	1.75	17.0	1929	1693	13.9	96.7	
16/03/08	196+500R	1.75	17.0	1898	1675	13.4	95.6	
16/03/08	196+200R	1.75	17.0	1938	1745	11.1	99.6	
16/03/08	195+900R	1.75	17.0	1914	1675	14.3	95.6	
16/03/08	195+800R	1.75	17.0	1950	1765	10.5	100.8	
16/03/08	196+100R	1.75	17.0	1843	1610	14.5	91.9	
18/03/08	196+400R	1.75	17.0	1915	1671	14.6	95.5	
18/03/08	196+300R	1.75	17.0	2004	1720	16.5	98.3	
18/03/08	196+100R	1.75	17.0	1954	1691	15.6	96.6	
19/03/08	194+800R	1.75	17.0	1890	1731	9.2	98.9	
19/03/08	195+300R	1.75	17.0	1792	1686	6.2	96.3	
19/03/08	195+000R	1.75	17.0	1853	1719	7.8	98.2	
19/03/08	195+500R	1.75	17.0	1901	1733	9.7	99.0	
19/03/08	194+760R	1.75	17.0	1832	1693	8.2	96.7	
19/03/08	194+900R	1.75	17.0	1835	1724	6.4	98.5	
19/03/08	195+700R	1.75	17.0	1934	1752	10.4	100.1	
19/03/08	195+400R	1.75	17.0	1984	1751	13.3	100.0	
19/03/08	195+200R	1.75	17.0	1891	1705	10.9	97.4	
19/03/08	195+600R	1.75	17.0	1860	1707	9.0	97.5	
19/03/08	195+100R	1.75	17.0	1827	1722	6.1	98.3	
23/03/08	196+520L	1.85	15.0	1982	1867	6.2	100.9	
23/03/08	197+050L	1.85	15.0	2018	1863	8.3	100.7	
23/03/08	197+950L	1.85	15.0	1978	1809	9.3	97.8	
23/03/08	197+550L	1.85	15.0	1866	1778	4.9	96.1	
23/03/08	197+250R	1.85	15.0	1926	1779	7.7	96.7	Red
23/03/08	197+350L	1.85	15.0	1995	1858	7.4	100.4	
23/03/08	197+350R	1.85	15.0	1986	1864	6.6	100.7	
23/03/08	196+950R	1.85	15.0	1948	1800	8.2	97.3	
23/03/08	197+150L	1.85	15.0	1903	1817	4.8	98.2	
23/03/08	197+150R	1.85	15.0	1930	1807	6.8	97.6	
23/03/08	197+650L	1.85	15.0	1944	1830	6.2	98.9	
23/03/08	197+750L	1.85	15.0	1971	1850	6.5	100.0	
23/03/08	197+850L	1.85	15.0	1904	1813	5.0	98.0	
23/03/08	196+950L	1.85	15.0	1955	1815	7.7	98.0	
23/03/08	197+450L	1.85	15.0	1899	1778	6.8	96.1	
23/03/08	197+250L	1.85	15.0					

Ethiopian Roads Authority Jimma Road Network